

Technical Information Report Queen City Farms Phase III Refill Project Maple Valley, King County, Washington

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Prepared for

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LIST OF ABBREVIATIONS AND ACRONYMS

ADT	average daily traffic
BMP.....	best management practice
cfs.....	cubic feet per second
CARA	critical aquifer recharge area
CHRL.....	Cedar Hills Regional Landfill
County.....	King County
DDES.....	King County Department of Development and Environmental Services
DNRP	King County Department of Natural Resources and Parks
DPER.....	King County Department of Permitting and Environmental Review
Ecology.....	Washington State Department of Ecology
ESC	erosion and sediment controls
ft.....	feet/foot
H:V	horizontal to vertical
in/hr	inches per hour
JARPA	Joint Aquatic Resources Program Application
KCC.....	King County Code
KCDOT	King County Department of Transportation
KCSWDM	King County Surface Water Design Manual
KCRTS	King County Runoff Time Series
LAI	Landau Associates, Inc.
LID	low impact development
NAVD88.....	North American Vertical Datum of 1988
NRCS.....	Natural Resources Conservation Service
O&M.....	Operations and Maintenance
PGIS.....	pollution-generating impervious surface
QCF.....	Queen City Farms
QM	Quarry Mining
SEPA.....	State Environmental Policy Act
Stoneway	Stoneway Rock and Recycling
SWD	King County Solid Waste Division
SWPPP.....	Stormwater Prevention and Pollution Plan
Talasaesa	Talasaesa Consultants, Inc.
TESC	temporary erosion and sediment controls
TIR	Technical Information Report
USDA	US Department of Agriculture
WAC	Washington Administrative Code

WDNR..... Washington State Department of Natural Resources
WQ..... Water Quality
WRIA water resource inventory area
WWHM Western Washington Hydrologic Model

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1.0 PROJECT OVERVIEW

The Queen City Farms (QCF) site is an old sand and gravel mine located in Maple Valley, Washington. The property is owned by Queen City Farms, Inc. QCF currently has a permit (GRDE15-0214) to refill the sand and gravel mine main pit on the eastern portion of the QCF property (Phase II Refill), in the area between Cedar Grove Road SE and Queen City Lake, with clean fill soil. A neighboring operation has a permit (GRDE15-0053) to refill the sand and gravel mine main pit on the western portion of the QCF property (Cedar Shores Refill, also referred to as Phase I Refill). In the next phase of refill (Phase III Refill), QCF is proposing to refill the sand and gravel mine main pit between the Phase I and Phase II Refills. The proposed Phase III Refill will establish new grades in this area of the site to restore the surface water drainage patterns to more closely resemble historical conditions, and support future use of the site as wildlife habitat. The Phase III refill will achieve similar objectives to reclamation of the former mine that would typically be required by the Washington State Department of Natural Resources (WDNR) under a reclamation permit, although no WDNR permit is active at the site..

This Technical Information Report (TIR) provides information to facilitate review by King County (County) Department of Permitting and Environmental Review (DPER) of the grading permit application and grading plans (site improvement plans) for the Phase III Refill Project. Phase I of the refill is currently permitted as GRDE15-0053 (Cedar Shores Mine Refill), and Phase II is currently approved under permit GRDE15-0214 (Queen City Pit Refill, continuation of Permit #1498-43). The Phase III Refill Project will fill in the gravel mine area between the Phase I and Phase II Refill Projects, and restore the discharge from Tributary 316A to its historical location at and near the west end of Queen City Lake. The engineered reach of Tributary 316A that formerly conveyed flow through the QCF property will no longer be considered a “type O aquatic area,” per County Code sections 21A.06.072C(A) and 21A.24.355(4), as it is not a type S, F, or N water and it will no longer be physically connected to type S, F, or N waters. It will be converted to a French drain beneath the Phase III fill. The approach and application for the Phase III Refill Project (PREA17-0003) was developed based on the series of voluntary pre-application meetings with DPER held on December 30, 2016; January 18, 2017; January 25, 2017; and May 2, 2017.

The DPER TIR worksheet is presented as Figure 1. The special reports and studies included as appendices to this TIR present the analyses, evaluations, and modeling results that support the site improvement plans for management of stormwater quantity and quality to meet the requirements of the County Department of Natural Resources and Parks’ (DNRP) King County Surface Water Design Manual (KCSWDM) (King County 2016). The following reports, found in Section 6, are copied directly from the 2007 TIR:

- Section 6.1: “Potential Changes to Plant Communities Resulting From Hydrologic Changes to Queen City Lake” by Talasaea Consultants (Talasaea)
- Section 6.2: “Geology, Surface Water Hydrology and Groundwater Hydrology, Queen City Farms Refill Project” by Landau Associates (LAI)

- Section 6.3: “Queen City Lake Estimated Infiltration Rates, Queen City Farms Refill Project” by LAI
- Section 6.5: “Evaluation of Proposed Refill Plan on Groundwater Contamination, Queen City Farms Refill Project” by LAI
- Section 6.7: “Evaluation of Higher Water Levels in Queen City Lake on the Existing Queen City Farms Vertical Barrier Wall System, Queen City Farms Refill Project” by LAI
- Section 6.8: “Surface Water Infiltration Evaluation, Queen City Farms Refill Project” by LAI
- Section 6.9: “Best Management Practices for Reclaiming Surface Mines in Washington and Oregon,” Washington Division of Geology and Earth Resources Open File Report 96-2

The following reports by LAI are new or substantially updated from the Phase II Refill Project TIR (LAI 2007):

- Section 6.1: “Queen City Lake Wetland Hydroperiod Analysis, Queen City Farms Phase III Refill”
- Section 6.4: “Slope Stability Analysis, Queen City Farms Phase III Refill”
- Section 6.6: “Tributary 316A Historical Discharge Review”
- Section 6.10: “Queen City Lake Basin – King County Runoff Time Series Modeling, Queen City Farms Phase III Refill”
- Section 6.11: Stormwater Calculations

The site is located just north of Cedar Grove Road SE in King County, Washington, in a large area (more than 1,000 acres) of industrial activity that includes Cedar Grove Composting, Cedar Hills Regional Landfill (CHRL), Stoneway Rock and Recycling (Stoneway), the QCF Superfund Site, and the former 4 TEK Industries. The proposed Phase III Refill Project is located above the 100-year Cedar River floodplain. Reclamation activities will not take place within 200 feet (ft) of the river. The site location is shown on Figure 2. The site location, site topography, and proximity to the Cedar River are shown on Figures 3a and 3b.

1.1 Project Description

The site grading associated with the Phase III Refill Project is located between the Phase I and II Refill Project areas, south of Queen City Lake, and north of Cedar Grove Road SE. The total Phase III refill area will be approximately 97 acres. The total Phase III refill volume is estimated at approximately 2.5 million cubic yards. Phase III refilling operations will be in accordance with the updated State Environmental Policy Act Checklist, attached in Appendix A, and the eventual DPER Clearing and Grading Permit Conditions of Approval.

Fill will be placed in approximately 20-ft staged lifts, starting from the outside finished slope edge and moving inward. Each lift will cover no more than 8 acres of fill area. The outside edge of each 20-ft lift (the finished slope) will be hydroseeded. The duration of filling for each lift will vary depending on the incoming fill volume. It is anticipated that each lift will not remain active for more than one year.

Because the Phase III refill will overlay the Phase I and II refill, no existing structures will need to be moved to accommodate the Phase III refill. The Cedar Grove Compost access road will be relocated as shown on the Phase III site improvement plans (Appendix B).

The water source for any necessary dust suppression or fire safety purposes will be the on-site well at Cedar Grove Compost.

1.2 Surface Water Features

The Phase III Refill will follow the completion of Phase II Refill. At the completion of the Phase II Refill, the primary site surface water features will include:

- Queen City Lake, a seasonal natural kettle lake with no natural surface water outlet (a two-stage overflow structure will be added as part of the Phase II Refill Project stormwater management system)
- Tributary 316A, a seasonally intermittent surface water course that discharges on-site to the Main Infiltration Area
- The Main Infiltration Area, an area of coarse soil that infiltrates all of the on-site flow from Tributary 316A and, historically, stormwater flow from the adjacent Stoneway gravel mine sedimentation pond
- QCF Spring, the only original surface water discharge from the site, located near Cedar Grove Road SE, directly south of the Main Infiltration Area.

As permitted with the Phase II Refill Project, the existing Main Gravel Pit Lake will be gradually modified and eventually eliminated during the Phase II Refill Project operations. In addition, the East Airstrip Spring, a seasonal spring that issues from perched Aquifer 1, and that was formed during gravel mining operations, will be routed to a new infiltration gallery that will be constructed along the main gravel pit face. This infiltration gallery will remain in place beneath the Phase III fill. The access manhole will be extended, if needed.

Primary site features and elements of the Phase III Refill Project operation are shown on the site improvement plans. Because the Phase III Refill will occur in the area of Tributary 316A, a key part of the Phase III Refill Project is the rerouting of Tributary 316A into Queen City Lake, which was its original discharge location prior to gravel mining operations at the site (see memo in Section 6.6).

1.2.1 Stormwater Management

Stormwater runoff from the Phase III Refill Project will be managed, in general, using the same structures as implemented for the Phase II Refill Project, with a few additions. The following stormwater management features were permitted as part of the Phase II Refill Project. They will either remain as designed, or will be modified as noted to accommodate the Phase III Refill Project:

- South Bioswale and Retention Pond: As permitted for the Phase II Refill Project, runoff from the southern side of the refill will be directed to an elongated retention pond and bioswale

oriented parallel to Cedar Grove Road SE. The elongated retention pond will discharge to the South Retention Pond for infiltration. The South Retention Pond will emergency overflow to the County-maintained stormwater conveyance along Cedar Grove Road SE.¹ This ditch is assumed to have sufficient overflow capacity based on the commitment from King County Solid Waste Division (SWD) and King County Department of Transportation (KCDOT). The South Retention Pond and bioswale are referred to in the site improvement plans as the South Stormwater Facility.

No changes to the South Stormwater Facility are proposed for the Phase III Refill, as the total contributing area will not increase.

- Queen City Lake: As permitted for the Phase II Refill Project, to provide additional stormwater storage capacity, the existing 36-inch outflow pipe from Queen City Lake will be modified to a two-stage outflow, and the pipe that currently discharges to the Main Gravel Pit Lake will be eliminated. A new outflow pipe will be installed and piped to the new East Retention Pond (East Stormwater Facility).

To accommodate the flow from Tributary 316A, the Queen City Lake overflow structure design has been modified. This revised structure will be constructed as part of the last sub-phase of the Phase II Refill Project operations. It replaces the proposed design that was approved with the Phase II TIR. The updated analysis of the Queen City Lake hydrology is included in Section 6.10. LAI assumes that DPER will include review and approval of engineered structural plans for the overflow structure as a condition of the Phase III permit.

- East Retention Pond: As part of the Phase II Refill Project, this pond was sized to infiltrate up to 10 cubic feet per second (cfs) of overflow from Queen City Lake.

For the Phase III Refill Project, peak overflow from Queen City Lake will increase to approximately 16.4 cfs. This pond will be enlarged to provide additional volume storage during peak storm events (up to 1 million gallons), and the footprint will be enlarged to provide additional infiltration capacity (up to a total of 13.9 cfs). East Pond and Queen City Lake outlet sizing calculations are included in Section 6.11.

- West Pond: As permitted with the Phase II Refill Project, runoff from the west side of the refill will be directed to the combined West Detention Facility and Wet Pond (West Stormwater Facility).

The West Stormwater Facility will be relocated, for the Phase III Refill Project, to provide the same detention and treatment volume as for Phase II, because the total contributing area will not increase.

- Main Infiltration Area: This area will receive less discharge as the Tributary 316A Engineered Reach will be eliminated and replaced by a French drain underneath the fill that will discharge runoff from a limited basin between the existing Compost Facility and the Compost Pad. The main infiltration area may receive overflow from the Compost Pad infiltration pond, the South Pond, and the West Pond.

¹ The County Solid Waste Division (SWD) and King County Department of Transportation (KCDOT) will upgrade the ditch along Cedar Grove Road SE as a stormwater facility that discharges to the Cedar River. This system discharges to the Cedar River and the Cedar Grove Channel wetlands (Wetlands 31 and 56) via a system of pipes, culverts, and maintained ditches.

- Temporary Erosion and Sediment Controls (TESC): During each phase of refill, areas of 8 acres or less will have drainage accommodated by sediment control pond facilities in accordance with the site improvement plans (Appendix B).

1.3 Key Project Elements

The key project elements and stormwater management elements that are described in this TIR and site improvement plans include:

- Assessing the hydrologic and ecological effect of rerouting Tributary 316A from its current channel into Queen City Lake
- Accommodating the higher inflow to Queen City Lake, in its role as a stormwater management facility:
 - Characterization of future stormwater inflow to Queen City Lake from CHRL, the Tributary 316A drainage basin, and the Phase III Refill Project
 - Modeling of 100-year peak outflows and Queen City Lake levels with the increased inflow
 - Redesign of Queen City Lake outlet structure to maintain the integrity of the QCF Superfund Site remedy with increased peak inflow and outflow
 - Potential effect on Queen City Lake wetlands conditions due to these changes
- Protecting the existing QCF Superfund Site slurry wall adjacent to Queen City Lake from changes in groundwater levels
- Managing stormwater runoff from the Phase III Refill Project area during refilling and after refilling is complete
- Establishing and maintaining fill soil stability.

1.4 Key Document Findings

The conclusions and proposed approach related to the key elements listed above are described in the following sections.

1.4.1 Tributary 316A

As part of the Phase III Refill project, Tributary 316A will be restored to its original discharge in Queen City Lake. Special Report Section 6.6 describes the historical and proposed conditions.

1.4.2 Queen City Lake

Queen City Lake is a natural glacial kettle lake that plays an integral and complex role in the hydrology of the area. A goal in developing the Phase II Refill Project approach was to increase the historical storage function of Queen City Lake (to compensate for refilling of the Main Gravel Pit Lake) while minimizing the impact on Aquifer 1 water levels; Queen City Lake infiltrates to Aquifer 1 (LAI 2007). This goal will be carried forward during the Phase III Refill Project.

Similar to the permitted Phase II Refill Project, the current Queen City Lake 36-inch outflow pipe will be replaced with a new two-stage outlet system routed to the new East Retention Pond. The new outlet will be designed to minimize the impact on average lake water levels, while allowing Queen City Lake to store stormwater during extreme storm events. The outlet will manage up to the 100-year storm event to keep lake water levels low enough to protect the adjacent superfund site.

After the channel restoration, the peak 100-year outflow from Queen City Lake will be approximately 16.4 cfs. The East Retention Pond will be designed to infiltrate 13.9 cfs, with retention capacity for the remaining volume during peak periods. This pond will have an emergency overflow to the roadside ditch along Cedar Grove Road SE. This ditch will be maintained by the County as a stormwater conveyance facility connected to the Cedar River (King County 2006).

The Phase III Refill Project design takes into account the planned long-term stormwater management goal at CHRL, which is to return the offsite discharge to pre-1978 forested levels. This will ultimately reduce the peak inflow to Queen City Lake compared to current conditions. While the restoration of the Tributary 316A channel and the changes in the outflow structure to Queen City Lake may cause lake water levels to rise slightly, the combined impact of the outflow structure modifications and changes on CHRL is predicted to result in lower Queen City Lake levels overall. This overall reduction is due to the effect of reduced recharge from the CHRL.

No significant wetland impacts to Queen City Lake are predicted as part of the refilling project. An analysis of the effect of the Phase III refill on wetland hydroperiods is described in Section 6.1.

1.4.3 Superfund Site Analysis

Essential elements of the existing QCF Superfund Site remedy are the Aquifer 1 slurry wall (vertical barrier wall system) and the recharge of clean water to Aquifer 2 to contribute to natural attenuation of the groundwater contaminant plume. The refill plan is designed to limit the increase in average water levels in Aquifer 1 to minimize the impact on the vertical barrier wall system. This will be achieved by ensuring the water depth in Queen City Lake does not exceed 9 ft (LAI 2007; Section 6.7). During extreme storm events, water levels in Aquifer 1 will temporarily increase over current levels; however, the slurry wall is designed to withstand these projected increases. All of the water that currently (and as permitted in the Phase I and Phase II refill projects) is infiltrated on-site will continue to be infiltrated on-site during and after implementation of the Phase III Refill Project. Therefore, the natural attenuation function associated with infiltration will not be significantly affected. Dataloggers will be installed to monitor water levels in Queen City Lake, Aquifer 1, and Aquifer 2 to monitor changes in site hydrology associated with implementation of the Phase II and III Refill Project plans.²

² Pressure transducers will be installed in Queen City Lake, Well E(1), Well F(2), Well I(2), and Well S(2) to monitor hydrologic changes associated with the refill plans.

1.4.4 Refill Area Runoff

Stormwater runoff from the Phase III Refill Project will be managed in the South Retention Pond and Bioswale, the West Detention Facility and Wet Pond, Queen City Lake, and the East Stormwater Facility. The West Detention Facility will discharge to the Main Infiltration Area. The other facilities will discharge by infiltration. Section 6.11 includes stormwater management calculations and a summary of modeling results.

1.4.5 Fill Soil Stability

An engineering analysis of fill soil stability was conducted for the planned Phase III Refill Project slopes. Section 6.4 includes the stability analysis report.

1.5 Site History and Adjacent Land Use

In the early 1970s, a roughly 393-acre area on the QCF property and the adjacent Stoneway property was zoned Q-M (Quarry Mining). Sand and gravel was mined from this area through the 1990s. The area west of Tributary 316A is known as the Cedar Shores Pit. Mining in this pit is completed and it is currently being refilled under DPER permit number GRDE15-0053. The approximately 80-acre area west of Tributary 316A is known as the Queen City Farms Pit. Mining operations are complete and refill operations are currently being conducted.

The adjacent property to the north of the QCF property is developed as the CHRL. The CHRL is a 960-acre property that contains an active landfill operated by the SWD. Both Queen City Lake and the QCF Superfund Site are located between the Phase II and Phase III Refill Project areas and the CHRL. The property is bordered to the south by Cedar Grove Road SE, beyond which is primarily an undeveloped wetland area. To the east of the property is 228th Avenue SE, which is the entrance road to the CHRL. Beyond this road are private residences. The former Cedar Shores Pit is located to the west of the refill area and occupies the adjacent property to the west. The Cedar Grove Composting facility is on the QCF property to the northwest of the Phase III Refill Project area.

1.6 Soil

The US Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS) Web Soil Survey data identifies soils in the project area as mainly Alderwood gravelly sandy loam, 8 to 15 percent slopes; and Everett very gravelly sandy loam, 8 to 30 percent slopes (USDA NRCS 2017). Original soil conditions are shown on Figure 4. Much of the original surface native soil has been removed due to gravel mining. The Phase I and II refill area, where native soil has generally been removed, is shown on Figure 4. In this disturbed area, ground surface characteristics of the proposed refill (rather than the mapped soil types) were used to determine runoff parameters for stormwater modeling. Refill areas for Phase I and II were previously modeled as till, pasture to reflect the land type at the completion of refill. Therefore, the Phase III refill areas have also been modeled as till, pasture land type.

Alderwood gravelly sandy loam soil is well-drained soil located in upland areas and is typically used for timber, pasture, berries, row crops, and urban uses. The soil is formed under conifer trees in glacial deposits. Surface and subsurface soil typically consists of dark-brown to very dark-brown or gray-brown gravelly sandy loam; the substratum consists of gray-brown, weakly to strongly consolidated glacial till.

Everett gravelly sandy loam soil is somewhat excessively drained soil located on terraces and terrace fronts. The soil is formed under conifer trees in very gravelly glacial outwash deposits. The soil is typically located in gently undulating and moderately steep landscape positions and is typically used for timber, pasture, and urban uses. Surface and subsurface soil typically consists of black or brown gravelly to very gravelly sandy loam over very gravelly sand (LAI 2007).

1.7 Natural Resources and Sensitive Areas

Natural resources in the vicinity of the property include the Cedar River, located southwest (Figures 2 and 3) of the QCF property. The Cedar River has been the subject of several studies by the County: Draft Cedar River Action Plan (February 1995), and Cedar River Current and Future Conditions Summary Report (May 1994). These studies document area conditions, including a valuable salmonid resource. The draft Cedar River Action Plan proposes specific mitigation measures that should occur in the vicinity of the property, as discussed in Section 2.2.1. The proposed reclamation design of the project is sensitive to these mitigation issues.

Tributaries 316 and 316A are located on and downstream of the property. Tributary 316A originates northwest of the QCF property and the Cedar Grove Composting facility. The tributary continues, as an artificial engineered drainage channel, in a southerly direction across the QCF site, where stormwater flows infiltrate into the ground approximately 350 ft from Cedar Grove Road SE at the Main Infiltration Area. Subsurface flow discharges nearby at the QCF Spring. The QCF Spring discharge flows through culverts to continue southwest under SE Lake Francis Road as Tributary 316. The tributary then meanders down to the Cedar River.

Tributary 316A will be restored to its original discharge location (Queen City Lake) as part of the Phase III Refill Project. This is further discussed in Special Report Section 6.6.

Tributary 316 originates on the south side of Cedar Grove Road SE at approximate elevation 250 ft, flows as a roadside ditch along 180th Street SW, and continues east of a mobile home site to the Cedar River.

The primary wetland on-site is Queen City Lake. The attributes of this wetland are discussed in Section 6.1.

Two main wetlands are in a channel south of Cedar Grove Road SE. Wetland 31 is an approximately 16.2-acre wetland located in the western portion of the channel. Wetland 31 receives recharge from

water flowing off the upland area to the south of the channel. The QCF Spring also contributes to Wetland 31 via a culvert under Cedar Grove Road SE. Discharge from Wetland 31 is to the Cedar River via discharge to underlying groundwater and to Tributary 316. Wetland 56 is an approximately 16.8-acre wetland located in the eastern portion of the channel. Wetland 56 receives recharge from water flowing off the upland area to the south of the channel. Discharge from Wetland 56 is to the Cedar River via discharge to groundwater and eventually to Tributary 316. The eastern portion of this wetland may also discharge to Issaquah Creek by way of surface water discharge via the Four Lakes area. Note that both Wetland 31 and Wetland 56 represent recharge areas to groundwater. This is demonstrated by strong downward hydraulic gradients within Aquifer 2 beneath the channel (LAI 2007). The location of Wetlands 31 and 56 are shown on Figure 6. A memorandum presenting the geology, surface water hydrology, and groundwater hydrology of the QCF Refill Project is attached in Section 6.2. A memorandum describing the assessment of existing wetlands and the impacts of restoring Tributary 316A is included in Section 6.12, which will be updated with more recent data collected in March 2019 from all the wetlands. The assessment was only qualitative, therefore a hydrological analysis will be completed using either hydrologic modeling or data collection, or a combination of both. LAI expects that DPER will issue the Phase III permit with the condition that an updated wetland memorandum and hydrological analysis will be completed prior to beginning Phase III Operation.

As part of the Tributary 316A re-route, the stream and riparian areas will be restored with the plantings shown on the site improvement plans. LAI expects that DPER will issue the Phase III permit with the condition that a qualitative functional analysis will be performed using the guidance outlined in the EPA/USFW document "A Function-Based Framework for Stream Assessments and Restoration Projects" (Appendix C-1), as a means to support the selected plantings.

Groundwater flow in the upper portion of the Aquifer 2 (termed Aquifer 2a), follows the channel alignment. It is likely that a significant component of the overall Aquifer 2 recharge is to the wetland and Tributary 316 stream complex at the west end of Cedar Grove Channel.

Steep slopes exist on the property. Some of these are natural slopes that will not be affected by this project because they exist outside of the refill area. Others are disturbed slopes that have been constructed by the mining operation, and will be reclaimed as described herein. Additional discussion of offsite natural resources and sensitive areas is provided in Section 3.0.

2.0 CONDITIONS AND REQUIREMENTS SUMMARY

2.1 Analysis of Core Requirements

This section details each of the core requirements, as described in Section 1.2 of the KCSWDM (King County 2016).

2.1.1 Requirement 1 - Discharge at the Natural Location

All surface water and stormwater runoff from the project will be discharged at the natural location, and will not be diverted onto or away from downstream properties. As discussed in Sections 3.0, 4.0, and 8.0, in general, surface water at the site currently infiltrates and, in the future, will continue to infiltrate to groundwater. Stormwater runoff from the Phase III Refill Project will be managed using stormwater best management practices (BMPs). A portion of runoff from Phase III fill will be managed in the Phase I stormwater ponds, which were permitted under GRDE15-0053, to provide the required flow control, but not full infiltration.

2.1.1.1 Discharge Requirement 1

Discharge requirement 1 applies to projects that propose to concentrate any runoff. The Phase III Refill Project proposes to re-route the ultimate discharge location of Tributary 316A. The purpose of the re-route is to restore the discharge from Tributary 316A to its historical location at Queen City Lake. Adequate dispersion will be provided to satisfy discharge requirement 1 via a channel outlet spreader prior to discharge into Queen City Lake, as shown on the site improvement plans.

2.1.1.2 Discharge Requirement 2

Discharge requirement 2 applies to projects that are located within a Landslide Hazard Drainage Area. A portion of the Phase III fill area will be draining to the Cedar Shores Stormwater Ponds through a Landslide Hazard Drainage Area (see Figure 5). Discharge requirement 2 requires a tightline system be provided through the landslide hazard area, unless:

1. DPER approves an alternative system based on a geotechnical evaluation/recommendation from a licensed geotechnical engineer that considers cumulative impacts on the hazard area under built out conditions, and
2. DPER determines that a tightline system is not physically feasible or will create a significant adverse impact based on a soils report by a geotechnical engineer.

The Phase III project will not send any additional runoff to the landslide hazard area, nor create any new drainage features within the landslide hazard drainage area; in fact, after the construction of Phase III, slightly less runoff will be routed to the Cedar Shores ponds than was approved by DPER in the Phase I grading permit. Therefore, discharge requirement 2 is met for the Phase III project.

2.1.1.3 Discharge Requirement 3

Discharge requirement 3 applies to projects that are adjacent to or containing a landslide, steep slope, or erosion hazard area, and requires demonstration that the onsite drainage facilities and/or flow control BMPs will not create a significant adverse impact to downhill properties or drainage systems.

The majority of all the stormwater runoff from the Phase III project area flows to drainage facilities or flow control BMPs that ultimately infiltrate, with the exception of the area draining to the Cedar Shores Stormwater Ponds, which are detention ponds. However, as explained above, these ponds have already been sized for a larger drainage area in the Phase I TIR compared to the drainage area from the Phase III fill area.

Therefore, it is expected that there will not be significant adverse impacts to downhill properties or drainage systems, and so Discharge requirement 3 is met for the Phase III project.

2.1.2 Requirement 2 - Offsite Analysis

The offsite analysis performed for this project is included in detail in Section 3.0 of this TIR.

2.1.3 Requirement 3 - Flow Control

The Phase III Refill Project is located in a Conservation Flow Control Area per the KCSWDM. This requires that developed discharge durations match the pre-developed durations for the range of pre-developed discharge rates from 50 percent of the 2-year peak flow up to the full 50-year peak flow. Developed peak discharge rates must match pre-developed peak discharge rates for the 2- and 10-year return periods. Historical site conditions must be assumed as the pre-developed condition. However, the stormwater managed in the new Phase III stormwater features fully infiltrates, and so the discharge rates and durations are zero for both the pre-developed and developed condition. The quantity and quality of stormwater flowing to the permitted Phase I and Phase II ponds will not change, and therefore the flow control requirement was not re-analyzed for these ponds.

The stormwater facilities are discussed in detail in Sections 4.1 and 4.2.

Because a portion of the Phase III runoff will be managed by the existing Cedar Shores stormwater ponds, a shared use agreement will be developed between QCF and the owner of the Cedar Shores stormwater ponds in compliance with KCSWDM Section 1.2.3.2.A. LAI expects that DPER will make this shared use agreement a condition of the grading permit issued for Phase III.

2.1.4 Requirement 4 - Conveyance System

Since this is and will be an ongoing refilling operation, the conveyance system comprises ditches, swales, and sheet flow across both bare ground and groundcover. During the Phase II Refill Project, the current piped conveyance system that conveys outflow from Queen City Lake to the Main Gravel Pit Lake will be replaced by a pipe that will convey outflow from Queen City Lake to the East Retention

Pond. The only planned piped conveyance system is the outlet pipe from Queen City Lake, and a subdrain pipe that will be included in the French drain at the current location of the Tributary 316A engineered channel. The new piped conveyance system is shown on the site improvement plans (Appendix B) and discussed in detail in Section 5.0.

2.1.5 Requirement 5 - Erosion and Sediment Control

Erosion control measures will be implemented, modified, and revised on-site as the refilling operation continues. The proposed site improvement plans (Appendix B) incorporate general erosion control measures to be implemented based on areas of disturbance. The exact location of these temporary facilities have not been defined because of the changing nature and elevation of the refilling operations. Each sediment pond is designed to accommodate 8 acres of drainage. The site improvement plans show construction sequences, associated notes and details, and other erosion and sediment control (ESC) related information.

Permanent erosion controls will be located at the perimeter of the fill areas and at the edges of the top flat-sloped fill areas. These are shown on Sheets 3 and 4 of the site improvement plans (Appendix B). Sizing calculations for these features are included in Section 6.11.

2.1.6 Requirement 6 - Maintenance and Operation

Drainage facilities will be maintained and operated in accordance with the maintenance standards included in the KCSWDM Appendix A, which is excerpted in Appendix C of this TIR.

2.1.7 Requirement 7 - Financial Guarantees and Liability

The Drainage Facilities Restoration and Site Stabilization Financial Guarantee and the Drainage Defect and Maintenance Financial Guarantee will be posted prior to starting refilling operations, as determined necessary.

2.1.8 Requirement 8 - Water Quality

Runoff water quality from the site can be detrimental to downstream systems if not properly managed. Sediment-laden water flowing offsite is not a concern because all stormwater from the Phase III area will be retained and infiltrated at the property, or managed in previously permitted water quality facilities. The site improvement plans (Appendix B) also incorporate erosion control, large sediment control facilities, and maintenance activities to minimize suspended sediment prior to infiltration.

Typical water quality concerns related to vehicular traffic on pavement surfaces do not apply because of the nature of this project. During the anticipated multi-year duration of this permit there may be areas subject to regular vehicular use by heavy equipment for durations that exceed those of a typical construction project. Therefore, without an approved drainage adjustment, some portions of the

proposed refill footprint would potentially be considered pollution-generating surface until final elevations are reached.

A drainage adjustment has been requested (see Appendix I) which clarifies how pollution generating surfaces will be defined for the Phase III project.. The following surfaces in the Phase III refill will not be considered pollution-generating impervious surfaces (PGIS): refill side slopes, noise and visual berms that are not accessed after construction and stabilization, infrequently used maintenance roads, active fill areas within closed depressions where vehicle traffic is limited to fill equipment, and other areas of the refill site without significant vehicle traffic located within closed depressions. Runoff from PGIS is appropriately managed. The only PGIS in Phase III is the access road to the Cedar Grove Compost Facility from Cedar Grove Road SE. This access road surface is approximately 1.5 acres. All of the road's runoff is designed to flow to one of the following, which will provide adequate water quality treatment: Cedar Shores Stormwater Ponds (wet ponds), Queen City Lake or West Pond (wet pond). The other designated impervious areas within the Phase III fill area (approximately 10.3 acres) will be replaced by pervious surfaces during Phase III. Runoff from these surfaces are similarly designed to flow to one of the following to provide water quality treatment: Cedar Shores Stormwater Ponds (wet ponds), Queen City Lake, West Pond (wet pond), and South Pond (bioswale).

As described in KCSWDM Section 1.2.8.1.B, projects that infiltrate stormwater within $\frac{1}{4}$ mile of a Sensitive Lake require Water Quality (WQ) treatment prior to infiltration. As shown in Figure 5, the Phase III project does include a Sensitive Lake WQ treatment area. However, because the Phase III area does not infiltrate runoff within $\frac{1}{4}$ mile of a phosphorus sensitive receiving water, Basic WQ treatment is sufficient to meet the KCSWDM requirements. Each stormwater facility on site incorporates Basin treatment prior to infiltration.

In addition, a portion of the Phase III fill area is within a critical aquifer recharge area (CARA). This is shown on Figure 5. To comply with KCSWDM groundwater protection requirements, no truck washout areas will be located within the CARA, and no asphalt shingles will be placed within the boundary of the CARA.

2.1.9 Requirement 9 – Low Impact Development

This project does not qualify for the basic exemption from Core Requirement #9 because it DOES create more than 2,000 square feet of new plus replaced impervious surface. More than 7,000 square feet of land disturbing activity will also occur.

WWHM model output for each modeled infiltration facility demonstrates that these facilities meet the low impact development (LID) standard. The facilities approved in Phase I and II were not re-modeled. Because the Phase III project does not increase the drainage areas, increase peak flows, or impact water quality flowing to the Phase I and II stormwater features, the LID standard is not applied to these facilities.

This approach satisfies the CARA groundwater protection requirements because water will not be infiltrated within a CARA without basic pretreatment.

2.2 Special Requirements

The following Special Requirements, as listed on the TIR Summary Sheet (Figure 1), are applicable to this project.

2.2.1 Special Requirement 1- Other Adopted Area Specific Requirements

The Cedar River has been the subject of several studies by the County, as mentioned in Section 1.7: Draft Cedar River Action Plan (King County 1995), and Cedar River Current and Future Conditions Summary Report (May 1994);. These studies document area conditions, including a valuable salmonid resource. The draft Cedar River Action Plan proposes specific mitigation measures that should occur in the vicinity of the property, as discussed below. The proposed reclamation design of the project is sensitive to these mitigation issues.

Washington Administrative Code (WAC) Chapter 173-508 Instream Resources Protection Program – Cedar – Sammamish Basin, Water Resource Inventory Area (WRIA) 8, closes the Cedar River to additional water withdrawals, but does not affect this project.

The Cedar River Draft Basin and Nonpoint Pollution Action Plan (King County 1995) defines specific flood control, water quality, and habitat enhancement recommendations for the Cedar River. The draft Action Plan mentions “Stoneway Concrete Stormwater Management” as a source of sediment to Tributaries 316 and 316A (recommendation NT 1, page 4-108), but allocates all responsibility for oversight to Washington State Department of Ecology (Ecology) by way of NPDES permits. The approach to infiltrate the majority of site stormwater will continue to minimize sediment contribution to Cedar River from the refill.

The QCF pit is located near River Mile 11.0 to 11.2, an area ranked by the draft Action Plan as high priority for open-space acquisition for habitat, flood reduction, and recreation values (Table 4-1, page 4-40). Tributary 316A is recommended to have a creek restoration project (Recommendation 3126, page 4-18). The proposed QCF Refill Project supports these Draft Action Plan objectives.

The draft Action Plan identifies that Level 4 Special Retention/Detention Requirements (pages 4-63 through 4-71) should be applied to projects in the Cedar Hills area, including the Cedar Shores Pit. The drainage controls proposed by LAI herein fulfill these special requirements and are aimed to maximize quantity and quality characteristics to Tributary 316A and onsite wetlands.

2.2.2 Special Requirement 2- Flood Hazard Area Delineation

Because Tributary 316A discharges well above the 100-year elevation of the downstream water body (Queen City Lake), and because the restored channel is sized to convey the 100-year flow with

sufficient freeboard, a floodplain/floodway analysis is not required in accordance with KCSWDM Section 4.4.2. to satisfy the flood hazard requirements of KCC 21A.24 and meet the relevant KCSWDM and code requirements. No easement for the floodplain will be required.

2.2.3 Special Requirement 3- Flood Protection Facilities

This special requirement does not apply to the Phase III project.

2.2.4 Special Requirement 4- Source Control

implementing source control BMPs required through other federal, state or local programs, such as the state permit for NPDES General or Individual permit or an inert waste permit, will satisfy the source control requirements as discussed in King County Code (KCC) 9.12.035.C, in place of the BMPs prescribed in the County's Stormwater Pollution Prevention Manual.

2.2.5 Special Requirement 5- Oil Control

A drainage adjustment is being requested for how oil control requirements apply to the Phase III site. The adjustment clarifies that the definition of a "high use site" as "a commercial or industrial site subject to an expected average daily traffic (ADT) count equal to or greater than 100 vehicles per 1,000 square feet of gross building area" is not applicable to the Phase III refill site. Only the portions of the site considered high use will be required to provide oil control treatment in addition to any other water quality controls required by the KCSWDM. No portion of the Phase III site is expected to be subject to petroleum storage or transfer in excess of 1,500 gallons per year. It is likely that the access roads through Phase III will be subject to daily use of 25 or more diesel vehicles that are over 10 tons net weight. These areas will be considered high use areas and will apply an oil control device from the high use menu in KCSWDM Section 6.1.5. LAI expects that DPER will make application of appropriate oil control measures a condition of the Phase III grading permit.

3.0 OFFSITE ANALYSIS

3.1 Study Area Definition

A Level 1 offsite analysis was conducted for the Phase III project, in accordance with KCSWDM Section 1.2.2. The study area extends downstream 1 mile from the proposed project site. The study area does not extend upstream, as back-water effects are not expected to impact upstream areas as part of the proposed project.

3.2 Resource Review

As part of the offsite analysis, the following resources, where available, were reviewed for existing/potential problems in the property area:

- Basin plans
- Drainage studies
- Basin reconnaissance summary reports
- Critical drainage area maps
- Federal Emergency Management Agency maps
- Other offsite analysis reports
- Sensitive areas folio
- DNRP drainage complaints and studies
- Road drainage problems
- County soil survey
- Wetlands inventory maps
- Migrating river studies.

Potential problems, where identified, are discussed in the following sections. Critical areas identified downgradient of the property (Figure 6) are discussed in Section 1.6.

3.3 Field Inspection

Levels 1, 2, and 3 field inspections and investigations were conducted in 2006 in support of the Phase II Refill Project. Preparations for Level 1 inspections were conducted including identification of current and future stormwater management requirements, review of site hydrogeologic monitoring results, photo and map evaluation activities, and upgradient information collected from the CHRL, including discussions with SWD representatives. Reconnaissance inspections were conducted on September 7 and October 11, 2006 to document site conditions including topography, existing stormwater management facilities, wetland conditions, potential locations for future stormwater management facilities, and existing surface water features including Queen City Lake, the East Airstrip Spring, and

the Main Gravel Pit Lake. One on-site meeting was conducted with agency personnel on October 11, 2006 at the QCF property to review specific questions with DDES representatives and project technical consultants including LAI, W&H Pacific, and Talasaea. During and subsequent to the meeting, Queen City Lake, the Main Gravel Pit Lake, the Main Infiltration Area, and QCF Spring were visited. Investigations and remediation monitoring conducted since the 1980s for the adjoining QCF Superfund Site assisted in defining hydrogeologic conditions that are applicable to evaluating groundwater flow and the ability of Aquifer 2 to accommodate infiltration (LAI 1990, 1991). This includes extensive geologic, groundwater, and surface water data collected by project personnel involved in preparation of this TIR.

Level 3 field inspections and investigations were conducted for the Phase II project (LAI 2007). These included an investigation of Queen City Lake wetlands vegetation; an elevation survey of the dry Queen City Lake bed; soil type observation and soil sample collection on October 4, 2006; and laboratory soil testing for the East Airstrip Spring infiltration area. Additional field surveys of wetland areas were conducted in 2019 and are reflected on the Phase III site improvement plans and in Section 6.12. Backhoe test pits and infiltration tests were conducted on November 2, 2006 (Bioswale and South Retention Pond) and November 9, 2006 (East Retention Pond). These previous investigations are still valid and are relied on for the Phase III Refill analysis. A drainage adjustment is requested to allow the use of infiltration tests that were conducted under a previous version of the KCSWDM.

3.4 Drainage System Description and Problem Descriptions

Figure 3A shows the drainage divide between the Issaquah Creek and Cedar River basins in the vicinity of the project. There are three drainage sub-basins that, together, cover most of the proposed QCF site (Smayda 2005). These drainage sub-basins guide the design and implementation of the Phase III Refill Project stormwater controls and understanding of offsite groundwater flow.

The Queen City Lake sub-basin consists of direct surface runoff to Queen City Lake, which is primarily the southern portion of the CHRL and Queen City Lake itself. The Main Gravel Pit sub-basin consists of areas of gravel refill that discharge to infiltration areas along the south of the site; and the Maple Hills sub-basin consists of surface inflow into Tributary 316A. All three of these drainage sub-basins are considered tributary to the Cedar River, although they all historically infiltrate on the site. The site improvement plans (Appendix B) show the basins associated with the final Phase III refill configuration. The Phase III refill will modify the Phase II site drainage patterns slightly, as shown on Figures 3A and 3B.

Surface water in all three drainage sub-basins has historically infiltrated to groundwater. In the future, during implementation and after completion of the Phase III Refill Project, all surface water will infiltrate to groundwater, except emergency overflows from the East and West stormwater ponds that exceed the 100-year design event, and overflows from the Cedar Shores ponds as permitted in the Phase I TIR. The only area where refilling will take place is within the former gravel mine, which

has limited vegetation. Refilling this area is not expected to generate additional excess volume of surface water runoff. Overall, the total amount of surface water infiltrated on-site in the future is expected to be roughly the same as the current condition. In the long term, peak amounts of surface water should actually decline due to stormwater facility upgrades on CHRL in the Queen City Lake sub-basin, which will reduce the amount of surface water inflow to Queen City Lake compared to the present condition.

On-site infiltration eventually discharges to Aquifer 2. Prior to the Phase II and III Refill Projects, infiltration forms a groundwater mound in Aquifer 2 directly north and west of the Main Gravel Pit Lake. Groundwater flows to the north, west, and south from the mound. Southerly and westerly groundwater flow discharges directly to the Cedar River. Southerly and westerly groundwater flow also discharges to the Cedar River via Tributary 316 and QCF Spring, and northerly groundwater flow discharges to Issaquah Creek via Mason Creek. There is no easterly component of groundwater flow because Aquifer 2 (and underlying aquifer units) pinches out directly east of the site (LAI 2007).

The Phase II and III Refill Projects have been designed to maintain infiltration patterns that are similar to pre-filling conditions. Infiltration that currently occurs from the Main Gravel Pit Lake will, in the future, be distributed as infiltration primarily to Queen City Lake/Aquifer 1, the East Airstrip Spring infiltration gallery, the East Retention Pond, and the South Retention Pond. This redistribution should cause the Aquifer 2 groundwater mound to move northward. However, the impact on the location of recharge will be moderate for the following reasons:

- The location of the mound is controlled to a large extent by geologic relationships. The relatively higher permeability of Aquifer 2 north of the Main Gravel Pit Lake directs infiltrating recharge to this area. This geologic control effect will also tend to direct East Retention Pond infiltration to this same area.
- The location of the mound is also strongly influenced by current levels of infiltration from Queen City Lake and Aquifer 1; recharge should increase slightly due to implementation of the Phase II and III Refill Projects.
- Redistribution of the Main Gravel Pit Lake infiltration will occur in close proximity to and around the current footprint of the Main Gravel Pit Lake.

While the Queen City Lake, Main Gravel Pit, and Maple Hills sub-basins are all within the surface watershed of the Cedar River, the groundwater beneath these sub-basins does not necessarily follow this same pattern. In particular, a significant portion of the groundwater flow beneath the Queen City Lake sub-basin is toward the north and Issaquah Creek via Mason Creek. Implementation of the Phase II and III Refill Projects will not significantly change the amount and location of recharge to Aquifer 2. Consequently, the amount of water flowing toward each discharge location will not significantly change.

Historically, large stormwater events within these three sub-basins have not resulted in downstream flooding problems within Cedar Grove Channel or Tributary 316A. This includes the December 1996/January 1997 rain-on-snow event that was reportedly a local 100-year runoff event. Direct

impacts to the Cedar River and Issaquah Creek are unlikely given the mitigating effect on peak discharge of infiltration. In summary, implementation of the Phase II and Phase III Refill Project plans is not expected to cause downstream drainage problems.

Prior to the Phase III Refill Project, the Main Infiltration Area received recharge from runoff in the Maple Hills sub-basin. This area also received some recharge from the Cedar Shores Pit via a culvert under the access road to the Cedar Grove Composting facility. During gravel mining of the Cedar Shores Pit, a large sedimentation pond collected runoff from a large portion of the pit (estimated to be about 70 acres).³ This sedimentation pond discharged to the Main Infiltration Area via the road culvert and an east-west trending ditch that lead from the culvert to the Main Infiltration Area (LAI 2007). This sedimentation pond has been removed. The TIR for the Cedar Shores Refill Project indicates that only 16.49 acres of stormwater discharge will occur from the Cedar Shores Pit to the (shared) Main Infiltration Area (Barghausen 2006). This is considered a significant reduction from historical conditions when gravel mining was active in this pit. As part of the Phase II and Phase III Refill Projects, stormwater will be routed to the Main Infiltration Area after treatment via the combined West Detention Facility and Wet Pond. The combined future flow to the Main Infiltration Area from the Cedar Shores Refill Project, the Phase II and Phase III Refill Projects, and the Maple Hills sub-basin is estimated to be at or below past discharge rates in this area. Consequently, the Main Infiltration Area will accommodate the amount of stormwater generated in the western portion of the refill.

Implementation of the Phase II and Phase III Refill Projects will include modifying the outflow structure from Queen City Lake. This modification is estimated to help mitigate (i.e., produce slightly higher water levels due to additional stormwater retention) impacts on wetland vegetation within the lake resulting from reduced stormwater flows from CHRL after landfill final closure. The outflow from Queen City Lake, up to and exceeding the 100-year flow frequency, will be fully infiltrated in the East Pond.

3.5 Mitigation of Existing or Potential Problems

The Phase III Refill Project is not anticipated to cause any stormwater drainage problems. Minor changes are anticipated to the Queen City Lake wetland; however, these impacts will be partly mitigated as discussed in Section 6.1. Accordingly, no mitigation for Phase III Refill Project impacts is proposed.

³ Approximately 50 acres on QCF property between the access road and the west QCF property line discharged to the sedimentation basin. Another approximately 20 acres from Cedar Shores property discharged to this basin. (Harrington 2007).

4.0 FLOW CONTROL, LOW IMPACT DEVELOPMENT AND WATER QUALITY FACILITY ANALYSIS AND DESIGN

The following sections include a summary of the existing site hydrology; expected hydrogeology of the site during and following refilling operations, a summary of the water quality and flow control systems including performance standards for each, and a summary of modeling results conducted as part of site improvement plans development.

4.1 Existing Site Hydrology

As described in Section 3.4, there are three drainage sub-basins on the QCF site (Figure 3A): the Queen City Lake sub-basin; the Maple Hills sub-basin, and the Main Gravel Pit sub-basin.

The principal historical surface water feature on the site is Queen City Lake, located on the north portion of the property. Review of aerial photographs since 1936 and US Geological Survey maps shows no historic surface water outlet from Queen City Lake (i.e., all the water in the lake infiltrated into the geologic materials). Including the changes that are proposed as part of the Phase III Refill Project (see Section 3.4), the Queen City Lake sub-basin is approximately 354 acres, approximately 280 acres of which are CHRL active or closed landfill areas. The remaining acreage is landfill buffer areas and wooded and wetland portions of the QCF property. The actual extent and attributes of this basin have continually changed since the 1960s due to landfilling activities. Consequently, stormwater runoff patterns have changed (see aerial photograph analysis discussion in the 2007 Talasaea Consultants report in Section 6.1). It is also the stated intent of SWD to return stormwater runoff conditions to 1979 conditions after closure of the landfill, currently projected for 2030. Therefore, the hydrologic modeling has been performed assuming forested land cover in this sub-basin.

In the late 1980s, mining formed a depression in the main gravel pit; the lake that formed in the depression became known as the Main Gravel Pit Lake. This man-made lake represents the surface expression of the regional aquifer (i.e., Aquifer 2); in the summer, the lake goes dry. The Phase II Refill Project will eliminate the seasonal Main Gravel Pit Lake, prior to commencing the Phase III Refill Project. Past mining also exposed a set of springs in the north face of the main gravel pit, known as the East Airstrip Spring or spring SP-4 (a, b, c, d). These springs represent discharge from the perched aquifer (i.e., Aquifer 1). The discharge from these springs flowed down the face of the main gravel pit into at rates as high as 1,000 gallons per minute (2.2 cfs). These springs will be rerouted to infiltration as part of the Phase II Refill Project, prior to commencing the Phase III Refill Project.

Historically, Tributary 316 flowed onto the QCF site from the northwest and discharged to Queen City Lake and infiltrated into permeable soil at the west end of the lake. As part of mining activities, Tributary 316A was rerouted from its historical discharge location south across the site in an engineered ditch or channel where it infiltrated at the Main Infiltration Area within the Cedar Grove Channel. The Main Infiltration Area is a natural recharge area that is capable of infiltrating very high

volumetric rates. In addition to Tributary 316A, high stormwater flow from the adjacent Cedar Shores Pit has historically been directed to the Main Infiltration Area.

The only surface water outlet from the site is the QCF Spring. Groundwater that infiltrates on-site discharges directly to the Cedar River, discharges to the Cedar River via Tributary 316, or discharges to Issaquah Creek via Mason Creek. In particular, surface water that infiltrates at the Main Infiltration Area appears to discharge predominantly at the QCF Spring. The spring discharge flows into Wetland 31 via a culvert underneath Cedar Grove Road. Wetland 31 is part of the wetland and stream complex that discharges to the Cedar River via Tributary 316 at the west end of the Cedar Grove Channel.

4.2 Developed Site Hydrology

Up to 80 ft of fill will be placed to achieve final grades of the Phase III Refill Project. The site will be refilled to the final elevations shown on the site improvement plans. The hydrology and stormwater management from the Phase III Refill Project will be managed with engineered ditches, detention, and infiltration elements. Some of these have been permitted and will be constructed as part of the Phase I and Phase II Refill Projects. The goal of this system is to manage stormwater run-on to the site as well as site-derived stormwater through full on-site infiltration to the maximum extent possible, as noted below. The ability of infiltration to be accommodated in the subsurface soil and aquifer was assessed as part of Phase II Refill Project permitting (LAI 2007):

- Tributary 316A will be restored to its original discharge location at and near Queen City Lake.
- The current outflow for Queen City Lake will be modified during the Phase II Refill Project to route stormwater overflow from Queen City Lake at lake levels above elevation 451.6 ft (North American Vertical Datum of 1988 [NAVD88]) to the East Retention Pond (see site improvement plans in Appendix B). The modification will: 1) slightly increase the average water level in the lake compared to the Phase II Refill Project, 2) retain and infiltrate stormwater runoff in Queen City Lake during extreme storm events, and 3) control the maximum lake level (and hence, the amount of infiltration to Aquifer 1) to minimize potential impact to the Superfund Site slurry wall.
- The East Retention Pond (East Stormwater Facility) will be constructed at the east end of the site. This facility will be enlarged for the Phase III Refill Project. The modified Queen City Lake outflow will be discharged to this infiltration pond. The East Retention Pond will overflow to the infiltration/conveyance channel along Cedar Grove Road SE being constructed and maintained by SWD (King County 2006). This channel is connected to Wetlands 31 and 56 via five culverts underneath Cedar Grove Road SE. The ditch and wetlands represent the current natural discharge path for stormwater overflows from the QCF site.
- The South Retention Pond and Bioswale (South Stormwater Facility) will be constructed as part of the Phase II Refill Project to collect and infiltrate runoff from the reclaimed area. This facility will overflow to the Main Infiltration Area.
- The West Stormwater Detention Facility and Wet Pond (West Stormwater Facility) will be constructed as part of the Phase II Refill Project to collect runoff from the reclaimed area. This

facility will overflow to the Main Infiltration Area. These ponds will be modified for Phase III to provide the same detention and treatment volume, but outside of the Phase III footprint.

- The existing engineered drainage channel portion of Tributary 316A will be converted to a French drain that will be covered by fill. The purpose of the French drain will be to convey limited stormwater generated in the area between the Compost Facility and the Compost Pad to the Main Infiltration Area. Also, the French drain may serve as a conduit for emergency overflow from the Compost Pad infiltration area, although it is not sized specifically for this flow.
- Portions of the Phase III refill area will drain to existing stormwater ponds that were permitted and constructed as part of the Phase I (Cedar Shores) development. Other areas that previously drained to these ponds will be rerouted to the Phase II or III drainage features. These areas are shown on Figure 3B. The net change in areas will not increase the flow or impact the water quality entering the Phase I ponds.

The existing permitted and proposed stormwater management features are shown in the site improvement plans (Appendix B).

4.2.1 Queen City Lake Changes

As permitted for the Phase II Refill Project, a new 24-inch outflow pipe would be installed with an invert at elevation 451.6 ft (NAVD88). An outlet structure would be installed in Queen City Lake that is sized to discharge approximately 2 cfs. However, during large storm events, the Lake's natural storage capacity would be used to detain stormwater, up to a maximum depth of about 8.5 ft during the 100-year event. This outlet structure would have an emergency overflow to accommodate greater than the 100-year event (LAI 2007).

For the Phase III Refill Project, additional surface flow will be routed to Queen City Lake from the Tributary 316A drainage basin. Therefore, the proposed outlet structure will be modified to pass up to the 100-year flow, while still maintaining the maximum water level in the Lake below 9 ft, which is necessary to protect the adjacent QCF Superfund Site barrier wall. The design and sizing of the outlet structure is described in Section 6.10. The effect on Queen City Lake water levels is presented in Section 6.1.

4.3 Performance Standards

This section addresses requirements contained within the KCSWDM (King County 2016). The TIR briefly discusses the application of various performance standards to the proposed Phase III Refill Project.

4.3.1 Area-Specific Flow Control Facility Standard

Projects subject to Core Requirement #3 of the KCSWDM must provide flow control facilities as specified by area-specific facility requirements (i.e., performance standards) for the designated flow control area in which the project is located. The QCF property is located within a Conservation Flow

Control Area, as shown on the Flow Control Applications Map included within the KCSWDM. The minimum requirement for projects within a Conservation Flow Control Area is to provide Level 2 Flow Control for sizing stormwater detention facilities. However, the South Stormwater Facility (South Pond) and the East Stormwater Facility (East Pond) are each designed to infiltrate the 100-year peak rainfall event; therefore, flow control requirements are met through 100 percent infiltration.

4.3.2 Flow Control Best Management Practice Requirements

Projects subject to Core Requirement #3 of the KCSWDM must also apply flow control BMPs to impervious surfaces. However, requirements for flow control BMPs do not apply to this project because of the infiltration facility exemption, which exempts these requirements if runoff from the impervious surface will be managed by an infiltration facility. The project does include replacement of approximately 2 acres of pollution generating impervious surface, which is the existing access road to the Cedar Grove Compost Facility. Runoff from this road will be directed to the West Pond or to the permitted Phase I stormwater ponds, which are sized to provide treatment for this runoff.

4.3.3 Conveyance System Capacity Standards

Projects subject to Core Requirement #4 of the KCSWDM must analyze, design, and construct new conveyance systems in accordance with requirements contained in KCSWDM Section 1.2.4.1, which stipulates that conveyance systems (e.g., pipe systems, culverts, ditches/channels) be designed to convey and contain (at minimum) the 25-year peak flow. Conveyance systems for this project were designed using a 100-year peak flow, thereby exceeding the standard. Design calculations are presented in Section 6.11.

4.3.4 Area-Specific Water Quality Treatment Menu

Projects subject to Core Requirement #8 of the KCSWDM must provide water quality treatment facilities to remove pollutants from runoff discharging from a project site in accordance with one of three area-specific water quality facility requirements found in the Manual. The project site is located within the water quality treatment area referred to as the Basic Water Quality Treatment Area, which includes a treatment goal of 80 percent removal of total suspended solids for a typical rainfall year. A portion of the Phase III project is also located within a Critical Aquifer Recharge Area and a Sensitive Lake Water Quality Treatment Area, as shown on Figure 5. Water Quality treatment is provided as described in Section 2.1.8.

The West Stormwater Facility, which employs a wet pond and the South Stormwater Facility, which employs a biofiltration swale were permitted as part of the Phase II Refill Project using this treatment goal. Basic Water Quality Treatment Area standards were not applied to the East Stormwater Facility because this facility only accepts outflow water from Queen City Lake, and adequate water quality treatment is provided in the lake. The Lake also receives direct sheet flow runoff from portions of the Phase III fill area, and provides basic water quality treatment for these flows as a Stormwater Wetland.

4.3.5 Source Control and Oil Control

Special Requirement #4, Source Controls, include both structural source controls and nonstructural source controls. In general, these controls will be addressed in the SWPPP prepared in accordance with the Sand and Gravel General Permit for the facility. Special Requirement #5 in the KCSWDM, Oil Control, does not apply to this project because the project is not a “high-use site” with respect to oil generation.

4.4 Flow Control System (Stormwater Control Facilities)

The existing permitted stormwater management system includes outflow structures, conveyance pipes, ditches, sedimentation ponds, and infiltration/retention ponds. The entire site is designed to discharge to infiltration, or to previously permitted flow control facilities, and so providing additional stormwater flow control was not a requirement for Phase III. The infiltration basins do have emergency overflows to the County’s stormwater management ditch along Cedar Grove Road SE.

Queen City Lake will have a proposed two-stage outlet structure that will provide some flow control to the discharge reaching the East Stormwater Basin; however, this was not a KCSWDM requirement.

The site improvement plans (Appendix B) show the permitted and proposed stormwater control facilities.

4.5 Water Quality System

The quality of stormwater will be managed primarily through retention and infiltration of site stormwater. Basic water quality treatment is incorporated into all stormwater management features proposed for the Phase III Refill Project. Temporary erosion and sediment control will be implemented during filling to reduce the amount of sediment that reaches the stormwater infiltration basins.

The site improvement plans (Appendix B) show the permitted and proposed stormwater control facilities.

4.6 Stormwater Management Modeling

Stormwater runoff modeling was conducted to estimate the effect of changes in the Queen City Lake, Tributary 316A, and the Main Gravel Pit (Refill area) sub-basins, to address stormwater management requirements and (for Queen City Lake) wetland vegetation impacts. The Western Washington Hydrologic Model (WWHM) was used to model stormwater control and conveyance structures, including the Queen City Lake outlet control structure and the Tributary 316A channel, and simulate Queen City Lake water levels to determine potential impacts to wetland vegetation. This modeling is described in Sections 6.1, 6.10, and 6.11.

To support hydrologic modeling, the topography of Queen City Lake was surveyed while it was dry during the summer of 2006 to facilitate effective modeling of Queen City Lake capacity and wetlands evaluation (LAI 2007). Infiltration rates based on previous observations for various Queen City Lake water elevations were incorporated into the modeling. A discussion of how infiltration rates were determined is presented in Section 6.3.

5.0 CONVEYANCE SYSTEM ANALYSIS AND DESIGN

Proposed conveyance systems for the site consist of an outflow pipe from Queen City Lake and a series of temporary and permanent open channels that will ultimately convey drainage by gravity flow to the stormwater retention or detention ponds. Temporary sediment traps and rock check dams will be constructed to help control the migration of sediment downstream. Site improvement plans (Appendix B) show temporary and permanent stormwater conveyance elements for the Phase III Refill Project.

5.1 Open Channels

The proposed temporary and permanent open ditch conveyance systems are to be constructed with 2-ft bottom widths and 2H:1V (horizontal to vertical) side slopes, and will provide for a 12-inch depth of flow with 6 inches of freeboard. The standard ditch will be constructed with an approximately 1 percent minimum slope. This design is based on the ESC measures/standards for surface water collection described in Section D.2.1.5.4 of the KCSWDM.

Permanent open ditch conveyances will use the same design. These permanent ditches will be constructed on top of the hydroseeded fill areas, where shown on the site improvement plans. These permanent ditches are sized to convey the 25-year peak flow from up to 32 acres of contributing area, based on the Rational Method sizing.

Rock lined downchute channels will be constructed in designated locations to intercept the side slope ditches, where shown on the site improvement plans.

Calculations for the open channel ditches are provided in Section 6.11.

5.2 Sediment Traps

Sediment ponds are detailed on the site improvement plans (Appendix B) and will be properly maintained in accordance with the KCSWDM. However, adjustments to the sizing of the sediment ponds have been made to accommodate the particular conditions of the refilling operation. This design is based on the ESC measures/standards for sediment retention described in Section D.2.1.5.1 of the KCSWDM.

5.3 Pipes

An outflow structure and pipe is used to route the high stage outflow and emergency outflow from Queen City Lake. The water will be conveyed by a pipeline to the East Retention Pond. Modeling results and information used to design the outflow structure and pipe are summarized in Section 6.10.

5.4 French Drain

A French drain will be constructed at the location of the existing engineered channel of Tributary 316A and covered by fill. As discussed in Section 4.2, the purpose of the French drain will be to convey limited stormwater generated in the area between the Compost Facility and the Compost Pad (approximately 13 acres) to the Main Infiltration Area. It may also provide a conduit for emergency overflow from the Compost Pad infiltration pond, although it is not sized for these flows. The French drain sizing calculations can be found in Section 6.11. The main intention of the design was to provide conveyance to the Main Infiltration Area. A subdrain pipe was added to the design because it was determined in the French drain sizing calculations that drainage gravel alone would not have adequate flow capacity to convey the 100-year flow rate of the proposed drainage area.

6.0 SPECIAL REPORTS AND STUDIES

The following sections describe special reports included in this TIR that support project plan analysis and design.

6.1 Wetlands Study

The Talasaea study of Queen City Lake wetland (Talasaea 2007) presented conclusions and recommendations related to impacts of the Phase II Refill Project on wetland vegetation. The evaluation used King County Runoff Time Series (KCRTS) modeling of the Queen City Lake sub-basin to estimate water levels in Queen City Lake and design the outflow structure and associated piping. The WWHM was used to establish wetland hydroperiods. The report concludes that the existing wetland plant community will respond to modified lake levels that are predicted to occur in the future caused by enhanced stormwater control facilities being constructed within the uphill basin area on CHRL. These changes will result in lower water levels in Queen City Lake. LAI prepared a technical memorandum titled “Queen City Lake Wetland Hydroperiod Analysis” to update the Talasaea study to account for the Phase III project. To provide a direct comparison to the Talasaea study, LAI used KCRTS to model surface water inflows to the Lake. This updated analysis investigated three different model scenarios (Scenario 1: pre-developed, Scenario 2: Phase II developed, and Scenario 3: Phase III developed), to compare the relative magnitude of the hydrologic changes. It concluded that implementation of the Phase III Refill Project will tend to mitigate the impacts of lower water levels somewhat; however, the combined effect of changes on CHRL and implementation of the Phase II and Phase III Refill Projects is predicted to result in lower lake water levels.

Because KCRTS is not an approved hydrologic model under the 2016 KCSWDM, LAI performed an analysis to confirm the results of Scenario 3 (with surface water inputs modeled in KCRTS) were at least as conservative as lake level modeling with surface water inputs modeled in WWHM. This analysis is described in the Drainage Adjustment Request (Appendix I).

This analysis demonstrates that the modeled lake level data from Scenario 3a is at least as conservative, if not more so, in terms of protecting wetland hydrology compared to Scenario 3b.

6.2 Geology, Surface Water Hydrology, and Groundwater Hydrology

This technical memorandum was developed for the Phase II TIR (LAI 2007) and presents a summary of geologic, surface water, and groundwater conditions in the vicinity of the Phase III Refill Project. An understanding of the geologic, surface water, and groundwater conditions is necessary to support stormwater management design and geotechnical engineering recommendations associated with the

project. This summary of site geology and hydrology is based in part on the results of previous hydrologic and geologic studies of the QCF property and adjacent properties.

6.3 Queen City Lake Infiltration Rates

This technical memorandum was developed for the Phase II TIR (LAI 2007) and summarizes calculated estimates of Queen City Lake infiltration rates per unit area based on different lake depths. Infiltration rates per unit area range from an estimated 0.13 inches per hour (in/hr) to 0.17 in/hr when the lake depth is between 0 ft and 7 ft and 0.45 in/hr to 0.9 in/hr when the lake depth is between 7 ft and 9 ft. This information supports the modeling of the Queen City Lake Sub-basin to develop the outlet structure design. A Drainage Adjustment (see Appendix I) is being requested to support the use of historic infiltration data as presented in the 2007 memorandum.

6.4 Geotechnical Slope Stability Evaluation

This technical memorandum is an evaluation of the stability of fill slopes to be constructed as part of the Phase III Refill Project. The Phase III Refill Project specifies use of maximum 4H:1V fill slopes along the southern boundary of the planned fill zone. The stability evaluation indicates that the planned 4H:1V fill slopes will be stable and have adequate factors of safety under static loading conditions, provided the fill materials are placed and compacted as recommended and stormwater is managed in accordance with the project refill plan. During a design seismic event without liquefaction, an estimated soil displacement of up to 2 ft may occur along some portions of the Phase III Refill Project boundaries. Widespread liquefaction of the import fill during the design seismic event appears unlikely. However, localized zones of liquefaction may occur, which could result in localized slope displacement on the order of several tens of feet. To minimize the possibility of liquefaction and liquefaction-induced flow failure, or if better slope performance during the design seismic event is required, quality control and compaction requirements can be established for the Phase II and Phase III import fill.

Recommended quality control and compaction requirements to improve seismic stability include fill gradation and moisture content requirements, deleterious material rejection, maximum allowable loose-lift thicknesses, and compaction by routing haul traffic over newly placed fill. Specifically, the following requirements are included on the site development plans:

- Fill materials should primarily consist of non-organic soil and non-degradable well-graded materials with a maximum irreducible dimension of approximately 2 ft.
- Loose lifts should be limited to 2 ft.
- Wet fill material should be spread and dried to near optimum water content prior to placement, and subgrade accepting new fill should be near optimum water content prior to placement of overlying fill.

- Each lift should be compacted by routing haul traffic or mechanized equipment prior to placement of subsequent fill. Each lift should be proof rolled with a fully-loaded dump truck and the resulting permanent rutting should be less than 2 inches.

The site will not be developed following completion of fill placement. A covenant or similar deed restriction will be required prior to completion to provide notification that no development will be allowed.

6.5 Evaluation of Proposed Refill Plan on Groundwater Contamination

This technical memorandum was developed for the Phase II TIR (LAI 2007). It describes the current groundwater contamination remedy at the QCF Superfund Site and provides an analysis of potential impacts to groundwater expected during implementation of the Phase III Refill Project. Impacts to groundwater are not expected as a result of implementation of the Phase III Refill Project.

6.6 Tributary 316A Historical Discharge

This technical memorandum summarizes the historical hydrology of Tributary 316A, a small intermittent drainage channel that flows on to the QCF property and that was channelized and routed to facilitate gravel mining operations. The purpose of this memorandum is to document the historical location of Tributary 316A discharge and discuss how the restoring this point of discharge will have a net positive ecological benefit by restoring seasonally steady recharge patterns to the wetland-stream complex in Cedar Grove Channel that is tributary to the Cedar River.

6.7 Evaluation of Higher Water Levels in Queen City Lake on the Existing Queen City Farms Vertical Barrier Wall System

This technical memorandum was developed for the Phase II TIR (LAI 2007) and provides an evaluation of the potential effect of higher peak water levels in Queen City Lake on the existing vertical barrier wall system at the QCF Superfund Site. The evaluation concludes that the planned higher water levels in Queen City Lake will not adversely affect the performance of the QCF vertical barrier wall system. This memorandum was developed based on the Phase II hydrologic modeling of Queen City Lake levels; however, the Phase III Queen City Lake level modeling shows that the water level will not exceed the Phase II maximum level, and so the conclusions of this 2007 analysis are still valid.

6.8 Infiltration Evaluation

This technical memorandum was developed for the Phase II TIR (LAI 2007) and presents geotechnical evaluations for infiltration of surface water at the property. It includes a review of geological and geotechnical information in the project area, a summary of additional subsurface explorations and infiltration tests performed at the property, a summary of geotechnical laboratory testing of site soil,

and geotechnical conclusions and recommendations for infiltration of surface water runoff at the property.

A Drainage Adjustment (see Appendix I) is being requested to support the use of historic infiltration data as presented in the 2007 memorandum.

6.9 Best Management Practices for Reclaiming Surface Mines

Although the Phase III Refill Project will be accomplished under a DPER Grading Permit and not a WDNR reclamation permit, several best management practices (BMPs) for reclaiming surface mines will be applicable, and will be used as appropriate.. The electronic file for the WDNR Open File Report number O-96-2, Best Management Practices for Reclaiming Surface Mines in Washington and Oregon, is attached in pdf format on a DVD.

6.10 Queen City Lake Storage Routing and Water Level Analysis

This technical memorandum summarizes WWHM modeling results for the Phase III Refill Project, including changes to the drainage basins and the restoration of Tributary 316A to its natural discharge location in and near Queen City Lake. This report presents the results of updated Queen City Lake sub-basin stormwater modeling using WWHM, including:

- WWHM modeling results/output files for the peak inflows to Queen City Lake;
- Design flow for the outlet structure from Queen City Lake.

6.11 Stormwater Calculations

This section includes calculations for the Phase III new or modified stormwater management facilities, including:

- Tributary 316A flow modeling in WWHM;
- Tributary 316A restoration channel sizing and material selection;
- Bypass conveyance pipe sizing calculations for Queen City Lake;
- East Stormwater Facility detention and infiltration calculations;
- East stormwater facility energy dissipater calculations;
- French drain discharge to the Main Infiltration Area; and
- Erosion control channel sizing.

WWHM Reports are also included in this section, which includes the modeling inputs.

6.12 Restoration of Tributary 316A and Impacts on Existing Wetlands

This memorandum describes the assessment of existing wetlands and the impacts of restoring Tributary 316A, which will be updated with more recent data collected in March 2019 from all the wetlands. The assessment was only qualitative, therefore a hydrological analysis will be completed using either hydrologic modeling or data collection, or a combination of both. LAI expects that DPER will issue the Phase III permit with the condition that an updated wetland memorandum and hydrological analysis will be completed prior to beginning Phase III operations.

Existing wetlands were delineated as described in the memorandum.

7.0 OTHER PERMITS

Several permits apply to different aspects of implementation of the Phase III Refill Project. No rezones, conditional use permits, variances, shoreline master development permits, plats, short plats, or lot line adjustments are needed for this proposed project. The existing permits and the permit requirements are summarized in the following sections.

7.1 Washington State Department of Natural Resources Surface Mining

The Application and Conditions from 1972 guided the original mining activities. The revised WDNR Surface Mining Reclamation Permit Conditions (WDNR Revised Permit No. 70-010880, dated January 13, 1999) was rescinded on March 27, 2011 and replaced by County grading permit GRDE15-0053. The Surface Mine Reclamation regulations (Washington Administrative Code [WAC] 332-18) and Reclamation Practices Manual (Best Management Practices for Reclaiming Surface Mines in Washington and Oregon (ODGMI and WDNR 1997), which document BMPs for reclamation activities, are generally used for guidance in the Phase III operations even though the WDNR permit is no longer active.

7.2 King County Department of Permitting and Environmental Review

Previous permits and approvals from DPER, formerly DDES, that apply to the Queen City Farms Phase II and Phase III Refill Projects include:

- DDES permits for mining at the Cedar Shores Gravel Mine (which included the property where the Queen City Farms Phase II and Phase III Refill Projects are located) including Grading Permit No. 1249-26; and Renewal No. 1249-657 with Grading Permit Conditions from 1992.
- DPER Permit No. GRDE15-0053, Cedar Shores Mine Refill (Phase I of the refill project). Previously permit No. L03CG141.
 - Note that the Phase I TIR and site improvement plans were revised and approved April 15, 2009.
- DPER Permit No. GRDE15-0214, The Queen City Pit Refill, a continuation of Permit #1498-43, is Phase II of the refill project. Previously permit No. L04CG384.
- DPER Permit No. L12GI017, Cedar Grove Composting Proposed Finished Product Storage Pad Project.
- DPER Permit No. PREA19-1093, Cedar Grove Composting Infiltration Pond Grading.

7.3 Washington State Department of Ecology

Permits and approvals from Ecology include:

- The Sand and Gravel Mine General Stormwater Permit No. WAG-50-3070. This permit currently covers the Phase I Refill Project. Appropriate notification will be submitted to Ecology to describe site changes associate with Phases II and III Refill Projects.
- WAC 173-508 Instream Resources Protection Program, Cedar – Sammamish Basin, Water Resource Inventory Area (WRIA) 8 addresses in-stream flows and limits groundwater withdrawals that may affect in-stream flows. The project approach to infiltrate the majority of site stormwater will assist in maintaining groundwater recharge to the Cedar River. Information related to the Cedar River Basin was also introduced for the adjacent Stoneway Fill Project documents (Barghausen 2006).

7.4 Washington State Joint Aquatic Resources Permit Application

Permits and approvals included under the Washington State Joint Aquatic Resources Permit Application (JARPA) include:

- Washington Department of Fish & Wildlife Hydraulic Project Approval (HPA)
- Ecology Section 401 Water Quality Certification
- U.S. Army Corps of Engineers permits: NWP 27 (Aquatic Habitat Restoration, Enhancement, and Establishment Activities), Section 404 (discharges into waters of the US).

8.0 CONSTRUCTION STORMWATER POLLUTION PREVENTION PLAN ANALYSIS AND DESIGN

This section of the TIR outlines the administrative and technical approach for managing construction stormwater during the reclamation period. Management of construction stormwater at the Phase III Refill Project site will primarily be achieved through continued implementation of the requirements of Ecology's Sand and Gravel General Permit. The Cedar Shores site is currently covered under this permit (WAG-503070) as part of the joint operating agreement between Stoneway and QCF. This permit covers the management of stormwater at the site during both the mining and reclamation/refill periods. A primary requirement of the Ecology Sand and Gravel General Stormwater Permit is the development and implementation of a SWPPP for the facility to include, among other components, an ESC plan. The existing SWPPP for the Stoneway/QCF facility will be modified for the Phase III Refill Project, following approval of the necessary permits to commence reclamation/refill but prior to actual reclamation/refill activities. LAI anticipates that modifying the Sand and Gravel General Permit WAG-503070 and preparing a modified SWPPP for Phase III will be required by DPER as a condition of the Phase III Grading Permit.

Several technical documents that describe construction stormwater BMPs are considered potentially applicable to the Phase III Refill Project. These include:

- Western Washington Stormwater Management Manual (Ecology 2014). The Sand and Gravel General Permit requires BMPs to be consistent with the BMPs contained in this manual.
- Best Management Practices for Reclaiming Surface Mines in Washington and Oregon (ODGMI and WDNR 1997).
- Erosion and Sediment Control Standards (King County 2016; Appendix D). Core Requirement #5 of the KCSWDM references these BMPs.

In general, each of these manuals contains similar objectives and technical approaches to managing construction stormwater. In each case, erosion control (i.e., through site stabilization measures such as covering of disturbed soil) is emphasized over sediment control as the most effective means of managing stormwater. The proposed general approach to managing stormwater during the reclamation/refill period (described above) complies with each of the above technical manuals.

The remainder of this section describes the general technical approach that will be included in the SWPPP to manage stormwater during the reclamation period. The erosion and sediment control approach will emphasize retaining and infiltrating all stormwater on-site. The general approach will include the use of a refill plan that maximizes the amount of runoff that will be directed toward the existing Main Gravel Pit Lake, where the water will readily infiltrate and not be discharged to surface water. This approach is illustrated on the refilling sequence shown on the site improvement plans (Appendix B), which show refilling initially being conducted along the east and south perimeters (Phase 1) and progressing toward the north. All runoff will initially be conveyed to temporary sediment control ponds constructed at appropriate locations near the refill area, as shown on

Drawing C4. As refilling proceeds to higher fill layers, the sediment ponds may need to be filled and relocated to accommodate the changing grades.

Erosion control methods (e.g., mulching, covering with plastic sheeting, etc.) will be relied on heavily to limit runoff of turbid water during the reclamation period. Any lift that completes the proposed grades, as shown on the site improvement plans (Appendix B), will be immediately hydroseeded and stabilized. Perimeter sediment control measures, including silt fencing and the use of check dams in perimeter ditches, will also be used as shown on the site improvement plans.

9.0 BOND QUANTITIES, FACILITY SUMMARIES, AND DECLARATION OF COVENANT

This section discussed the applicability of bond quantities, facility summaries, and declaration of covenants for stormwater facilities.

9.1 Bond Quantities Worksheet

A draft Bond Quantities Worksheet is attached as Appendix D. The ongoing Phase III work may affect timing of the release of portions of the financial guarantees required for the Phase II permit.

9.2 Stormwater Facility Summary Sheet

Stormwater Facility Summary Sheets for each Natural Discharge Location are provided in Appendix G. These include existing or previously permitted WQ facilities that are being modified or utilized by the Phase III Refill Project.

9.3 Declaration of Covenant for Privately Maintained Flow Control and Water Quality Facilities

Because the Phase III Refill Project includes shared facilities offsite and proposes to modify previously permitted facilities on-site, an updated drainage facility declaration of covenant (KCSWDM Reference 8-J) is provided in Appendix H.

9.4 Declaration of Covenant for Privately Maintained Flow Control Best Management Practices

No new flow control best management practices are proposed as part of the Phase III Refill Project.

10.0 OPERATIONS AND MAINTENANCE PLAN

The implementation of refilling of the QCF gravel pit will be in accordance with the general construction sequence outlined on the site improvement plans (Appendix B). The Operations and Maintenance (O&M) Plan developed for this project will use similar procedures to those approved for the Cedar Shores Refill Project, a companion project to the Phase III Refill Project. In addition to the physical management of fill materials and control of stormwater quantity and quality, the O&M procedures for the project will address the environmental quality of soil materials accepted as fill. This section also presents a summary of the planned fill material acceptance policy.

10.1 Operations and Maintenance Procedures

Enclosed in Section 6.9 of this TIR is the WDNR Manual presenting the BMPs for Reclaiming Surface Mines in Washington and Oregon. This WDNR manual discusses general maintenance and reclamation procedures. The general O&M manual outlined in Appendix A (attached) of the KCSWDM provides many elements of operations and maintenance for a filling site.

The project anticipates that specific procedures for placing fill material; grading; constructing temporary roads and stormwater controls; reclaimed area vegetation requirements; maintenance of facilities; mitigation (if needed); and monitoring will be developed following approval of the site refilling plans. The requirements and applicable guidelines are included in the site improvement plans (Appendix B).

10.1.1 Bioswale Maintenance Considerations

The Phase III Refill Project includes the use of a bioswale (upstream of the South Pond) for treatment of stormwater. Erosion controls within the Phase III fill area will reduce the amount of sediment entering the bioswale.

Bioswale maintenance will occur in accordance with Section 6.3.1.2 of the KCSWDM, which includes “routine mowing, sediment and debris removal, and repair of eroded or scoured channel sections as described below:

1. Grass should be mowed to maintain an average grass height between 4 inches and 9 inches, depending on the site situation. Monthly mowing is needed from May through September to maintain grass vigor. If a swale is not mowed at least annually, trees and brush will invade the swale and inhibit grass growth, compromising the swale's performance for water quality treatment.
2. Grass clippings should be removed from the swale and composted onsite (away from the swale), or disposed of properly offsite.
3. Sediment deposited at the head of the swale should be removed if grass growth is being inhibited for more than 10 percent of the swale length or if the sediment is blocking the even

spreading or entry of water to the rest of the swale. Annual sediment removal and spot reseeded will probably be necessary.

4. If flow channelization or erosion has occurred, the swale should be regraded to produce a flat bottom width, and then reseeded as necessary. If the channel results from constant base flow, it may be better to install a low-flow drain rather than to regrade. Regrading should not be required every year.
5. For swales with underdrains, vehicular access to the swale bottom (other than grass mowing equipment) should be avoided because the drainpipe cannot support vehicle weight. Consideration should be given to providing wheel strips in the swale bottom if access is needed.”

10.2 Fill Material Acceptance Policy

The intent of the Phase III Refill Project is to accept clean soil material. To assist with this intent, soil acceptance documentation and inspection will be conducted. Prior to delivery, clean soil fill material will be certified to be free of hazardous substances, as defined in Ecology Regulations WAC 173-340; radioactive, dangerous or extremely hazardous wastes, as defined in WAC 173-303; and solid wastes, as defined in WAC 173-350 and 173-351. To provide water quality protection, no recycled asphalt will be accepted for placement within the CARA area of Phase III. A Fill Material Acceptance Agreement will be signed by an owner or officer of the originating company.

All fill material is subject to inspection and sampling prior to acceptance at the property. Sampling may be a requirement of the originating company, prior to acceptance of the fill material at the QCF site. Any material not meeting the above-stated criteria will be rejected, and the originating company will be responsible for the removal and disposal of any rejected material. Rejected fill material will be removed from the property within 24 hours of notifying the originating company.

11.0 USE OF REPORT

This TIR has been prepared for the exclusive use of QCF, for specific application to the Phase III Refill Project. No other party is entitled to rely on the information, conclusions, and recommendations included in this document without the express written consent of QCF and LAI. Further, the reuse of information, conclusions, and recommendations provided herein for extensions of the project or for any other project, without review and authorization by LAI, shall be at the user's sole risk. LAI warrants that within the limitations of scope, schedule, and budget, our services have been provided in a manner consistent with that level of care and skill ordinarily exercised by members of the profession currently practicing in the same locality under similar conditions as this project. We make no other warranty, either express or implied.

12.0 REFERENCES

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- LAI. 2007. Technical Information Report, Queen City Farms Refill Project, Cedar Grove Road SE, King County, Washington. Landau Associates, Inc.
- ODGMI and WDNR. 1997. Best Management Practices for Reclaiming Surface Mines in Washington and Oregon. Oregon Department of Geology and Mineral Industries and Washington State Department of Natural Resources.
- Smayda. 2005. Cedar Shores Refill - Queen City Farms Offsite Flow Bypass Plan. Smayda Environmental Associates, Inc.

Talasaeta. 2007. Potential Changes to Plant Communities Resulting from Hydrologic Changes to Queen City Lake, Queen City Farms, King County, Washington. Talasaeta Consultants, Inc.

USDA NRCS. 2017. Web Soil Survey. US Department of Agriculture Natural Resources Conservation Service.

TECHNICAL INFORMATION REPORT (TIR) WORKSHEET

Part 1 PROJECT OWNER AND PROJECT ENGINEER	
Project Owner	Queen City Farms
Phone	Stephan Banchero, 206-832-3001
Address	7343 East Marginal Way South Seattle, WA 98108
Project Engineer	Katie Saltanovitz, P.E.
Company	Landau Associates, Inc.
Phone	425-329-0268

Part 2 PROJECT LOCATION AND DESCRIPTION	
Project Name	Queen City Farms Refill
DPER Permit #	GRDE18-0048
Location Township	23 N
Range	6 E
Section	28
Site Address	17825 Cedar Grove Rd SE King Cty, WA

Part 3 TYPE OF PERMIT APPLICATION	
<input type="checkbox"/>	Landuse (e.g., Subdivision / Short Subd. / UPD)
<input type="checkbox"/>	Building (e.g., M/F / Commercial / SFR)
<input checked="" type="checkbox"/>	Clearing and Grading
<input type="checkbox"/>	Right-of-Way Use
<input type="checkbox"/>	Other _____

Part 4 OTHER REVIEWS AND PERMITS			
<input type="checkbox"/>	DFW HPA	<input type="checkbox"/>	Shoreline Management
<input type="checkbox"/>	COE 404	<input type="checkbox"/>	Structural Rockery/Vault/_____
<input type="checkbox"/>	DOE Dam Safety	<input type="checkbox"/>	ESA Section 7
<input type="checkbox"/>	FEMA Floodplain	<input type="checkbox"/>	
<input checked="" type="checkbox"/>	COE Wetlands		
<input checked="" type="checkbox"/>	Other SEPA Review		

Part 5 PLAN AND REPORT INFORMATION			
Technical Information Report		Site Improvement Plan (Engr. Plans)	
Type of Drainage Review (check one):	<input checked="" type="checkbox"/> Full <input type="checkbox"/> Targeted <input type="checkbox"/> Simplified <input type="checkbox"/> Large Project <input type="checkbox"/> Directed	Plan Type (check one):	<input checked="" type="checkbox"/> Full <input type="checkbox"/> Modified <input type="checkbox"/> Simplified
Date (include revision dates):	4/10/18 Rev - 8/30/19	Date (include revision dates):	4/10/18 Rev - 8/30/19
Date of Final:	_____	Date of Final:	_____

Part 6 SWDM ADJUSTMENT APPROVALS	
Type (circle one):	Standard / Experimental / Blanket
Description: (include conditions in TIR Section 2)	

Approved Adjustment No.	Date of Approval:
_____	_____

TECHNICAL INFORMATION REPORT (TIR) WORKSHEET

Part 7 MONITORING REQUIREMENTS

Monitoring Required: Yes / <input checked="" type="radio"/> No Start Date: _____ Completion Date: _____	Describe: _____ _____ Re: KCSWDM Adjustment No. _____
---	---

Part 8 SITE COMMUNITY AND DRAINAGE BASIN

Community Plan : Tahoma-Raven
 Special District Overlap: Heights N/A
 Drainage Basin: Issaquah Creek and Lower Cedar River
 Stormwater Requirements: N/A

Part 9 ONSITE AND ADJACENT SENSITIVE AREAS

<input checked="" type="checkbox"/> River/Stream <u>Cedar River, Tributary 316A</u>	<input type="checkbox"/> Steep Slope _____
<input checked="" type="checkbox"/> Lake <u>Queen City Lake</u>	<input type="checkbox"/> Erosion Hazard _____
<input checked="" type="checkbox"/> Wetlands <u>Adjacent to Project Area</u>	<input checked="" type="checkbox"/> Landslide Hazard _____
<input type="checkbox"/> Closed Depression _____	<input type="checkbox"/> Coal Mine Hazard _____
<input type="checkbox"/> Floodplain _____	<input type="checkbox"/> Seismic Hazard _____
<input checked="" type="checkbox"/> Other <u>Adjacent Queen City Farms Superfund Site</u>	<input type="checkbox"/> Habitat Protection _____
	<input type="checkbox"/> _____

Part 10 SOILS

Soil Type	Slopes	Erosion Potential
<u>Alderwood gravelly sandy loam</u>	<u>8 - 15%</u>	<u>Moderate</u>
<u>Everett very gravelly sandy loam</u>	<u>8 - 30%</u>	<u>Moderate</u>
_____	_____	_____
_____	_____	_____

High Groundwater Table (within 5 feet) Sole Source Aquifer
 Other _____ Seeps/Springs

Additional Sheets Attached

TECHNICAL INFORMATION REPORT (TIR) WORKSHEET

Part 11 DRAINAGE DESIGN LIMITATIONS	
REFERENCE	LIMITATION / SITE CONSTRAINT
<input type="checkbox"/> Core 2 – Offsite Analysis _____	See TIR text _____
<input type="checkbox"/> Sensitive/Critical Areas _____	_____
<input type="checkbox"/> SEPA _____	_____
<input type="checkbox"/> LID Infeasibility _____	_____
<input type="checkbox"/> Other _____	_____
<input type="checkbox"/> _____	_____
<input type="checkbox"/> Additional Sheets Attached	

Part 12 TIR SUMMARY SHEET (provide one TIR Summary Sheet per Threshold Discharge Area)

Threshold Discharge Area: (name or description)	Queen City Lake/ Tributary 316A
Core Requirements (all 8 apply):	
Discharge at Natural Location	Number of Natural Discharge Locations: 1
Offsite Analysis	Level: ① / 2 / 3 dated: February 28, 2018
Flow Control (include facility summary sheet)	Level: 1 / ② / 3 or Exemption Number _____ Flow Control BMPs See stormwater facilities in plans
Conveyance System	Spill containment located at: N/A, no offsite conveyance
Erosion and Sediment Control / Construction Stormwater Pollution Prevention	CSWPP/CESCL/ESC Site Supervisor: Adrienne Finch Contact Phone: 206-437-5703 (mobile) _____ After Hours Phone: _____
Maintenance and Operation	Responsibility (circle one): Private / Public If Private, Maintenance Log Required: Yes / No
Financial Guarantees and Liability	Provided: Yes / No To be completed following KCDDDES approval of approach
Water Quality (include facility summary sheet)	Type (circle one): Basic / Sens. Lake / Enhanced Basic / Bog or Exemption No. _____ Landscape Management Plan: Yes / No
Special Requirements (as applicable):	
Area Specific Drainage Requirements	Type: CDA / SDO / MDP / BP / LMP / Shared Fac. / None Name: _____
Floodplain/Floodway Delineation	Type (circle one): Major / Minor / Exemption / None 100-year Base Flood Elevation (or range): _____ Datum: _____
Flood Protection Facilities	Describe: N/A

TECHNICAL INFORMATION REPORT (TIR) WORKSHEET

Part 12 TIR SUMMARY SHEET (provide one TIR Summary Sheet per Threshold Discharge Area)	
Source Control (commercial / industrial land use)	Describe land use: Describe any structural controls:
Oil Control	High-use Site: <input checked="" type="radio"/> Yes / No Treatment BMP: Oil/water separator _____ Maintenance Agreement: Yes / <input checked="" type="radio"/> No with whom? N/A _____
Other Drainage Structures	
Describe:	

TECHNICAL INFORMATION REPORT (TIR) WORKSHEET

Part 12 (cont'd)

Part 12 TIR SUMMARY SHEET (provide one TIR Summary Sheet per Threshold Discharge Area)	
Threshold Discharge Area: (name or description)	Cedar Shores Stormwater Ponds
Core Requirements (all 8 apply):	
Discharge at Natural Location	Number of Natural Discharge Locations: 1
Offsite Analysis	Level: ① / 2 / 3 dated: February 28, 2018
Flow Control (include facility summary sheet)	Level: 1 / ② / 3 or Exemption Number _____ Flow Control BMPs <u>See Stormwater Facilities in Design Plans</u>
Conveyance System	Spill containment located at: N/A, no offsite conveyance ____
Erosion and Sediment Control / Construction Stormwater Pollution Prevention	CSWPP/CESCL/ESC Site Supervisor: Adrienne Finch Contact Phone: 206-437-5703 (mobile) ____ After Hours Phone: _____
Maintenance and Operation	Responsibility (circle one): <u>Private</u> / Public If Private, Maintenance Log Required: <u>Yes</u> / No
Financial Guarantees and Liability	Provided: Yes / No To be completed following KCDDDES approval of approach _____
Water Quality (include facility summary sheet)	Type (circle one): <u>Basic</u> / Sens. Lake / Enhanced Basic / Bog or Exemption No. _____ Landscape Management Plan: Yes / <u>No</u>
Special Requirements (as applicable):	
Area Specific Drainage Requirements	Type: CDA / SDO / MDP / BP / LMP / <u>Shared Fac.</u> / None Name: _____
Floodplain/Floodway Delineation	Type (circle one): Major / Minor / Exemption / <u>None</u> 100-year Base Flood Elevation (or range): _____ Datum: _____
Flood Protection Facilities	Describe: N/A

TECHNICAL INFORMATION REPORT (TIR) WORKSHEET

Part 12 TIR SUMMARY SHEET (provide one TIR Summary Sheet per Threshold Discharge Area)	
Source Control (commercial / industrial land use)	Describe land use: Describe any structural controls:
Oil Control	High-use Site: Yes / <input checked="" type="radio"/> No Treatment BMP: N/A _____ Maintenance Agreement: Yes / <input checked="" type="radio"/> No with whom? N/A _____
Other Drainage Structures	
Describe:	

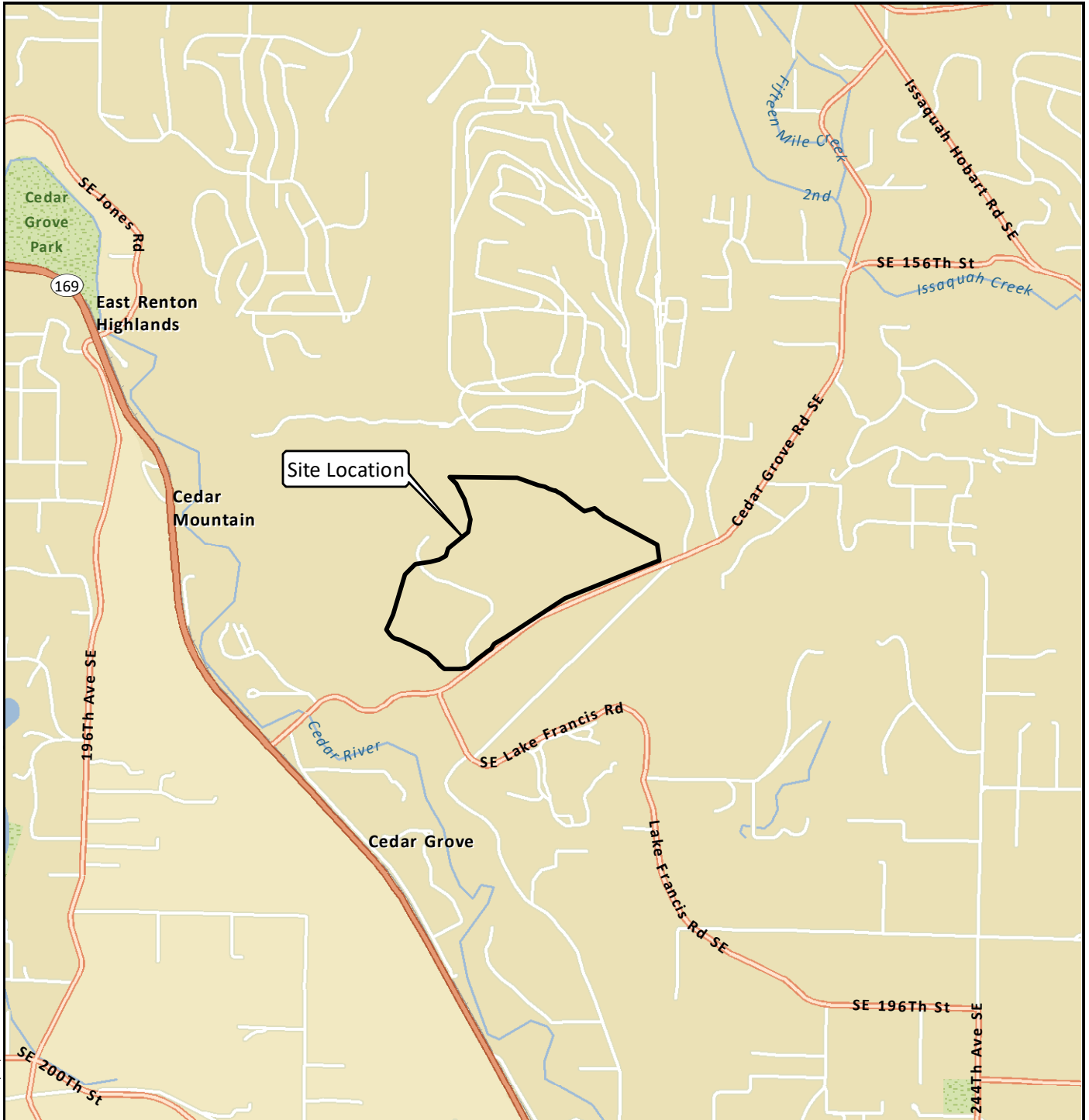
Part 13 EROSION AND SEDIMENT CONTROL REQUIREMENTS	
<p style="text-align: center;">MINIMUM ESC REQUIREMENTS DURING CONSTRUCTION</p> <ul style="list-style-type: none"> <input checked="" type="checkbox"/> Clearing Limits <input checked="" type="checkbox"/> Cover Measures <input type="checkbox"/> Perimeter Protection <input type="checkbox"/> Traffic Area Stabilization <input checked="" type="checkbox"/> Sediment Retention <input type="checkbox"/> Surface Water Collection <input type="checkbox"/> Dewatering Control <input type="checkbox"/> Dust Control <input type="checkbox"/> Flow Control <input type="checkbox"/> Protection of Flow Control BMP Facilities (existing and proposed) <input type="checkbox"/> Maintain BMPs / Manage Project 	<p style="text-align: center;">MINIMUM ESC REQUIREMENTS AFTER CONSTRUCTION</p> <ul style="list-style-type: none"> <input checked="" type="checkbox"/> Stabilize exposed surfaces <input checked="" type="checkbox"/> Remove and restore Temporary ESC Facilities <input checked="" type="checkbox"/> Clean and remove all silt and debris, ensure operation of Permanent Facilities, restore operation of Flow Control BMP Facilities as necessary <input type="checkbox"/> Flag limits of SAO and open space preservation areas <input type="checkbox"/> Other _____

Part 14 STORMWATER FACILITY DESCRIPTIONS (Note: Include Facility Summary and Sketch)			
Flow Control	Type/Description	Water Quality	Type/Description
<input checked="" type="checkbox"/> Detention	West Pond & Cedar Shores Ponds, see plans	<input type="checkbox"/> Vegetated Flowpath	_____
<input checked="" type="checkbox"/> Infiltration	East & South Ponds, see plans	<input checked="" type="checkbox"/> Wetpool	West Pond & Cedar Shores Ponds, see plans
<input type="checkbox"/> Regional Facility	_____	<input type="checkbox"/> Filtration	_____
<input type="checkbox"/> Shared Facility	_____	<input type="checkbox"/> Oil Control	_____
<input type="checkbox"/> Flow Control BMPs	_____	<input type="checkbox"/> Spill Control	_____
<input type="checkbox"/> Other	_____	<input type="checkbox"/> Flow Control BMPs	_____
		<input type="checkbox"/> Other	_____

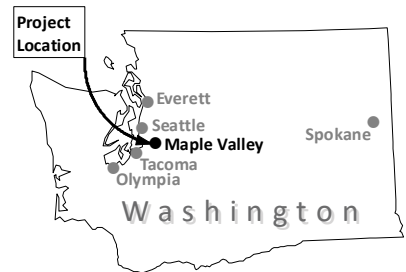
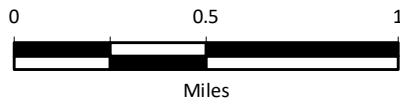
TECHNICAL INFORMATION REPORT (TIR) WORKSHEET

Part 15 EASEMENTS/TRACTS	Part 16 STRUCTURAL ANALYSIS
<input type="checkbox"/> Drainage Easement <input type="checkbox"/> Covenant <input type="checkbox"/> Native Growth Protection Covenant <input type="checkbox"/> Tract <input type="checkbox"/> Other _____	<input type="checkbox"/> Cast in Place Vault <input type="checkbox"/> Retaining Wall <input type="checkbox"/> Rockery > 4' High <input type="checkbox"/> Structural on Steep Slope <input type="checkbox"/> Other _____

Part 17 SIGNATURE OF PROFESSIONAL ENGINEER
<p>I, or a civil engineer under my supervision, have visited the site. Actual site conditions as observed were incorporated into this worksheet and the attached Technical Information Report. To the best of my knowledge the information provided here is accurate.</p> <p style="text-align: right;"> August 30, 2019 <i>Kate Saltz</i> APRIL 10, 2018 </p> <hr/> <p style="text-align: right;"><i>Signed/Date</i></p>



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Data Source: Esri 2012

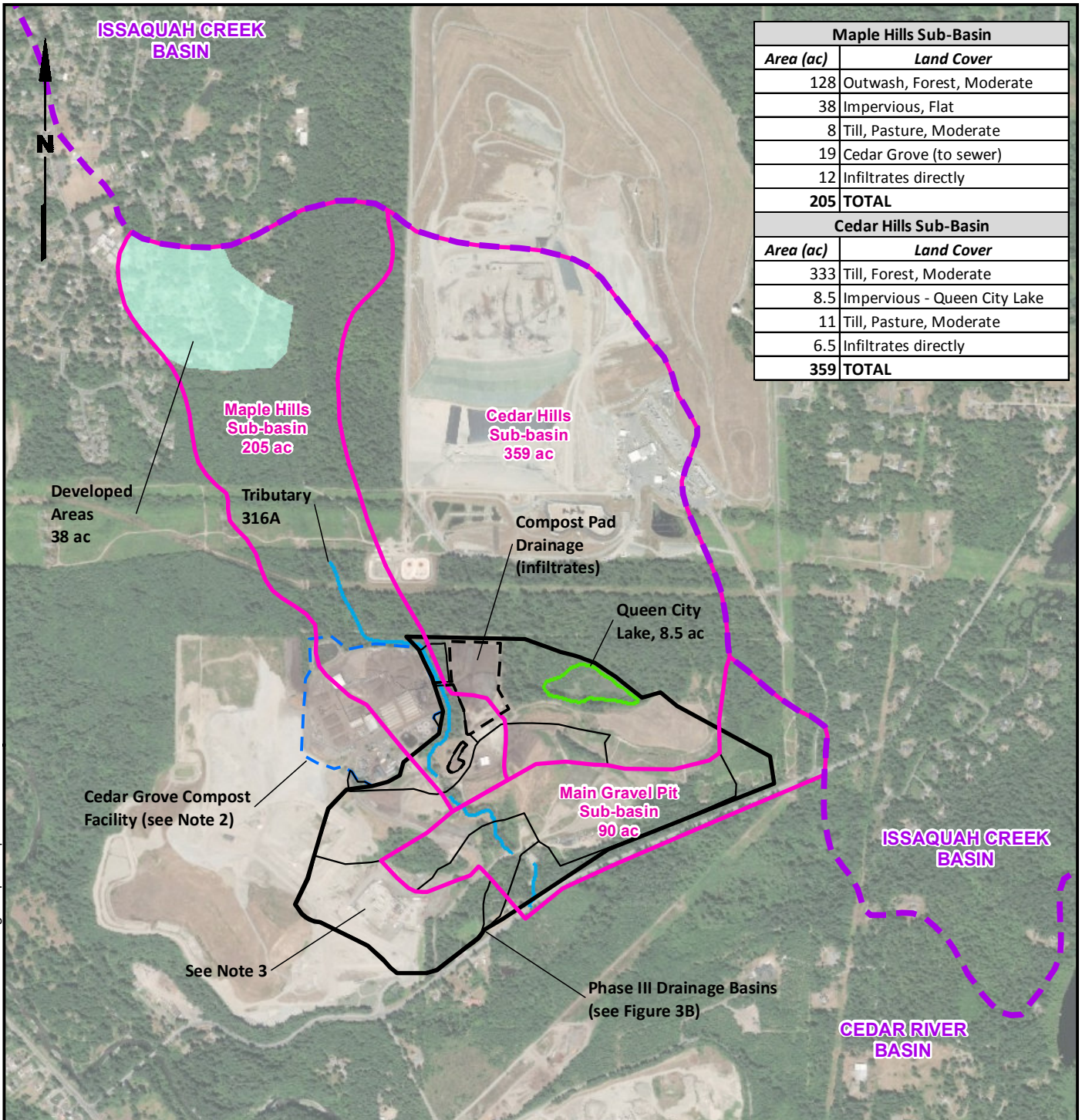


Queen City Farms
Phase III Refill
Maple Valley, Washington

Site Location Map

Figure
2

Landau Associates | G:\Projects\992\002\050\051\Phase III TIR\F03A DrainageMap.mxd | 8/29/2019 11:48:13 AM



Maple Hills Sub-Basin	
Area (ac)	Land Cover
128	Outwash, Forest, Moderate
38	Impervious, Flat
8	Till, Pasture, Moderate
19	Cedar Grove (to sewer)
12	Infiltrates directly
205	TOTAL
Cedar Hills Sub-Basin	
Area (ac)	Land Cover
333	Till, Forest, Moderate
8.5	Impervious - Queen City Lake
11	Till, Pasture, Moderate
6.5	Infiltrates directly
359	TOTAL

Legend

- Basin Divide
- Sub-basin



Notes

1. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.
2. The entire Cedar Grove Compost Facility drains to a sanitary sewer.
3. Stormwater that falls in the portion of the Phase III Fill outside the Maple Hills and Main Gravel Pit sub-basins flows to the Cedar Shores stormwater ponds and Queen City Lake.

Base Map Source: Terrain Navigator 2002
 Data Sources: Smayda 2005; King County 2006

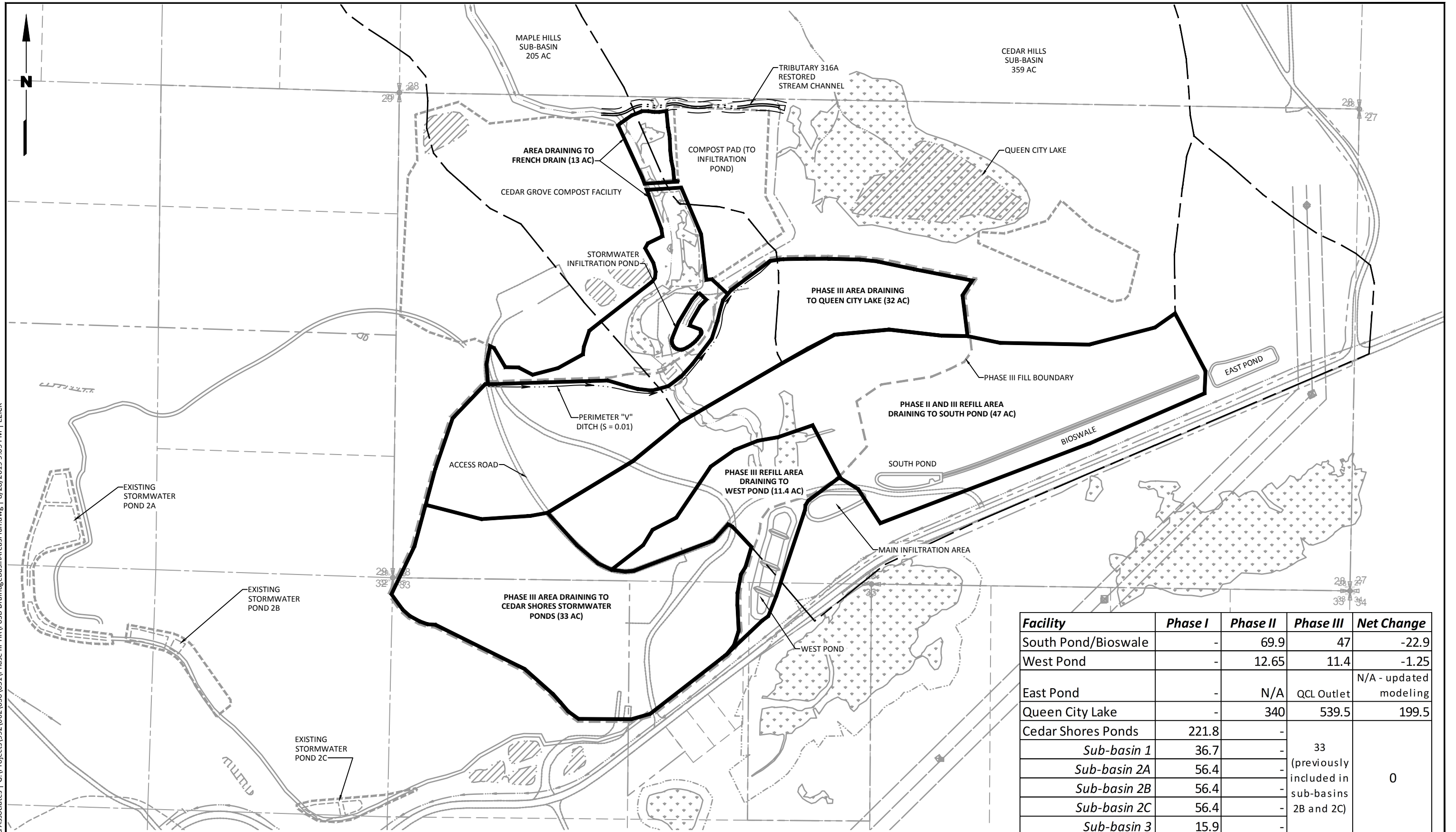


Queen City Farms
 Phase III Refill
 Maple Valley, Washington

**Drainage Basins Map:
 Overview**

Figure
3A

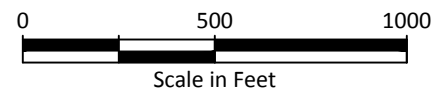
Landau Associates | G:\Projects\992\002\050\051\Phase III TIR\F03B DrainageBasinAreasPlan.dwg | 8/28/2019 9:09 PM | EZICK

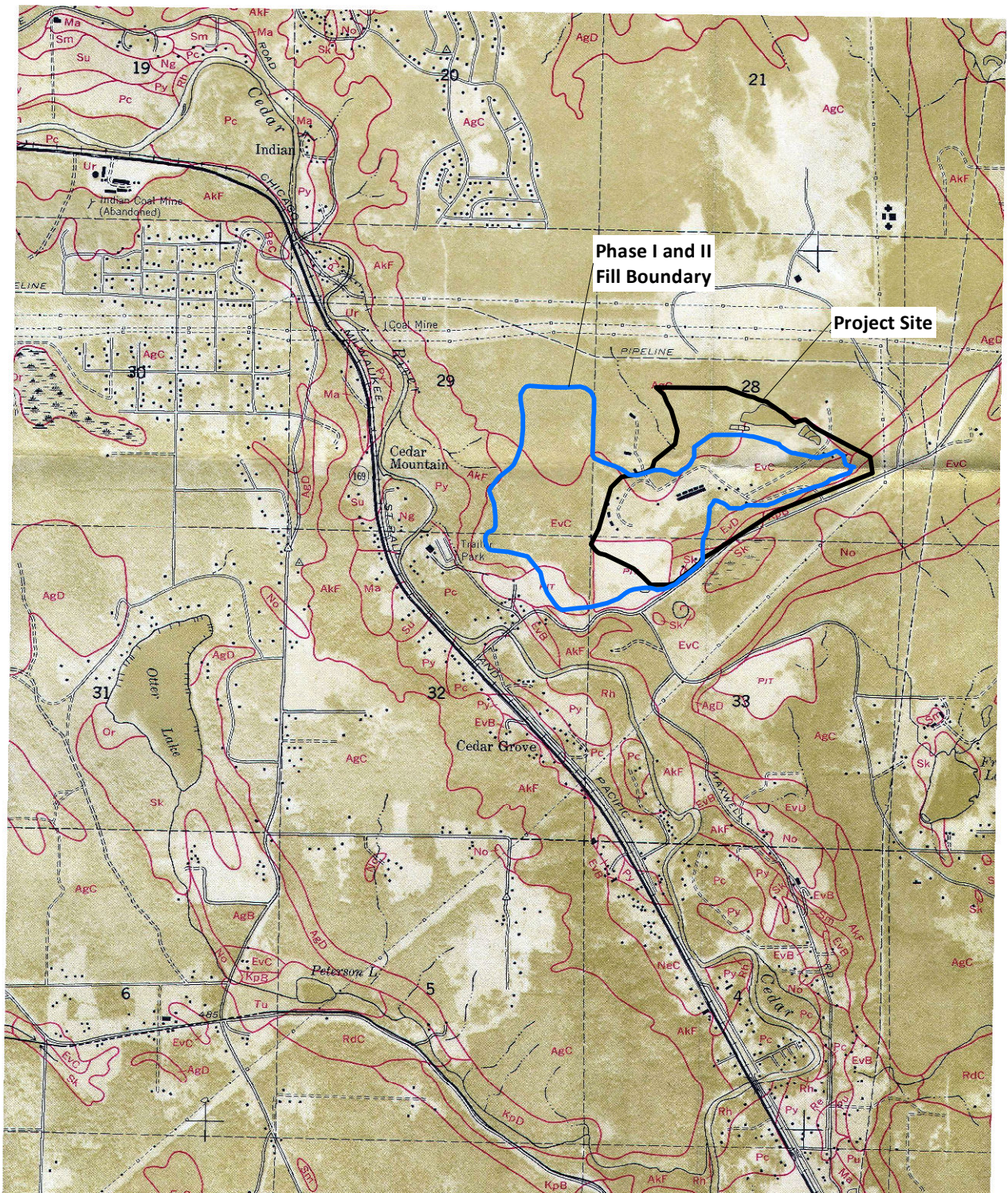


Facility	Phase I	Phase II	Phase III	Net Change
South Pond/Bioswale	-	69.9	47	-22.9
West Pond	-	12.65	11.4	-1.25
East Pond	-	N/A	QCL Outlet	N/A - updated modeling
Queen City Lake	-	340	539.5	199.5
Cedar Shores Ponds	221.8	-	-	-
Sub-basin 1	36.7	-	33	0
Sub-basin 2A	56.4	-	(previously included in sub-basins 2B and 2C)	
Sub-basin 2B	56.4	-		
Sub-basin 2C	56.4	-		
Sub-basin 3	15.9	-		

Note

1. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.





Note

1. See TIR section 1.6 for soil unit descriptions.
2. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.



Data Source: Soil Survey of King County Area, Washington (USDA NRCS 2006)

<p>Queen City Farms Phase III Refill Maple Valley, Washington</p>	<p>Soils</p>	<p>Figure 4</p>
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LANDAU ASSOCIATES

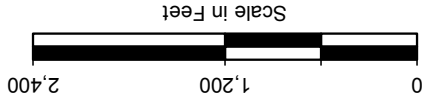
Queen City Farms
Phase III Refill
Maple Valley, Washington

County Designated Areas

Figure 5

Source: Esri World Imagery; King County GIS, 2019

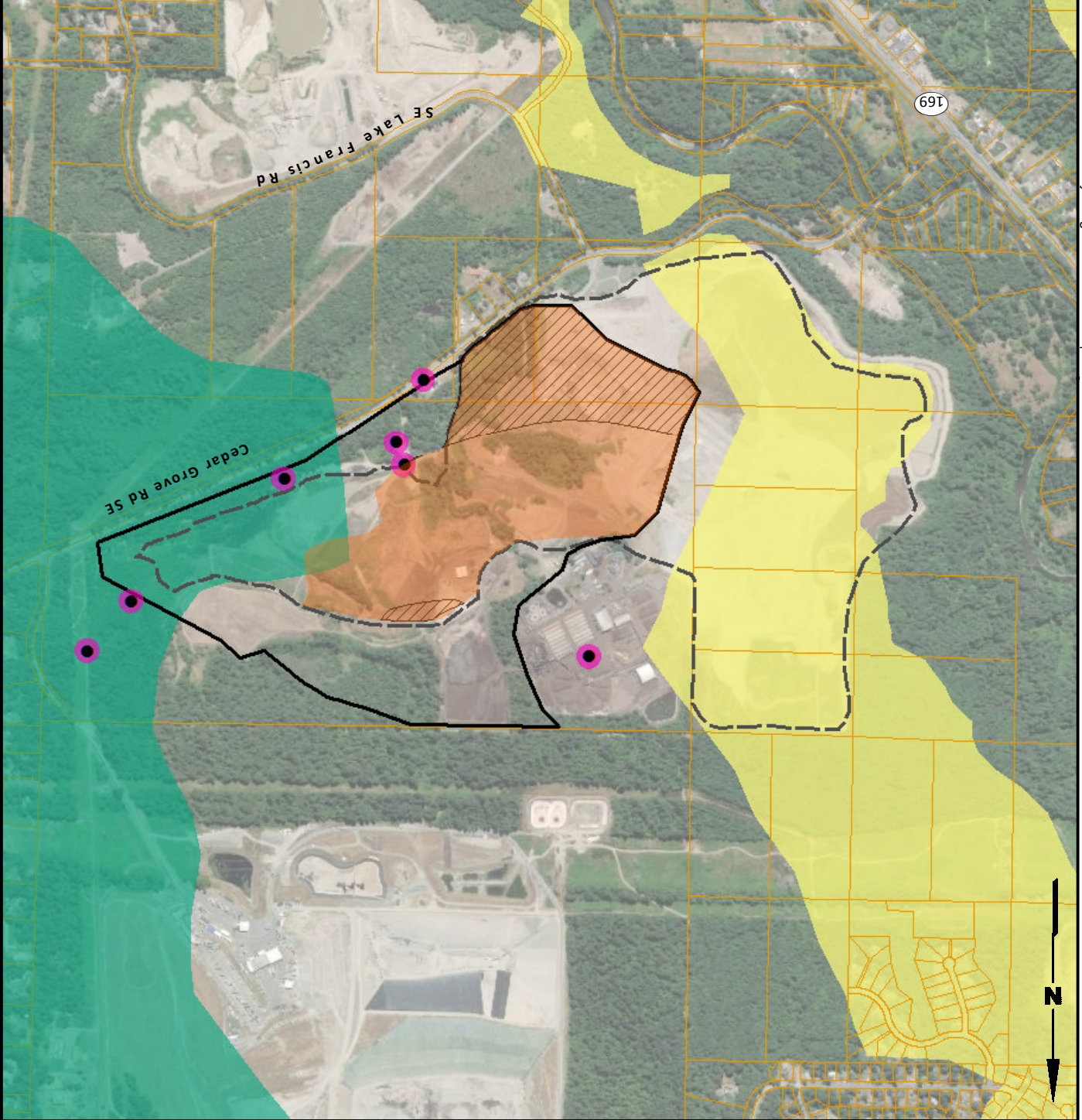
Note
1. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

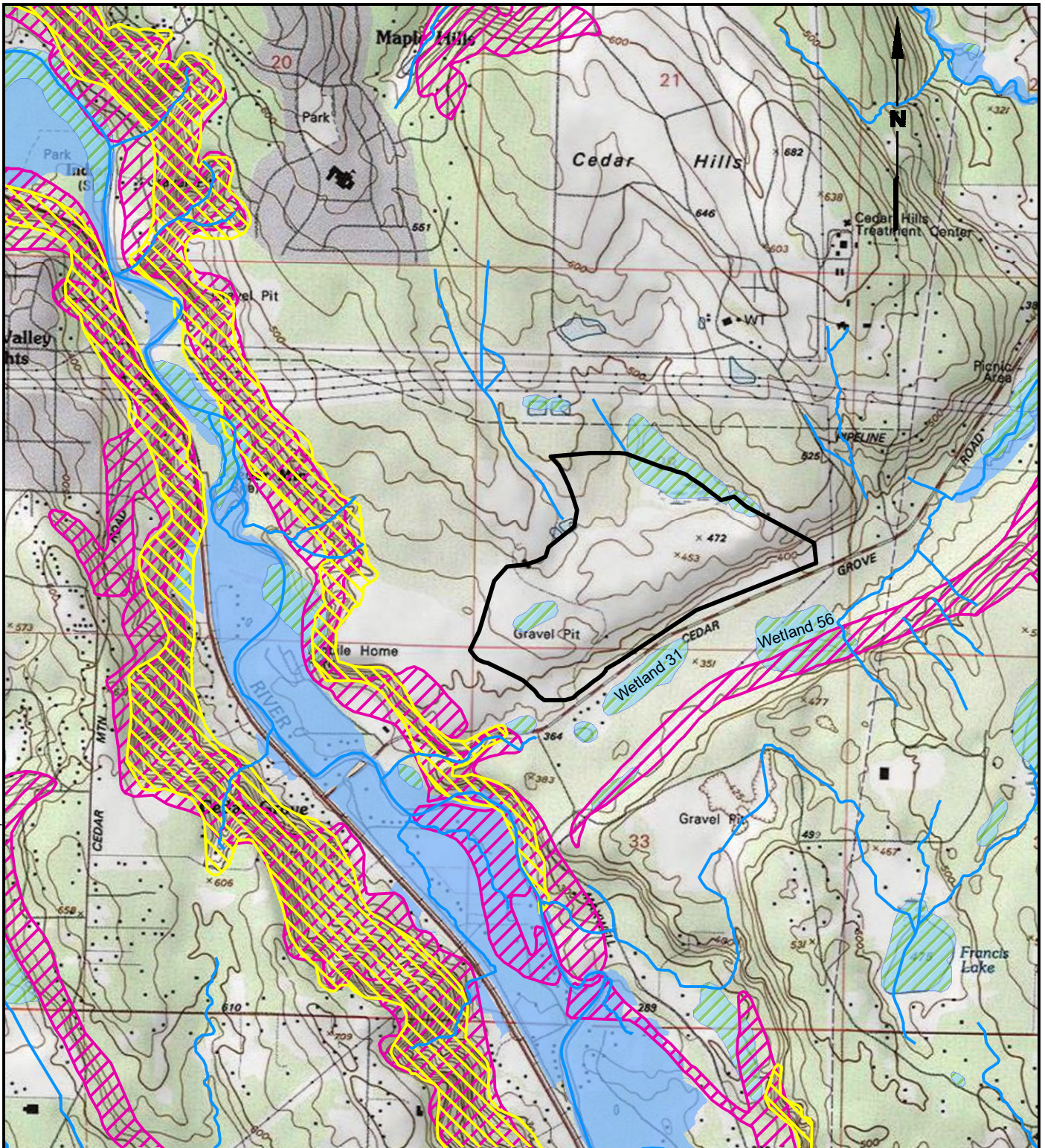


- King County Parcel Lines
- Sensitive Lake Water Quality
- Treatment Area
- Landslide Hazard Drainage Area
- Critical Aquifer Recharge Areas**
- Category 2 - 34.03 ac

- Well Location
- 100 ft Radius from Well
- Project Site
- Phase I and II Fill Boundary
- Phase III Fill Boundary

Legend





Legend

- Project Area
- Stream
- Wetland Area
- Landslide Hazard Area
- Erosion Hazard Area
- 100-Year Flood Plain Area

Note

Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

0 2,000 4,000



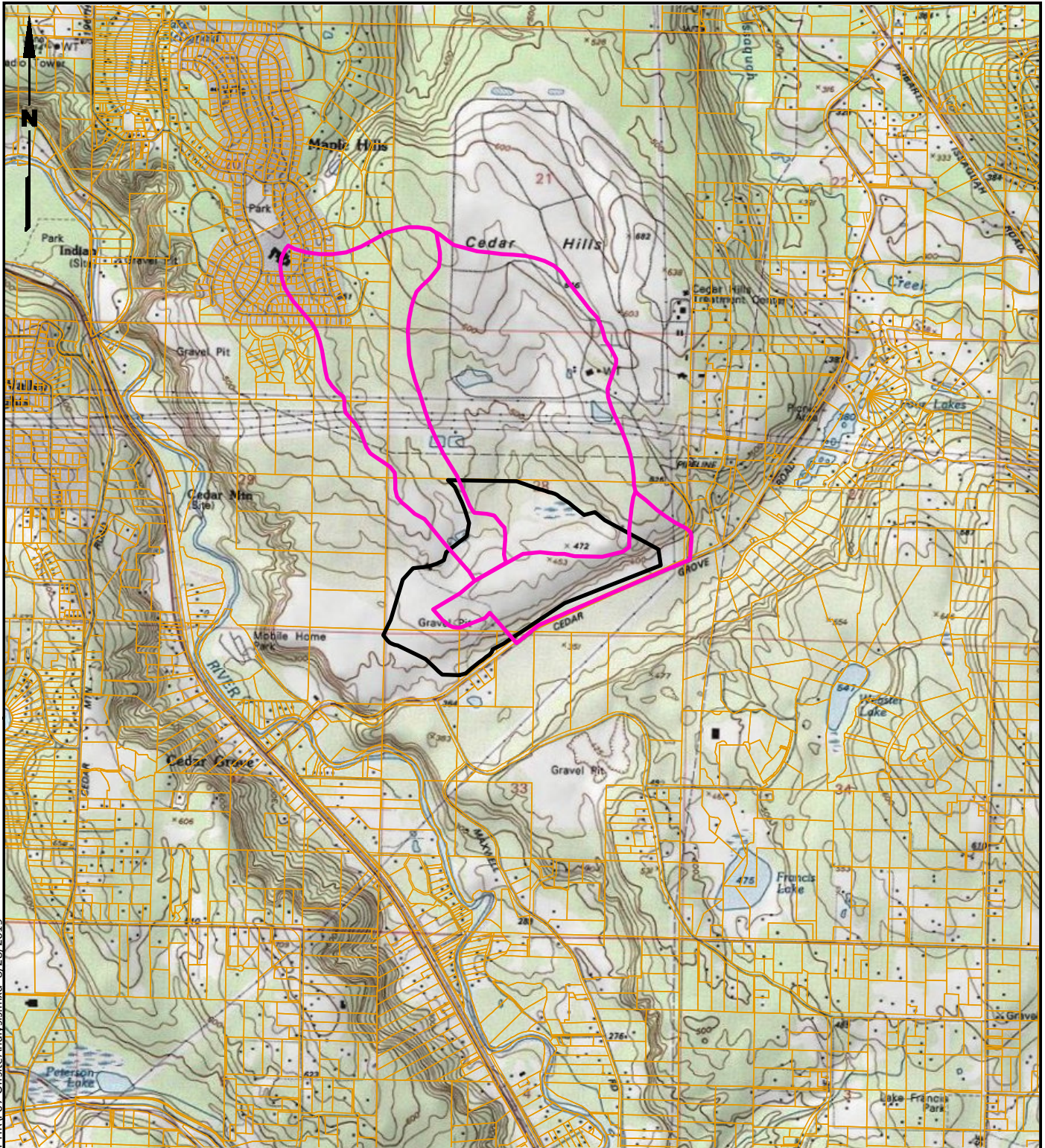
Scale in Feet

Base Map Source: USGS/National Geographic Society
Data Source: King County 2006

Queen City Farms
Phase III Refill
Maple Valley, Washington

Critical Areas Map

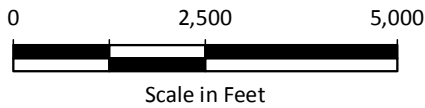
Figure
6



G:\Projects\1992\002\050\051\Phase III\TIR\F07 OffsiteAnalysis.mxd 8/28/2019

Legend

- Project Site
- Sub-basin
- King County Parcel Lines



Notes

1. There are no downstream drainage systems affected by this project
2. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

Data Source: USGS/National Geographic Society



Queen City Farms
Phase III Refill
Maple Valley, Washington

**Offsite Analysis
Study Area Map**

Figure
7

Phase III State Environmental Policy Act Checklist And GHG Emissions Worksheet

SEPA ENVIRONMENTAL CHECKLIST

Purpose of checklist:

Governmental agencies use this checklist to help determine whether the environmental impacts of your proposal are significant. This information is also helpful to determine if available avoidance, minimization or compensatory mitigation measures will address the probable significant impacts or if an environmental impact statement will be prepared to further analyze the proposal.

Instructions for applicants:

This environmental checklist asks you to describe some basic information about your proposal. Please answer each question accurately and carefully, to the best of your knowledge. You may need to consult with an agency specialist or private consultant for some questions. You may use "not applicable" or "does not apply" only when you can explain why it does not apply and not when the answer is unknown. You may also attach or incorporate by reference additional studies reports. Complete and accurate answers to these questions often avoid delays with the SEPA process as well as later in the decision-making process.

The checklist questions apply to all parts of your proposal, even if you plan to do them over a period of time or on different parcels of land. Attach any additional information that will help describe your proposal or its environmental effects. The agency to which you submit this checklist may ask you to explain your answers or provide additional information reasonably related to determining if there may be significant adverse impact.

Instructions for Lead Agencies:

Please adjust the format of this template as needed. Additional information may be necessary to evaluate the existing environment, all interrelated aspects of the proposal and an analysis of adverse impacts. The checklist is considered the first but not necessarily the only source of information needed to make an adequate threshold determination. Once a threshold determination is made, the lead agency is responsible for the completeness and accuracy of the checklist and other supporting documents.

Use of checklist for nonproject proposals: [\[help\]](#)

For nonproject proposals (such as ordinances, regulations, plans and programs), complete the applicable parts of sections A and B plus the [SUPPLEMENTAL SHEET FOR NONPROJECT ACTIONS \(part D\)](#). Please completely answer all questions that apply and note that the words "project," "applicant," and "property or site" should be read as "proposal," "proponent," and "affected geographic area," respectively. The lead agency may exclude (for non-projects) questions in Part B - Environmental Elements –that do not contribute meaningfully to the analysis of the proposal.

A. Background [\[help\]](#)

1. Name of proposed project, if applicable:

Queen City Farms Phase III Refill

2. Name of applicant: [\[help\]](#)

Queen City Farms, Inc.

3. Address and phone number of applicant and contact person: [\[help\]](#)
- | | |
|-------------------------------------|----------------------------|
| Steve Banchero, President | Eric Weber, LHG |
| 7343 East Marginal Way South | Landau Associates |
| Seattle, WA 98108 | 2107 South C Street |
| (206) 832-3001 | Tacoma, WA 98402 |
| | (253) 926-2493 |
4. Date checklist prepared: [\[help\]](#)
March 30, 2018
5. Agency requesting checklist: [\[help\]](#)
King County Department of Permitting and Environmental Review (DPER)
6. Proposed timing or schedule (including phasing, if applicable): [\[help\]](#)
The Phase III Refill Project will commence as the Phase II Refill Project nears completion in approximately 2025.
7. Do you have any plans for future additions, expansion, or further activity related to or connected with this proposal? If yes, explain. [\[help\]](#)
No future plans are associated with this proposal.
8. List any environmental information you know about that has been prepared, or will be prepared, directly related to this proposal. [\[help\]](#)
- a) **Queen City Farms Phase III Refill Project Technical Information Report (TIR), prepared by Landau Associates, Inc., April 2018.**
 - b) **King County DDES (DDES) permits for mining at the Cedar Shores Gravel Mine (which included the property where the Queen City Farms Phase III Refill Project is located) including Grading Permit No. 1249-26; and Renewal No. 1249-657 with Grading Permit Conditions from 1992.**
 - c) **Expanded SEPA Checklist submitted to DDES for the Cedar Shores grading permit application, dated October 13, 2006, which includes traffic and noise studies relevant to this proposal.**
9. Do you know whether applications are pending for governmental approvals of other proposals directly affecting the property covered by your proposal? If yes, explain. [\[help\]](#)
None.
10. List any government approvals or permits that will be needed for your proposal, if known.
- a) **King County clearing and grading permit**
 - b) **Washington State Department of Natural Resources (WDNR) approval of modified surface mine reclamation permit**
 - c) **Maintaining coverage under Washington State Department of Ecology (Ecology) Sand & Gravel NPDES Permit (The Sand and Gravel Mine General Stormwater Permit No. WAG-50-3070)**
 - d) **US Army Corps of Engineers Nationwide Permit #27**
 - e) **Washington Department of Fish and Wildlife Hydraulic Project Approval**

11. Give brief, complete description of your proposal, including the proposed uses and the size of the project and site. There are several questions later in this checklist that ask you to describe certain aspects of your proposal. You do not need to repeat those answers on this page. (Lead agencies may modify this form to include additional specific information on project description.) [\[help\]](#)

The proposal is to refill a portion of the main gravel pit located between the Phase I and Phase II Refill Project areas, south of Queen City Lake and north of Cedar Grove Road SE in a manner that protects surface and subsurface hydrology and reclaims the former mine. The total Phase III Refill Project area is about 97 acres. The estimated refill volume is 2.5 million cubic yards (cy). The Phase III Refill operations will commence when Phase II Refill operations near completion. Refill operations will be conducted similarly to operations for Phase II. Fill will be placed in 20-ft staged lifts. Each lift will be hydroseeded and reclaimed. The maximum daily (1,640) and PM peak hour (100) number of truck trips set for Cedar Shores would continue for Queen City Farms. The night haul route and related noise mitigations set for Cedar Shores would also continue in effect for Queen City Farms site operations.

12. Location of the proposal. Give sufficient information for a person to understand the precise location of your proposed project, including a street address, if any, and section, township, and range, if known. If a proposal would occur over a range of area, provide the range or boundaries of the site(s). Provide a legal description, site plan, vicinity map, and topographic map, if reasonably available. While you should submit any plans required by the agency, you are not required to duplicate maps or detailed plans submitted with any permit applications related to this checklist. [\[help\]](#)

17800 Block of Cedar Grove Road SE. See plan set and figures accompanying the Phase III Refill TIR.

B. ENVIRONMENTAL ELEMENTS [\[help\]](#)

1. Earth [\[help\]](#)

- a. General description of the site: [\[help\]](#)

(circle one): **Flat (on top of refill hills and site to the north)**, rolling, hilly, **steep slopes (on refill side slopes)**, mountainous, other _____

- b. What is the steepest slope on the site (approximate percent slope)? [\[help\]](#)

The steepest slope prior to this phase of project work is 4H:1V (approximately a 25 percent slope). This represents the outside slope of the Phase I and Phase II Refill Projects. The Phase III Refill Project will have a maximum 4H:1V permanent fill slope along the northern and southern boundary of the planned fill zone.

- c. What general types of soils are found on the site (for example, clay, sand, gravel, peat, muck)? If you know the classification of agricultural soils, specify them and note any agricultural land of long-term commercial significance and whether the proposal results in removing any of these soils. [\[help\]](#)

United States Department of Agriculture, Natural Resources Conservation Service Web Soil Survey data (2017) identify soils in the project area as mainly Alderwood gravelly sandy loam, 8 to 15 percent slopes and Everett very gravelly sandy loam, 8 to 30 percent slopes.

- d. Are there surface indications or history of unstable soils in the immediate vicinity? If so, describe. [\[help\]](#)

King County's iMap (2018) identifies some steep slopes in the immediate vicinity of the project area, but there are no known surface indications of unstable soils. This mapping identifies an area to the west of the project area as having an erosion hazard, and to the east of the project area, a landslide hazard area is mapped.

- e. Describe the purpose, type, total area, and approximate quantities and total affected area of any filling, excavation, and grading proposed. Indicate source of fill. [\[help\]](#)
The purpose of the Phase III Refill Project is to accomplish reclamation of the former mine required by the WDNR reclamation permit number 70-010880. The total Phase III Refill Project area will be about 97 acres. The total Phase III refill volume is approximately 2.5 million cy.

The Phase III Refill Project intends to accept clean soil material. Clean soil accepted as fill material will be certified to be free of hazardous substances as defined in Ecology Regulations Washington Administrative Code (WAC) Chapter 173-340; radioactive, dangerous, or extremely hazardous wastes as defined in WAC 173-303; and solid wastes as defined in WAC 173-350 and 173-351. All sources or purveyors of fill materials will be required to sign a clean soils fill agreement verifying compliance with these requirements. Any material not meeting the above-stated criteria will be rejected.

Irreducible fill materials shall have a maximum dimension of 18 inches and shall be intermixed with materials of size and quantities to fill all potential voids and to ensure compactibility. If concrete material is used, it will not contain rebar or other material that could pose a safety hazard. If asphalt fill materials are used, they will not be placed in locations that are subject to seasonal or perched groundwater, or near hydrogeologic recharge areas.

Fill material is expected to come from sources such as building foundation excavations, road cuts, and other construction projects. The material is expected to consist predominantly of fine-grained soil that are generally unsuitable for construction or commercial purposes.

- f. Could erosion occur as a result of clearing, construction, or use? If so, generally describe. Project activities will include filling and grading. Although not anticipated, erosion could occur along the slope of fill soils and temporary truck haul routes. A temporary erosion and sediment control (TESC) plan will be developed for the project and implemented, modified, and revised on site as the refilling operation continues. The TESC drawings incorporate general erosion control measures implemented based on disturbance. Appropriate best management practices (BMPs) will

be used during site activities. Construction stormwater pollution prevention plan (SWPPP) measures will also be implemented and followed.

- g. About what percent of the site will be covered with impervious surfaces after project construction (for example, asphalt or buildings)? [\[help\]](#)

The project includes <5 percent construction of “new impervious surfaces,” as defined in to the King County Surface Water Design Manual . The Phase III fill area covers 97 acres, of which 1.4 acres are considered “new impervious surfaces.” The remaining fill is on top of other existing impervious fill areas. The total project site area is approximately 200 acres.

- h. Proposed measures to reduce or control erosion, or other impacts to the earth, if any: [\[help\]](#)
Erosion control BMPs will be implemented to control erosion from fill soils. Fill will occur in lifts. Hydroseeding with an alder seed mix will be conducted along the finished exterior downslope of each lift. BMPs are described in the TIR and associated grading plans.

2. Air [\[help\]](#)

- a. What types of emissions to the air would result from the proposal during construction, operation, and maintenance when the project is completed? If any, generally describe and give approximate quantities if known. [\[help\]](#)

Project activities will generate engine exhaust and soil dust from haul trucks and earth-moving equipment. No additional emissions will result from the completed project.

- b. Are there any off-site sources of emissions or odor that may affect your proposal? If so, generally describe. [\[help\]](#)
Daily traffic on adjacent roadways is anticipated to be a source of emissions and odor; however, it is not expected to negatively impact the project.

- c. Proposed measures to reduce or control emissions or other impacts to air, if any: [\[help\]](#)
All reasonable precautions to avoid or minimize fugitive dust emissions will be taken, including watering and stabilizing exposed soils. Construction equipment will not be left idling when not in use to reduce exhaust emissions to air. Therefore, the potential for significant offsite air quality impacts will be minimized.

3. Water [\[help\]](#)

- a. Surface Water:

1) Is there any surface water body on or in the immediate vicinity of the site (including year-round and seasonal streams, saltwater, lakes, ponds, wetlands)? If yes, describe type and provide names. If appropriate, state what stream or river it flows into. [\[help\]](#)

- Queen City Lake, a seasonal natural kettle lake with no natural surface water outlet (a two-stage overflow structure will be added as part of the Phase II Refill stormwater management system)
- Tributary 316A, a seasonally intermittent surface water course that discharges on site to the Main Infiltration Area

- **The Main Infiltration Area, an area of coarse soil that infiltrates all of the on-site flow from Tributary 316A and, historically, stormwater flow from the adjacent Stoneway gravel mine sedimentation pond.**
- **QCF Spring, the only original surface water discharge from the site, located near Cedar Grove Road SE, directly south of the Main Infiltration Area.**

2) Will the project require any work over, in, or adjacent to (within 200 feet) the described waters? If yes, please describe and attach available plans. [\[help\]](#)
Reclamation activities will not take place within 200 ft of the Cedar River or within the Queen City Lake wetland buffer. Tributary 316A will be restored to its original discharge location prior to mining.

3) Estimate the amount of fill and dredge material that would be placed in or removed from surface water or wetlands and indicate the area of the site that would be affected. Indicate the source of fill material. [\[help\]](#)
Fill will be placed in the existing engineered Tributary 316A channel during the Phase III project. The Tributary 316A channel will be restored in its original location, outside the Phase III fill footprint.

4) Will the proposal require surface water withdrawals or diversions? Give general description, purpose, and approximate quantities if known. [\[help\]](#)
The Tributary 316A channel will be restored to discharge in Queen City Lake instead of into the Main Infiltration Area.

5) Does the proposal lie within a 100-year floodplain? If so, note location on the site plan.
No, the project does not lie within a 100-year floodplain.

6) Does the proposal involve any discharges of waste materials to surface waters? If so, describe the type of waste and anticipated volume of discharge. [\[help\]](#)
The project does not involve any discharges of waste materials to surface waters.

b. Ground Water:

1) Will groundwater be withdrawn from a well for drinking water or other purposes? If so, give a general description of the well, proposed uses and approximate quantities withdrawn from the well. Will water be discharged to groundwater? Give general description, purpose, and approximate quantities if known. [\[help\]](#)
Groundwater will not be withdrawn from a well for drinking water or other purposes, nor will water be discharged to groundwater.

2) Describe waste material that will be discharged into the ground from septic tanks or other sources, if any (for example: Domestic sewage; industrial, containing the following chemicals. . . ; agricultural; etc.). Describe the general size of the system, the number of such systems, the number of houses to be served (if applicable), or the number of animals or humans the system(s) are expected to serve. [\[help\]](#)
Waste material will not be discharged into the ground via septic tanks or other sources as a result of the project.

c. Water runoff (including stormwater):

- 1) Describe the source of runoff (including storm water) and method of collection and disposal, if any (include quantities, if known). Where will this water flow? Will this water flow into other waters? If so, describe. [\[help\]](#)

Stormwater runoff from the southern side of the the Phase III Refill Project will be directed to the South and West stormwater facilities, as permitted for Phase II. The total area draining to the South and West Stormwater Facilities will not increase. Stormwater runoff from the northern side of the Phase III Refill will drain by surface flow to Queen City Lake, whose outlet structure will be modified to accommodate the stormwater inflow. Overflow from Queen City Lake will drain to the East Rentention Pond which will be enlarged to provide additional volume storage and infiltration.

- 2) Could waste materials enter ground or surface waters? If so, generally describe. [\[help\]](#)
It is not anticipated that waste materials will enter ground or surface waters.

- 3) Does the proposal alter or otherwise affect drainage patterns in the vicinity of the site? If so, describe. [\[help\]](#)

Surface water in all three drainage sub-basins currently infiltrates to groundwater and will continue to after completion of the Phase III Refill Project. Refilling is not expected to generate additional surface water runoff. Overall, the total amount of surface water infiltrated on site from the Phase III project is expected to be roughly the same as the current condition.

d. Proposed measures to reduce or control surface, ground, and runoff water, and drainage pattern impacts, if any: [\[help\]](#)

Proposed project activities are not anticipated to change the quantity of water infiltrating and running off site.

4. Plants [\[help\]](#)

- a. Check the types of vegetation found on the site: [\[help\]](#)

- deciduous tree: alder, maple, aspen, other**
 evergreen tree: fir, cedar, pine, other
 shrubs
 grass
 pasture
 crop or grain
 Orchards, vineyards or other permanent crops.
 wet soil plants: cattail, buttercup, bullrush, skunk cabbage, other
 water plants: water lily, eelgrass, milfoil, other
 other types of vegetation:

- b. What kind and amount of vegetation will be removed or altered? [\[help\]](#)

The project area will have limited vegetation, as a large portion of it will have undergone partial refill during Phases I and II of the proposed project. See plans accompanying TIR that depict the area of site disturbance.

c. List threatened and endangered species known to be on or near the site. [\[help\]](#)
None documented. WDNR Natural Heritage Program data does not identify any listed plants on site.

d. Proposed landscaping, use of native plants, or other measures to preserve or enhance vegetation on the site, if any: [\[help\]](#)
As the edges of the 20-ft thick vertical lifts of fill are completed, and as final grades are elsewhere achieved, these areas will be hydroseeded with a King County-approved seed mix that includes grasses, clover, and alders.

e. List all noxious weeds and invasive species known to be on or near the site. [\[help\]](#)
Small amounts of reed canarygrass and Himalayan blackberry are present on-site.

5. Animals [\[help\]](#)

a. List any birds and other animals which have been observed on or near the site or are known to be on or near the site. [\[help\]](#)

Examples include: birds: ~~hawk, heron, eagle, songbirds~~, other:
mammals: ~~deer, bear, elk~~, beaver, other:
fish: bass, salmon, ~~trout~~, herring, shellfish, other _____

b. List any threatened and endangered species known to be on or near the site. [\[help\]](#)
Washington Department of Fish & Wildlife Priority Habitats and Species data (2018) does not identify any threatened or endangered species on or near the project area.

c. Is the site part of a migration route? If so, explain. [\[help\]](#)
As the project is within the Pacific Flyway for North American migrating birds, birds may use portions of the property during their migration.

d. Proposed measures to preserve or enhance wildlife, if any: [\[help\]](#)
Refill will occur only in previously mined areas. No portion of the site within the upland Queen City Lake stormwater basin will be subject to refill operations. Revegetation of refill areas will occur continuously over the life of refill operations.

e. List any invasive animal species known to be on or near the site. [\[help\]](#)
No known invasive animal species are known to be on or near the site.

6. Energy and Natural Resources [\[help\]](#)

a. What kinds of energy (electric, natural gas, oil, wood stove, solar) will be used to meet the completed project's energy needs? Describe whether it will be used for heating, manufacturing, etc. [\[help\]](#)

No energy sources will be used with the completed project.

b. Would your project affect the potential use of solar energy by adjacent properties?
If so, generally describe. [\[help\]](#)

The project is not anticipated to affect potential use of solar energy by adjacent properties.

c. What kinds of energy conservation features are included in the plans of this proposal?

List other proposed measures to reduce or control energy impacts, if any: [\[help\]](#)

None are proposed as the completed project does not require energy.

7. Environmental Health [\[help\]](#)

a. Are there any environmental health hazards, including exposure to toxic chemicals, risk of fire and explosion, spill, or hazardous waste, that could occur as a result of this proposal? If so, describe. [\[help\]](#)

The possibility of accidental fuel spills from mechanized equipment exists; however, a spill response plan and a construction SWPPP (if applicable) will be followed to prevent and clean up any spills.

1) Describe any known or possible contamination at the site from present or past uses.

The project area is part of an active Superfund Site. Inorganic, organic, halogenated, metal, and polychlorinated biphenyl contaminants have been identified in site groundwater and soil, and non-halogenated solvents, pesticides, petroleum products, and polycyclic aromatic hydrocarbons have been identified in groundwater.

2) Describe existing hazardous chemicals/conditions that might affect project development and design. This includes underground hazardous liquid and gas transmission pipelines located within the project area and in the vicinity. [\[help\]](#)

No hazardous chemicals or conditions are anticipated to affect the project.

3) Describe any toxic or hazardous chemicals that might be stored, used, or produced during the project's development or construction, or at any time during the operating life of the project. [\[help\]](#)

Fuel sources for earth-moving equipment will be used on site during filling and grading activities.

4) Describe special emergency services that might be required. [\[help\]](#)

No special emergency services are anticipated.

5) Proposed measures to reduce or control environmental health hazards, if any: [\[help\]](#)

BMPs for control and clean-up of any fuel spills will be maintained and used, along with TESC and construction SWPPP measures for stormwater, if applicable.

b. Noise [\[help\]](#)

1) What types of noise exist in the area which may affect your project (for example: traffic, equipment, operation, other)? [\[help\]](#)

The property is surrounded by Mineral and Rural Residential zoned properties. Surrounding development includes a King County landfill, an active composting facility, and a small number of single family residences. Daily traffic from nearby roadways is also anticipated to be a source of noise; however, noises from surrounding uses are not expected to impact the project.

- 2) What types and levels of noise would be created by or associated with the project on a short-term or a long-term basis (for example: traffic, construction, operation, other)? Indicate what hours noise would come from the site. [\[help\]](#)

There will be some short-term noise associated with the project due to truck and equipment use. Activities will follow noise requirements of the King County Code (KCC); however, the proposal includes episodic 24 hours per day operations on an as needed basis (with a minimum of three business days' advance notice to the DPER grading inspector) in order to accommodate the episodic need for construction related nighttime hauling operations. For site-generated noise levels associated with planned episodic nighttime hauling and truck unloading operations, see the October 11, 2006 Noise Ordinance compliance letter report prepared by JGL Acoustics. This letter was previously submitted to DPER as part of the Expanded SEPA Checklist submitted for the Cedar Shores grading permit application, dated October 13, 2006. There will not be any long-term additional noise associated with the completed project.

- 3) Proposed measures to reduce or control noise impacts, if any: [\[help\]](#)

Project activities will be conducted in compliance with the KCC noise regulations. Episodic night truck hauling operations will make use of the same night haul route approved for Cedar Shores refill grading permit and follow similar mitigation measures to control noise impacts, including the following:

- 1) Limiting the maximum number of inbound haul truck trips to 75 per hour and limiting the maximum number of outbound haul truck trips to 75 per hour.**
- 2) Use of the planned new alternative access driveway/internal haul road across the Cedar Shores site.**
- 3) Construction of a sound barrier along the south side of that planned new alternative access driveway/internal haul road.**
- 4) Having the loader (assisting in the operation of unloading of haul trucks) and the haul trucks themselves on site operate in locations where they will be shielded from SR 169 and Cedar Grove Road SE.**
- 5) Use of grading machinery during night hours shall be limited to assisting unloading of haul trucks.**

No additional noise will be generated by the completed project.

8. Land and Shoreline Use [\[help\]](#)

- a. What is the current use of the site and adjacent properties? Will the proposal affect current land uses on nearby or adjacent properties? If so, describe. [\[help\]](#)

The project area is currently a mined out gravel pit subject to WDNR surface mine reclamation requirements. Adjacent properties are zoned Mineral and Rural Residential. The proposed project will not affect land uses of nearby and adjacent properties.

- b. Has the project site been used as working farmlands or working forest lands? If so, describe. How much agricultural or forest land of long-term commercial significance will be converted to other uses as a result of the proposal, if any? If resource lands have not been designated, how many acres in farmland or forest land tax status will be converted to nonfarm or nonforest use? [\[help\]](#)

There is no evidence that the site has been used for forestry. A portion of the site was long ago used as a pig farm. No working farm or forest lands will be converted as a result of this project.

1) Will the proposal affect or be affected by surrounding working farm or forest land normal business operations, such as oversized equipment access, the application of pesticides, tilling, and harvesting? If so, how: [\[help\]](#)

The project is not anticipated to affect or be affected by surrounding working farm or forest land.

c. Describe any structures on the site. [\[help\]](#)

There are no structures on site.

d. Will any structures be demolished? If so, what? [\[help\]](#)

No.

e. What is the current zoning classification of the site? [\[help\]](#)

The current zoning classification is Mineral (M).

f. What is the current comprehensive plan designation of the site? [\[help\]](#)

The current comprehensive plan land use designation of the site is mining.

g. If applicable, what is the current shoreline master program designation of the site? [\[help\]](#)

Not applicable.

h. Has any part of the site been classified as a critical area by the city or county? If so, specify.

Steep slopes, wetlands, and a stream are located within the project area.

i. Approximately how many people would reside or work in the completed project? [\[help\]](#)

No people will work or reside on-site as a result of the completion of the project.

j. Approximately how many people would the completed project displace? [\[help\]](#)

The completed project will not displace any people.

k. Proposed measures to avoid or reduce displacement impacts, if any: [\[help\]](#)

Not applicable.

l. Proposed measures to ensure the proposal is compatible with existing and projected land uses and plans, if any: [\[help\]](#)

The proposed activities are consistent by definition with the existing land uses and land use plans. As the project area is a Mineral-designated zone and already being utilized for refilling and other uses consistent with those that have historically taken place on the site in conjunction with previous gravel mining, the proposed fill and grading activities will not adversely affect offsite activities.

m. Proposed measures to reduce or control impacts to agricultural and forest lands of long-term commercial significance, if any: [\[help\]](#)

There are no known nearby agricultural or forest lands of long-term commercial significance.

9. **Housing** [\[help\]](#)

- a. Approximately how many units would be provided, if any? Indicate whether high, middle, or low-income housing. [\[help\]](#)

Not applicable.

- b. Approximately how many units, if any, would be eliminated? Indicate whether high, middle, or low-income housing. [\[help\]](#)

Not applicable.

- c. Proposed measures to reduce or control housing impacts, if any: [\[help\]](#)

Not applicable.

10. **Aesthetics** [\[help\]](#)

- a. What is the tallest height of any proposed structure(s), not including antennas; what is the principal exterior building material(s) proposed? [\[help\]](#)

No structures are proposed with the project.

- b. What views in the immediate vicinity would be altered or obstructed? [\[help\]](#)

Properties in the surrounding area have territorial views (if any). It is presumed that nearby residents generally orient themselves to the south for light, views, and to avoid the existing and past operations of Cedar Shores Mine, Queen City Farms Mine, Queen City Farms Superfund Site, Cedar Grove Composting, and the Cedar Hills Landfill. The surrounding terrain is rolling and the landscape is largely forested in areas that are not developed with residences or industrial/resource land uses. Views of the site from the south will be buffered by the proposed 50-ft-wide vegetated perimeter setback. As the project is already underway to some extent under existing permits, views of the site will continue to be of haul trucks, machinery, and fill dirt during the course of the project.

When each of the 20-ft thick layers of the refill is completed to the fill's outer edge, the outer edge will be hydroseeded with a seed mix that includes grasses, clover, and alders. Neighbors will eventually have views of an alder forested hillside, and later views of an alder/evergreen forest.

- c. Proposed measures to reduce or control aesthetic impacts, if any: [\[help\]](#)

The proposed refill will mitigate past aesthetic impacts of gravel mining that occurred. The project proposal is to refill an open, scarred, gravel pit landscape and replace it over time with a gently sloping hillside. The hillside will be hydroseeded, eventually developing into an alder forest and later an alder/evergreen forest. Alder trees grow quickly and are better suited than evergreen trees for the thick, poorly draining soils that will be brought on site as fill. Alder trees also help create soil conditions suitable to the recruitment of evergreen trees. Over time the alder forest will naturally give way to a successional forest containing a mix of alder, fir and, hemlock due to the presence of these evergreens on all perimeters of the fill area.

11. Light and Glare [\[help\]](#)

- a. What type of light or glare will the proposal produce? What time of day would it mainly occur? [\[help\]](#)
Site lighting, lighting at the entry, and headlights of trucks during after dark hauling would produce some light/glare when entering or leaving the site. This type of light or glare already occurs due to the Cedar Grove Composting facility, commencement of refilling a portion of the site years ago under existing permits, and prior decades of gravel mining at the site.
- b. Could light or glare from the finished project be a safety hazard or interfere with views?
Not applicable.
- c. What existing off-site sources of light or glare may affect your proposal? [\[help\]](#)
No offsite sources of light or glare are anticipated to affect the proposed project.
- d. Proposed measures to reduce or control light and glare impacts, if any: [\[help\]](#)
Not applicable.

12. Recreation [\[help\]](#)

- a. What designated and informal recreational opportunities are in the immediate vicinity?
No known designated or informal recreational opportunities are in the immediate vicinity of the project area.
- b. Would the proposed project displace any existing recreational uses? If so, describe. [\[help\]](#)
The proposed project will not displace any existing recreational uses.
- c. Proposed measures to reduce or control impacts on recreation, including recreation opportunities to be provided by the project or applicant, if any: [\[help\]](#)
Not applicable.

13. Historic and cultural preservation [\[help\]](#)

- a. Are there any buildings, structures, or sites, located on or near the site that are over 45 years old listed in or eligible for listing in national, state, or local preservation registers ? If so, specifically describe. [\[help\]](#)
No buildings on or near the site were identified as eligible for inclusion in national, state, or local preservation registers.
- b. Are there any landmarks, features, or other evidence of Indian or historic use or occupation? This may include human burials or old cemeteries. Are there any material evidence, artifacts, or areas of cultural importance on or near the site? Please list any professional studies conducted at the site to identify such resources. [\[help\]](#)
No landmarks, features, or other evidence of Indian or historic use or occupation are known to be associated with the project area.
- c. Describe the methods used to assess the potential impacts to cultural and historic resources on or near the project site. Examples include consultation with tribes and the department of archeology and historic preservation, archaeological surveys, historic maps, GIS data, etc.

National Register of Historic Places (National Park Service) and Washington State Department of Archaeology and Historic Preservation online WISAARD.

- d. Proposed measures to avoid, minimize, or compensate for loss, changes to, and disturbance to resources. Please include plans for the above and any permits that may be required. [\[help\]](#)
Not applicable.

14. Transportation [\[help\]](#)

- a. Identify public streets and highways serving the site or affected geographic area and describe proposed access to the existing street system. Show on site plans, if any. [\[help\]](#)

Cedar Grove Road SE provides access to the site from SR 169, which is located approximately 4,000 ft to the west of the site entryway.

- b. Is the site or affected geographic area currently served by public transit? If so, generally describe. If not, what is the approximate distance to the nearest transit stop? [\[help\]](#)

There is no transit immediately near the site. The nearest transit stop is approximately 5 miles south at the Maple Valley Park and Ride (King County Metro Transit).

- c. How many additional parking spaces would the completed project or non-project proposal have? How many would the project or proposal eliminate? [\[help\]](#)

No parking spaces are proposed to be added or eliminated.

- d. Will the proposal require any new or improvements to existing roads, streets, pedestrian, bicycle or state transportation facilities, not including driveways? If so, generally describe (indicate whether public or private). [\[help\]](#)

A new gravel alternative access driveway/internal haul road will be created for Queen City Farms refill operations, designed to replace old access roads within the Phase III footprint.

- e. Will the project or proposal use (or occur in the immediate vicinity of) water, rail, or air transportation? If so, generally describe. [\[help\]](#)

The proposed project will not use water, rail, or air transportation.

- f. How many vehicular trips per day would be generated by the completed project or proposal? If known, indicate when peak volumes would occur and what percentage of the volume would be trucks (such as commercial and nonpassenger vehicles). What data or transportation models were used to make these estimates? [\[help\]](#)

Average daily one-way trip volumes are estimated at 640. A peak volume is set at 1,640 one-way trips per day. Peak volumes will not occur during peak hours of I-405 congestion, since 85 to 95 percent of haul truck trips are expected to travel I-405. In addition, peak hauling operations are expected to be of an episodic nature, occurring to service the needs of large public infrastructure and private construction projects. There will be more variation in project traffic volumes in comparison to typical gravel pit operations.

- g. Will the proposal interfere with, affect or be affected by the movement of agricultural and forest products on roads or streets in the area? If so, generally describe. [\[help\]](#)

The project is not anticipated to interfere, affect, or be affected by the movement of agricultural or forest products in the area.

- h. Proposed measures to reduce or control transportation impacts, if any: [\[help\]](#)
Evening peak hour one-way trips will be limited to 100.

15. **Public Services** [\[help\]](#)

- a. Would the project result in an increased need for public services (for example: fire protection, police protection, public transit, health care, schools, other)? If so, generally describe. [\[help\]](#)
The project would not affect the need for public services.

- b. Proposed measures to reduce or control direct impacts on public services, if any. [\[help\]](#)
The proposed project is not anticipated to directly impact public services.

16. **Utilities** [\[help\]](#)

- a. Circle utilities currently available at the site: [\[help\]](#)
electricity, natural gas, water, refuse service, telephone, sanitary sewer, septic system, other _____
- b. Describe the utilities that are proposed for the project, the utility providing the service, and the general construction activities on the site or in the immediate vicinity which might be needed. [\[help\]](#)
The project will not require any new utilities.

C. Signature [\[help\]](#)

The above answers are true and complete to the best of my knowledge. I understand that the lead agency is relying on them to make its decision.

Signature: Eric Weber

Name of signee Eric Weber, LHG

Position and Agency/Organization Principal/Landau Associates

Date Submitted: April 10, 2018

D. supplemental sheet for nonproject actions [\[help\]](#)

(IT IS NOT NECESSARY to use this sheet for project actions)

Because these questions are very general, it may be helpful to read them in conjunction with the list of the elements of the environment.

When answering these questions, be aware of the extent the proposal, or the types of activities likely to result from the proposal, would affect the item at a greater intensity or at a faster rate than if the proposal were not implemented. Respond briefly and in general terms.

1. How would the proposal be likely to increase discharge to water; emissions to air; production, storage, or release of toxic or hazardous substances; or production of noise?

Proposed measures to avoid or reduce such increases are:

2. How would the proposal be likely to affect plants, animals, fish, or marine life?

Proposed measures to protect or conserve plants, animals, fish, or marine life are:

3. How would the proposal be likely to deplete energy or natural resources?

Proposed measures to protect or conserve energy and natural resources are:

4. How would the proposal be likely to use or affect environmentally sensitive areas or areas designated (or eligible or under study) for governmental protection; such as parks, wilderness, wild and scenic rivers, threatened or endangered species habitat, historic or cultural sites, wetlands, floodplains, or prime farmlands?

Proposed measures to protect such resources or to avoid or reduce impacts are:

5. How would the proposal be likely to affect land and shoreline use, including whether it would allow or encourage land or shoreline uses incompatible with existing plans?

Proposed measures to avoid or reduce shoreline and land use impacts are:

6. How would the proposal be likely to increase demands on transportation or public services and utilities?

Proposed measures to reduce or respond to such demand(s) are:

7. Identify, if possible, whether the proposal may conflict with local, state, or federal laws or requirements for the protection of the environment.

Backup Documentation

Cleanup Site Details

King County iMAP

Priority Habitat Species Report

Soil Map

KING COUNTY

SITE ID:	QUEEN CITY FARMS A	Cleanup Site ID: 2877	FS ID: 140
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Alternate Name(s): **QUEEN CITY FARMS A**

LOCATION:	WRIA: 8	Lat/Long: 47.451 -122.044	View Vicinity Map
Address:	22420 SE 168TH WAY ISSAQUAH 98027	Township: 23N Range: 6E Section: 28	Legislative District: 5 Congressional District: 8

STATUS:	Cleanup Started	Rank: 0	View Site Web Page	View Site Documents
	Responsible Unit: EPA	Site Manager: EPA	Statute: Federal - CERCLA	
	Is Brownfield?	Has Environmental Covenant?	Is PSI Site?	
	NFA Received?	NFA Date:	NFA Reason:	

ASSOCIATED CLEANUP UNIT(s)

culD	Cleanup Unit Name	Unit Type	Process Type	Unit Status	Size (Acres)	ERTS ID
72	QUEEN CITY FARMS A	Upland	Federal-supervised or conducted	Cleanup Started		

SITE ACTIVITIES:

Applies to:	Related ID (Unit-LUST-VCP)	Activity Display Name	Status	Start Date	End Date	Legal Mechanism	Performed By	Project Manager
CleanupSite		Initial Investigation / Federal Preliminary Assessment	Completed	11/15/1989	11/15/1989		Ecology	Ruef, Michael H.
CleanupSite		Hazardous Sites Listing/NPL	Completed	2/22/1995	2/22/1995			Ruef, Michael H.
Milestone		Remedial Investigation and/or Feasibility Study	Completed	6/1/1988	7/15/1992			Ruef, Michael H.
Milestone		Cleanup Action Plan	Completed	9/1/1992	12/23/1992			Ruef, Michael H.
Milestone		Cleanup Action - Engineering Design	In Process	1/4/1994	1/4/1996			Ruef, Michael H.
Milestone		Interim Action	Completed	10/1/1985	11/1/1986			Ruef, Michael H.

AFFECTED MEDIA & CONTAMINANTS:

Media:

Contaminant:	Ground Water	Surface Water	Soil	Sediment	Air	Bedrock
Conventional Contaminants, Inorganic	C		C			
Conventional Contaminants, Organic	C		C			
Halogenated Organics	C		C			
Metals - Other	C		C			
Metals Priority Pollutants	C		C			

Key:

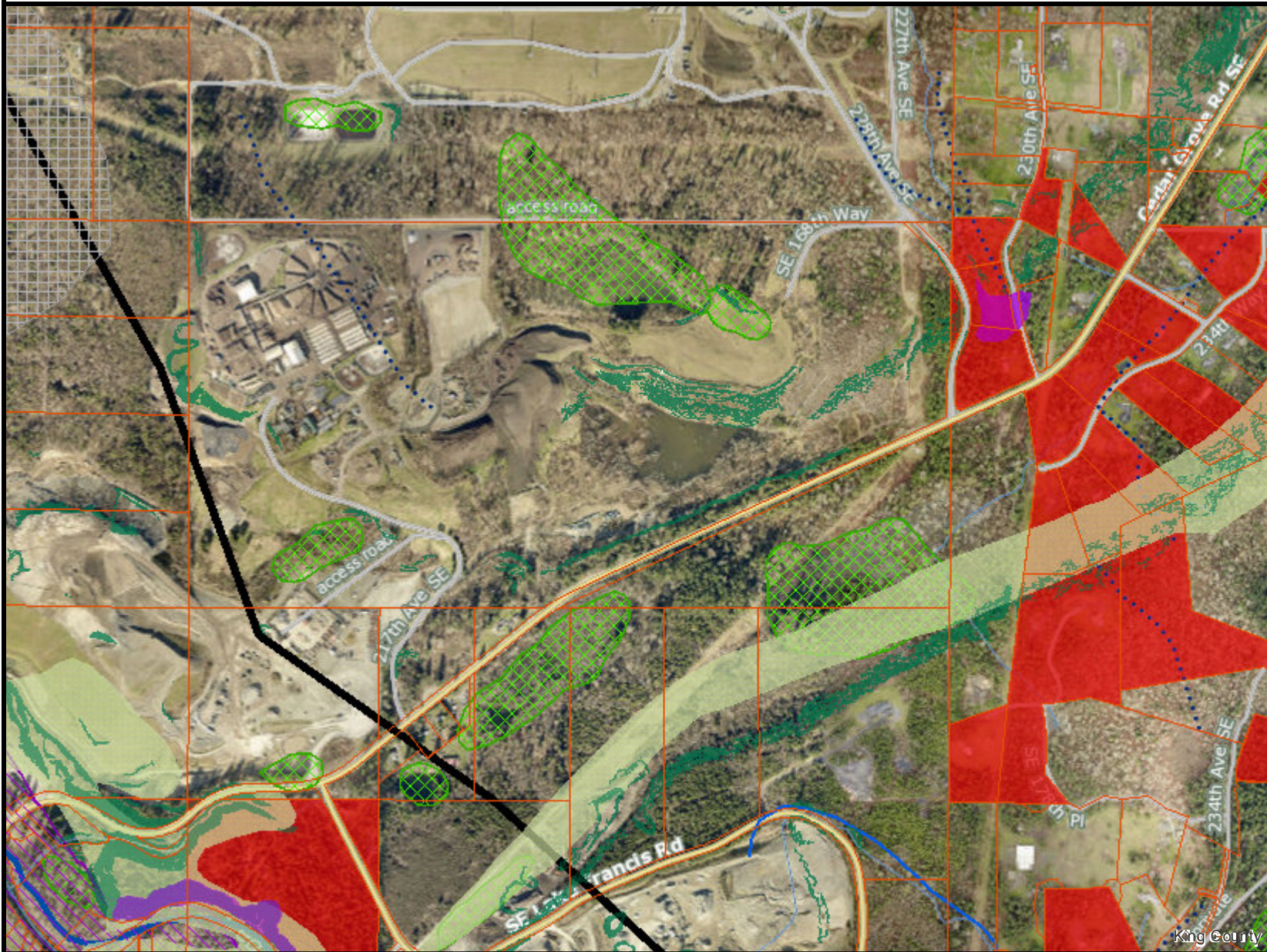
B - Below Cleanup Level
C - Confirmed Above Cleanup Level
S - Suspected

R - Remediated
RA - Remediated-Above
RB - Remediated-Below














Non-Halogenated Solvents	C					
Pesticides-Unspecified	C					
Petroleum Products-Unspecified	C					
Polychlorinated biPhenyls (PCB)	C		C			
Polycyclic Aromatic Hydrocarbons	C					

CleanupSiteDetails2014

King County iMap



Legend

-  Parcels
-  Potential landslide hazard areas (2016, see explanation-->)
-  Potential steep slope hazard areas (2016, see explanation-->)
-  Erosion hazard (1990 SAO)
-  Seismic hazard (1990 SAO)
-  Coal mine hazard (1990 SAO)
-  class 1
-  class 2 perennial
-  class 2 salmonid
-  class 3
-  unclassified
-  Wetland (1990 SAO)
-  Sensitive area notice on title

The information included on this map has been compiled by King County staff from a variety of sources and is subject to change without notice. King County makes no representations or warranties, express or implied, as to accuracy, completeness, timeliness, or rights to the use of such information. This document is not intended for use as a survey product. King County shall not be liable for any general, special, indirect, incidental, or consequential damages including, but not limited to, lost revenues or lost profits resulting from the use or misuse of the information contained on this map. Any sale of this map or information on this map is prohibited except by written permission of King County.

Date: 2/21/2018

Notes:



WASHINGTON DEPARTMENT OF FISH AND WILDLIFE PRIORITY HABITATS AND SPECIES REPORT

SOURCE DATASET: PHSPublic
REPORT DATE: 03/13/2018 3.57

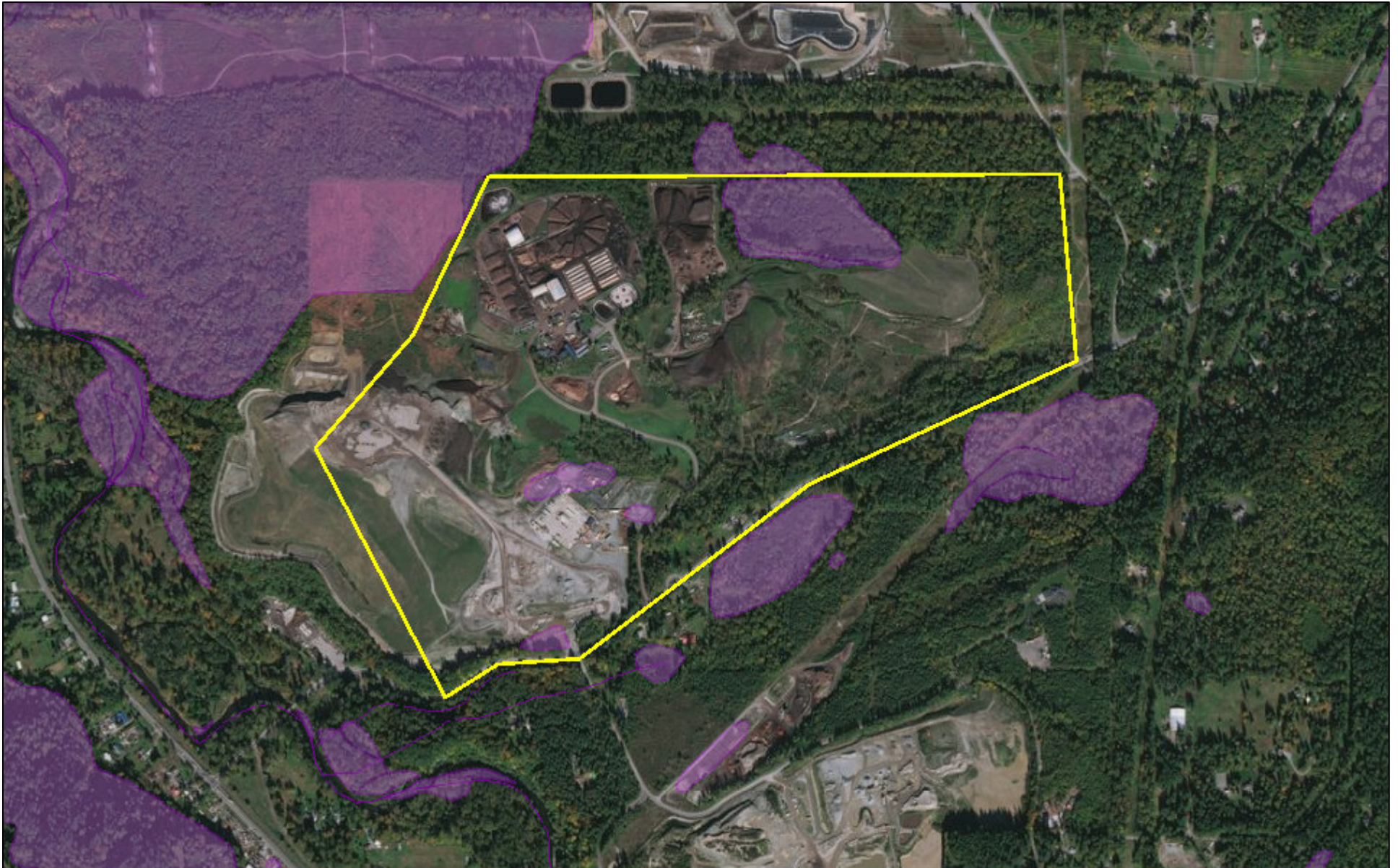
Query ID: P180313155640

Common Name	Site Name	Priority Area	Accuracy	Federal Status	Sensitive Data	Source Entity
Scientific Name	Source Dataset	Occurrence Type		State Status	Resolution	Geometry Type
Notes	Source Record	More Information (URL)		PHS Listing Status		
	Source Date	Mgmt Recommendations				
Freshwater Emergent	N/A	Aquatic Habitat	NA	N/A	N	US Fish and Wildlife Service
	NWIIWetlands	Aquatic habitat		N/A	AS MAPPED	Polygons
		http://www.ecy.wa.gov		PHS Listed		
Freshwater Forested/Shrub	N/A	Aquatic Habitat	NA	N/A	N	US Fish and Wildlife Service
	NWIIWetlands	Aquatic habitat		N/A	AS MAPPED	Polygons
		http://www.ecy.wa.gov		PHS Listed		
Freshwater Forested/Shrub	N/A	Aquatic Habitat	NA	N/A	N	US Fish and Wildlife Service
	NWIIWetlands	Aquatic habitat		N/A	AS MAPPED	Polygons
		http://www.ecy.wa.gov		PHS Listed		
Other	N/A	Aquatic Habitat	NA	N/A	N	US Fish and Wildlife Service
	NWIIWetlands	Aquatic habitat		N/A	AS MAPPED	Polygons
		http://www.ecy.wa.gov		PHS Listed		
Other	N/A	Aquatic Habitat	NA	N/A	N	US Fish and Wildlife Service
	NWIIWetlands	Aquatic habitat		N/A	AS MAPPED	Polygons
		http://www.ecy.wa.gov		PHS Listed		
Other	N/A	Aquatic Habitat	NA	N/A	N	US Fish and Wildlife Service
	NWIIWetlands	Aquatic habitat		N/A	AS MAPPED	Polygons
		http://www.ecy.wa.gov		PHS Listed		
Wetlands	CEDAR RIVER WETLANDS	Aquatic Habitat	1/4 mile (Quarter	N/A	N	WA Dept. of Fish and Wildlife
	PHSREGION	N/A		N/A	AS MAPPED	Polygons
	902522	http://www.ecy.wa.gov		PHS LISTED		








Common Name	Site Name	Priority Area	Accuracy	Federal Status	Sensitive Data	Source Entity
Scientific Name	Source Dataset	Occurrence Type		State Status	Resolution	Geometry Type
	Source Record	More Information (URL)		PHS Listing Status		
Notes	Source Date	Mgmt Recommendations				

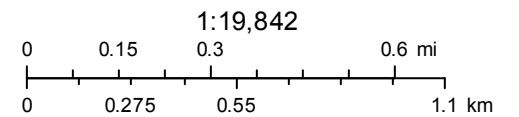
DISCLAIMER. This report includes information that the Washington Department of Fish and Wildlife (WDFW) maintains in a central computer database. It is not an attempt to provide you with an official agency response as to the impacts of your project on fish and wildlife. This information only documents the location of fish and wildlife resources to the best of our knowledge. It is not a complete inventory and it is important to note that fish and wildlife resources may occur in areas not currently known to WDFW biologists, or in areas for which comprehensive surveys have not been conducted. Site specific surveys are frequently necessary to rule out the presence of priority resources. Locations of fish and wildlife resources are subject to variation caused by disturbance, changes in season and weather, and other factors. WDFW does not recommend using reports more than six months old.

WDFW Test Map



March 13, 2018

- | | | | | | |
|---|----------------------|---|---|---|----------|
|  | PHS Report Clip Area | POLY |  | QTR-TWP | |
|  | PT |  | AS MAPPED |  | TOWNSHIP |
|  | LN |  | SECTION | | |

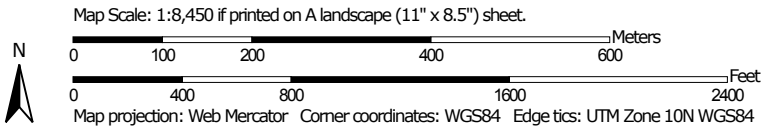


Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Soil Map—King County Area, Washington
(QCF SEPA)




Soil Map may not be valid at this scale.




MAP LEGEND

Area of Interest (AOI)

 Area of Interest (AOI)

Soils

 Soil Map Unit Polygons

 Soil Map Unit Lines

 Soil Map Unit Points

Special Point Features



Blowout



Borrow Pit



Clay Spot



Closed Depression



Gravel Pit



Gravelly Spot



Landfill



Lava Flow



Marsh or swamp



Mine or Quarry



Miscellaneous Water



Perennial Water



Rock Outcrop



Saline Spot



Sandy Spot



Severely Eroded Spot



Sinkhole



Slide or Slip



Sodic Spot



Spoil Area



Stony Spot



Very Stony Spot



Wet Spot



Other



Special Line Features

Water Features



Streams and Canals

Transportation



Rails



Interstate Highways



US Routes



Major Roads



Local Roads

Background



Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service

Web Soil Survey URL:

Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: King County Area, Washington

Survey Area Data: Version 13, Sep 7, 2017

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Aug 1, 2011—Oct 10, 2016

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

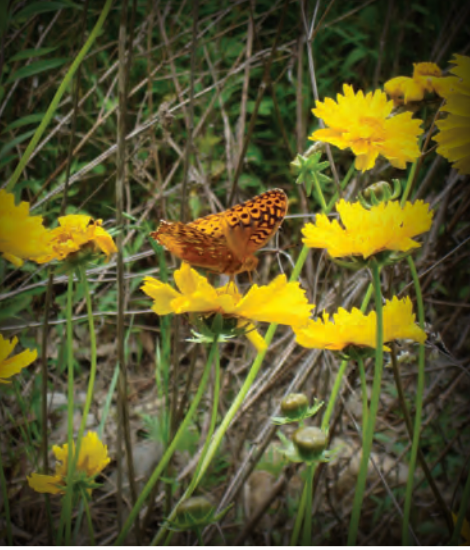
Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
AgC	Alderwood gravelly sandy loam, 8 to 15 percent slopes	21.1	14.9%
EvC	Everett very gravelly sandy loam, 8 to 15 percent slopes	87.5	62.0%
EvD	Everett very gravelly sandy loam, 15 to 30 percent slopes	4.6	3.3%
PITS	Pits	27.7	19.6%
W	Water	0.3	0.2%
Totals for Area of Interest		141.1	100.0%

Phase II Refill Site Improvement Plans

Full-size plans accompany this report separately.

Reference Documents



APPENDIX
C-1



A Function-Based Framework for Stream Assessment & Restoration Projects

EPA 843-K-12-006 » May 2012

Title: A Function-Based Framework for Stream Assessments and Restoration Projects

Date: May 2012

Prepared By:

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- Richard Starr, US Fish and Wildlife Service, Chesapeake Bay Field Office, MD (Chapters 1, 4, 8, 11)
- Melanie Carter, Carter Land and Water (Chapter 5, 8, 9, 10)
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- Micky Clemmons, Michael Baker Corporation, Pittsburgh, PA (Chapter 10)
- Kristi Suggs, Michael Baker Corporation, Pittsburgh, PA (Chapter 9)
- Christine Miller, Michael Baker Corporation, Pittsburgh, PA (Chapter 8)

Appropriate Citation:

Harman, W., R. Starr, M. Carter, K. Tweedy, M. Clemmons, K. Suggs, C. Miller. 2012. *A Function-Based Framework for Stream Assessment and Restoration Projects*. US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC EPA 843-K-12-006.

The findings and conclusions in this document are those of the authors and do not necessarily represent the views of the US Fish and Wildlife Service (FWS) or the US Environmental Protection Agency (EPA).

Authors' Note:

This document provides a new framework for approaching stream assessment and restoration from a function-based perspective; as such, it will benefit from review, comments, and example experiences and applications. Please share these with the authors so the concepts, examples and templates can be revised and expanded. Contact any one of the following: Will Harman, lead author (wharman@stream-mechanics.com, 919-747-9448), Brian Topping, EPA project sponsor (topping.brian@epa.gov, 202-566-5680) or Rich Starr, FWS project sponsor (rich_starr@fws.gov, 410-573-4583).

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This document would not have been possible without the assistance of numerous scientists from EPA and other organizations. Special thanks to Palmer Hough and Brian Topping with EPA headquarters for the idea to provide training and support regarding stream functional assessments, for their commitment to secure project funding, and for their careful review and guidance throughout all stages of the project. The FWS is also recognized for providing in-kind financial support and project oversight.

The Framework presented in this document was tested through a pilot workshop at the FWS National Conservation Training Center in the summer of 2010. EPA staff from around the country attended the workshop and provided comments on how to improve the Framework and workshop. They also provided real-world examples of stream impacts and restoration needs from various regions that could be used to develop case studies. These scientists and managers included: Eric Somerville, Ed Reiner, Robert Montgomerie, Stephanie Chin, Carol Petrow, David Rider, Bill Ainslie, Mara Lindsley, Sue Elston, Melissa Gebien, Melanie Haveman, Scott McWhorter, Catherine Holston, Jason Daniels, Richard Clark, Toney Ott, Tracie Nadeau, Linda Storm, Brent Johnson, Greg Pond, Joy Gillespie, Brian Topping and Palmer Hough.

Special thanks to Brian Topping, Palmer Hough, Tracie Nadeau, Bill Ainslie, Eric Somerville, Bob Lord, Julia McCarthy, Jason Daniels, Brent Johnson, Ken Fritz, Greg Pond, Craig Fischenich, Chris Noble, Rich Sumner, Linda Storm and Toney Ott for additional review comments and guidance as the second version of the document was prepared. Their insight and expertise greatly improved the content and breadth of the document.

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GLOSSARY OF TERMS

Biology Function: Level 5 functions of the Stream Functions Pyramid that involve the biodiversity and the life histories of aquatic and riparian organisms. These functions are placed at the top of the Pyramid because they are affected by all underlying Levels (Chapters 4 and 10).

Condition: The relative ability of an aquatic resource to support and maintain a community of organisms having a species composition, diversity and functional organization comparable to reference aquatic resources in the region (Chapter 2).

Compensatory Mitigation: The restoration (re-establishment or rehabilitation), establishment (creation), enhancement and/or, in certain circumstances, preservation of aquatic resources for the purpose of offsetting unavoidable adverse impacts that remain after all appropriate and practicable avoidance and minimization has been achieved (Chapters 2 and 11).

Credit: A unit of measure representing the accrual or attainment of aquatic functions at a compensatory mitigation site. The measure of aquatic resource functions is based on the resources restored, established, enhanced or preserved (Chapters 2 and 11).

Credit Production: The number of credits should reflect the difference between pre- and post-compensatory mitigation project site conditions, as determined by a functional assessment or other suitable method (Chapters 2 and 11).

Debit: A unit of measure representing the loss of aquatic functions at an impact or project site. The measure of aquatic resource functions is based on the resources impacted by the authorized activity (Chapters 2 and 11).

Determination of Credits: A description of the number of credits to be provided, which includes a brief explanation of the rationale for this determination (Chapters 2 and 11).

Enhancement: The manipulation of the physical, chemical or biological characteristics of an aquatic resource to heighten, intensify or improve a specific aquatic resource function(s). Enhancement results in the gain of selected aquatic resource function(s), but may also lead to a decline in other aquatic resource function(s). Enhancement does not result in a gain in an aquatic resource area (Chapters 2, 4 and 11).

Functions: The physical, chemical and biological processes that occur in ecosystems.

Glossary of Terms

Function-Based Parameters: Parameters that are used to quantify or describe the functional statement provided in the broad-level view of the Stream Functions Pyramid. They can be a structural type of parameter that describes a stream condition at a point in time, or they can be an actual function expressed as a rate that directly relates to a stream process (Chapter 4).

Functional Capacity: The degree to which an area of aquatic resource performs a specific function (Chapter 2).

Functional Category: The term for each level of the Stream Functions Pyramid, which includes five levels: Hydrology (Level 1), Hydraulics (Level 2), Geomorphology (Level 3), Physicochemical (Level 4), and Biology (Level 5) (Chapter 4).

Functional Statement: The statement that describes the functions for each Functional Category, e.g., the transport of water from the watershed to the channel for Level 1 (Chapter 4).

Geomorphology Function: Level 3 functions on the Stream Functions Pyramid that involve transport of wood and sediment within the channel to create diverse bed forms and dynamic equilibrium (Chapters 4 and 8).

Hydraulic Function: Level 2 functions on the Stream Functions Pyramid that involve transport of water in the channel, through sediments, and on the floodplain (Chapters 4 and 7).

Hydrology Function: Functions at the base of the Stream Functions Pyramid (Level 1) that involve the transport of water from the watershed to the channel (Chapter 6).

Impact: An adverse affect.

Interagency Review Team (IRT): An interagency group of federal, tribal, state and/or local regulatory and resource agency representatives that reviews documentation for, and advises the district engineer on, the establishment and management of a mitigation bank or in-lieu fee program.

Measurement Methods: A wide range of tools, techniques, metrics and assessment approaches that qualify or quantify the Function-Based Parameters. Each measurement method is assigned a category for Type, Level of Effort, Level of Complexity, and whether it is a Direct or Indirect measure. Refer to Chapter 4 and Appendix Ac for a comprehensive list of the measurement methods and their assigned categories.

Mitigation Rule: The 2008 Federal Compensatory Mitigation Rule administered by the US Corps of Engineers and the US Environmental Protection Agency (33 CFR Parts 325 and 332; 40 CFR Part 230).

Glossary of Terms

Performance Standards: Observable or measurable physical (including hydrological), chemical and/or biological attributes that are used to determine if the compensatory mitigation project meets its objectives.

Physicochemical Function: Level 4 functions on the Stream Functions Pyramid that involve water quality associated with the Biology Function, including water chemistry, nutrients and organic matter (Chapters 4 and 9).

Reference Aquatic Resource: A set of aquatic resources that represents the full range of variability exhibited by a regional class of aquatic resources as a result of natural processes and anthropogenic disturbances (Chapter 2).

Reference Condition: A contextual background against which the degree of degradation, range of condition, and benefits of restoration can be measured.

Reference Reach: A term often used in Natural Channel Design for developing dimensionless ratios to assess channel dimension, pattern and profile.

Restoration: The manipulation of the physical, chemical and biological characteristics of a site with the goal of returning natural/historic functions to a former or degraded aquatic resource.

Restoration Priority Levels: Also referred to as the Rosgen Priority Levels of Restoration. Includes four restoration approaches for restoring incised channels (Chapters 3 and 11).

Riparian Areas: Lands adjacent to streams, rivers, lakes and estuarine shorelines that provide a variety of ecological functions and services and help improve or maintain water quality.

Service Area: The geographic area within which impacts can be mitigated at a specific mitigation bank or an in-lieu fee program.

Stream Functions Pyramid: The hierarchical representation of stream functions with five levels: Hydrology, Hydraulics, Geomorphology, Physicochemical and Biology.

Stream Functions Pyramid Framework: The four components of the Stream Functions Pyramid. First, broad-level view shows the five functional categories (Levels) with the underlying controlling variables of geology and climate. Second, function-based parameters are provided for each functional category. Third, measurement methods are provided for each function-based parameter. And fourth, where possible, performance standards are provided for the measurement methods.

EXECUTIVE SUMMARY

Stream restoration efforts have increased significantly in the US over the past few decades and are now recognized as a billion-dollar industry. These restoration efforts stem from centuries of abuse as humans continue to alter the riverine landscape for a variety of purposes, including farming, logging, mining and development on the floodplain, and the subsequent need for channelization and flood control. These activities have significantly diminished the natural functions of our stream corridors.

Today stream corridor restoration efforts seek to improve or restore these lost functions. A variety of federal, state and local programs, along with efforts from non-profit organizations, provide funding for these programs. The goals are varied and range from simple streambank stabilization projects to watershed scale restoration. For these projects to be successful it is important to know *why* the project is being completed and *what techniques* are best suited to restore the lost functions. **Knowing why a project is needed requires some form of functional assessment followed by clear project goals. To successfully restore stream functions, it is necessary to understand how these different functions work together and which restoration techniques influence a given function. It is also imperative to understand that stream functions are interrelated and build on each other in a specific order, a functional hierarchy. If this hierarchy is understood, it is easier to establish project goals. And with clearer goals, it is easier to evaluate project success.**

A large amount of funding for stream restoration is related to compensatory mitigation required as part of Clean Water Act (FWPCA, 1972) Section 404 permits issued by the US Army Corps of Engineers (USACE). As part of a 404 permit authorizing impacts to streams in one location, the 404 permit may require the permittee to conduct stream restoration or enhancement activities in a nearby stream to compensate or offset the loss of stream functions at the permitted impact site. The 2008 Federal Mitigation Rule recommends that a functional or condition assessment be completed at the impact site to quantify ecological losses (debits) and at the mitigation site to quantify projected ecological gains (credits), which would be realized if the mitigation project is successfully implemented (33 CFR 332.3(f)(1), 2008). Credits generated at the mitigation site should offset the debits estimated at the impact site. Success criteria and performance standards are required to measure mitigation project success and ensure that mitigation projects do indeed generate the amount of credits initially projected.

Interagency Review Teams (IRTs) associated with each USACE District can provide valuable support in the effective implementation of the 2008 Mitigation Rule, including the development of region-specific Standard Operating Procedures (SOPs) designed to aid in assessing debits and credits. However, the science of stream assessment is complex and the practice of stream restoration is relatively young and rapidly evolving. Additionally, many IRT staff have a stronger background in wetland science than fluvial geomorphology or stream ecology, making the development of effective SOPs a significant challenge for IRTs.

Document Goals

In order to address the central stream restoration issues delineated above, this document presents three primary goals:

1. Help the restoration community understand that stream functions are inter-related and generally build on each other in a specific order, a functional hierarchy, and understand that parameters can be used to assess those functions even if some parameters are functions and others are structural measures.

This goal is addressed in the document in several ways. First, an overview of watershed and stream corridor processes is provided in Chapter 3. This chapter describes the basic interplay of processes that work together in order for the watershed and stream corridor to function; it serves as a watershed science “refresher” and includes references to other sources for a deeper understanding of how watersheds work. Also provided in this chapter is the background science necessary to understand the Stream Functions Pyramid Framework that is presented in Chapter 4 and fully described throughout the remainder of the document. The Stream Functions Pyramid Framework illustrates the hierarchy of stream functions and provides a list of function-based parameters and measurement methods that can be used to describe the functions. Performance standards are also provided for each measurement method, when available.

2. Place reach scale restoration projects into watershed context and recognize that site selection is as important as the reach scale activities themselves.

The importance of site selection is discussed in several places throughout the document, including in Chapters 3 and 11. Site selection is a critical part of a stream restoration project, especially if the goal is to provide physicochemical and/or biological improvements. This step can make the difference between a successful and an unsuccessful project.

3. Provide informal guidance and ideas on how SOPs might incorporate stream functions into debit/credit determination methods, function-based assessments and performance standards.

This is a core element of the document. Chapter 11 provides examples of how the Stream Functions Pyramid can be used to develop these parts of the SOP. Chapters 6 through 10 provide detailed information about the relative importance of each function-based parameter, their measurement method and performance standard, where applicable.

This document is not a stand-alone stream assessment method, list of performance standards or mitigation SOP, and in no cases should all of the measures or example performance standards be used on a single project. In addition, there may be special projects that require parameters, measurement methods and performance standards that are not included in this framework; it is not all-inclusive. As discussed in each chapter, many of the measures are only appropriate in certain stream types or landscape positions, and often multiple measures of the same function are reviewed. Practitioners should take care to ensure the measures used are appropriate for the stream type, fully capture the existing condition and can accurately measure achievement of the goals of the project.

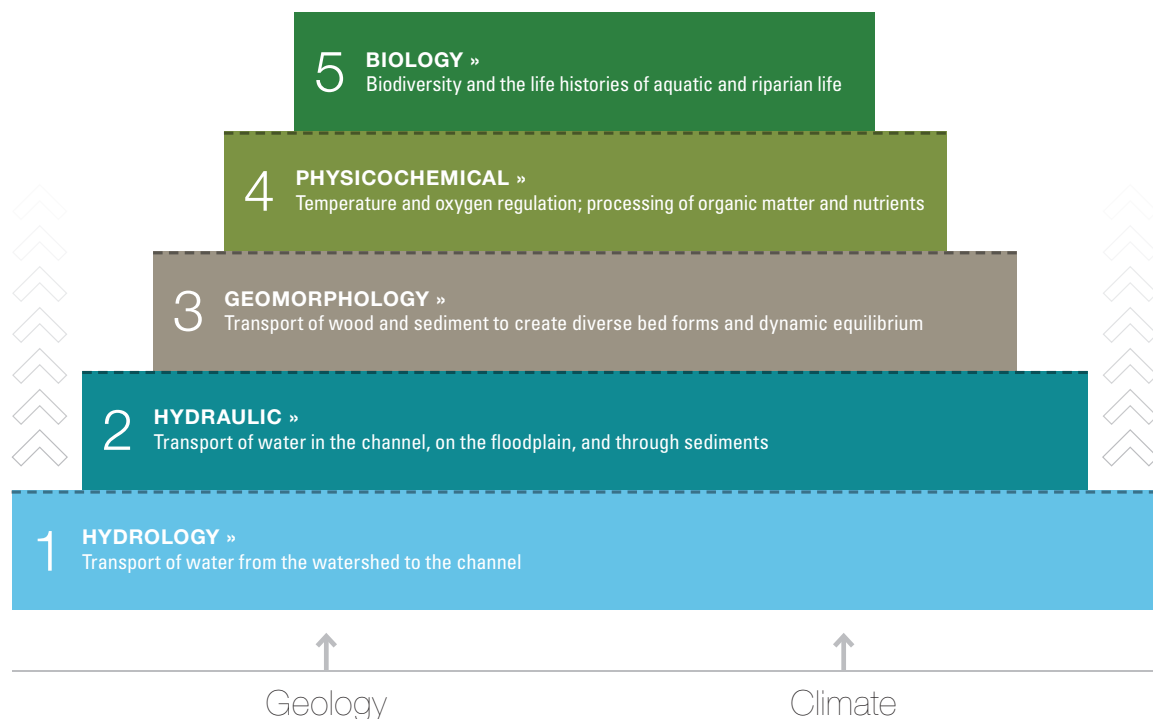
Executive Summary

Stream Functions Pyramid Framework

The Framework used in this document was inspired by Fischenich (2006), where the USACE and a group of scientists and practitioners developed functional objectives for stream restoration projects. This document uses different terminology than the Fischenich (2006) document in an attempt to tie stream functions to common parameters that can be used to describe functions. This document does not delineate between parameters that are functions versus those that are structural measures. Rather, the parameters are called function-based because each parameter can be used to help understand the overall function for a given category, which is described below. Stream functions are separated into a hierarchy of categories, ranging from Level 1 to Level 5 and include:

- Hydrology (Level 1)
- Hydraulic (Level 2)
- Geomorphology (Level 3)
- Physicochemical (Level 4)
- Biology (Level 5)

Within this hierarchical Framework, higher-level functions are supported by lower-level functions, like a pyramid. For example, Hydraulic functions cannot occur without Hydrologic functions, and so on. Chapter 4 describes each level in detail, and the full Pyramid Framework synopsis, including measurement methods and performance standards, is provided in Appendix A.



Executive Summary

Social and recreational functions and values like fishing or boating are not included in this document, and the hierarchy of functions is not all-inclusive. There are many other parameters that can be assessed in order to describe a given function. However, this document provides a structure and organization that can easily be adapted to fit individual project goals and environmental settings. Since the lower-level functions of Hydrology, Hydraulics and Geomorphology are required before Physicochemical and Biology functions can be realized, this document places more focus on the lower-level functions. In addition, these lower-level foundational functions have traditionally been addressed more in stream restoration designs.

Stream Functions Pyramid Application

Chapter 11 provides detailed information about how the Pyramid can be applied. But in general, there are three main areas where the Pyramid can provide guidance: setting project goals and objectives, developing/reviewing specific function-based stream assessment methods, and creating SOPs for stream mitigation programs.

Setting Project Goals and Objectives

A common stream restoration goal that is often stated in stream mitigation plans is the improvement of channel dimension, pattern and profile so that the channel does not aggrade or degrade. This goal primarily addresses channel stability. The Pyramid can be used to develop goals that more directly relate to the improvement of functions. Well-conceived goals should help answer the question, “Why is this project being pursued and what functional improvements are being targeted?” Once a goal has been established, the Pyramid can be used to develop objectives that call out which parameters, measurement methods, or even performance standards will be used to evaluate the functional improvement. In addition, once function-based goals and objectives have been selected and identified within a certain level, the Pyramid can be used to determine which supporting functions (lower levels) also need to be addressed.

Developing Function-based Stream Assessment Methods

Although it is not a functional assessment methodology, the Pyramid is a Framework that can be used to create functional assessments or at least function-based assessments. Using the Pyramid as a guide for developing function-based stream assessments will help ensure that a protocol addresses parameters in the correct order based on function. These assessment methodologies should include parameters from each level as it applies to site and/or regional conditions and constraints. In addition, simple parameters may be selected for rapid-based assessments, and more time-intensive parameters may be selected for more complex studies. Parameters could also be selected to show functional gain or improvement at a restoration or mitigation site, or functional loss at a proposed impact site. Somerville (2010) provides a good overview of existing function-based assessments, including their strengths and weaknesses.

Creating SOPs for Stream Mitigation Programs

The Pyramid can also be used by Interagency Review Teams (IRTs) to develop debit and credit determination methods and performance standards for stream mitigation projects. In addition, if reference reaches are also assessed using a function-based approach, the functional capacity of the mitigation site can be addressed. This will help IRTs to move away from attaching credits to restoring dimension, pattern and profile, and move toward changes in parameters that describe or are themselves functions. Example templates are provided in Chapter 11 to give IRTs ideas about how to create function-based debit/credit determination methods. Additional case studies representing a variety of scenarios are also provided in Appendix B. These example templates and case studies are truly meant to be examples and are not a policy recommendation. They should be considered “food for thought” as each IRT develops an SOP that fits their region.

Understanding the functional hierarchy of stream restoration is vital to our nation’s efforts to reclaim and restore its riverine landscapes. This document is meant to become a comprehensive resource for the public, private and non-profit organizations and agencies whose goals include stream restoration. The hope is that when this hierarchy (the Stream Functions Pyramid) is fully comprehended, embraced and applied, the efforts to restore our nation’s streams will become more focused, precise...and successful.

Chapter 1

Introduction

Stream restoration efforts have increased significantly in the US over the past few decades and are now recognized as a billion-dollar industry (Bernhardt et al., 2005). These restoration efforts stem from centuries of abuse as humans continue to alter the riverine landscape for a variety of purposes, including farming, logging, mining and development on the floodplain with its subsequent need for channelization and flood control. These activities have significantly diminished the natural functions of our stream corridors (Wohl, 2004).

Today stream corridor restoration efforts seek to improve or restore these lost functions. A variety of federal, state and local programs, along with efforts from non-profit organizations, provide funding for restoration efforts. The goals are varied and range from simple streambank stabilization to watershed scale restoration. Stream/wetland mitigation for permitted impacts to aquatic resources also contributes to a large portion of the overall restoration effort. For these projects to be successful, it is important to know *why* the project is being completed and *what techniques* are best suited to restore the lost functions. Knowing why a project is needed requires some form of functional assessment to determine the nature and magnitude of the impairment, followed by clear project goals designed to best address the impairment. To successfully restore stream functions, it is necessary to understand how these different functions work together and which restoration techniques influence a given function.

It is also important to know that stream functions are interrelated and build on each other in a specific order, a functional hierarchy. If this hierarchy is understood, it is easier to establish project goals. And with clearer goals, it is easier to evaluate project success. **One goal of this document is to help the restoration community understand that stream functions occur in a general order, and that parameters can be used to assess those functions even if some parameters are functions and others are structural measures. Functions should be addressed in the order shown to have a successful project. Another goal is to place reach scale restoration projects into a watershed context and recognize that site selection is as important, if not more important, than the reach scale activities themselves.**

A large amount of funding for stream restoration is related to compensatory mitigation required as part of Clean Water Act Section 404 permits issued by the US Army Corps of Engineers (USACE). As part of a 404 permit authorizing impacts to streams in one location, the 404 permit may require the permittee to conduct stream restoration or enhancement activities in a nearby stream to compensate or offset the loss of stream functions at the permitted impact site. The 2008 Federal Mitigation Rule recommends

that a functional or condition assessment be completed at the impact site to quantify ecological losses (debits) and at the mitigation site to quantify projected ecological gains (credits), which would be realized if the mitigation project is successfully implemented (33 CFR 332.3(f)(1), 2008). Credits generated at the mitigation site should offset the debits estimated at the impact site. Success criteria and performance standards are required to measure mitigation project success and ensure that mitigation projects do indeed generate the amount of credits necessary to offset permitted impacts.

Interagency Review Teams (IRTs) associated with each USACE District can provide valuable support in the effective implementation of the 2008 Mitigation Rule, including the development of region-specific Standard Operating Procedures (SOPs) designed to aid in assessing debits and credits. However, the science of stream assessment is complex and the practice of stream restoration is relatively young and rapidly evolving. Additionally, many IRT staff have a stronger background in wetland science than fluvial geomorphology or stream ecology, making the development of effective SOPs a significant challenge for IRTs. **Consequently, another goal of this document is to provide recommendations and ideas on how SOPs might incorporate stream functions into debit/credit determination methods, function-based assessments and performance standards.**

1.1 » DOCUMENT OVERVIEW

The document is organized as follows:

Chapter 2: Overview of Federal Compensatory Mitigation Regulations: This chapter provides a brief overview of the 2008 Federal Compensatory Mitigation Rule and how this document supports the implementation of this Mitigation Rule. This chapter may be helpful to those who are not familiar with stream mitigation and its associated terminology.

Chapter 3: Watershed and River Corridor Processes: This chapter describes the basic interplay of processes that work together for the watershed and stream corridor to function; it serves as a watershed science “refresher” and includes references to other sources for a deeper understanding of how watersheds work, as well as provides the background science necessary to understand the Stream Functions Pyramid and Framework described in Chapter 4.

Chapter 4: The Stream Functions Pyramid: This chapter provides a detailed overview of the Framework used in this document to assess stream functions. This Framework, called the Stream Functions Pyramid Framework, describes the proposed hierarchy of stream functions and provides a list of function-based parameters, measurement methods and performance standards that can be used to describe the functions. *It is important to read this chapter before proceeding to the Hydrology through Biology chapters (Chapters 6 through 10).*

Chapter 5: Reference Streams: This chapter provides an overview of how reference stream reaches are used in natural channel design, stream assessments and stream mitiga-

tion. An introduction section provides a discussion about why a reference reach is important and the different ways it can be used. Information is also provided about how to select a reference reach based on project goals and objectives. A variety of existing field assessment and data analysis methods are provided.

Chapters 6-10: Hydrology, Hydraulic, Geomorphology, Physicochemical and Biology — These five chapters provide detailed information about the relative importance of each function-based parameter, their measurement methods and performance standards, where applicable. Some parameters and measurement methods do not have performance standards, but instead have design standards. Design standard sections are included for those parameters that are critical for understanding stream processes but are not appropriate for performance standards (typically because the research does not currently support a standard, and sometimes because the parameter is too variable or too site specific). Sediment transport competency and capacity are examples of parameters that include a section on design standards but not performance standards. These chapters represent the bulk of the document and are intended to serve as a reference or guide for those who are developing function-based assessments, restoration goals or performance standards.

Chapter 11: Applications — This chapter shows how the Stream Functions Pyramid can be used to help develop stream restoration goals, function-based assessments and debit/credit determination methods for stream mitigation SOPs. Examples of each are provided. For the SOP example, different scenarios are provided that represent the bulk of stream impacts and restoration needs from across the country.

It should be noted that this document is not a stand-alone stream assessment method, list of performance standards or mitigation SOP, and it is not necessary or recommended to apply all of the measures or example performance standards for a single project. In addition, there may be important parameters that are not included, especially for rare or unique settings. As discussed in each chapter, many of the measures are only appropriate in certain stream types, environmental settings, climates or landscape positions, and often multiple measures of the same parameter are provided. In addition, actual stream assessments may utilize a combination of parameters to determine an overall functional score, something that this document does not provide. Practitioners should take care to ensure the measures used are appropriate for the stream type, fully capture the existing condition, and can accurately measure achievement of the project goals.

1.2 » WHAT THE DOCUMENT DOES AND DOES NOT PROVIDE

This document does provide:

- An overview of watershed and riverine processes.
- A hierarchical framework illustrating the relative relationship of stream functions and parameters that can be used to describe those functions. The hierarchical Framework,

called the Stream Functions Pyramid, shows that functions build on each other in a general order and that physical functions — like the transport of water and sediment — support physicochemical and biological functions. Parameters include structural and functional measures, which together are considered to be function-based. Most importantly, the hierarchy provides a logical framework of parameters that practitioners can use to evaluate stream functions.

- The state of the science and tools to help create function-based goals, assessment methods, debit/credit determination methods and performance standards.
- Examples of how the Stream Functions Pyramid can be applied to setting project goals and objectives, developing specific function-based stream assessment methods, and creating debit/credit determination methods for stream mitigation programs.
- References to key textbooks, peer-reviewed papers and websites for more in-depth information.

This document does not provide:

- A Standard Operating Procedure for stream assessments and mitigation.
- Stream debit and credit formulas. However, IRTs can use select parameters and their corresponding methods of measurement and performance standards as a guide for creating formulas for their region.
- A specific functional assessment methodology.
- A specific monitoring approach.
- Even though the Framework includes a wide range of parameters that can be used to describe functions in their respective category, the document does not promote using all of these parameters in a given assessment or restoration project. The same is true for the measurement methods. A variety of measurement methods are provided for each parameter. Rather than use all of the measurement methods for a given parameter, the user should pick the best methods given the project goals and budget.
- A manual or textbook on fluvial processes and stream assessment. However, references are provided that cover a wide range of stream processes and functions.
- Function-based parameters in this document are not all-inclusive. Other function-based parameters, measurement methods and performance standards may exist that are more suitable based on project objectives.

1.3 » PROJECT PARTNERSHIPS

The development of this document is through a partnership between the US Fish and Wildlife Service (FWS) and US Environmental Protection Agency (EPA). The FWS and EPA entered into a partnership in 2006 to develop and provide standardized tools and training modules on how to evaluate stream assessments and restoration designs. The FWS and EPA recognized the need for these tools and training modules to improve the link between stream restoration and compensatory mitigation under Section 404 of the Clean Water Act. Additionally, such tools and training modules are relevant to a suite of state, local and federal natural resource agencies that are regularly tasked with reviewing

the merits of stream restoration, enhancement and/or protection projects proposed as restoration, or to compensate for authorized impacts to streams.

The first stream tool and training module developed under this agreement was the *Natural Channel Design Review Checklist*. The Checklist provides guidance on important factors to consider when reviewing natural channel designs. It is intended to provide the reviewer with a rapid method for determining whether a project design contains an appropriate level of information. The Checklist consists of a list of questions that must be answered as part of a design review and includes the following sections: Watershed and Geomorphic Assessment, Preliminary Design, Final Design, and Maintenance and Monitoring Plans. The training module uses a 3.5-day training course and includes an overview of stream processes, channel stability and function, restoration potential, and natural channel design techniques.

More information on offerings of the trainings can be found at training.fws.gov and www.stream-mechanics.com. The *Natural Channel Design Review Checklist* and other stream mitigation resources can be found on EPA's website for compensatory mitigation under the "Technical Resources for Stream Mitigation" section: water.epa.gov/lawsregs/guidance/wetlands/wetlandsmitigation_index.cfm.

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Chapter 2

Overview of Federal Compensatory Mitigation Regulations

2.1 » OVERVIEW

Since a major goal of this document is to provide IRTs with tools that can be used to develop Standard Operating Procedures (SOPs), a brief background is provided on the Federal Mitigation Regulations as it pertains to credit determination methods, functional assessments and performance standards. This overview is provided for informational purposes only and should not be considered an official source of regulatory information. The interpretations are those of the authors and do not necessarily represent the views of the EPA or the USACE.

In April 2008 the USACE and the EPA jointly issued new regulations clarifying compensatory mitigation requirements for Department of the Army permits (33 C.F.R. § 332/40 C.F.R. § 230). The 2008 Mitigation Rule was designed to improve the planning, implementation and management of compensatory mitigation projects. It emphasizes a watershed approach in selecting compensatory mitigation project locations, requires measurable performance standards, requires regular monitoring for all types of compensation, and specifies the components of a complete compensatory mitigation plan. This plan includes assurances for long-term protection of compensation sites, financial assurances, and identification of parties responsible for specific project tasks. The 2008 Mitigation Rule also applies equivalent standards to the three mechanisms for providing compensatory mitigation: permittee-responsible compensatory mitigation, mitigation banks and in-lieu fee mitigation.

While traditional approaches to determining the appropriate amount of compensation involved reliance on measures of acres or linear feet, the USACE and EPA explicitly stated in the preamble to the Final Rule that, *“With this rule, we are encouraging the use of functional and condition assessments to determine the appropriate amount of compensatory mitigation needed to offset authorized impacts, instead of relying primarily on surrogate measures such as acres and linear feet. In the future, there will be more assessment methods available to quantify impacts and compensatory mitigation.”* (FR Vol 73, 19633) The Rule recognizes that science-based rapid function or condition assessment methodologies provide a more objective, systematic and reliable approach to characterize and quantify the expected aquatic resource losses or debits at impact sites, as well as the potential aquatic resource gains or credits at compensatory mitigation sites.

To ensure that functional gains have indeed occurred at a mitigation site, the permittee (or mitigation provider in the case of mitigation banks or in-lieu fee programs) must meet a set of ecological performance standards tailored to its specific compensation project.

The 2008 Mitigation Rule requires that these performance standards be based on the best available science that can be measured or assessed in a practicable manner. The rule states that performance standards must be based on attributes that are objective and verifiable, which may include variables or measures of functional capacity from the following:

- Functional assessment methodologies,
- Measurements of aquatic resource structural characteristics, and/or
- Comparisons to reference aquatic resources of similar type and landscape position.

Implementation of effective performance standards provides the USACE, other members of the IRT and other regulatory agencies with observable and measurable parameters to ensure that compensatory mitigation is meeting its objectives. To ensure that performance standards are met, a project's mitigation plan must also include mechanisms to provide adequate monitoring, maintenance strategies and long-term stewardship.

2.2 » RESOURCES

The EPA provides stream and wetland mitigation resources on their website (water.epa.gov/lawsregs/guidance/wetlands/wetlandsmitigation_index.cfm). The Federal Mitigation Regulations can be downloaded from this website along with a wealth of additional information, including fact sheets, guidance manuals, training resources and technical resources. Terms from the regulations are used throughout this document, and their definitions are provided in the glossary.

Chapter 3

Watershed and River Corridor Processes

3.1 » WATERSHED PROCESSES

Streams and rivers are integral parts of the landscape, carrying water and sediment from higher elevations to downstream lakes, estuaries and oceans. Along the way, they provide life-giving water to a wide array of ecosystems, including wetlands, bogs, ponds, forests and floodplains.

The land area draining to a stream or river is called its watershed. When rain falls in a watershed, it runs off the land surface, infiltrates the soil or evaporates, forming the fundamental components of the hydrologic cycle (Figure 3.1). From the standpoint of stream formation, the greatest concern is with the hydrologic processes of runoff and infiltration. Surface runoff, whereby excess water collects on the ground surface and flows over land toward watershed valleys and stream systems, is produced when rainfall exceeds the rate at which water can infiltrate the soil. Surface runoff is the process by which stream levels rise and fall during and following rainfall events.

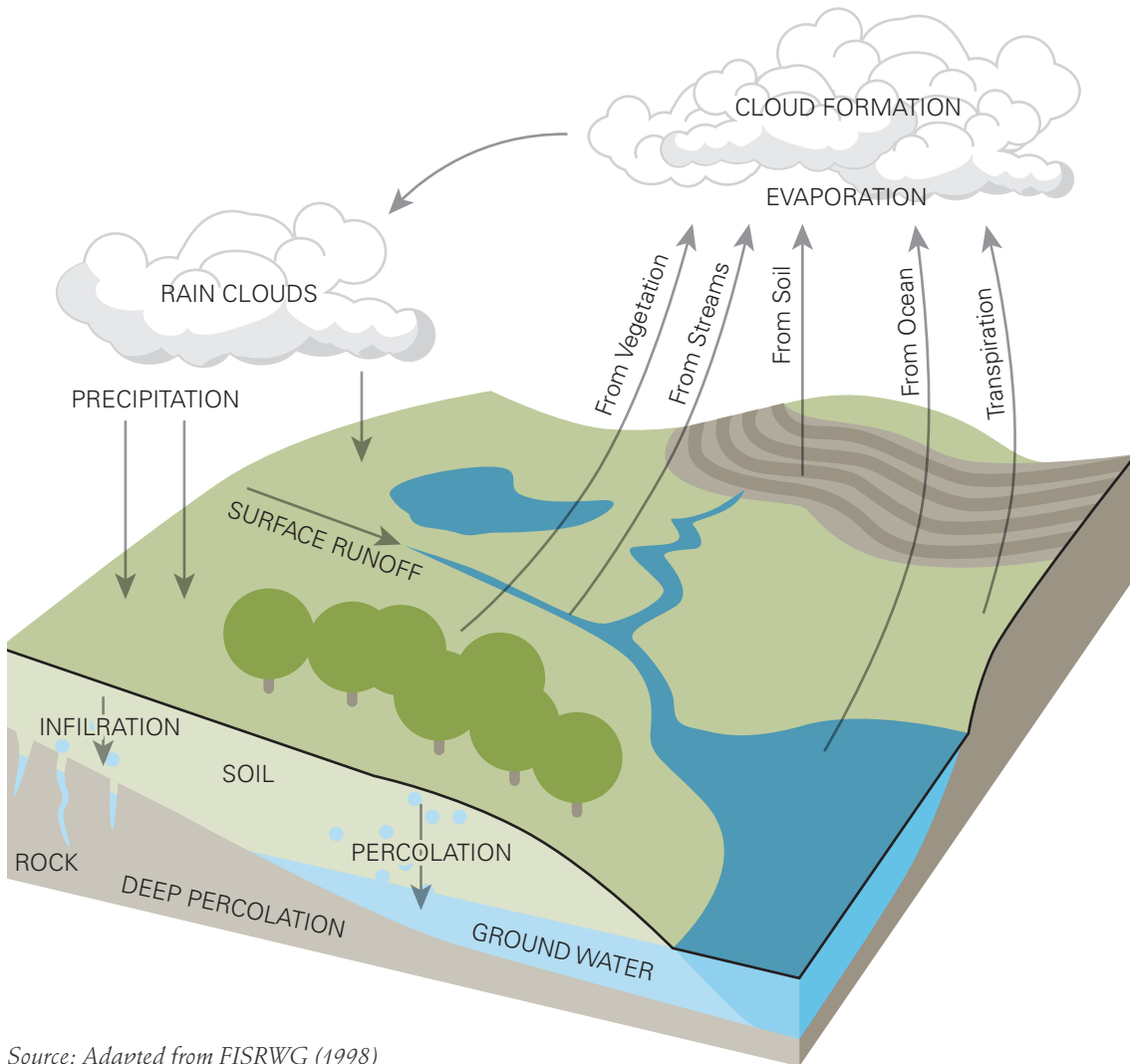
In most systems, a large portion of the water that infiltrates the soil also reaches the stream system, but by sub-surface or groundwater flow. This process occurs much more slowly and steadily than surface runoff. Groundwater discharge is the main source of water that produces baseflow conditions in stream channels.

The hydrologic processes (precipitation, infiltration, runoff, evaporation) that occur at the watershed level influence the character and functions of streams. Small stream channels form at the higher elevations, or headwater regions, of a watershed and become progressively larger in size as the watershed size increases (i.e., moving downstream). In the headwater regions of a watershed, surface runoff concentrates and moves downhill, forming small ephemeral channels and gullies. Ephemeral channels carry only surface runoff and thus flow only for short periods of time (generally less than 24 hours) following rainfall events. Moving down the watershed, ephemeral channels carry more and more water and become intermittent channels, which carry water for extended periods following rainfall events and during wet seasons. Intermittent channels carry surface runoff but also receive discharge from shallow groundwater, particularly during wet portions of the year. Farther downstream, intermittent channels give way to perennial channels, which generally flow year round. Perennial channels carry not only surface runoff, but also groundwater discharge that maintains baseflow conditions in the stream. During drought periods, groundwater levels can drop, and even perennial stream channels can stop flowing for periods of time. But in general, perennial channels maintain some permanent water level that sustains aquatic life and provides the functions that are

most associated with creeks and rivers. (For more information on the hydrologic cycle and its role in the development of streams, see *Stream Corridor Restoration: Principles, Processes and Practices* (FISRWG, 1998) www.nrcs.usda.gov/technical/stream_restoration.)

A stream and its watershed comprise a dynamic balance where the floodplain, channel and stream bed evolve through natural processes that erode, transport, sort and deposit sediments. Land-use changes in the watershed, channel straightening, culverts, removal of streambank vegetation, impoundments and other activities can upset this balance. As a result, adjustments in channel form often occur with changes in the watershed. A new equilibrium may eventually result, but not before the associated aquatic and terrestrial environment are altered, often severely. By understanding the processes that occur at the watershed scale, the role and function of the river is better understood, and proper decisions for its care and protection can be made.

FIGURE 3.1 THE HYDROLOGIC CYCLE



Source: Adapted from FISRWG (1998)

3.2 » RIVER CORRIDOR PROCESSES

River Form and Function

The interaction of streamflow with the banks and bed produces a wide variety of stream channel forms (Knighton, 1998). Though streams and rivers vary in size, shape, slope and bed materials, all streams share common characteristics and functions. Streams have banks and beds consisting of mixtures of substrate (i.e., cobble, gravel, sand or silt/clay) that usually differ from the surrounding floodplain soils. Other physical characteristics shared by some stream types include pools, riffles, steps, point bars, meanders, floodplains and terraces. All of these stream characteristics collectively describe the river's form and are driven by the interactions between climate, geology, topography, vegetation and land use changes in the watershed.

Stable streams in wide valleys migrate across the landscape slowly over geologic time, while maintaining their overall form and function. Naturally stable streams must be able to transport the sediment load supplied by their watershed. Instability occurs when scouring causes the channel bed to erode (degrade), or excessive deposition causes the channel bed to rise (aggrade). Often, instability results from changes in the watershed. For example, stream degradation can result from urbanization influences. During storm events, increased impervious surfaces in a watershed produce greater runoff amounts, and stream flooding frequency and intensity also increase, leading to excessive stream bed scour and degradation. Stream aggradation can result from poor land-use practices that lead to excess sediment in runoff reaching the stream, increasing the sediment load of a stream above that which it can adequately transport.

A generalized relationship of stream stability is shown as a schematic drawing in Figure 3.2, often referred to as Lane's Diagram (Lane, 1955). The drawing illustrates that sediment size and load is proportional to channel slope and discharge. A change in any one of these variables can cause a physical adjustment in the stream channel form. Therefore, channel form characteristics and changes in channel form over time are often used to assess channel stability and whether the channel is in equilibrium with its watershed. The most commonly used parameters to describe and quantify channel form are dimension, pattern and profile, each of which is described below.

3.3 » CHANNEL FORM

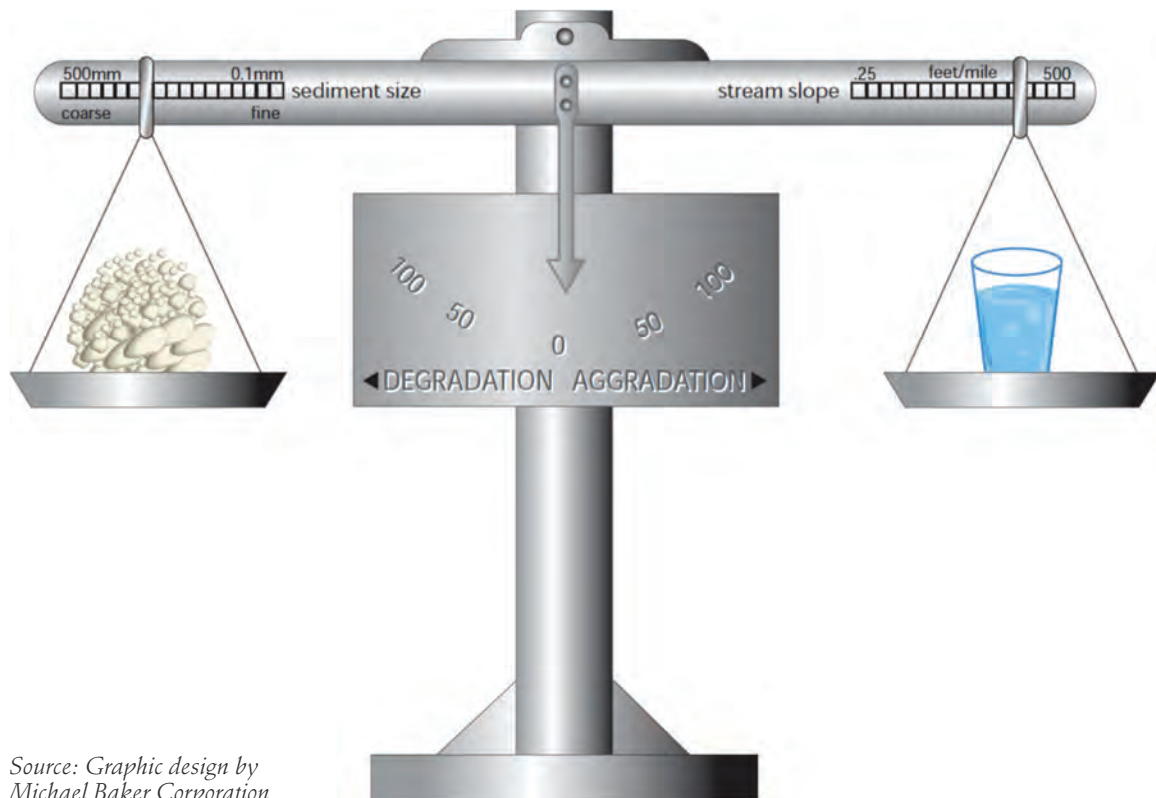
Channel Dimension

The dimension of a stream refers to the cross-sectional shape of the channel and includes such parameters as width, depth, bank height, hydraulic radius, etc. The width of a stream generally increases in the downstream direction in proportion to the square root of discharge. The width and depth of a stream are also influenced by discharge (occurrence and magnitude), the sediment the stream transports (size and type), stream bank vegetation, and the stream bed and bank materials. For example, in the humid, Southeastern portions of the US, stream channels tend to have narrow widths and deeper depths due to dense vegetation and cohesive floodplain soils. In the arid to semi-arid

Southwestern regions, stream channels tend to be much wider and shallower, with less streambank vegetation and more erodible bank sediments.

FIGURE 3.2 LANE'S DIAGRAM

(Illustrating factors affecting channel degradation and aggradation)



Source: Graphic design by Michael Baker Corporation

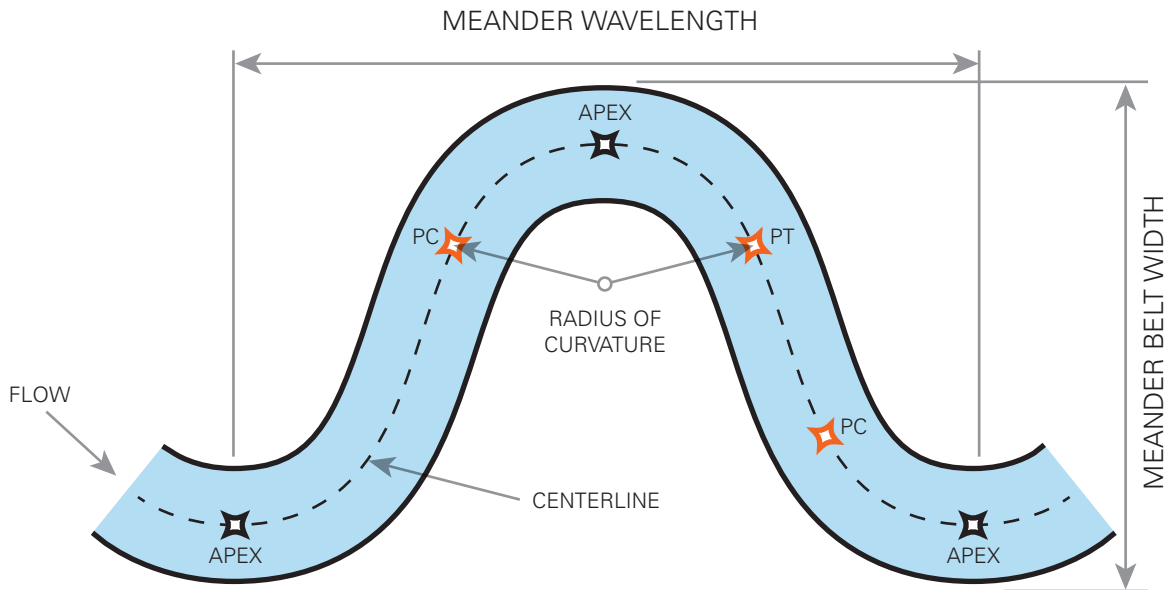
Channel Pattern

Stream pattern refers to the aerial view of a channel. Streams located in steep, narrow valleys tend to be straighter and follow the alignment of the valley, whereas streams on broad, flat floodplains tend to follow a more sinuous path. Quantitatively, stream pattern can be defined by measuring sinuosity, meander wavelength, radius of curvature, amplitude, and belt width (Figure 3.3). The sinuosity of a stream is defined as the channel length divided by the valley length, which is measured along the direction of fall of the valley. A meandering stream reach increases resistance and reduces channel gradient relative to a straight reach. The geometry of the meander and spacing of riffles and pools adjust so that the stream performs minimal work and balances its energy.

Channel Profile

The profile of a stream refers to its longitudinal slope. At the watershed scale, channel slope generally decreases as you move downstream. The size of the bed material also

FIGURE 3.3 PATTERN MEASUREMENTS OF A MEANDER BEND

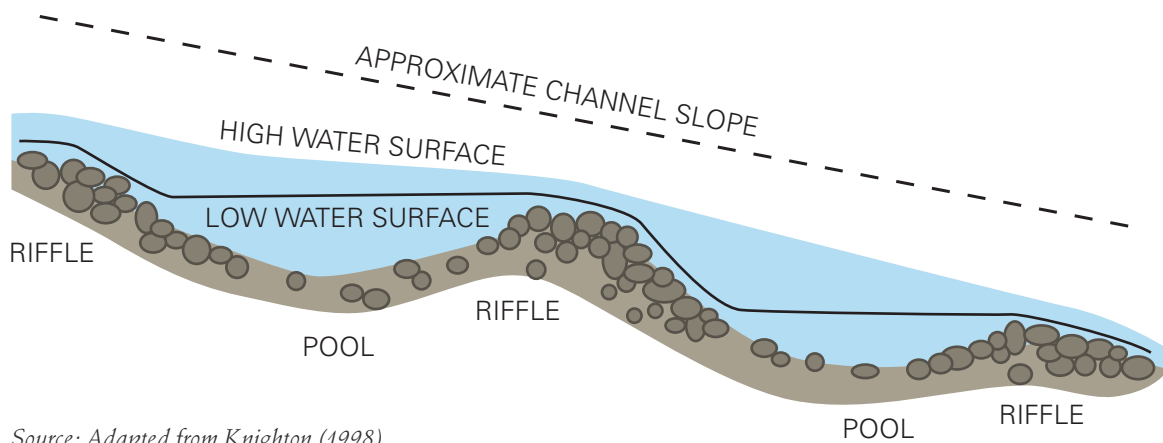


PC = Point of Curvature = point at which the straight section of a riffle meets the curved section of a meander bend.

PT = Point of Tangency = point at which the curved section of a meander bend meets the straight section of a riffle.

Source: Adapted from Rosgen (1996)

FIGURE 3.4 LONGITUDINAL PROFILE OF A STREAM



Source: Adapted from Knighton (1998)

typically decreases in the downstream direction. Channel slope is inversely related to sinuosity. This means that steep streams have low sinuosity and flat streams have high sinuosity. The profile of the stream bed can be irregular because of variations in bed material size and shape, riffle-pool spacing and other variables. The water surface profile mimics the bed profile at low flows. As water rises in a channel during storms, the water surface profile becomes more uniform (Figure 3.4).

3.4 » OVERVIEW OF STREAM FUNCTIONS

Streams carry the water supplied by their watershed. The resulting hydrology and hydraulic processes provide the basic foundation for all other functions that streams provide. The relationships between precipitation, runoff, infiltration and groundwater flow determine the amount of water that the stream carries at any given time, the energy of the water to move sediment, the physicochemical processes that affect water quality, and the biological processes that the stream will support. Stream channels that are connected with their floodplains attenuate flood pulses and spread nutrients and organic matter during flooding events. Streamflows rise and fall with precipitation and snowmelt events, resulting in the dynamic range of flows, which defines the channel form on which many other processes and functions rely. Groundwater is both recharged and discharged along stream channels, providing another hydrologic link between the stream channel and the landscape.

At the interface between the stream channel and the soil surface lays the hyporheic zone, a layer of sediment, soil and porous space where interchanges between streamflow and groundwater occur. Water that moves from the stream into the hyporheic zone is held for a longer retention time than normal streamflow. In addition, because of the intermixing between nutrient rich groundwater and oxygen rich stream water, the hyporheic zone is of critical importance to the chemical transformations that affect nutrients and other compounds within stream systems.

The transport of water and sediment is reflected in the bed features that are formed within a stream channel. Natural streams have sequences of riffles and pools or steps and pools that maintain channel slope and stability (Figure 3.4). The riffle is a bed feature that may have gravel or larger rock particles. The water depth is relatively shallow, and the slope is steeper than the average slope of the channel. At low flows, water moves faster over riffles, which removes fine sediments and provides oxygen to the stream. Riffles enter and exit meanders and control the stream bed elevation. Pools are located on the outside bends of meanders between riffles. The pool has a near-flat water surface (very low slope) and is much deeper than the stream's average depth. At low flows, pools are depositional features and riffles are scour features. At high flows, however, the pool scours and the bed material deposits on the riffle. This occurs because a force applied to the stream bed, called shear stress, increases with depth and slope. Depth and slope increase rapidly over the pools during large storms, increasing shear stress and causing scour.

Stream channels, corridors and floodplains form a valuable ecosystem network. In addition to transporting water and sediment, natural streams provide habitat for many

aquatic organisms including fish, amphibians, aquatic insects, mollusks and plants.

Riffles and pools, and other bed features such as runs and glides, form a diversity of aquatic habitats and provide the foundation for many of the biological and water quality functions that streams provide. Macrobenthic organisms cling to rocks and coarse substrates in riffle areas, filtering food from the flowing water and thriving on the oxygen-rich water. Many fish species utilize meander pool areas due to the cover provided for protection and ambush and for cooler water temperatures afforded by the deeper water depth. Even within a single meander pool, there are aquatic organisms that prefer to live at varying water depths and locations within the pool, illustrating the natural diversity and biological functions that stream systems provide. The hyporheic zone also serves as a habitat zone for certain aquatic species and microbial life that is especially suited for life in this transition zone between groundwater and surface waters.

Trees and shrubs along the streambanks regulate water temperatures through shading and provide organic matter to the system, which is stored and transported forming the energy web that supports aquatic life and diversity. The processes of energy transfer in streams are simplistically described by the river continuum concept (RCC). The RCC is a generalization that is based on the idea that a watercourse is an open ecosystem in constant interaction with the streambank and bed, and moving from source to mouth, constantly changing (Gordon et al., 2004). Beginning in its headwaters, the energy available to a river is highly influenced by the organic material that is delivered from its watershed, or sources external to the stream itself. Moving downstream, the impact of direct contributions of new material to the river becomes less important as the material delivered from upstream continues to be processed and transformed, and primary production within the river becomes a more dominant source of energy than external inputs of organic matter. The RCC provides a theoretical model for visualizing the importance that energy relationships have on biodiversity and chemical functions of a stream system.

Streams affect groundwater levels and the transfer of water and nutrients between adjacent wetlands and riparian areas, supporting ecosystem diversity beyond the limits of the stream channel itself. Riparian buffers along streams filter sediment and pollutants from runoff, and promote uptake of nutrients and chemical reactions in the soil and water column that improve water quality. Streams also provide recreational functions, such as fishing, boating, swimming, wildlife viewing and green space.

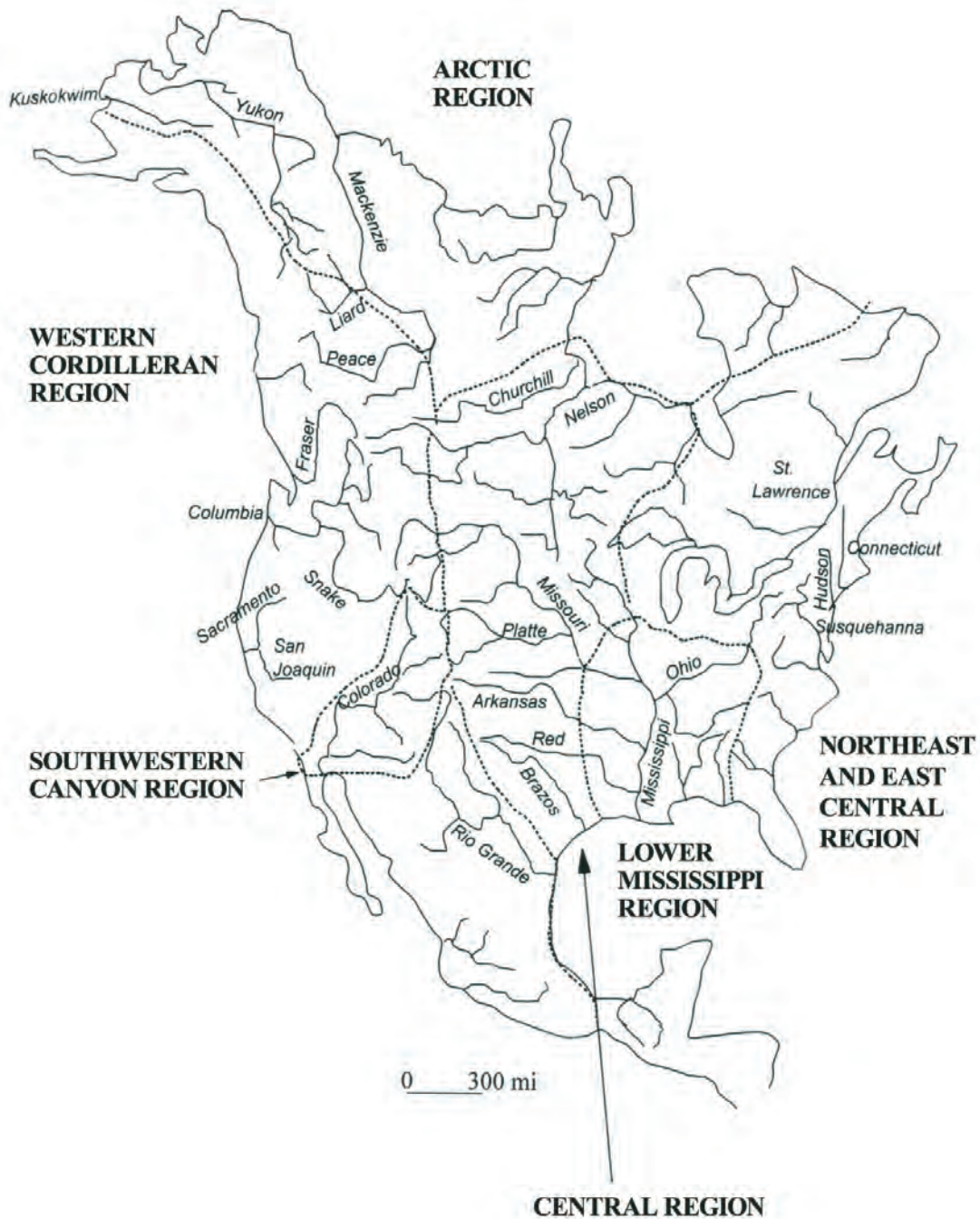
All the functions described above relate back to the river's form and its relationship with its watershed. For more information regarding the river's form and its relationship to processes and functions, see Knighton (1998), Leopold et al., (1992) and Wohl (2004).

3.5 » AMERICAN RIVER REGIONS

North America supports a wide variety of river and stream systems, owing to the wide range of climatic and geologic conditions across the continent. River systems of the continent can be divided into six major regions, as proposed by Wohl (2004). Figure 3.5 shows the location of each of these regions, and a brief summary of each region (as described by Wohl, 2004), is provided below. Wohl's river regions can be considered a

broad delineation for North America. For more detailed information on major river basins within North America and the functions they provide, see *Rivers of North America*, edited by Benke and Cushing (2005).

FIGURE 3.5 RIVER REGIONS MAP OF NORTH AMERICA (Wohl, 2004)



Source: Adapted from Wohl (2004)

Arctic Region

The rivers in the Arctic Region drain north to the Arctic Ocean. Rivers of this region are characterized by high sediment loads (in part from glacier melt and streambank erosion due to freeze/thaw cycles) and ice flows, and often exhibit braided channel forms. The Mackenzie and Yukon Rivers are the largest river drainages within the region. Streams of the region support very little year-round aquatic species, but are host to some of the largest yearly runs of anadromous fish species, such as salmon, anywhere in the world.

Western Cordilleran Region

The Western Cordilleran rivers drain primarily to the Pacific Ocean, although some originate east of the continental divide and drain to the Atlantic Ocean. The region stretches from southern California north to Alaska, and from the Pacific Ocean to roughly the continental divide. Rivers of the region are diverse but are commonly characterized as steep, mountain streams. Many of this region's rivers begin at their headwaters as high-gradient, step-pool channels, where high sediment loads, debris flows and landslides are common. Moving further down gradient, the rivers become large and meandering, with moderate sediment loads and course substrates. Like the Arctic Region rivers, rivers of the Western Cordilleran Region were once home to large populations of trout and seasonal runs of salmon; however, degraded stream habitat, flow durations and water quality in the region have reduced or eliminated many of these populations.

Central Region

Rivers of the Central Region are generally characterized as broad, shallow, meandering river systems. Streams of the northern Central Region drain to Hudson Bay, while streams of the central and lower portion of the region drain to the Mississippi River and the Gulf of Mexico. Peak flows occur during spring and early summer, as a result of snow melt and intense rains. Fine sediment loads are often high. The streams of the region are very diverse biologically, supporting a wide range of fish and aquatic species.

Northeast and East-Central Region

The Northeast and East-Central Region rivers drain east to the Atlantic Ocean. The St. Lawrence River drains the upper portion of the region. Along the central-Atlantic Coast, a variety of rivers begin in the Appalachian Mountains, crossing the Piedmont and Coastal Plain physiographic regions on their way to the Atlantic Ocean. Rivers of the region mostly drain densely vegetated catchments, keeping sediment loads relatively low. High flows typically occur in the fall and winter, with the exception of large tropical systems that can drop large amounts of rainfall quickly and cause significant flooding during the summer and early fall months. Rivers of this region, like those of the Lower Mississippi Region, support the greatest species richness and highest number of endemic species of any of the rivers in North America.

Lower Mississippi Region

Rivers of the Lower Mississippi Region drain to the Gulf of Mexico and originate in

the southwestern portion of the Appalachian Mountains and the eastern edges of the great interior plains. These rivers meander broadly over low-slope floodplains created by long-term sediment deposition. Suspended sediment loads are often high, as commonly observed with the lower Mississippi River. Rivers of this region have been highly manipulated with levees and channelization to decrease the threat of flooding and provide more land for development. Species diversity is high throughout the region.

Southwestern Canyon Region

The Southwestern Canyon Region rivers and streams are characterized by deeply-incised channels and canyon valleys that have downcut over geologic time to keep pace with uplift of the Colorado Plateau by geologic forces. These streams flow through desert lands, with the larger rivers being perennial streams that flow year-round, while many of the smaller streams only flow for portions of the year. Suspended sediment loads are high due to the highly erodible soils and sedimentary rocks of the region. Many of the native fish species are endemic species that are limited to the Colorado River Basin.

3.6 » STREAM CLASSIFICATION

Stream classification is an important tool to communicate information about streams using a common language. There have been many stream classification systems published over the past century, beginning with Davis (1899) that classified streams in terms of age (youthful, mature and old age). These classification systems use different approaches to categorize streams based on qualitative and quantitative assessment at different spatial and temporal scales, e.g., Montgomery and Buffington (1993) developed a stream classification system that is applicable to the Pacific Northwest region. For further details about stream classification history, refer to Naiman et al. (1992) and Rosgen (1994). In general, the most useful stream classification system should encompass a broad spatial and temporal scale, integrate structural and functional characteristics under different disturbance regimes, provide information about form and process mechanisms that control stream features, and be easily applied by stream practitioners (Naiman et al., 1992). For the purposes of this publication, the Rosgen (1994) stream classification system will be referenced when describing stream types. This system can be applied consistently over a large geographic area using quantitative descriptions. It has also been referenced by many USACE Districts as part of the compensatory mitigation program (USACE Wilmington District et al., 2003; USACE Savannah District, 2004; USACE Norfolk District and VDEQ, 2007; and USACE Charleston District, 2010).

The specific objectives of the Rosgen stream classification system (Rosgen, 1996) include:

1. Predict a river's behavior from its appearance.
2. Develop specific hydraulic and sediment relationships for a given stream type.
3. Provide a mechanism to extrapolate site-specific data to stream reaches having similar characteristics.
4. Provide a consistent frame of reference for communicating stream morphology and condition among a variety of disciplines and interested parties.

The Rosgen (1994) classification and assessment system consists of four levels (Levels I through IV), ranging from broad qualitative descriptions to detailed quantitative assessments (Figure 3.6). Level I and Level II are the predominant parts used to characterize the stream. Level I is a broad geomorphic characterization that categorizes streams into eight different stream types (A through G) using the integration of landform and fluvial features of valley morphology with channel slope, pattern, profile and dimension. Level II is called the morphological description and requires field measurements. The stream types are divided into discrete slope ranges and dominant channel-material particle sizes, which are given numbers 1 (bedrock) through 6 (silt/clay). Figure 3.7 presents a key for the Rosgen system for Level I and Level II.

Details for Level III and Level IV are not provided in this publication but can be found in Rosgen (1994; 1996). In general, Level III is an evaluation of stream condition and stability that requires an assessment and prediction of channel erosion, riparian condition, channel modification and other characteristics. Level IV is verification of predictions made in Level III and consists of sediment transport, streamflow and stability measurements.

3.7 » WATERSHED AND STREAM RESTORATION

Watershed Scale Restoration

Many of the impairments present in today's rivers and streams are a result of processes that occur at the watershed level. Poor sediment and erosion control practices lead to excess fine sediments that are delivered to water courses. Increased urbanization and impervious surfaces result in increased runoff during rainfall events, and higher peak streamflows that cause erosion and stream down-cutting. Pollution, both from point sources and non-point sources, enters streams and impairs water quality. To address these impairments, improvements and restoration must be performed at a watershed scale.

"A watershed approach is the most effective framework to address today's water resource challenges. Watersheds supply drinking water, provide recreation and respite, and sustain life. More than \$450 billion in food and fiber, manufactured goods, and tourism depends on clean water and healthy watersheds."

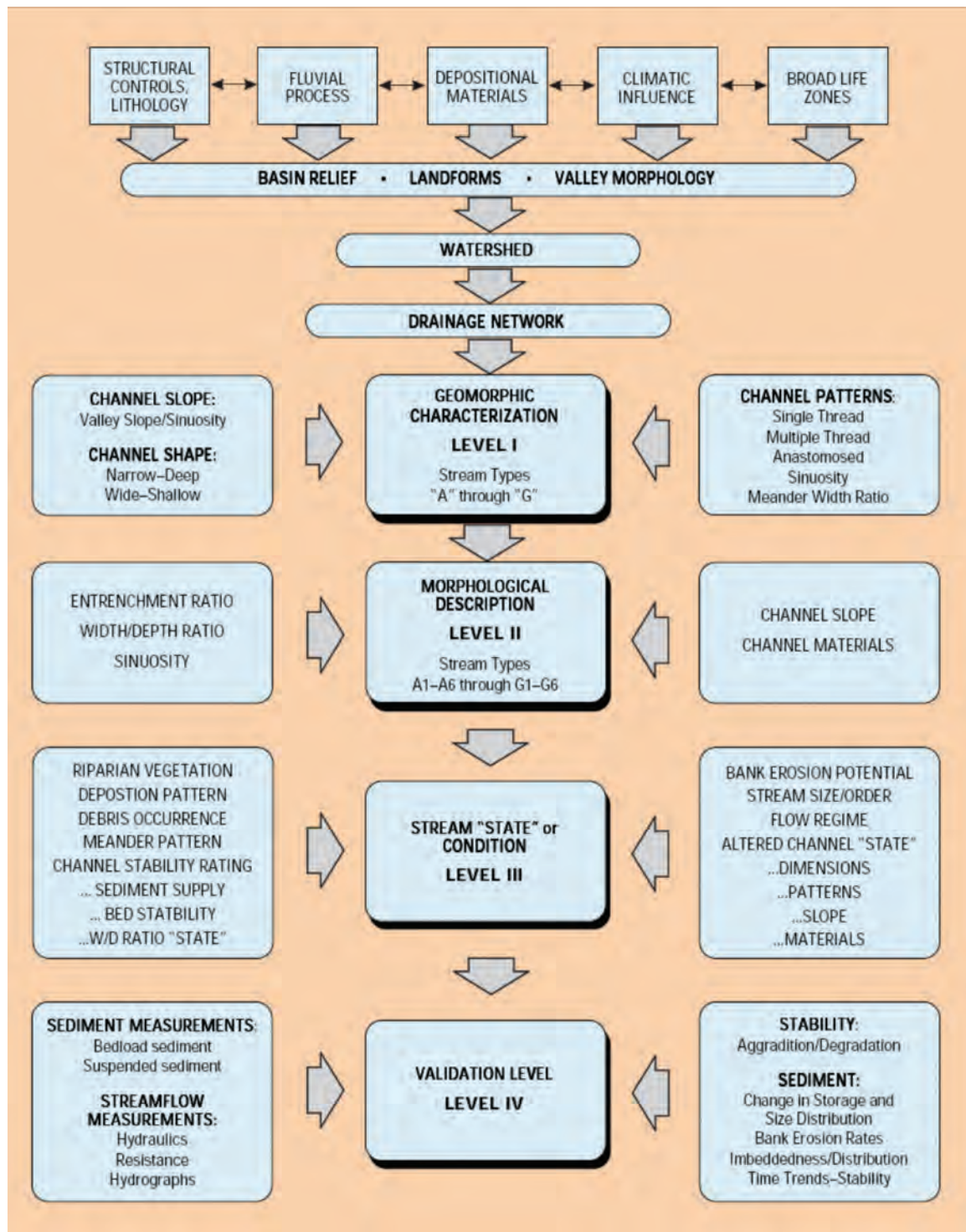
~US Environmental Protection Agency
(water.epa.gov/type/watersheds/approach.cfm)

"We cannot save trout without saving their river and floodplain habitats. We cannot save river and floodplain habitats — and the plants and insects of the trout's food web — if we do not also maintain the processes controlling water and sediment entering the river corridor from the surrounding hillslopes and uplands. They go hand in hand."

~Ellen Wohl, *Disconnected Rivers*, 2004

Emphasis on watershed-level restoration and water-quality improvements is increasing, and the tools being used are also expanding. Over the past two decades, there have been considerable interest and use of best management practices (BMPs) as a tool for address-

FIGURE 3.6 THE HIERARCHY OF RIVER INVENTORY AND ASSESSMENT (Rosgen, 1996)



Source: Reproduced with permission from Wildland Hydrology

FIGURE 3.7 KEY TO THE ROSGEN STREAM CLASSIFICATION OF NATURAL RIVERS (Rosgen, 1996)

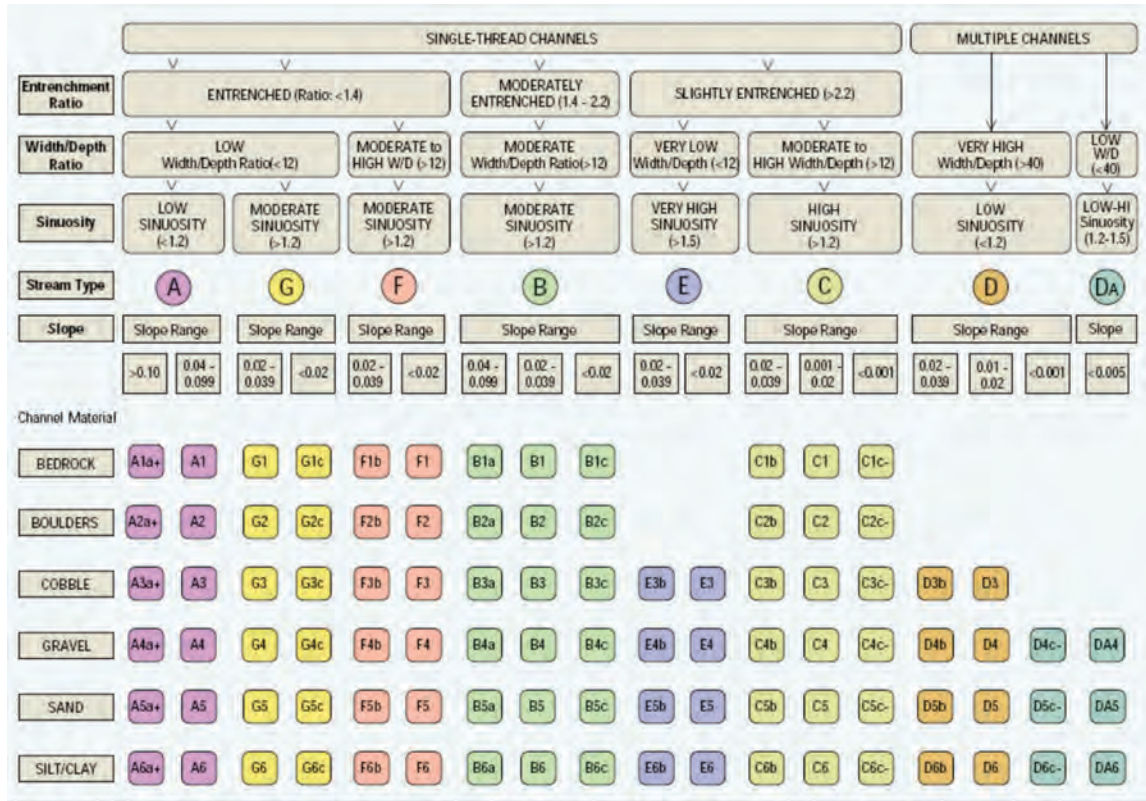


Figure 3. Key to the Rosgen Classification of Natural Rivers. As a function of the "continuum of physical variables" within stream reaches, values of entrenchment and sinuosity ratios can vary by +/- 0.2 units; while values for width/depth ratios can vary by +/- 2.0 units.

Source: Reproduced with permission from *Wildland Hydrology*

ing watershed health. Common BMP practices such as created wetlands, retention basins, bioretention areas, infiltration areas and restoration of riparian buffers are but a few of the practices that have been implemented to improve watershed health. These practices generally seek to reduce the amount of runoff delivered to streams (detention), reduce the rate at which runoff reaches streams (attenuation), increase the amount of water that percolates into the soil (infiltration), and/or promote physical and chemical processes that remove pollutants and sediment from runoff waters. Most of these practices are installed on smaller headwater catchments of a watershed, where such approaches are more feasible and cost effective, and where pollutants can be trapped near their sources.

River restoration is a technique that is applied at the stream reach scale and is generally used to complement the other techniques described above. BMP approaches can help to improve the quality and timing of water entering a receiving stream; river restoration approaches can address stability and water quality problems that are expressed or develop in the river itself, such as channel incision, streambank erosion and loss of aquatic habitat.

River Restoration

River or stream restoration has been defined in many different terms, but is generally considered to describe a set of activities that help improve the environmental health of a stream. Other terms commonly used for stream restoration include stream reclamation, stream stabilization, natural channel design and channel rehabilitation. Depending on the person using the term, stream restoration can have different meanings and associations, and can cover a wide range of practices and approaches to improving watercourses.

The practice of stream restoration began to achieve momentum in the 1980s, as interest grew in addressing stream stability problems in a way that was sustainable long-term and also improved recreational uses and ecological functions. Until that time, the primary approach used to stabilize streams was to harden the channel and/or streambanks

River or stream restoration has been defined in many different terms, but is generally considered to describe a set of activities that help improve the environmental health of a stream. Other terms commonly used for stream restoration include stream reclamation, stream stabilization, natural channel design and channel rehabilitation.

with such materials as loose rock (rip-rap), gabion baskets, concrete, retaining walls, etc. Such practices addressed the stability problems with the stream, but often resulted in a dramatic loss of ecological function and aquatic life due to loss of aquatic cover, appropriate bed materials, shade and food sources. In addition, since these “hard” approaches did not address overall channel geometry issues, they often lead to downstream instability.

Practitioners began to develop techniques that would not only address stability issues, but also improve aquatic habitat functions and recreational uses, such as fishing. The movement began in the US in the Western states, where there was increasing concern

over the degraded condition of trout and salmon rivers, and spread eastward across the country. The resulting designs, often referred to as *natural channel designs*, seek to replicate the channel forms seen in stable, natural rivers in order to restore stability and functions to degraded rivers.

Natural channel design can be defined as a stream restoration technique that seeks to create a stable stream channel that balances its flow of water and sediment over time, so that the channel does not aggrade or degrade. A variety of methods and tools are available to practitioners, but nearly all focus on several important design concepts:

- Providing connection between the channel and its floodplain (floodplain connectivity);
- Sizing low-flow channels to carry a given flow that over time carries the most sediment (channel-forming discharge concept);
- Designing channels to carry both their water and sediment loads; and
- Constructing channels to mimic the functions of natural channels to the extent possible.

For more information on specific design components commonly used in the practice of stream restoration, see the NRCS National Engineering Handbook Part 654 — Stream Restoration Design (USDA NRCS, 2007) directives.sc.egov.usda.gov/viewerFS.aspx?id=3492.

In 2008 the USACE and EPA issued regulations improving and standardizing mitigation policies, and increasing the emphasis placed on the restoration of functions. The rules specifically identify streams as a difficult-to-replace resource for which avoidance and minimization should be emphasized. Where compensatory mitigation for streams is needed, the rules emphasize in-kind rehabilitation, enhancement or preservation and outline stream specific considerations for site selection, providing design plans for review, monitoring requirements and ecological performance standards. This increased emphasis on the restoration of streams ensures that techniques such as natural channel design will continue to be the preferred methods for river restoration. For more information on natural channel design techniques for river restoration, see FISRWG (1998) and USDA NRCS (2007).

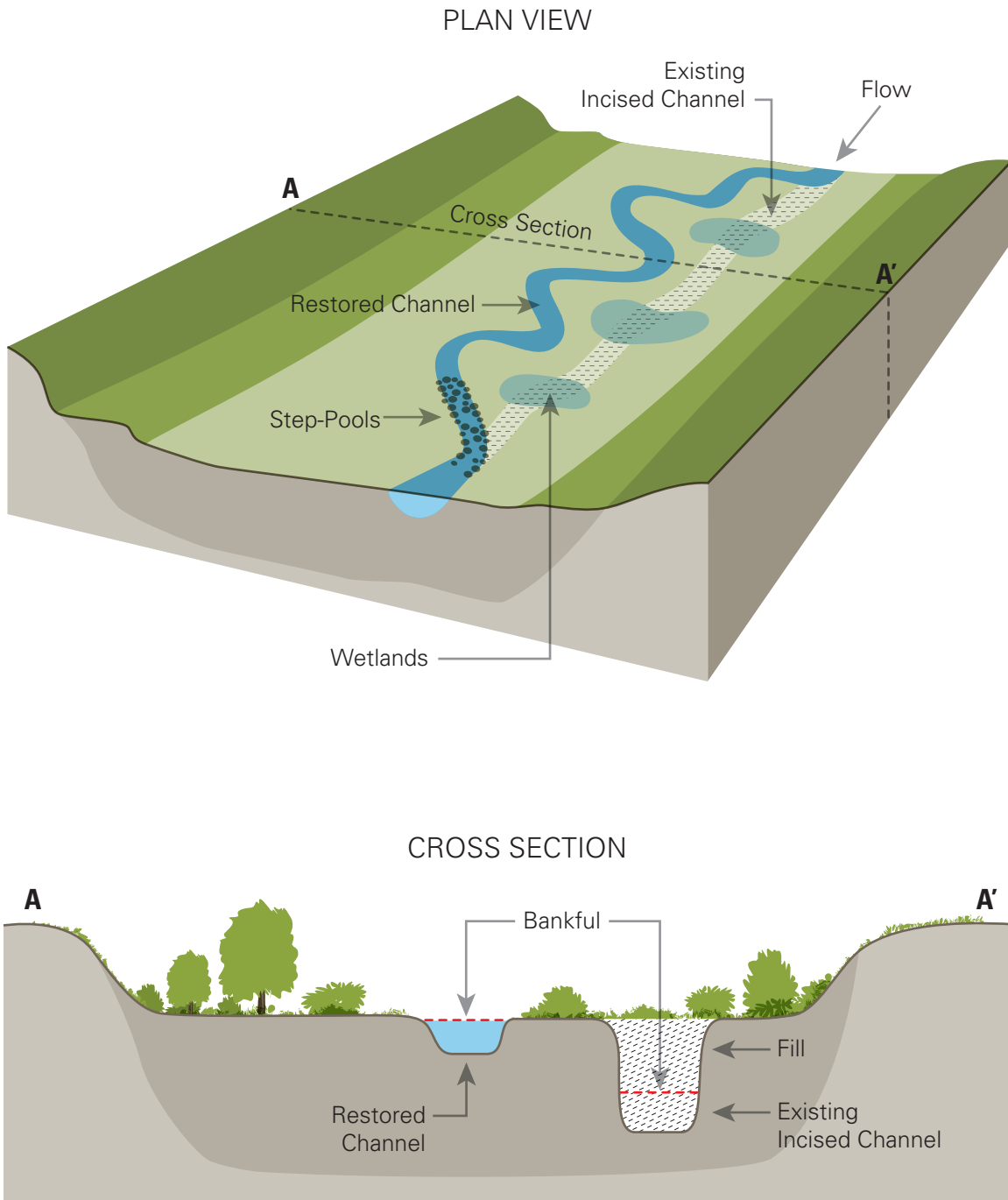
Natural channel design can be defined as a stream restoration technique that seeks to create a stable stream channel that balances its flow of water and sediment over time, so that the channel does not aggrade or degrade.

3.8 » PRIORITY LEVELS OF RESTORATION

Priority Levels for the restoration of incised streams were developed by Rosgen (1997). The “Rosgen Priority Levels” range from Priority Level 1 to Priority Level 4 and are chosen based on factors including both physical and economic constraints. These Priority Levels are often referred to in stream mitigation programs as restoration approaches (USACE Wilmington District et al., 2003; USACE Savannah District, 2004; and USACE Norfolk District and VDEQ, 2007). For example, a Priority Level 1 is often considered the highest level of restoration and receives the most credits per foot, while Priority Level 3 approaches often receive enhancement level credits. Chapter 11 and Appendix B of this document illustrate how select Priority Levels can be merged into a more function-based approach to developing stream credits. A brief description of the Priority Levels is provided below, and a more detailed description can be found in Rosgen (1997).

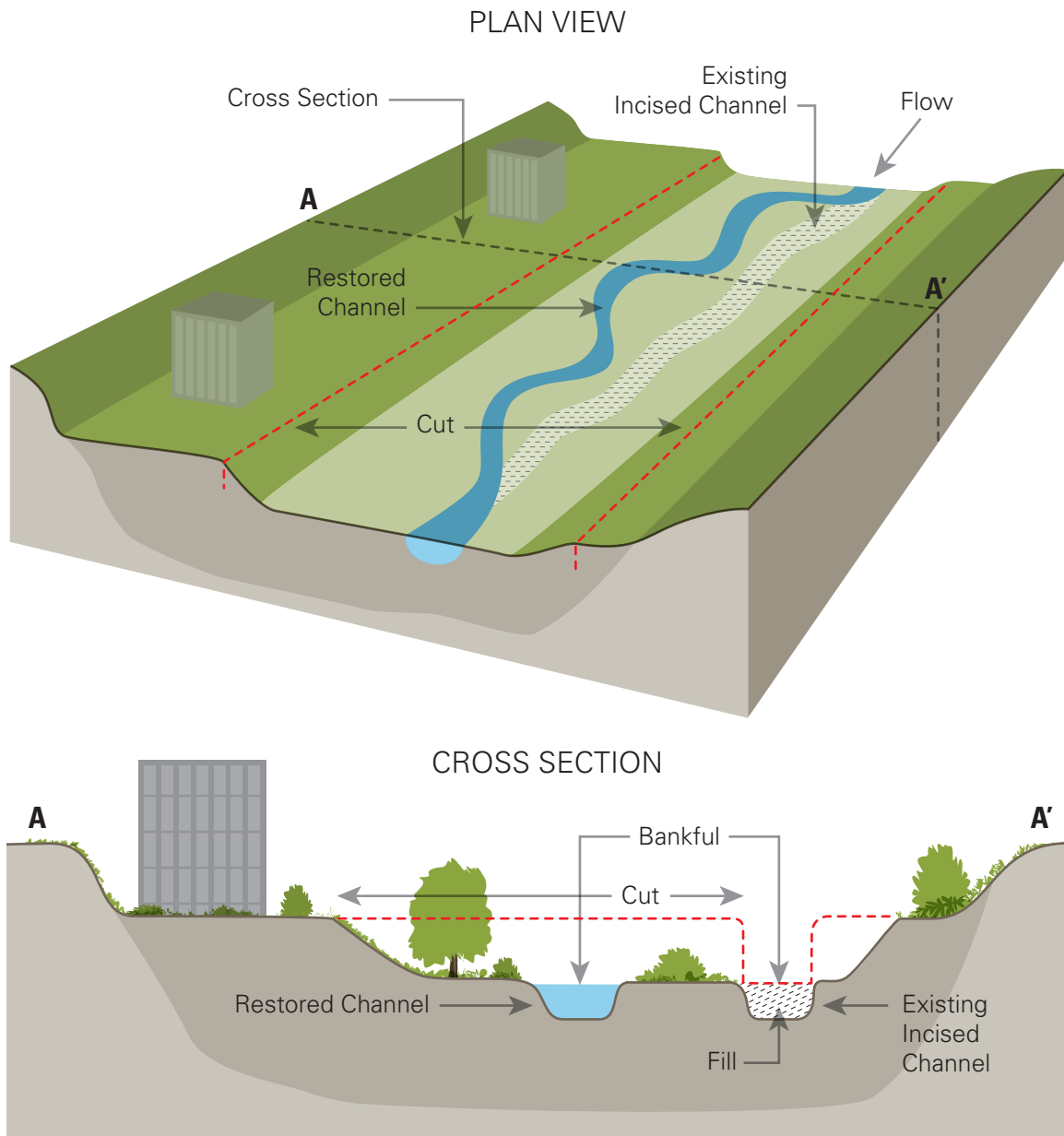
A Priority Level 1 restoration creates a new stable channel that is reconnected to the previous (higher in elevation) floodplain. A new stream channel is excavated on the original floodplain by raising the stream bed elevation. This approach requires an abrupt change in bed elevation at the upstream end of the project, e.g., culvert outfall or knick-point. The former incised channel is filled, converting it to a floodplain feature. This approach is used in areas where there are few lateral constraints and where flooding on the adjacent land can be increased. An example of the plan form and dimension improvements created by a Rosgen Priority 1 is shown in Figure 3.8.

FIGURE 3.8 ROSGEN PRIORITY LEVEL 1 RESTORATION APPROACH



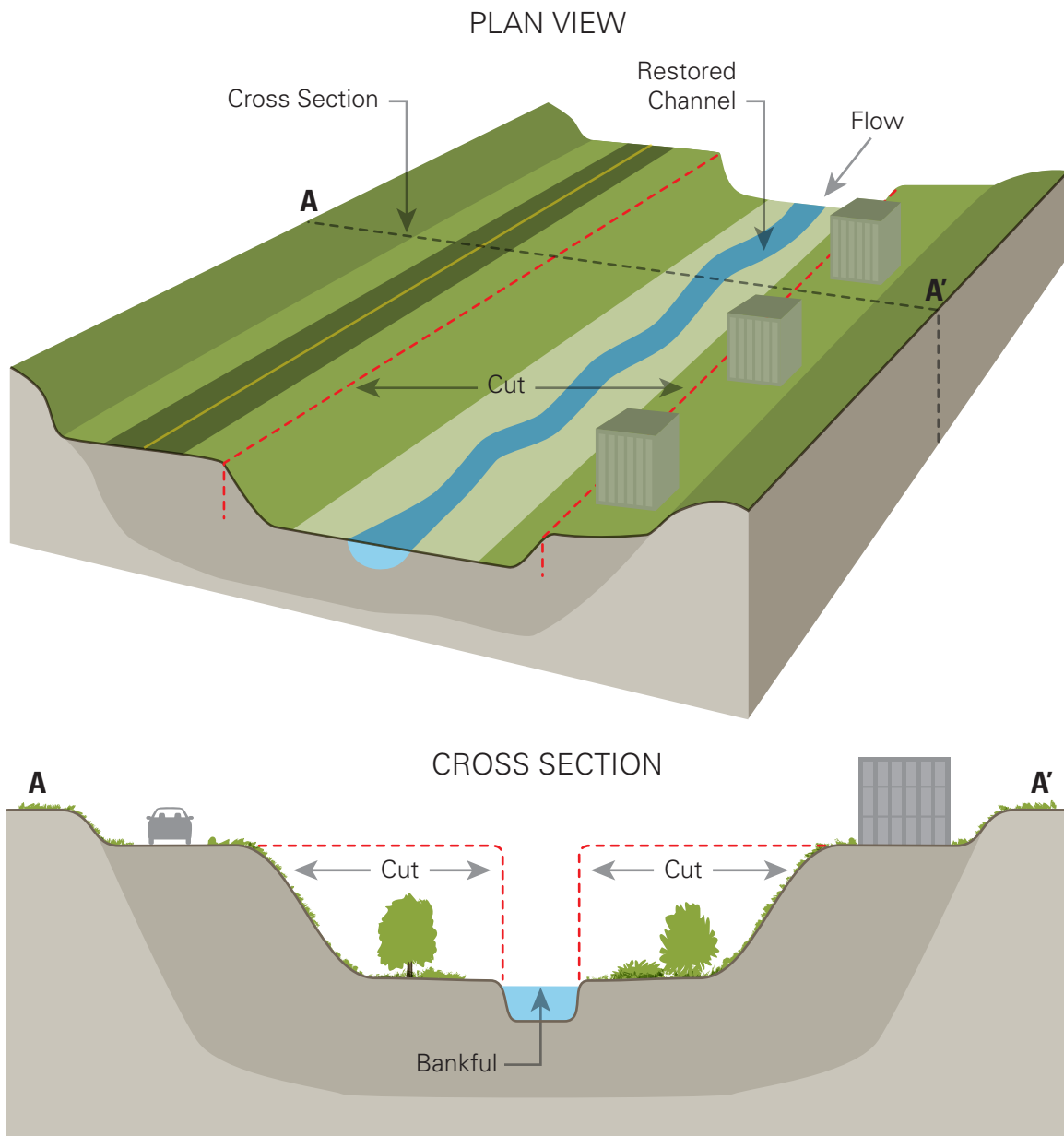
A Priority Level 2 restoration also creates a new stable channel that is connected to the floodplain, but the floodplain is excavated at the existing bankfull elevation, i.e., the bed elevation of the stream remains nearly the same. The formerly channelized and incised stream is re-meandered through the excavated floodplain. This approach is typically used if there is not a knickpoint or other abrupt change in grade upstream of the project, in larger streams, or in cases where flooding cannot be increased on adjacent property. A plan view and cross-section example is shown below in Figure 3.9.

FIGURE 3.9 ROSGEN PRIORITY LEVEL 2 RESTORATION APPROACH



A Priority Level 3 restoration converts a channelized and incised channel, often with poor bed form diversity, into a step-pool type of channel. The existing channel alignment stays nearly the same. Bankfull benches are excavated at the existing bankfull elevation to provide limited floodplain connectivity. In-stream structures are required to dissipate energy along the streambanks and to create step/pool bed forms. Priority Level 3 is often used where constraints inhibit meandering and flood elevations cannot be increased, e.g., urban environments. A plan view and cross-section example is shown below in Figure 3.10.

FIGURE 3.10 ROSGEN PRIORITY LEVEL 3 RESTORATION APPROACH



A Priority Level 4 stabilizes the channel in place, using in-stream structures and bioengineering to decrease stream bed and streambank erosion. This approach is typically used in highly constrained environments, such as backyards and highway right-of-ways. A Priority Level 4 is rarely used to create stream mitigation credits and is generally not considered restoration, only stabilization.

3.9 » IMPORTANCE OF SITE SELECTION IN RIVER RESTORATION

In the context of watershed health and the restoration of river functions, initial selection of river restoration sites is critically important. Sites that will provide the most functional lift are those that have few restoration constraints, have relatively healthy watersheds upstream, and have causes of impairment that are linked to the reach itself. An example would be a stream that is heavily degraded by direct cattle access, but has a relatively healthy watershed upstream and good water quality flowing into the site. In this situation, the primary causes of impairment are linked to the river restoration site itself, and include loss of riparian vegetation from grazing, eroding streambanks due to loss of vegetation and hoof-shear, elevated fine sediments in the river due to bank erosion and cattle crossings, and high bacterial loads due to cattle fecal matter. Assuming there are no constraints to the restoration work, such a project has a high probability of providing dramatic functional uplift because the primary sources of impairment can be addressed. Excluding cattle from the stream system, restoring a proper river form and restoring riparian vegetation will greatly decrease sediment and bacteria loads, provide improved aquatic habitat, provide shading and carbon sources, and improve overall channel stability and function.

In contrast, consider a proposed restoration site that is highly constrained by adjacent buildings and the streamflow entering the site is of poor quality. In this situation, the functional lift provided by stream restoration practices will be minimal, as the causes of watershed impairment are upstream of the project and restoration approaches are limited by the site constraints. Such a restoration site could address local instability, but will provide little in the way of water quality benefits.

The chapters that follow discuss the restoration of stream functions in depth; however, the practitioner should always be mindful that the degree to which functional lift can be provided is determined at the site selection phase of a project.

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Chapter 4

The Stream Functions Pyramid

The Stream Functions Pyramid, developed by Harman (2009), provides a framework that organizes stream functions in a pyramid form. The Stream Functions Pyramid illustrates that stream functions are supported by lower-level functions in a hierarchical structure. The Pyramid is a useful tool in goal setting, developing and reviewing stream assessment methodologies, and creating standard operating procedures (SOPs) for regulatory and non-regulatory stream restoration programs. This chapter provides a detailed overview of the Stream Functions Pyramid along with simple examples of how it can be applied. Detailed applications are provided in Chapter 11.

4.1 » FUNCTIONAL OBJECTIVES FOR STREAM RESTORATION

A stream functions framework was created by the US Army Corp of Engineers (USACE) for determining and evaluating objectives for stream restoration projects (Fischenich, 2006). This framework provided the foundation for development of the Stream Functions Pyramid. It identifies a suite of 15 functions critical to the health of stream and riparian ecosystems. These functions are summarized in Table 4.1. The USACE functional framework is appealing since it has a scientific basis in stream functions, is based on processes, and attempts to describe the interactions between identified functions.

TABLE 4.1 FUNCTIONS CRITICAL TO STREAM AND RIPARIAN ECOSYSTEM HEALTH (Fischenich 2006)

FUNCTION	DESCRIPTION
1. Maintain Stream Evolution Processes	Maintains appropriate energy levels; promotes diversity and variability of biotic communities.
2. Energy Management Processes	Allows for conversion between potential and kinetic energy through changes in the system.
3. Provide for Riparian Succession	Changes in vegetation structure promote diversity and ecological vigor, vegetation necessary for system stability and nutrient cycling.
4. Surface Water Storage Processes	Provides temporary water storage during high flows, regulates soil moisture, provides pathway for aquatic organism movement, and provides contact time for biogeochemical processes.

Chapter 4: The Stream Functions Pyramid

TABLE 4.1 FUNCTIONS CRITICAL TO STREAM AND RIPARIAN ECOSYSTEM HEALTH
(Fischenich 2006)

FUNCTION	DESCRIPTION
5. Maintain Surface/ Subsurface Water Connections and Processes	Provides bi-directional exchange from open channel to subsurface soils; allows exchange of chemicals, nutrients and water.
6. General Hydrodynamic Balance	Provides proper flow conditions at the appropriate seasons for support of the biotic community.
7. Sediment Continuity	Provides for appropriate erosion, transport and deposition processes.
8. Maintain Substrate and Structural Processes	Provides substrate and structural architecture to support diverse habitats and biotic communities.
9. Quality and Quantity of Sediments	Determines the physical character of the system relative to the primary variables: sediment yield and character.
10. Support Biological Communities and Processes	Provides diverse assemblages of native species.
11. Provide Necessary Habitats	Produces and sustains habitats to support vigorous aquatic and riparian biotic communities.
12. Maintain Trophic Structures and Processes	Promotes growth and reproduction of biotic communities across trophic levels.
13. Maintain Water and Soil Quality	Promotes favorable conditions for riparian communities that trap, retain and remove particulate and dissolved constituents from surface and overland flow.
14. Maintain Chemical Processes and Nutrient Cycles	Provides for complex reactions to maintain equilibrium and supply required elements to biota.
15. Maintain Landscape Pathways	Maintains connectivity to allow for biotic and abiotic energy process pathways.

The functions characterized by Fischenich (2006) are ordered into a hierarchy of functions, where the relative significance of each function is inferred by assessing the interrelations among functions. Functions that affect the greatest number of other functions are ranked highest, while functions that have the least effect on other functions are ranked lower (Table 4.2). For example, the General Hydrodynamic Balance function (1), which describes a system's flow characteristics, supports directly or indirectly all other functions listed in the Framework, such as sediment transport, energy, biotic and chemical functions. In contrast, the Provide Necessary Habitats function (15) directly affects three other functions, which are all related to the biological systems that are supported by streams.

Chapter 4: The Stream Functions Pyramid

TABLE 4.2 RANKINGS OF FUNCTIONS PROPOSED BY FISCHENICH (2006)

FUNCTION	FUNCTIONS DIRECTLY AFFECTED	FUNCTIONS INDIRECTLY AFFECTED
1. General Hydrodynamic Balance	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15	13
2. Maintain Stream Evolution Processes	1, 3, 4, 5, 6, 7, 8, 10, 11, 12, 14, 15	9, 13
3. Surface Water Storage Processes	1, 4, 6, 10, 11, 12, 14, 15	2, 5, 7, 8, 9, 13
4. Sediment Continuity	3, 5, 6, 7, 8, 9, 11, 15	1, 13, 14
5. Provide for Riparian Succession	1, 2, 3, 4, 6, 12, 14, 15	9, 13
6. Energy Management Processes	1, 2, 3, 4, 5, 7, 8, 15	--
7. Maintain Substrate and Structural Processes	1, 2, 4, 6, 7, 10, 15	5, 9, 11, 13
8. Quality and Quantity of Sediments	2, 4, 5, 6, 7, 10, 15	1, 9, 11, 14
9. Support Biological Communities and Processes	5, 11, 13, 14, 15	1, 2, 3, 7, 8, 10, 12
10. Maintain Surface/Subsurface Water Connections and Processes	1, 5, 11, 15	3, 9, 12, 13
11. Maintain Water and Soil Quality	8, 9, 13, 14	5
12. Maintain Landscape Pathways	9, 13, 14, 15	6
13. Maintain Trophic Structures and Processes	9, 11, 14	8
14. Maintain Chemical Processes and Nutrient Cycles	8, 9, 13	6
15. Provide Necessary Habitats	9, 12, 13	–

Fischenich (2006) notes that efforts to restore streams are often ineffective because they fail to address the underlying processes that create and maintain the biological functions. The purpose of this hierarchy is to indicate the complex set of linkages that exists between functions of stream and riparian systems and to indicate which functions are most critical and interrelated to the restoration of stream and riparian functions.

Fischenich (2006) found that the most critical functions include those that address hydrodynamic processes (1, 3, 6), sediment transport processes (4, 7), stream stability (2) and riparian buffer restoration (5, 11). By addressing these fundamental functions and processes, a restored stream and riparian system are capable of supporting more dependent functions that typically require time to establish, such as diverse biological communities (9), chemical and nutrient processes (14), diverse habitats (15) and improved water and soil quality (11).

4.2 » THE STREAM FUNCTIONS PYRAMID

The Stream Functions Pyramid builds on the USACE work by placing stream functions in a hierarchy. However, the Pyramid uses parameters and measurement methods that are more often used in stream restoration approaches and assessment methodologies. It also provides a clear illustration of how physical functions support chemical and biological functions. This helps scientists, engineers and managers ensure that they are not only addressing the functions they are directly concerned about, but also the supporting functions that are required to achieve success.

The Stream Functions Pyramid Framework consists of four components that increase in detail. First, the broad-level view shows the five functional categories (Levels) with the underlying controlling variables of geology and climate. Second, function-based parameters are provided for each functional category. Third, measurement methods are provided for each function-based parameter. And fourth, where possible, performance standards are provided for the measurement methods. These terms can easily be confused with broader definitions of parameter, metric, tool and others. To help avoid confusion, definitions for these terms along with the criteria used to select function-based parameters, measurement methods and performance standards are provided below. See Appendix A for the entire Stream Functions Pyramid Framework. Also reference the Stream Functions Pyramid page at www.stream-mechanics.com for updates and examples of how the Pyramid is being used.

The Stream Functions Pyramid Framework consists of four components that increase in detail.

Typically, the Pyramid is applied at a reach scale even though some of the functions occur at a watershed scale, e.g., hydrology functions. Applications are discussed in detail in Chapter 11, including examples of how the Pyramid can be used in reach-scale function-based assessments and watershed management plans. However, even when used in watershed management plans, many of the measurement methods described below are conducted at a reach scale. The reach scale information can then be used in the broader context of watershed health, i.e., providing reaches that are functionally impaired or healthy, and as an aid in identifying potential restoration sites.

4.3 » STREAM FUNCTIONS PYRAMID: BROAD-LEVEL VIEW

The broad-level view is shown in Figure 4.1. The functional categories have been

modified from Fischenich (2006) to more closely match functions with parameters that are commonly used in the fields of hydrology, hydraulics, geomorphology, physicochemistry (called physicochemical on the Pyramid) and biology. The purpose of the broad-level Pyramid view is to show that the primary direction of cause-and-effect relationships flows from the bottom of the Pyramid to the top. In other words, functions higher on the Pyramid are more dependent on lower-level functions. This does not mean that cause-and-effect relationships can't or don't flow from higher levels to lower levels. The intention of the Pyramid is to show the dominant flow of cause-and-effect relationships. A dashed line is used to separate the functional categories to illustrate that the transition between categories is not a "hard" boundary. Cause-and-effect relationships can flow in both directions. For example, everything in the Pyramid is ultimately controlled by geology and the region's climate. If climate changes or there is a major geologic event, e.g., volcanic eruption, changes will occur throughout the Pyramid. Within the Pyramid, Hydrology and Hydraulic functions support Geomorphology functions like sediment transport, i.e., without water being contributed from the watershed and creating flow dynamics in the channel, sediment transport would not occur. Of course, channel form (geomorphology) does affect hydraulics through channel slope, sediment supply and boundary conditions. This is a downward example of cause and effect, but it is not as dominant as the requirement for water to be in the channel. Wohl (2004) alludes to these cause-and-effect relationships by stating, "We cannot save trout without saving their river and floodplain habitats. We cannot save river and floodplain habitats — and the plants and insects of the trout's food web — if we do not also maintain the processes controlling water and sediment entering the river corridor from the surrounding hillslopes and uplands." This concept exemplifies how the underlying physical functions support the biological functions.

This may seem obvious; however, many assessment methodologies address biological indicators without addressing the underlying controls provided by geomorphology, hydraulics and hydrology (Somerville, 2010). This concept also helps the practitioner match the project goal with the corresponding stream functions to avoid problems where practitioners design ineffective projects because they ignore the underlying hydrology, hydraulic and geomorphic functions (Fischenich, 2006).

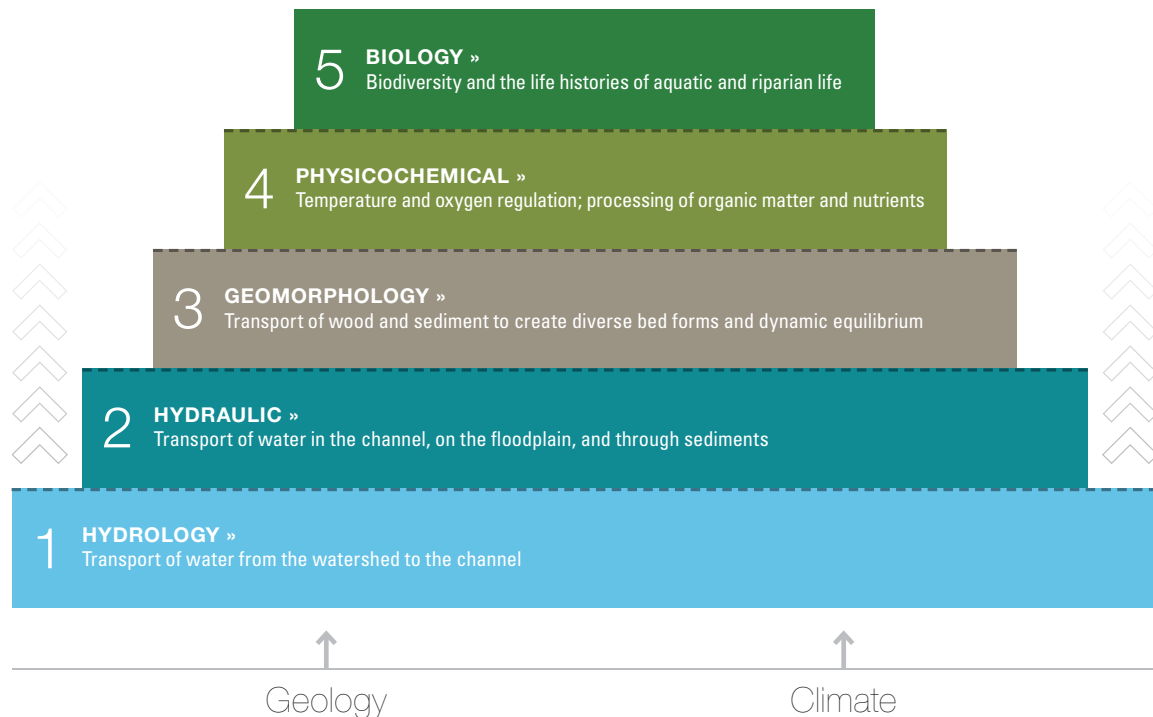
Function Descriptions by Level

Function-based parameters and measurement methods are not shown on the broad-level Pyramid. Rather, a statement is provided to define the overall function of a given

The intention of the Pyramid is to show the dominant flow of cause-and-effect relationships. A dashed line is used to separate the functional categories to illustrate that the transition between categories is not a "hard" boundary.

Chapter 4: The Stream Functions Pyramid

FIGURE 4.1 STREAM FUNCTIONS PYRAMID — OVERVIEW
(See Appendix A for a full-size version.)



category. This information is based on Fischenich (2006), Somerville (2010), industry standards and professional experience. A description is provided below for each functional category. These statements are used to help select function-based parameters in the next Pyramid view.

Level 1: Hydrology

Hydrology functions transport water from the watershed to the channel. Hydrology is placed at the bottom of the Pyramid because water contributed from the watershed strongly affects the higher-level functions. Very simply put, without surface water flow, there would not be channel formation and the subsequent aquatic ecosystem. This definition of hydrology is most common in the engineering community and although it is related to hydraulics, the calculations are made separately, e.g., the USACE hydrologic model HEC-HMS (Scharffenberg and Fleming, 2010) and the USACE hydraulic model HEC-RAS (Brunner, 2010). Physical and life scientists tend to merge hydraulics into hydrology. However, from a stream assessment and restoration perspective, there are advantages to having both categories. The Pyramid keeps these functions separate for two reasons: 1) When conducting assessments or implementing a stream restoration project, it is important to distinguish between watershed scale functions of water transport (Hydrology) and reach scale relationships that describe how water interacts with the channel

(Hydraulics); and 2) The opportunity for functional lift is very different between the two.

Level 2: Hydraulics

Hydraulic functions transport water in the channel, on the floodplain and through sediments. Again, this is a broad statement — it defines how water behaves once it reaches a channel and how it interacts with the bed, banks, floodplain, hyporheic zone, etc. (Dingman, 2008). It is important to note that this function works in channels of all sizes, from valley bottom swales (ephemeral channels) to large rivers. It is also present in all forms of geology and climate zones (Knighton, 1998). The energy associated with moving water has the ability to do work, such as transporting sediment, which is a geomorphology function (Leopold et al., 1992). The Hydraulic functions are closely related to Geomorphology functions and many interrelationships exist between these two categories. For example, sinuosity (Level 3) affects channel slope, which in turn affects channel velocity (Level 2). However, the dominant cause-and-effect relationships involve Hydraulics supporting Geomorphology. At a basic level, water must be present in the channel before sediment can be moved, regardless of sinuosity and other measures of channel form. Hydraulic functions also affect many functions in Levels 4 and 5 because they determine the amount of force and power that is exerted by the water on aquatic habitats.

Level 3: Geomorphology

The function of geomorphology, as defined here, is the transport of wood and sediment to create diverse bed forms and dynamic equilibrium. The relative importance or even presence of certain Geomorphology functions varies greatly with changes in geology and climate. For example, wood transport and storage is extremely important to channel stability in headwater mountain streams but not important in low-gradient, grassland streams. In addition, some streams are naturally unstable and are not in a state of dynamic equilibrium, e.g., glacial outwash plains and some alluvial fans. However, the Hydrology and Hydraulic functions come together with the Geomorphology functions to create a channel form that is appropriate for the underlying geology and climate of the region. From a stream assessment and restoration perspective, we are most interested in these functions as they relate to the creation of diverse bed forms and channel stability (dynamic equilibrium) that has a dramatic effect on Level 4 and 5 functions, which are often the ultimate desire of a restoration project.

Level 4: Physicochemical

Physicochemical functions include temperature and oxygen regulation, and processing of organic matter and nutrients. These functions are generally more affected by the underlying functions than vice versa, even though some of these functions occur as soon as water is present in the channel, e.g., water temperature. However, the Physicochemical category was placed above Geomorphology because a restoration practitioner would typically address functions here (Level 3) in order to see improvements in Physicochemical functions. For example, fast riffles and deep pools (bed form diversity), along with

shade and a wide buffer help regulate stream temperature. It is true that some projects may only need to address water-quality stressors, e.g., a point-source discharge and animal waste inputs, rather than restore the underlying functions. However, even in these cases, an assessment should be made to ensure that the underlying, supporting functions are present so that the stream will naturally recover once the stressor is removed.

Level 5: Biology

Biology is located at the top of the Pyramid because these functions are dependent on all the underlying functions. These functions include the biodiversity and the life histories of aquatic and riparian organisms. Biology functions can affect lower-level functions, e.g., beaver activities; however, as with the other levels, the dominant cause-and-effect relationship is upward. A healthy aquatic ecosystem must have sufficient water contributed from the watershed, the right levels of hydraulic forces, proper bed form diversity and channel stability, suitable temperature and oxygen regimes, and so on. The value of the Pyramid at this level is that it helps regulators, scientists and engineers to identify the underlying functions that must be present in order to achieve functional improvements in biology. This is currently not happening. As Somerville (2010) points out, many assessment methods omit these underlying functions.

4.4 » STREAM FUNCTIONS PYRAMID: FUNCTION-BASED PARAMETERS

Figure 4.2 shows a more detailed view of the Pyramid with examples of function-based parameters that can be used to quantify or describe the *functional statement* provided in the broad-level view. The term “function-based” is used to acknowledge that the parameter may be a “structural” type of parameter or an actual function. Structural

The Stream Functions Pyramid uses the term function-based parameter to take the emphasis off of structural measures versus actual functions. Rather, function-based parameters are used individually or in combination to quantify or describe a particular aspect of the functional statement provided in the broad-level view.

parameters describe a stream condition at a point in time, e.g., percent riffle and pool. A function parameter is expressed as a rate and directly relates to a stream process that helps create and maintain the character of the stream corridor (Allan, 1995). The Stream Functions Pyramid uses the term function-based parameter to take the emphasis off of structural measures versus actual functions. Rather, function-based parameters are used individually or in combination to quantify or describe a particular aspect of the functional statement provided in the broad-level view. For example, within the Hydrology category (Level 1), flood frequency is a function-based parameter that can be used to quantify the occurrence of a given discharge. It is not a function, but it does

provide critical information about the transport of water from the watershed to the channel, which is a function. Another example is bed form diversity, a function-based parameter in Geomorphology (Level 3). Bed form diversity is not a function, it is a structural measure. However, complex bed form diversity, e.g., gravel riffles with low embeddedness and slow-moving deep pools are an indication that sediment transport processes are working appropriately. Sediment transport is a function; however, it is much more difficult to measure than bed form diversity and may not be necessary for stream assessments that are focused on functionality. This does not mean that sediment transport should not be assessed for vertical stability or for a restoration design. In the end, stream assessments and designs may include a mix of structural measures and functions based on the complexity of the project and financial constraints. However, the combination of structural measures and functions can be considered function-based if they help describe or quantify a particular functional category, as expressed by the functional statement in Figure 4.1 (The Stream Functions Pyramid — Overview).

The function-based parameters shown on the Pyramid are fairly comprehensive and can be used in a wide range of settings. However, they should be considered as examples. Some parameters may be more important than others for a given region. In addition, some regions or unique projects within a region may need to add parameters. The criteria used to include function-based parameters within the Pyramid are provided below.

The function-based parameters shown on the Pyramid are fairly comprehensive and can be used in a wide range of settings. However, they should be considered as examples.

Criteria for Selecting Function-Based Parameters

For all Pyramid Levels

- Quantifies or describes (typically quantitative, but can be qualitative) a portion of the functional statement. The functional statements are provided above in Function Descriptions by Level.
- Has at least one measurement method that can be assigned. A function-based parameter can typically be measured in multiple ways, hence, it is broader than a measurement method.
- Can be a structural measure or a function.
- May or may not be applicable to all climate zones, geologic settings and eco-regions.

For Levels 1 through 3

- Must be a parameter that a practitioner can calculate or measure and use for restoration design and/or stream assessments.
- For restoration projects, typically include parameters that can be manipulated by the practitioner to create functional lift.

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For Levels 4 through 5

- If adding a parameter to these Levels, consider if there are supporting lower-level parameters.

Ultimately, the suite of parameters selected will be dependent on the project's goals and budget, since some parameters can be measured quickly and inexpensively and others require long-term monitoring and expensive equipment. These issues can be addressed by selecting the appropriate measurement method. Chapter 11 provides examples of how to select parameters and measurement methods for various applications.

FIGURE 4.2 STREAM FUNCTIONS PYRAMID — FUNCTIONS & PARAMETERS
(See Appendix A for full-size version.)



4.5 » STREAM FUNCTIONS PYRAMID: MEASUREMENT METHODS

Table 4.3 shows examples of measurement methods associated with each parameter. Measurement methods are more specific than function-based parameters by including specific calculations, simple spreadsheet models, sophisticated computer models, rapid field-based assessments, and in some cases, assessment methods that influence more than one function-based parameter. However, unlike the function-based parameter, there is typically a well-defined approach for conducting the measurement method.

Most parameters have at least two measurement methods and some, like the Geomor-

phology category, have several for each parameter. Some measurement methods are rapid-based approaches (requiring a small amount of time and effort to make the measurement) and others require intensive monitoring and analysis. This provides the user with a wide selection of methods to quantify, describe, and understand stream functions. General descriptions about the individual measurement methods are provided in Chapters 6-10. These chapters correspond to a functional category (Hydrology, Hydraulics, etc) with the measurement methods under the function-based parameter sections. This document does not provide a lot of detail about how the measurement methods relate to each other. As real-world applications are developed, these relationships should become clearer. In the meantime, users will find links and references to additional resources that can be used to develop a more comprehensive understanding of how multiple measurement methods can be used together to quantify a function-based parameter.

Ultimately, the suite of function-based parameters and measurement methods selected will depend on the purpose of the assessment and the funding level. Again, Chapter 11 provides examples of how to select parameters and measurement methods for various applications.

Table 4.3 provides a list of all the measurement methods associated with the function-based parameters that have been included in this document. These measurement methods should not be considered all-inclusive, but rather, represent examples that are frequently used in stream assessment and restoration. A more detailed table is provided in Appendix Ac that includes additional information about each measurement method, including: type, level of effort, level of complexity, and whether or not the measure is a direct versus indirect measurement of a function-based parameter. The criteria used to make these determinations are provided below and details for each parameter are provided in Chapters 6-10.

Type of Measurement Method

As discussed above, the measurement methods include a wide range of tools, techniques, metrics and even assessment approaches. Appendix Ac identifies each type of measurement method, using the following criteria/definitions:

- Tool: Includes spreadsheet and computer models, typically with predictive ability. Tools are more automated than a technique.
- Technique: Techniques are empirical equations, statistical approaches and field survey techniques/methods. Techniques are not part of a larger computer model/tool, e.g., HEC-RAS, which is a tool.

Measurement methods are more specific than function-based parameters by including specific calculations, simple spreadsheet models, sophisticated computer models, rapid field-based assessments, and in some cases, assessment methods that influence more than one function-based parameter.

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- **Metric:** A metric or parameter, which is more specific than a function-based parameter. It has a well-defined method for being measured. For example, flow dynamics is a function-based parameter and velocity is a measurement method of the metric type. This is a subtle, but important difference.
- **Assessment Approach:** Includes established assessment approaches, e.g., rapid bioassessment protocol. It often assesses more than the function-based parameter shown in the Pyramid, meaning that the Pyramid is only referring to a portion of the assessment methodology.

Level of Effort

Appendix Ac assigns a level of effort to each measurement method, including rapid, moderate and intensive. The overriding criteria is to determine how much effort is required to arrive at a final answer, so level of effort can include field and office/lab work. In general, rapid measurement methods require less than half a day in the field to assess a one-mile stream reach. Some rapid measurement methods use simple spreadsheets, maps or other office-based measurement methods that do not require field work. Other measurement methods, like regional curves, are simple to use if the curve has been developed, moderate if developing a watershed specific curve, and intensive for developing regional curves for a hydro-physiographic region. A moderate level of effort generally requires one day to one week of fieldwork for a one-mile stream assessment and another day or more to process and analyze the data. Some methods may not require field data, but still require time to collect existing data, e.g., from websites and databases. The results can be compared to existing performance standards and do not require monitoring over time, e.g., annual surveys to determine functionality. Intensive measurement methods require long-term (multi-year) monitoring efforts in order to develop trends that are often compared to reference conditions. The actual monitoring effort may be rapid, i.e., it takes less than half a day to assess one mile of stream; however, achieving results will take multiple measurements over time to develop a trend and is therefore intensive. The level of effort should not be confused with level of expertise, since some of the more qualitative and rapid measurement methods rely on professional judgment and, therefore, a high level of expertise.

Level of Complexity

Appendix Ac assigns a level of complexity to each measurement method, including simple, moderate and complex. Simple methods can be assessed after minimal training, e.g., on-the-job training and workshops. Simple can also mean that the sample is relatively easy to collect and analyze without the need of sophisticated equipment. Simple methods do not require elaborate or lengthy steps or processes to acquire the data. Moderately complex measurement methods require more effort and expertise than simple methods. These measurement methods often require someone with formal training and some experience. They may also require several steps to collect and analyze the data or to make calculations and estimates. Complex measurement methods should be completed by professionals with sufficient academic training and professional experience. These methods often require complex field and/or office procedures or complex modeling and analysis.

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Direct Versus Indirect

Appendix Ac also shows if the measurement method is a direct or indirect measure of the function-based parameter. Direct measurement methods often do not require additional interpretation about the function-based parameter; they directly measure or assess the parameter. Indirect measures may require additional interpretation or only provide a partial, or incomplete, understanding of the function-based parameter. Assessment approaches typically include the additional interpretation needed for translating indirect measures to function-based parameters. Direct measures provide a more straightforward answer about a function-based parameter, whereas an indirect measure is more of an estimate.

TABLE 4.3 PARAMETERS AND MEASUREMENT METHODS

HYDROLOGY	
PARAMETER	MEASUREMENT METHOD
Channel-Forming Discharge	1. Regional Curves
Precipitation/Runoff Relationship	1. Rational Method 2. HEC-HMS 3. USGS Regional Regression Equations
Flood Frequency	1. Bulletin 17b
Flow Duration	1. Flow Duration Curve 2. Crest Gage 3. Monitoring Devices 4. Rapid Indicators
HYDRAULICS	
PARAMETER	MEASUREMENT METHOD
Floodplain Connectivity	1. Bank Height Ratio 2. Entrenchment Ratio 3. Stage Versus Discharge
Flow Dynamics	1. Stream Velocity 2. Shear Stress 3. Stream Power
Groundwater/Surface Water Exchange	1. Piezometers 2. Tracers 3. Seepage Meters
GEOMORPHOLOGY	
PARAMETER	MEASUREMENT METHOD
Sediment Transport Competency	1. Shear Stress Curve 2. Required Depth and Slope 3. Spreadsheets and Computer Models

TABLE 4.3 PARAMETERS AND MEASUREMENT METHODS (CONT.)

GEOMORPHOLOGY	
PARAMETER	MEASUREMENT METHOD
Sediment Transport Capacity	<ol style="list-style-type: none"> 1. Computer Models 2. FLOWSED and POWERSED 3. BAGS
Large Woody Debris Transport and Storage	<ol style="list-style-type: none"> 1. Wohl LWD Assessment 2. Large Woody Debris Index
Channel Evolution	<ol style="list-style-type: none"> 1. Simon Channel Evolution Model 2. Rosgen Stream Type Succession Scenarios
Bank Migration/Lateral Stability	<ol style="list-style-type: none"> 1. Meander Width Ratio 2. BEHI / NBS 3. Bank Pins 4. Bank Profiles 5. Cross-Sectional Surveys 6. Bank Stability and Toe Erosion Model
Riparian Vegetation	<ol style="list-style-type: none"> 1. Buffer Width 2. Buffer Density 3. Buffer Composition 4. Buffer Age 5. Buffer Growth 6. Canopy Density 7. Proper Functioning Condition (PFC) 8. NRCS Visual Assessment Protocol 9. Rapid Bioassessment Protocol 10. Watershed Assessment of River Stability and Sediment Supply (WARSSS) 11. USFWS Stream Assessment Ranking Protocol (SAR)
Bed Form Diversity	<ol style="list-style-type: none"> 1. Percent Riffle and Pool 2. Facet Slope 3. Pool-to-Pool Spacing 4. Depth Variability
Bed Material Characterization	<ol style="list-style-type: none"> 1. Size Class Pebble Count Analyzer 2. Riffle Stability Index (RSI)

TABLE 4.3 PARAMETERS AND MEASUREMENT METHODS (CONT.)

PHYSICOCHEMICAL	
PARAMETER	MEASUREMENT METHOD
Water Quality	<ol style="list-style-type: none"> 1. Temperature 2. Dissolved Oxygen 3. Conductivity 4. pH 5. Turbidity
Nutrients	<ol style="list-style-type: none"> 1. Field test kits using reagents reactions 2. Laboratory analysis
Organic Carbon	<ol style="list-style-type: none"> 1. Laboratory analysis
BIOLOGY	
PARAMETER	MEASUREMENT METHOD
Microbial Communities	<ol style="list-style-type: none"> 1. Taxonomic Methods 2. Non-Taxonomic Methods 3. Biological Indices
Macrophyte Communities	<ol style="list-style-type: none"> 1. Taxonomic Methods 2. Non-Taxonomic Methods 3. Biological Indices
Benthic Macroinvertebrate Communities	<ol style="list-style-type: none"> 1. Taxonomic Methods 2. Non-Taxonomic Methods 3. Biological Indices
Fish Communities	<ol style="list-style-type: none"> 1. Taxonomic Methods 2. Non-Taxonomic Methods 3. Biological Indices
Landscape Connectivity	<ol style="list-style-type: none"> 1. Spatial Analysis 2. Species Tracking 3. Habitat Models

4.6 » FUNCTION-BASED PARAMETERS AND MEASUREMENT METHOD: DESCRIPTIONS BY CATEGORY

A more detailed description of the function-based parameters and measurement methods shown in Table 4.3 is provided below. These descriptions are stratified by functional category and discuss how the function-based parameters and measurement methods work together. In addition, information is provided about how the parameters and measurement methods relate to stream restoration.

Level 1: Hydrology

The function-based parameters shown on the Pyramid are used by practitioners to

determine how much water will reach the channel and how much water the channel should carry to maintain dynamic equilibrium. The parameters used to assess these functions include precipitation/runoff relationships, channel forming discharge, flood frequency and flow duration. Each parameter and its associated measurement method are discussed in detail in Chapter 6.

Hydrology parameters are typically independent parameters in a stream restoration project, meaning, for example, that a designer does not have the ability to influence or change the precipitation/runoff relationship or channel forming discharge. These parameters are simply quantified and then used as inputs for a more detailed hydraulic analysis. While this is common, it is not always the case. There are scenarios where a project may be able to “improve” the runoff relationship, such as by implementing stormwater best management practices. This can be a critical component of stream restoration projects in urban environments.

Level 2: Hydraulic

Results from Level 1 are used as input parameters in Level 2 to quantify two broad-level parameters: floodplain connectivity and flow dynamics. Floodplain connectivity is measured by the bank height ratio, entrenchment ratio and stage-versus-discharge relationships (rating curves). These measurement methods are used to determine if the channel can accommodate the targeted volume of water consistent with design goals and/or management objectives. The bank height ratio is a common method used to assess floodplain connectivity by comparing the bankfull depth to the total depth of the channel. Ideally, channels should not carry more than the bankfull discharge. For streams in alluvial valleys, flood flows should be spread across the floodplain. The entrenchment ratio, which describes the width of the floodprone area in relation to the bankfull width, is used to further describe floodplain connectivity (Rosgen 2009). In addition, estimates of the stage-versus-discharge relationship can be measured or estimated to directly assess floodplain connectivity. Flow dynamics is assessed through measures of velocity, shear stress and stream power, which change with increasing stage and discharge. Groundwater/surface water exchange is also included because this is an important process that supports physicochemical and biological processes that will be described later (Knighton, 1998). A detailed description of each Hydraulic parameter and its measurement method is described in Chapter 7.

Like Hydrology, Hydraulic parameters and measurement methods include structural measures and functions. Discharge and groundwater/surface water exchange are functions and can be quantified as rates-per-unit time, and they have a significant effect on the form of the channel and influence functions in Levels 3-5. Bank height and entrenchment ratios are structural measures, expressed as dimensionless ratios. However, they do relate to functions since the bank height ratio correlates to the stage that transports the bankfull discharge, and the entrenchment ratio describes the flow area inundated with the discharge at twice the stage of bankfull. In other words, they help to describe flow dynamics.

Stream restoration projects have the greatest effect on Level 2 and Level 3 functions

because projects occur at a reach scale and most of these functions can be modified as part of the design process. For example, the majority of stream restoration projects located in alluvial valleys and perennial streams include the goal of reconnecting the stream to a floodplain. Designers may accomplish this goal by raising the stream bed, lowering the floodplain or creating a bankfull bench. This approach often follows Rosgen's Priority Levels of restoring incised channels, as described in Chapter 3 (Rosgen 1997). To accomplish this goal, the designer calculates the bankfull discharge (Level 1) and then designs a cross section that will convey flows up to the bankfull discharge (Level 2). The degree of functional lift is determined by assessing the difference in pre- and post-restoration incision, which can easily be represented by the bank height ratio and entrenchment ratio. Re-establishing floodplain connectivity is one of the most important things that a restoration project can do at a reach scale because it affects so many of the upper-level functions.

Level 3: Geomorphology

The parameters used to assess Geomorphology functions include sediment transport competency, sediment transport capacity, large woody debris transport and storage, channel evolution, lateral stability, riparian vegetation, bed form diversity and bed material characterization. There are many different measurement methods provided for these parameters — more than any other category. Of these parameters, sediment transport, lateral stability and components of the riparian vegetation are quantified as rates and are considered functional measures. Channel evolution is not measured as a rate, but does imply a change in form over time and relates to channel-forming processes. However, the amount of time is not quantified. Bed form diversity is a structural measure, usually assessed as the percent of riffle and pool length per unit of channel length, depth variability and/or substrate distributions. Nevertheless, bed form diversity is an important structural measure that quantifies the effects of sediment transport and is much easier to assess. The transport of wood is also an important function in this category, although its degree of importance varies by stream type. For some stream types (Rosgen A and B), wood transport and storage is important for maintaining channel stability. For other stream types (Rosgen C and E) wood and organic matter transport and storage can be important for stability, but is more important in its role for supporting Level 4 and 5 functions. A detailed description of each parameter and measurement method is provided in Chapter 8.

Stream restoration designs often focus on Level 3 parameters. Like Level 2, a restoration project can affect these parameters at a reach scale, although the longer the reach the better with regard to functional lift. Restoration activities associated with Level 3 often include improving bed form diversity and reducing streambank erosion. Bed form diversity is often improved by designing the appropriate dimension, pattern and profile for the given valley type. Meandering perennial streams in alluvial valleys, for instance, create riffle-pool sequences. Large woody debris and in-stream rock and wood structures are used to further improve depth variability and channel stability and complexity. In addition, most stream restoration projects include planting vegetation on the streambanks and the riparian zone to provide bank stability and to support Level 4 and 5 functions.

Level 4: Physicochemical

Physicochemical functions include physical and chemical processes that create baseline water chemistry, breakdown organic matter and transform nutrients. It could be argued that once water reaches the channel (Hydrology and Hydraulic functions) chemical and biological processes begin to occur. However, from a stream restoration perspective, these functions are affected (and can be improved) by the presence of water and its interaction with bed forms, structures like woody debris, and the riparian vegetation. For example, dissolved oxygen can be increased by lowering the temperature through a robust riparian buffer and by the presence of steep, rocky riffles. These parameters are addressed in the lower levels.

Physicochemical water quality assessments include the following parameters: nutrients, organic carbon, dissolved oxygen, temperature, pH, specific conductivity and turbidity. Nutrients and organic carbon can be assessed rapidly in the field with test kits, but are more often measured in a laboratory. Organic matter and nutrient processing are always measured as rates and significantly contribute to the character of the stream system; therefore, these parameters are direct measures of function. Dissolved oxygen, temperature, pH and conductivity are typically measured at a point in time rather than a rate over time and are considered a structural measure. However, with continuous monitoring, parameters such as temperature can be considered a function. For example, the rate of change in water temperature as air temperature changes is a functional measure of thermal regulation. A detailed description of each parameter and measurement method is provided in Chapter 9.

It is difficult for stream restoration projects to directly affect Physicochemical parameters because they are affected by so many variables. They are supported by the lower-level functions, but they are also sensitive to weather and climate change, inputs from the upstream watershed and adjacent land uses, and even Level 5 functions. The relationship to Level 5 is discussed in more detail below. A reach scale stream restoration project often has very little control over these factors. Therefore, if a primary goal of a restoration project is to improve these functions, project site selection is as important (if not more important) than the reach scale activities associated with Levels 1-3, but especially Levels 2 and 3. The ideal situation for a restoration project that seeks to restore Level 4 functions is to have a healthy upstream watershed and reach scale impairments that can be improved by restoration activities. In this case, once the reach scale restoration activities have been completed, the project can benefit from a healthy watershed and not be limited by poor water quality. Common Level 2 and 3 restoration activities that support Level 4 functions include floodplain connectivity, bed form diversity, lateral stability, overhanging vegetation and a wide riparian buffer. This does not mean that Level 4 functions cannot be achieved in the future if the upstream health of the watershed improves. Watershed management plans are important tools that can combine reach scale restoration with preservation, stormwater BMP's, and other forms of water quality improvements to restore watersheds beyond individual stream reaches.

Level 5: Biology

Biology functions describe the processes that support the life histories of aquatic and riparian plants and animals. These life histories are dependent on all the lower-level functions, which is why Biology is at the top of the Pyramid. For instance, healthy fish populations cannot exist without the proper flow duration, velocity distributions, bed forms, temperature, water chemistry, etc. that are created through the interactions of all five levels. Parameters that describe Biology functions include microbial communities, macrophytes, macroinvertebrate communities, fish communities and landscape pathways. A detailed description of each parameter and various measurement methods is provided in Chapter 10.

Like Level 4, most reach scale restoration activities that support Level 5 occur at Levels 2 and 3. If a project goal is to have a healthy native fish population, the stream reach must have the proper flow duration, flow dynamics, bed form diversity, lateral stability, vegetative cover, temperature regulation, dissolved oxygen, pH and conductivity. As discussed in Level 4, site selection is just as critical as the reach scale restoration efforts because the quality of water and sediments entering the project reach are critical to the health of the aquatic life.

4.7 » STREAM FUNCTIONS PYRAMID: PERFORMANCE STANDARDS

The final layer to the Framework includes performance standards associated with the measurement methods. The performance standards are divided into functional capacity types, including: Functioning, Functioning-at-Risk, and Not Functioning, which are similar to the categories used in the Proper Functioning Condition method (Prichard et al., 1998). These categories are defined below:

- **Functioning:** A Functioning score means that the measurement method is quantifying or describing one or more aspects of a function-based parameter in a way that **does support** a healthy aquatic ecosystem. A single functioning measurement method may not mean that the function-based parameter or overall category (e.g., Geomorphology) is functioning.
- **Functioning-at-Risk:** A Functioning-at-Risk score means that the measurement method is quantifying or describing one or more aspects of a function-based parameter in a way that **can support** a healthy aquatic ecosystem. In many cases, this indicates the function-based parameter is adjusting in response to changes in the reach or the watershed. The trend may be towards lower or higher function. A Functioning-at-Risk score implies that the aspect of the function-based parameter, described by the measurement method, is between Functioning and Not Functioning.
- **Not Functioning:** A Not Functioning score means that the measurement method is quantifying or describing one or more aspects of a function-based parameter in a way that **does not support** a healthy aquatic ecosystem. A single functioning measurement method may not mean that the function-based parameter or overall category (e.g., Geomorphology) is not functioning.

Most published performance standards are not described in terms of Functioning, Functioning-at-Risk or Not Functioning, so professional judgment was required to distribute the values. Performance standards that are available for each measurement method are provided in Chapters 6-10, and a summary of all the performance standards is provided in Appendix Ad. Many of the performance standard values, especially the dimensionless ratios, should be considered as examples that can be modified based on regional variations in reference condition.

Many of the performance standard values, especially the dimensionless ratios, should be considered as examples that can be modified based on regional variations in reference condition.

Some measurement methods do not include performance standards because they either do not exist or the measurement method is more associated with design than the actual performance of a function-based parameter. An example is the bankfull

discharge, a Level 1 measurement method for the channel-forming discharge parameter. The bankfull discharge is used in natural channel designs and geomorphic assessments and it drives many of the functions in Level 2 and 3, thereby supporting functions in Levels 4 and 5. It is a critically important measurement method; however, it is a result of the watershed characteristics and is unique to every stream. Therefore, it would be difficult to create a reliable performance standard for the bankfull discharge. There are other measurement methods, such as the bank height ratio used to measure floodplain connectivity, that are closely related to the bankfull discharge, can be much easier to measure, and have performance standards that can be used, irrespective of geology or climate.

The criteria used to select performance standards, in priority order, include:

The criteria used to select performance standards, in priority order, include:

- Provided in peer-reviewed journals;
- Provided in government documents;
- Provided in books or proceeding papers; and
- Professional judgment of the authors.

4.8 » STREAM FUNCTIONS PYRAMID AND RESTORATION ACTIVITIES

The above discussion provided an overview of the Stream Functions Pyramid Framework, describing the functions by category and listing the function-based parameters and measurement methods that can be used to describe the functions. A description of performance standards was also provided. In the following section, an example is provided to illustrate how restoration activities can improve stream functions using the Pyramid as a guide. This will help explain how a stream restoration project can improve stream functions at a reach scale or as part of a larger watershed improvement effort. However, not all types of stream restoration or water quality improvement projects fit neatly into the Pyramid.

Restoration of Channelized and Incised Channels

The restoration of channelized, incised streams is used as an example because it is a common approach in areas with well-established stream restoration and mitigation programs. Therefore, many stream mitigation programs appropriately discuss the importance of channel evolution and floodplain connectivity in their SOP (USACE Wilmington District et al., 2003; USACE Savannah District, 2004; USACE Norfolk District and VDEQ, 2007; and USACE Charleston District, 2010). Early stream mitigation programs were prevalent in the eastern United States, a region where channelized and incised streams are abundant. As mitigation programs continue to develop in the western regions, other types of impairments will increasingly be addressed by stream mitigation programs. However, incised channels are prevalent throughout the United States and will continue to be addressed by restoration and mitigation programs.

Background

Channelization is an engineering practice with a long history in the United States, starting in the 19th century. From 1820 to 1970, more than 200,000 miles of streams and rivers were channelized to reduce flooding, provide drainage for agriculture, and improve navigation (Wohl, 2004). Locally, channelization increases drainage and reduces flooding by increasing stream gradient (typically by straightening the channel), thereby increasing stream power, which typically leads to further incision (Darby and Thornes, 1992; Hupp, 1992). The increased width, depth and cross-sectional area following channelization and incision reduce floodplain inundation, decreasing water and sediment storage on the floodplain (Kroes and Hupp, 2010; Pizzuto, 1987). Shields et al. (2010) compared physical, chemical and biological functions between an incised channel and non-incised channel with a similar mix of agriculture and forested land uses in northern Mississippi. The results of this study showed that the incised channel had turbidity and suspended solids levels that were two to three times higher than the non-incised channel. Total phosphorus, total Kjeldahl nitrogen, and chlorophyll a concentrations were significantly higher in the incised channel; however, nitrate was significantly higher in the non-incised channel. There were twice as many fish species with four times the amount of biomass in the non-incised stream. Correlation analysis showed that hydrologic perturbations were associated with the water quality degradation, leading the authors to recommend that ecological engineering should provide as much attention on mediating hydrologic perturbations and habitat quality as on pollutant loading. The research cited above did not use the Stream Functions Pyramid or the Fischenich (2006) framework; however, it did show that negative changes to lower-level (physical) functions, like Hydrology, Hydraulics and Geomorphology (Levels 1-3) had negative impacts on Physicochemical and Biology functions (Levels 4-5). The research also showed that restoration efforts should address these lower-level functions in order to show changes in the higher-level functions. Examples of how to use the Pyramid to link restoration activities to functional improvement is provided below.

Linking Restoration Approach to Stream Functions Pyramid

Typically, restoration credits are based on restoration and enhancement definitions that include changes to dimension, pattern and profile (e.g., USACE Wilmington District et al., 2003). The Stream Functions Pyramid is a tool that can help change the definitions of restoration and enhancement to focus on functional lift rather than changes to dimension, pattern and profile. Consider the example in Table 4.4 showing restoration activities that are used to restore incised, channelized streams. The restoration activities are shown in the first column. The second column links a function-based parameter from the Pyramid that is *directly* improved as part of the design and implementation phase of the restoration activity. The third column shows *indirect* improvements of other function-based

The Stream Functions Pyramid is a tool that can help change the definitions of restoration and enhancement to focus on functional lift rather than changes to dimension, pattern and profile.

parameters within the same function category (level) or higher. This implies that the restoration activity and direct manipulation of function-based parameters in Pyramid Levels 2 and 3 will *support* the improvement of certain function-based parameters in Levels 2 through 5. The word support is stressed, because these restoration activities are implemented at a reach scale and cannot change the condition of the upstream watershed. It is possible that poor upstream

conditions can prevent functional lift at the project reach, especially with Level 4 and 5 functions. Performance standards and subsequent monitoring are used to determine if the direct and indirect functional improvements are actually achieved.

TABLE 4.4 LINK BETWEEN RESTORATION ACTIVITY AND FUNCTIONAL IMPROVEMENT

RESTORATION ACTIVITY	FUNCTION-BASED PARAMETER that is <i>directly</i> changed during the design and implementation phases	OTHER FUNCTION-BASED PARAMETERS that are <i>indirectly</i> supported
Re-connect the stream to the floodplain by raising the channel or excavating the floodplain	Level 2 – Floodplain connectivity	Level 2 – Groundwater/surface water exchange, flow dynamics Level 3 – Sediment transport competency and capacity, bank migration/lateral stability Level 4 – Nutrients Level 5 – Microbial Communities, Macrophyte Communities, benthic macroinvertebrates, fish communities

TABLE 4.4 LINK BETWEEN RESTORATION ACTIVITY AND FUNCTIONAL IMPROVEMENT (CONT.)

RESTORATION ACTIVITY	FUNCTION-BASED PARAMETER that is <i>directly</i> changed during the design and implementation phases	OTHER FUNCTION-BASED PARAMETERS that are <i>indirectly</i> supported
Re-meander the stream on the floodplain	Level 3 – Bed form diversity	Level 2 – flow dynamics, groundwater/surface water interaction Level 3 – Sediment transport competency and capacity, bank migration/lateral stability Level 4 – Water quality, Nutrients, Organic Carbon Level 5 – Microbial Communities, Macrophyte Communities, Benthic macroinvertebrates, fish communities
Add bed form structure and complexity, e.g. in-stream structures	Level 3 – Bed form diversity	Level 3 – Large woody debris transport and storage, bed material characterization Level 4 – Water quality, Nutrients, Organic Carbon Level 5 – Microbial Communities, Macrophyte Communities, Benthic macroinvertebrates, fish communities
Plant streambank and riparian vegetation	Level 3 – Riparian Vegetation	Level 3 – Bank migration/lateral stability Level 4 – Water quality, Nutrients, Organic Carbon Level 5 – Microbial Communities, Macrophyte Communities, Benthic macroinvertebrates, fish communities

Example Projects that May Not Need the Pyramid

The Stream Functions Pyramid Framework is more applicable to some types of projects and less to others. Stream restoration projects that involve physical manipulation to intermittent and perennial stream channels can benefit from the Stream Functions Pyramid. Stormwater Best Management Practices, regenerative design (Flores et al., 2011), Low Impact Development, and other practices that occur in ephemeral channels and uplands may benefit less from using the Pyramid. In addition, water quality solutions, like treat-

ing point source discharges and lime dosing, may not need the Pyramid to set project goals or develop assessment methods. However, even in these cases, it is always appropriate to ask, “What are the supporting functions that are required to meet the desired result?”

This is important because other problems may exist in addition to the obvious impairment.

For example, low pH is a commonly known problem in many West Virginia streams. The state agencies have created a dosing program to add lime to the stream and increase pH. Results have been positive; however, in a presentation at the 2011 Mid-Atlantic Stream Restoration Conference, Anderson (2011) showed variable improvements in trout populations. The reasons are not known; however, very little additional information (other than water chemistry) was collected. The goal of this effort was to restore the trout fishery. Therefore, an understanding of key functions in all five levels is needed in order to find a solution. Reducing pH may be the most important part of the solution, but other function-based parameters may also need to be addressed, e.g., improved bed form diversity, to recover trout populations.

Implementation of upland stormwater BMPs probably does not need the Pyramid. The goals of these projects are typically to reduce flow energy, reduce nutrients and remove other inorganic and organic compounds. These projects would rely more on conventional approaches to stormwater treatment.

4.9 » APPLICATION OF THE STREAM FUNCTIONS PYRAMID FRAMEWORK

The Stream Functions Pyramid is a conceptual model, a broad-level view showing the supporting relationships between functions. It also provides *examples* of function-based parameters, measurement methods and performance standards. Together they create the Stream Functions Pyramid Framework. It is not an all-inclusive framework and other parameters, measurement methods and performance standards can be added. The Pyramid framework is more of a thought process than a set of guidelines, and it is definitely not a cookbook. As such, it can be challenging to figure out how to start applying the Pyramid or how to “enter” the Pyramid. This section provides general explanations and examples about how to think about and apply the Pyramid as it relates to goal setting, function-based assessments and developing Standard Operating Procedures (SOPs). Refer to Chapter 11 for more detailed information about how the Pyramid can be applied.

Setting Project Goals and Objectives

Fischenich (2006) reports that a common goal of stream restoration is to restore stream habitat. However, he points out that habitat has the least effect on the other functions and is affected by the most functions. The Stream Functions Pyramid can be used by practitioners to establish goals that are more specific than restoring habitat. It can also be used to identify and think through the underlying, supporting functions that would need to be addressed to achieve a desired result.

Restoring habitat as a goal is too broad. One could ask, “Habitat for whom?” Most of the planet provides habitat for something, so a goal like this does not communicate why the project is needed or what it hopes to accomplish. A better goal would be to restore

habitat for a specific species of concern, e.g., native, southern brook trout. Of course, this goal should come after some form of functional assessment has been completed to determine that brook trout habitat is in need of restoration and that the watershed can support brook trout if the reach is restored. The Pyramid framework can assist with this process by helping the restoration team think through the underlying functions that are needed to support brook trout. First, it must be acknowledged that restoring brook trout is a Level 5 function; it relates to the life history of an aquatic organism (brook trout). So the team would “enter” the Pyramid at Level 5. If they enter at Level 5, there must be supporting functions in Levels 1-4. Now the team must identify those functions and function-based parameters. Again, this is not a cookbook, and the Pyramid does not automatically prescribe the supporting functions. This is a thought process that requires qualified professionals to be able to identify the appropriate parameters. For example, the first question might be, “What are the Level 4 function-based parameters that are needed to support native brook trout?” The answer would include appropriate temperature and oxygen regulation, as trout need cool, highly oxygenated water. Water quality must also be sufficient to support native brook trout populations, which could be affected by lower-level functions at a reach scale, as well as the health of the upstream watershed. Using the temperature and oxygen regulation as an example to further explore how the Pyramid can be used, the team might ask, “How do we achieve the proper temperature and oxygen regulation? What are the supporting function-based parameters?” The answer is found in Level 3.

Geomorphology function-based parameters like bank migration/lateral stability, bed form diversity and riparian vegetation affect temperature and oxygen regulation. This is a critical understanding because these parameters can be manipulated as part of the design to change oxygen and temperature regulation. For example, the channel form can be changed to create riffles and deep pools, banks can be stabilized and the riparian corridor can be planted. The level 4 parameter of oxygen and temperature regulation cannot be directly manipulated; rather, changes at level 3 are made to affect changes at level 4.

The thought process continues. The team can now ask, “What Hydraulic (Level 2) function-based parameters are needed to support bank migration/lateral stability, bed form diversity and riparian vegetation?” In this case, all of the Level 2 function-based parameters (floodplain connectivity, flow dynamics and groundwater/surface water exchange) are important to support the identified Level 3 functions, as well as Level 4 functions. Floodplain connectivity minimizes the amount of energy and force within the channel banks by dissipating flood energy on a floodplain or floodprone area. However, the appropriate amount of energy is maintained in the channel to support the creation of appropriate bed forms, e.g., riffles and pools. Floodplain connectivity also affects flow dynamics and groundwater/surface water interaction, which helps create healthy hyporheic zones that can regulate water temperature and support macroinvertebrate populations, among other benefits. Floodplain connectivity is also a function-based parameter that can be directly modified by a restoration team and is often considered the most important restoration activity because it supports Levels 2-5 functions.

Finally, the team can ask, “What Level 1 function-based parameters are needed to support the higher-level function-based parameters listed above?” These function-based parameters support functions from Level 1 through Level 5. Level 1 function-based parameters, including channel-forming discharge, precipitation/runoff and flow duration, are important to restoring native brook trout. The channel-forming discharge is used to determine how large the channel should be and is directly used to determine floodplain connectivity. Runoff is a watershed calculation and may or may not be modified based on the size of the watershed, property control and condition. Flow duration is typically determined by watershed conditions, but can be moderately improved by some restoration activities. It is important to evaluate these Level 1 parameters to make sure that the Hydrology can support the project goals. And of course, if the underlying geology or climate regime does not support brook trout, the project should not be attempted.

This is a simple example of how the Pyramid can be used as a process for developing and thinking through reach scale project goals. Other function-based parameters could be identified, but questions about the supporting functions would be the same. And there are certainly many other goals that could be considered. For example, improving water quality is another common goal. Like habitat, this goal could be improved by being more specific. What water quality issues are being addressed (temperature and oxygen, nutrients, conductivity, pH, etc.)? The answer to this question will help the restoration team identify the supporting functions required to make this improvement and to determine if restoration activities that change function-based parameters are needed; or the team can determine if things outside of the Pyramid should be addressed, e.g., a treatment plant or lime dosing.

The last example discussed here relates to stream mitigation. Many stream mitigation SOPs (USACE Wilmington District et al., 2003; USACE Savannah District, 2004; USACE Norfolk District, 2007; USACE Charleston District, 2010) link restoration credits to changes in dimension, pattern and profile, based on the Rosgen (1996) definition of a stable channel. While this is an appropriate definition of channel stability, it does not explicitly relate to a stream function. This has resulted in numerous projects where the stated goal is to improve dimension, pattern and profile with no thought given to why these changes are being made, i.e., what functional improvements are desired. At worst, this has resulted in projects that have completely reconstructed channels that did not need reconstruction. At best, it resulted in projects where the improvements were misunderstood, e.g., the achievable goal was to reduce sediment supply from eroding stream-banks, but assumptions were made that it should improve macroinvertebrates. If stream mitigation programs changed the definition to the restoration of function-based parameters identified on the Pyramid, then it could better clarify why the project was being completed. In addition, the mitigation program could then require the restoration team to identify the supporting function-based parameters and what restoration activities will be used to achieve the goal.

Developing Function-Based Stream Assessment Methods

The Stream Functions Pyramid Framework can be used as an aid to develop function-based assessments and to select or evaluate existing assessments. It can also be used as a way to organize watershed assessment plans. The term function-based is used instead of functional because the Pyramid includes a combination of functions and structural measures. However, this combination is considered function-based because the parameters and measurement methods are used to quantify or qualitatively describe the overall functional statement for a given Level. A detailed description of how the Pyramid Framework can be applied to function-based assessments, including developing, reviewing and organizing watershed management plans, is provided in Chapter 11. A general overview and example is provided below.

Stream assessments can be completed for a wide range of reasons, including but not limited to: fisheries management; threatened or endangered species recovery plans; drinking water source assessment; watershed/land use planning; compliance monitoring for State or Federal permits; documenting water quality trends (Somerville and Pruitt, 2004); before and after comparisons of stream restoration projects; and to determine the restoration potential for a degraded stream reach. Restoration potential is the highest level of restoration that can be achieved given the results of the function-based assessment, health of the upstream watershed and the project constraints.

Somerville (2010) found that the eight most commonly assessed parameters for regulatory and non-regulatory programs were: discharge, channel habitat units (bed forms), sinuosity, substrate particle size, bank stability and dominant bank material, riparian canopy cover, water temperature, and benthic macroinvertebrates. These parameters were often included in categories like physical, chemical and biological to meet the Clean Water Act categorization of functions or some form of modification, like habitat. In his study, hydrologic parameters were the least represented; even though studies like Fischenich (2006) and Shields et al. (2010) show that hydrologic parameters are critically important to supporting other functions.

Hughes et al. (2010) completed an evaluation of four qualitative indexes of physical habitat to see if they yielded similar results when applied to streams with varying disturbance and ecoregion. They also compared the results with independent assessments of vertebrate and invertebrate assemblage condition. The results showed that there were varying meanings of the term “habitat”; however, the different methods did yield similar results. The results were not as favorable when the physical habitat index scores were compared to biological index scores. This led the authors to conclude that there is more to

The Pyramid Framework may help remedy this problem or at least improve predicative power by including those parameters that are known to support biological conditions. As Somerville (2010) illustrated, many of the current assessment methodologies do not include hydrologic parameters.

learn about the factors that control biotic-assemblage structure across broad regional scales.

The Pyramid Framework may help remedy this problem or at least improve predicative power by including those parameters that are known to support biological conditions. As Somerville (2010) illustrated, many of the current assessment methodologies do not include hydrologic parameters. The Pyramid Framework takes this a step further by providing a structure for assessment developers to select biological parameters and then supporting parameters that are appropriate for their region. If the Pyramid Level 1-5 categories are used to organize the parameters, it will be easier to identify other supporting parameters that should be included.

In addition, since the Pyramid is a hierarchy, a framework is provided that can be used as a logical structure for creating functional assessment scores or indexes. For example, parameters lower in the Pyramid may be weighted differently than those higher in the Pyramid. For these applications, the assessments would likely have a method for summing values within a category to create an overall value, e.g., a Geomorphology score. Since measurement methods quantify a portion of a function-based parameter, and the function-based parameter describes the functional statement within a category, it is recommended that overall scores take place at the category level. There may be cases where the score could be made at the function-based parameter level; however, they should not be made at the measurement method level because a single measurement method rarely, if ever, fully describes the function-based parameter. Scoring based solely on an individual measurement method can lead to unintended consequences where the function-based parameter is not properly assessed, scored, or evaluated. For example, pool-to-pool spacing and pool depth variability are two measurement methods that quantify bed form diversity. Used together, they are appropriate indicators of the number of pools that are present in a study reach and the quality (depth) of those pools. However, if only one measurement method is used, the result is an inaccurate portrayal of bed form diversity. If pool depth alone is used, the result could be one deep pool out of a long stream length, e.g., one pool over a length of 2,000 feet. The score would show that bed form diversity is functioning when clearly it is not. Just using pool-to-pool spacing could yield a similar result. A reach could have the appropriate number of pools, but they may all be too shallow, perhaps from excessive sedimentation or an overly wide channel. Great care should be given to selecting measurement methods that fully describe the function-based parameter. And to avoid over emphasizing the measurement method, scoring should role up to the function-based parameter or category level.

Weighting will also apply to stream mitigation programs that ultimately need to link a score to debits and credits that relate to functional loss and lift, respectively. A step-wise approach for developing function-based assessments is provided in Chapter 11. However, weighting examples are not provided in this document. These examples will come from actual applications of the Framework and will be made available on the Stream Mechanics website (www.stream-mechanics.com).

Creating SOPs for Stream Mitigation Programs

The Pyramid can be used by Interagency Review Teams (IRTs) to develop debit and credit determination methods and performance standards for stream mitigation projects. This was discussed in the text above regarding stream restoration; and Chapter 11 provides templates that show how the Pyramid Framework can be used to develop debits and credits. Appendix B also provides some case studies for a variety of debit and credit scenarios.

Developing SOPs Beyond Stream Mitigation

The Stream Functions Pyramid can serve as an aid in creating SOPs for federal, state and local programs not associated with stream mitigation. These may include grant programs, impaired waters programs working on the development of Total Maximum Daily Loads (TMDLs), non-point source and stormwater management programs and others. Any program that deals with improving or preserving natural waterways can benefit from working through the thought process, questions and criteria that are outlined above.

4.10 » SUMMARY

The Stream Functions Pyramid is a simple, conceptual framework. It illustrates that stream functions should be addressed in a certain order while maintaining the concept that stream functions are interrelated. Many of the parameters support functions in their own level, upper levels and sometimes a lower level. It must be restated that the Pyramid was not developed to capture all the interrelationships between the parameters that are used to describe the functions. Fischenich (2006) is a better reference for showing specific interrelationships between functions.

The Pyramid can serve as a communication tool among the various disciplines that work in the fields of stream assessment, restoration and mitigation. There are very few individuals who are well versed in all five levels, so having a framework like the Pyramid makes it easier to communicate across disciplines and helps to ensure that future assessments do not make the same mistake illustrated by Fischenich (2006) and Somerville (2010), i.e., that most function-based assessments include habitat measures and rarely include hydrologic functions (split on the Pyramid into Hydrology and Hydraulic). This is critical because, as Fischenich (2006) and the Pyramid illustrate, these hydrologic functions must be working (at least to some level) in order to support Physicochemical and Biological functions. Existing assessments may be skewed towards Biological parameters because they are often prepared by biologists or ecologists who do not have a strong background in the hydrological sciences or geomorphology. Comparatively, there have been numerous “channel improvement” projects performed by hydraulic engineers that just deal with the Hydrology and Hydraulic functions and do not address Geomorphology, Physicochemical or Biology functions described by the Pyramid. This trend is changing and the Pyramid can be used as a guide to develop more comprehensive designs (and assessments) that address a wider range of stream corridor functions.

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Chapter 5

Reference Streams

5.1 » USE OF REFERENCE REACH DATA IN THIS DOCUMENT

The concepts of reference stream and reference condition are used throughout this document. They are used in various performance standards in Chapters 6-10, and tied to project goals and debit/credit determination methods in Chapter 11. The use of reference stream condition is most prevalent in the development of performance standards for the Physicochemical and Biology functions described in Chapters 9 and 10, respectively. The use of reference condition is also used to develop performance standards for several Geomorphology measurement methods, e.g., riparian vegetation and bed form diversity.

The use of reference stream condition is most prevalent in the development of performance standards for the Physicochemical and Biology functions described in Chapters 9 and 10, respectively.

The reason for this is due to the lack of data and knowledge about what constitutes healthy water chemistry, biology and geomorphology for every stream in the US.

These parameters are simply too variable and dependent on all the supporting functions and weather/climate patterns to establish universal performance standards. For example, a bottomland hardwood forest is common to reference streams in the East, but certainly not the arid portions of the

West. Some states and regions, however, have better reference condition databases than other places, and, in these cases, it may be possible to modify the performance standards to provide specific ranges. Hopefully over time, reference stream databases will be provided for a wide range of regions and the performance standards can be revised to include less subjective and more quantitative guidance.

5.2 » BACKGROUND

There are many different views of what a reference stream is and how it should be used. The term “reference stream” or “reference reach” is used throughout the remainder of this document to develop measurement methods and performance standards for certain parameters. Therefore, it is important to have a clear understanding of what is meant by a reference stream, how it is used in the context of stream assessment and stream restoration design, how to select stream reference reaches, and how to collect and analyze the data. An ecosystem reference represents “some target, benchmark, standard, model or template from which or to which ecosystem biological integrity, structure,

function, condition or relative health are compared” (Miller et al., 2011). While a reference condition can be established for a single stream reach, whenever possible, the reference condition should come from several stream reaches that can more accurately reflect the range of natural variability.

Regulatory and non-regulatory stream assessment programs often use the term “reference condition” to describe the quality of a reference stream. The 2008 Mitigation Rule defines condition as “the relative ability of an aquatic resource to support and maintain a community of organisms having a species composition, diversity and functional organization comparable to reference aquatic resources in the region.” The Rule goes on to define Functions as “the physical, chemical and biological processes that occur in ecosystems” and Functional Capacity as “the degree to which an area of aquatic resource performs a specific function.” All of these regulatory definitions point to the need to demonstrate that a stream restoration project functions like some reference condition, at least within the constraints established through the project’s goals and objectives. Stoddard et al. (2006) provides a discussion of the various ways that reference condition can be interpreted, along with definitions of reference condition types, including historical condition, least-disturbed condition, minimally disturbed condition and best-attainable condition. Miller et al. (2011) and Pruitt et al. (2012) prepared USACE technical notes that build on the Stoddard et al. (1996) concepts of reference condition. Reference condition is defined as “a contextual background against which the degree of degradation, range of condition, and benefits of restoration can be measured.” The goal of these publications is to develop a common understanding of the reference condition concept to better interpret environmental regulations and to improve selection of reference ecosystems to meet restoration project objectives.

In stream ecosystems, the reference condition can be determined using information collected from reference streams that are used for comparison with both impaired and restored reaches, as well as development of a natural channel design for stream restoration. Rosgen (1998) developed the concept of a reference reach approach as a blueprint for developing a natural channel design. His definition of a reference reach is “a stream that can transport the flows and sediment produced by its watershed so that the dimension, pattern and profile are maintained without aggrading or degrading.” In the Rosgen definition, the channel does not necessarily require a pristine condition without human disturbance; the stream simply needs to be in balance with watershed flow and sediment processes. Therefore, this concept of a reference stream focuses more on Hydrology, Hydraulic and Geomorphology functions (Levels 1-3) than Physicochemical and Biology functions (Levels 4 and 5). Historically, stream restoration practitioners have focused more on using reference reaches as defined by Rosgen to better understand Level 1-3 functions because they can directly manipulate, and thereby improve, these functions. However, with some adaptations to selecting and analyzing reference reach data, these reference streams can also be used to evaluate the condition and functional lift of Level 4 and 5 functions. Since the approaches are different for Levels 1-3 and Levels 4-5, the site selection and assessment method sections below are stratified accordingly.

Uses of Reference Streams in Restoration

Before moving into site selection and assessment methods, more information is needed on how reference stream data are used. These uses were introduced above and include the following:

1. As a blueprint for a natural channel design.
2. Structure and function comparison between an impaired stream and a reference condition, which can be determined using one or more reference streams. This assessment is often completed for:
 - a. Establishing the baseline condition at a proposed restoration site;
 - b. Determining functional loss at a site proposed for an impact; and
 - c. Evaluating the success (functional lift) of a stream restoration project, i.e., establishment of performance standards.

Blueprint for Natural Channel Design

This document does not focus on stream restoration design, so a detailed overview of how reference reaches are used to develop natural channel designs is not provided. It is important to note, however, that reference reaches are commonly used by practitioners, especially those that use the Rosgen method for natural channel design (Rosgen 1998). A detailed description of how these reference reaches are used in natural channel design processes is included in the Natural Resources Conservation Service, National Engineering Handbook, Chapter 11. This handbook is available at directives.sc.egov.usda.gov/viewerFS.aspx?id=3491.

Comparison Between Impaired/Restored Streams and Reference Streams

Reference streams represent stable and highly functioning channels. Therefore, data collected from reference streams to determine the reference condition will provide a standard against which lower-functioning streams can be compared. Comparing a project reach to a reference stream(s) prior to restoration helps establish the level of impairment. This information can also help understand the potential to restore stream functions and to establish realistic project goals. This type of comparison can also be used to evaluate proposed impact sites. The project stream can be compared to a reference condition to determine the level of impairment that may occur from the impact, i.e., highly functioning streams would have more functional loss than streams that are already impaired.

Reference streams can also be used to evaluate the success of stream restoration projects. This comparison can be somewhat complicated because a stream restoration project must evolve for many years before it will function like a reference stream. The rate of this evolution varies by the functional category (categories shown on the Pyramid). Generally, improvements to Hydraulic functions (Level 2) quickly meet performance standards that resemble reference reach conditions. Re-establishing floodplain connectivity is a great example. The stream is either vertically connected to the floodplain or it is not, and connectivity can easily be measured by the bank height ratio at any riffle along the entire project reach. Functional improvements in Geomorphology (Level

3) take more time to achieve reference reach conditions, primarily because many of the processes are affected by the establishment of the riparian buffer. For this reason, most practitioners design a channel form that will evolve over time as the permanent vegetation matures. Physicochemical and Biology functions (Level 4 and 5) may take even longer to represent reference condition, and, depending on the health of the upstream watershed, they may never evolve to the reference condition. This is why site selection is so important in choosing a restoration project when the goal is to restore Level 4 and/or 5 functions.

5.3 » SITE SELECTION

Choosing a reference reach will depend on the purpose of the project established by the goals and objectives. For example, selecting a reference reach for stream restoration design purposes will require Hydrology, Hydraulic and Geomorphology functions more so than Physicochemical and Biology functions. The reference reach length may be shorter and have more water quality impairments than a reference reach selected to address Physicochemical or Biology functions. Therefore, the site selection criteria described below is divided into two sections, one for Levels 1-3 and the other for Levels 4-5.

Geomorphology Reference Reaches (Levels 1-3)

Identifying an appropriate site for a Geomorphology reference reach requires diligence and time spent in the field assessing potential sites. Reference reaches will be hardest to locate in areas that have been intensively modified for agriculture, forestry, mining and development. In these areas, most stream channels have been modified.

Hey (2006) shows that, unlike regional curves, reference reaches do not need to come from the same hydro-physiographic region as the project site. Therefore, it is important to look in different regions if a reference cannot be found near the project. In general, Geomorphology reference reaches should meet the criteria outlined below:

1. Stable dimension, pattern and profile.
2. Bank height ratio less than 1.2, preferably 1.0 (See Chapter 8, Floodplain Connectivity section for a description of the bank height ratio).
3. Stable banks — (See Chapter 8, Lateral Stability section for techniques to assess lateral stability).
4. Natural features such as point bars may be present, but without excessive bar development, like mid-channel or transverse bars.
5. Same stream type as the project reach after restoration (i.e., C4, E5, etc.).
6. Same valley type and approximate slope as study reach.
7. Same bed material as study reach (i.e., sand, gravel, cobble, bedrock, etc.).
8. Same type of bank vegetation as the project reach (e.g., do not use a mature bottom land hardwood forest reference reach for a restoration project that will only include a herbaceous buffer).

In order to select an appropriate reference reach, several tools are used in support of the identification process:

1. US Geological Survey Quadrangle Maps: Quadrangle maps can be used to identify streams of a particular watershed size, valley type and slope. Quadrangle maps also provide general information on watershed conditions and land use, although these data should be checked against other more recent data sources (such as aerial photographs), since quadrangle maps are not updated very frequently.
2. Aerial Photographs: Aerial photographs can be very useful in identifying potential reference reaches and further evaluating reference reaches identified by other maps, such as from a USGS quadrangle map. Evaluating multiple aerial photographs over time can provide additional support regarding stream stability by documenting stream dimension and pattern before and after flood events.
3. Windshield Surveys: Many reference reach sites have been identified by simply driving and looking at streams upstream or downstream of roadway crossings. Ensure that landowner permission to access the stream is obtained before entering private property.
4. Discussions with Local Residents: Landowners and local residents are often very familiar with their land and the land that is nearby. These resources can often be used to identify streams that are in good condition and may potentially serve as a reference reach.
5. Looking Upstream and Downstream of the Project Reach: When available, this is one of the best sources for reference reach data, because the reference reach and impaired reach targeted for restoration share the same climatic, topographic and watershed conditions. As with windshield surveys, ensure that landowner permission to access the stream is obtained before entering private property.
6. Existing Watershed and Stream Assessment Reports and Reference Reach Databases: Many agencies and organizations have produced assessment reports that identify stable and unstable stream reaches. These reports are an excellent source as an initial step in identifying potential reference reaches. Furthermore, some of these agencies and organizations have already developed reference reach databases that are available to the public.
7. Discussions with Environmental Professionals: There are many environmental professionals who, as part of the jobs, are required to walk many stream miles. These folks can provide expert opinions on the location of potential reference sites.

In urban and other highly altered environments, it is often difficult to identify true reference reach sites that meet the criteria above. Often, urban streams have been highly modified, either by direct manipulation or through modified hydrology from increased impervious surface runoff. While it is often difficult to identify a stable urban reference reach, it is not uncommon to find short segments of stable urban channel that can be used to evaluate stable bankfull dimensions. Such a stream segment is ideally located just upstream or downstream of the study reach, allowing for direct correlations to proper bankfull dimensions for the design. Finding an applicable reach can be a time-consuming process, and a thorough investigation should be completed to ensure a suitable reference reach is located.

Physicochemical and Biology Reference Reaches (Levels 4-5)

Selecting reference streams that represent high-quality Physicochemical and Biology functions is similar to selecting sites for Geomorphology functions (Levels 1-3) with one large exception. It is possible to have a stable channel with proper bed form diversity in a watershed with point and non-point sources of pollution. However, reference streams used to determine the reference condition for Physicochemical and Biology functions require a healthy upstream watershed with limited point and non-point sources of pollution. Therefore, additional site selection criteria are needed. Additional recommended criteria for reference streams used for Physicochemical and Biology functions are provided below:

1. Most of the watershed is at the natural climax vegetative community, e.g., forested, scrub shrub, grassland.
2. Adequate/comparable flow duration for species of interest.
3. No point sources of pollution (preferable) or point sources that have not impacted aquatic life.

In addition to the tools provided for the Geomorphology section above, the tools listed below may be helpful in identifying Physicochemical and Biology reference reach streams.

1. Choose from state designated sites. Most state water protection agencies have designated hundreds of reference sites based on robust region-specific reference site criteria for assessing aquatic-life use attainment.
2. Check water quality designations. Investigate state water quality designation lists and look for High Quality Waters (HQW), Outstanding Resources Waters (ORW) or similar designations.
3. Search on public land. Look for reference streams in national/state parks, national/state forests and designated wilderness areas.

Many of these streams will not be pristine due to historical impacts; however, they may represent the highest level of functionality that is achievable. This is an important consideration when selecting a site for Physicochemical and Biology functions. Some projects may strive to restore functions to a pre-disturbance, pre-European settlement condition — a worthy, but very difficult goal. Most projects try to restore functions to the highest level possible given the constraints of human development. If so, a reference stream should be selected that reflects this condition, i.e., healthy but not pristine. This is one of the most difficult and controversial issues related to determining the reference condition. Stoddard et al. (2006) and Miller et al. (2011) provide guidance for determining the reference condition type, e.g., historical condition, best attainable condition, and reference condition approach that may best fit with geographic constraints and legacy impacts.

5.4 » ASSESSING REFERENCE REACHES

There are dozens of ways to assess reference reaches, many of which can also be used to assess impaired reaches. However, assessment methods vary greatly in what and how they assess stream functions. Some methods are rapid and others are very time intensive

and costly. Some methods focus on physical functions and others focus on biological functions; few assess all functions. Therefore, it is critically important to know the reason for conducting a reference reach assessment prior to the assessment or survey. Having clear project goals and objectives will serve as an aid in selecting the proper type of reference reach.

Building on the discussion above about the uses of reference reach streams, the following list of assessment methods is provided for Hydrology, Hydraulic and Geomorphology references (Levels 1-3), and assessment methods that focus on Physicochemical and/or Biology conditions (Levels 4-5). The title of the assessment method, a brief description and Web link to the source document is provided. Refer to Somerville and Pruitt (2004) and Somerville (2010) for a description of additional assessment methodologies. These reports can be downloaded, respectively, from the EPA website at: water.epa.gov/lawsregs/guidance/wetlands/upload/2004_09_01_wetlands_PhysicalStreamAssessmentSep2004Final.pdf and water.epa.gov/lawsregs/guidance/wetlands/upload/Stream-Protocols_2010.pdf. USACE is currently developing reference assessment approaches for reference stream condition built upon their Hydrogeomorphic (HGM) Approach that was initially applied to wetlands. The approach has been applied to intermittent streams in the Appalachian region (USACE, 2010), but not to perennial streams at this time. Pruitt et al. (2012) further describes a proposed Reference Condition Index (RCI) that could be used to guide the application of reference condition to an assessment of environmental benefits in aquatic ecosystems.

However, assessment methods vary greatly in what and how they assess stream functions. Some methods are rapid and others are very time intensive and costly. Some methods focus on physical functions and others focus on biological functions; few assess all functions. Therefore, it is critically important to know the reason for conducting a reference reach assessment prior to the assessment or survey. Having clear project goals and objectives will serve as an aid in selecting the proper type of reference reach.

Pyramid Level 1-3 Methods for Assessing Reference Stream Condition

The following list highlights assessment methods that focus on Pyramid Level 1-3 functions. Therefore, these methods are more physically based than biological. Some are used more for natural channel design and others for assessing sediment supply and channel stability.

Title: [Stream Channel Reference Sites: An Illustrated Guide to Field Technique](#)

Description: Provides basic overview of surveying procedures (differential leveling) for channel cross sections and profiles. Also provides methods for conducting pebble counts,

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staff gauge installation, discharge measurements and pebble count procedures.

Link: www.stream.fs.fed.us/publications/PDFs/RM245E.PDF

Title: [The Reference Reach — A Blueprint for Natural Channel Design](#)

Description: A Proceeding paper that describes the Rosgen method for collecting and using reference reach survey data. Primarily used for natural channel design and comparing the geomorphology of reference streams to impaired streams.

Link: www.wildlandhydrology.com/assets/The_Reference_Reach_II.pdf

Title: [Rosgen Geomorphic Channel Design](#)

Description: Part 654, Chapter 11 in the NRCS Stream Restoration Design National Engineering Handbook. Provides a detailed description of how these reference reaches are used in natural channel design processes.

Link: directives.sc.egov.usda.gov/viewerFS.aspx?id=3491

Title: [Proper Functioning Condition](#)

Description: A rapid qualitative approach that uses a checklist to determine channel and riparian condition. Checklist includes questions about hydrology, vegetation and erosion/deposition. The final result places the stream into one of three categories: Proper Functioning Condition, Functional-at-Risk and Nonfunctional.

Link: <ftp://blm.gov/pub/nstc/techrefs/Final%20TR%201737-9.pdf>

Title: [Watershed Assessment of River Stability and Sediment Supply](#)

Description: A geomorphological approach for quantifying the effects of land uses on sediment supply and channel stability. Provides sub-watershed rankings and prioritizes stream reaches based on broad-level screening approaches, but also provides more detailed assessment procedures.

Link: water.epa.gov/scitech/datait/tools/warsss/index.cfm

Title: [Size Class Pebble Count Analyzer](#)

Description: A spreadsheet tool that is used to identify shifts in the fine gravel and smaller portions of the grain size distribution, rather than the median. It can be used to compare grain size distributions at an impaired site and determine if the distribution is statistically different than a reference site. It can also be used for before and after restoration comparisons.

Link: www.stream.fs.fed.us/publications/software.html

Title: [Channel Evolution Models/Stream Type Succession Scenarios](#)

Description: These two methodologies illustrate how streams evolve after a disturbance. They would rarely be used as a standalone assessment method, but are a valuable addition to most other assessment methodologies. A reference stream would typically function at an evolutionary endpoint; however, an impaired stream may be moving towards

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or away from a reference condition.

Link: Simon Channel Evolution Model: www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/alphabetical/water/restoration/?&cid=stelprdb1043448 (Chapter 7)

Link: Rosgen Stream Type Succession Scenarios: water.epa.gov/scitech/datait/tools/warsss/successn.cfm

Title: [Regional Curves](#)

Description: Many of the assessment methodologies used to evaluate Pyramid Level 1-3 functions require an estimate of the bankfull discharge and corresponding stage. Regional curves, while not an assessment methodology, are excellent tools for validating field estimates of the bankfull stage.

Link: water.epa.gov/lawsregs/guidance/wetlands/upload/Appendix-A_Regional_Curves.pdf

Pyramid Level 4-5 Methods for Assessing Reference Stream Condition

A wide variety of stream assessment protocols that focus on Physicochemical and Biology functions are available, probably more than for the Hydrology, Hydraulic and Geomorphology functions. Since both of these functions vary greatly across the country, most state water quality programs have developed their own assessment methods. However, many of these are based on the Rapid Bioassessment Protocol or Index of Biotic Integrity that are discussed below. Like the discussion above about assessing the reference condition of Pyramid Level 1-3 functions, selecting the correct reference reach assessment method for Pyramid Levels 4-5 will depend on the project goals and objectives. Some of the more common assessment methods are listed below; however, many projects may require a tailored approach.

Title: [EPA Rapid Bio-assessment Protocol \(RBP\)](#)

Description: A rapid assessment method that provides basic aquatic life data for water quality management purposes such as problem screening, site ranking and trend monitoring. The RBPs are a synthesis of existing methods from state water resource agencies and include three aquatic assemblages (periphyton, benthic macroinvertebrates, fish) and habitat assessment methodologies.

Link: water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm

Title: [Index of Biotic Integrity \(IBI\)](#)

Description: The original version included 12 metrics that were used to evaluate stream health based on fish data. The metrics and scoring have been modified over time and expanded to include an IBI for macroinvertebrates.

Link: www.epa.gov/bioiweb1/html/ibi_history.html

Title: [NRCS Stream Visual Assessment Protocol](#)

Description: A simple assessment of stream condition that includes qualitative observations of Pyramid Level 1-5 parameters. It is intended to be a first approximation of stream

condition rather than an intensive assessment of stream function.

Link: www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/alphabetical/water/restoration/?&cid=stelprdb1043249

Title: [Monitoring Wilderness Stream Ecosystems](#)

Description: This document is a manual that presents a protocol for monitoring a variety of Pyramid Level 1-5 parameters and includes measures of structure and function. The document also includes guidance on setting monitoring goals and objectives, selecting sampling location and analyzing data.

Link: www.fs.fed.us/rm/pubs/rmrs_gtr70.pdf

Title: [US 301 Environmental Stewardship Study](#)

Description: The US 301 Environmental Stewardship Study is a green infrastructure study that included a stream assessment component. The stream assessment component consists of a GIS-based coarse stream stability assessment and a rapid stream habitat and stability assessment and restoration feasibility methods. The rapid assessment methods provide a numerical score which can be used for ranking and prioritization purposes.

Link: www.fws.gov/chesapeakebay/streampub.html

5.5 » MONITORING APPROACHES

The above methodologies can be used to assess reference streams that can then be used as a comparison against an impaired stream. However, it is important that reference streams are in the same hydro-physiographic region and ecoregion as the project site for Physicochemical and Biology function assessments. In addition, some reference reach and project reach assessments may need to focus on a few select parameters, rather than an overall assessment of channel condition or function that is typically provided by “canned” methodologies. For example, one project may have a goal to increase the grain size

The above methodologies can be used to assess reference streams that can then be used as a comparison against an impaired stream. However, it is important that reference streams are in the same hydro-physiographic region and ecoregion as the project site for Physicochemical and Biology function assessments.

distribution in a gravel bed stream to reference conditions. Another project may want to improve dissolved oxygen, temperature and nutrient levels to reference conditions. There are two common monitoring approaches that can be used to help show statistical differences in a project reach versus a reference reach: upstream/downstream and paired watershed monitoring. However, determining the correct statistical approach to use within these two sampling regimes is critical and should often be provided by a trained statistician. The EPA provides a statistical primer with a variety of examples at <http://www.epa.gov/bioindica->

[tors/statprimer/statistical_testing.html](#). USEPA (1997a) also provides instruction on how to statistically evaluate the effectiveness of best management practices, like stream restoration, on improving water quality.

Upstream/Downstream Monitoring

The ideal scenario for performance standards that use reference reach data is for the reference reach to be located upstream of the project reach. This makes it much easier to have a goal of restoring a project reach to a reference condition. The parameters and measurement methods are selected, again based on project goals and the potential to restore those functions. The monitoring must occur upstream of the project reach and downstream of the project reach and before and after restoration, lasting long enough to complete the statistical analysis. The purpose in this approach is to show that, over time, the downstream monitoring station becomes statistically similar to the upstream monitoring station. Upstream/downstream monitoring can also be used if the reach upstream of the project is not of reference condition. However, in this case, it is more likely that the project will show improvements to Pyramid Level 3 parameters like lateral stability (sediment supply from bank erosion) than to Pyramid Level 5 parameters like macroinvertebrate communities.

Paired Watershed Monitoring

If a reference stream cannot be found upstream of the project reach, a paired watershed approach may be practical, especially for small headwater catchments. This monitoring approach compares monitoring/assessment results from a stable watershed to the impaired watershed. However, for this approach to work, the stable watershed must remain stable throughout the life of the project. Both sites must be monitored before and after restoration for a long enough time to show statistical differences. The Size Class Pebble Count Analyzer discussed above under Pyramid Level 1-3 Method for Assessing Reference Condition provides an example of using a paired watershed approach.

Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls (USEPA, 1997a) is a good resource for designing monitoring plans that use statistical techniques to show that stream improvements were caused by a best management practice, in this case stream restoration.

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Chapter 6

Hydrology

The study of hydrology, especially by engineers, quantifies the transport of water that is contributed from the watershed and delivered to a stream channel. Hydrology functions are the base of the Stream Functions Pyramid (Level 1) and therefore support all other functions. Common ways to assess and quantify this hydrologic function include channel-forming discharge, precipitation/runoff relationships, flood frequency and flow duration. Table 6.1 provides a list of parameters discussed in this chapter along with the measurement methods. There are other measures of Hydrology; however, the ones provided here are most closely associated with stream assessment and restoration techniques. Appendix Ac includes a list of all the Hydrology measurement methods along with information about the method's type, level of effort, level of complexity, and whether it is a direct or indirect measure of the function-based parameter. The criteria used to make these determinations are provided in Chapter 4.

TABLE 6.1 HYDROLOGY PARAMETERS, MEASUREMENT METHODS AND AVAILABILITY OF PERFORMANCE STANDARDS

PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD
Channel-Forming Discharge	1. Regional Curves	No
Precipitation/Runoff Relationship	1. Rational Method 2. HEC-HMS 3. USGS Regional Regression Equations	No No No
Flood Frequency	1. Bulletin 17b	No
Flow Duration	1. Flow Duration Curve 2. Crest Gage 3. Monitoring Devices 4. Rapid Indicators	No No No No

For most stream restoration projects, Hydrology parameters are independent variables, meaning that the restoration practitioner cannot change them as part of the design process. They are primarily used to characterize the watershed and as input parameters for Hydraulic assessments; therefore, the Hydraulics Chapter in this document discusses their importance and associated performance standards. There can be exceptions, how-

ever, especially if the stream restoration project is part of a larger watershed management plan. It may be possible to use stormwater BMPs, or other practices to reduce runoff. In these cases, a performance standard could be established for the reduction in runoff. Other scenarios include highly modified headwater systems, such as impacts associated with mining through springs and headwater streams. Here, restoring flow duration is a critical component of the restoration project and should include the development of performance standards. Hydrology parameters are included even without performance standards because of their importance in supporting the higher-level functions. Without an assessment of these parameters, many of the higher-level computations cannot be completed; therefore, it would be remiss to not include them.

6.1 » PARAMETER: CHANNEL-FORMING DISCHARGE

Description

Channel-forming discharge theory suggests that a unique flow over an extended period of time would yield the same channel morphology that is shaped by the natural sequence of flows. Inglis (1947) stated that at this discharge, equilibrium is most closely approached and the tendency to change is least. This condition may be regarded as the integrated effect of all varying conditions over a long period of time. Channel-forming discharge theory is often described as dominant discharge, effective discharge and the bankfull discharge (Knighton, 1998). Dominant discharge is simply a synonym for channel-forming discharge theory. Effective discharge is the product of the flow duration curve and the sediment transport rating curve; therefore, it is the discharge that moves the most sediment over time and is a key parameter in determining channel size (Wolman and Miller, 1960). Bankfull discharge fills a stream channel to the elevation of the active floodplain, thereby delineating the break between erosional (channel forming) and depositional features in a floodplain (Dunne and Leopold, 1978; FISRWG, 1998). Since this discharge leaves a geomorphic indicator, it has become the method used most often to describe channel-forming discharge theory. It is also the design discharge for natural channel designs.

Measurement Method

1. Regional Curves

The identification of bankfull stage and its associated dimensions and discharge are often used in stream assessment and restoration projects using natural channel design techniques. The identification of the bankfull stage is one of the first measurements made during a geomorphic assessment because the Rosgen stream classification system and stability assessments (vertical and lateral) are all dependent on knowing the bankfull stage. In addition, many of the Hydraulic and Geomorphic parameters, such as floodplain connectivity, are dependent on being able to identify and verify the bankfull stage and its corresponding dimensions (especially cross-sectional area). There are several documents that discuss how to field identify and verify bankfull. Rosgen (2006), as part of the Watershed Assessment of River Stability and Sediment Supply (WARSSS), provides a

detailed description of field methods for identifying and calibrating the bankfull stage. (WARSSS is available on the EPA website at www.epa.gov/warsss.) Harrelson et al. (1994) provides a more concise summary of field methods for identifying bankfull (www.stream.fs.fed.us/publications/PDFs/RM245E.PDF). Harman (2000) provides methods for identifying bankfull in North Carolina streams, which also include a detailed description of how to measure and calculate the bankfull cross-sectional area (www.bae.ncsu.edu/programs/extension/wqg/srp/rv-crs-3.pdf).

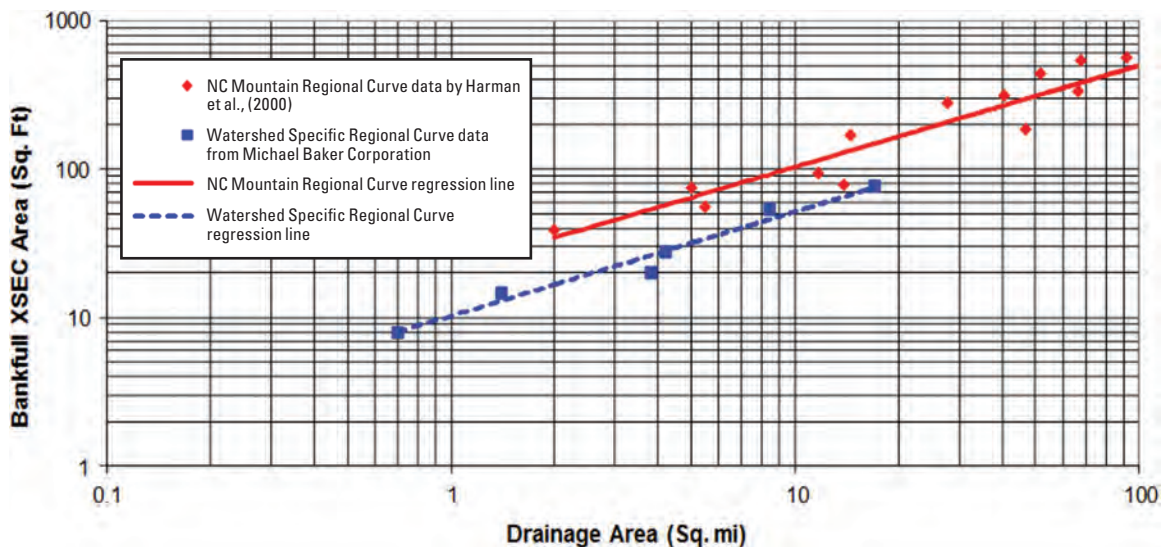
All of these references rely on regional curves as the primary method for verifying the bankfull stage. These curves are tools that can be used to verify the bankfull stage in projects prior to restoration, as a design aid and as a tool for assessing performance. Regional curves relate bankfull discharge and channel dimensions (i.e., width, depth and cross-sectional area) to drainage area. (See Figure 6.1 for an example regional curve.) Regional curves are empirically derived, primarily from USGS gauge stations, and can be developed for a single watershed or multiple watersheds in the same hydro-physiographic region (FISRWG, 1998). Developing watershed-specific regional curves requires a moderate level of effort; however, developing regional curves for an entire physiographic region is an intensive level of effort. If existing regional curves are used, then the level of effort required to use the curve is considered rapid. Likewise, using an existing regional curve is not complex and is categorized as simple in Appendix Ac; however, developing a regional curve is complex, requiring experience and expertise.

Regional curves were first developed by Dunne and Leopold (1978). In recent years, regional curves have been developed across many regions to assist in geomorphic assessments and natural channel design (Cinotto, 2003; Keaton et al., 2005; Miller and Davis, 2003; Harman et al., 1999; Harman et al., 2000; McCandless and Everett, 2002; McCandless, 2003a and 2003b; Sweet and Geratz, 2003; Castro and Jackson, 2001; Chaplin, 2005; Doll et al., 2002; Dudley, 2004; Dutnell, 2000; Mulvihill et al., 2005; and Metcalf, 2004). Somerville (2010) provides a comprehensive list of regional curves published throughout the United States.

When using existing regional curves, care should be taken to determine that the regional curves are appropriate for the project site, i.e., that they are in the same hydro-physiographic region and that the curves were created through unbiased surveys of bankfull indicators. The dimensions (area, width and depth) should come from cross-sectional surveys taken at stable riffles. There have been cases where the 1.5-year return interval was used as bankfull, rather than a physical assessment of the geomorphic indicator. There are other cases where the terrace was used as the bankfull stage, which often results in a return interval that is greater than two.

FIGURE 6.1 REGIONAL CURVE EXAMPLE

North Carolina Mountain Regional Curve (Harman et al., 2000) overlaid with a watershed specific curve within the same region. The blue line is lower because it is in a region of the mountains with lower rainfall. The red line represents the entire mountain region of NC, including high and low rainfall areas. Note that while the magnitude of the cross-sectional area is different between the two curves, the slope of the two lines is similar.



Source: Reproduced with permission from Michael Baker Corporation

Design Standard

As mentioned above, the bankfull discharge is the design flow for a natural channel design project. The design review process should be used to determine that the appropriate bankfull discharge was selected. The easiest way to determine if the bankfull discharge was used in the design is to compare the design value with the results from a regional curve. However, this does not ensure that the project was constructed properly, i.e., that the design bankfull cross-sectional area was constructed. Therefore, performance standards should be developed to determine that the as-built and subsequent monitoring results prove that the appropriate bankfull cross-sectional area was constructed. This will require a field determination of the bankfull stage, as discussed above. The bankfull cross-sectional area from the as-built survey or monitoring report should show that the channel is not incised (too deep), or that it is not too small. Therefore, the best performance measure for determining this is the bank-height ratio, which is discussed in detail in the Hydraulics Chapter under Floodplain Connectivity.

It should be noted, however, that in some cases the design may include a design discharge that is less than the bankfull discharge. If the sediment supply is low, this could result in a stream with greater functionality due to better floodplain connectivity and more riparian wetlands. But if sediment supply is high, it could result in channel aggradation and bank erosion. Therefore, caution should be used when assigning functional

performance standards based solely on the bankfull discharge. An example of a project that used a design discharge that was less than the bankfull discharge is shown below in Figure 6.2. The result is a channel that is much smaller than a typical channel size designed using the bankfull discharge (Art Parola, 2011, personal communication).

FIGURE 6.2

Photos of a project near Lexington, KY that was sized using a discharge smaller than the bankfull discharge. The channel has remained stable after numerous floods. Flow duration has significantly improved due to improved groundwater/surface water interaction, converting an intermittent channel into a perennial channel. This approach works because, among other things, the sediment supply is fairly low, grade control is used in the channel and beneath the floodplain, and vegetation is allowed to establish before the stream flow is moved to the new channel. This approach should not be used in streams with a large sediment load that must be transported through the reach.



Photo by Will Harman

6.2 » PARAMETER: PRECIPITATION/RUNOFF RELATIONSHIP

Description

The amount of precipitation that does not soak into the ground and instead “runs off” the ground surface is a critical component in determining the size of a stream channel. Regions that have high precipitation and runoff (precipitation/runoff) rates often have larger channels than areas with lower precipitation/runoff rates. In humid areas like the Southeastern United States, perennial channels form in watersheds with drainage areas considerably less than one-half of a square mile. In arid regions, however, ephemeral channels exist in watersheds with drainage areas that are hundreds of square miles. This has a major effect on functions in Pyramid Levels 4 and 5.

The effect of precipitation/runoff variability can be seen in comparisons of regional curves of bankfull discharge and cross-sectional area versus drainage area. Regional curves are power function regression equations. Regions with higher precipitation/runoff rates have higher y-intercept values than regions with lower precipitation/runoff relation-

ships; however, the slope of the regression line for all these curves is remarkably consistent. In other words, while the processes that create channel shape and size are similar across regions, variations in the precipitation/runoff relationship create different size channels. An example of this is shown above in Figure 6.1.

Measurement Method

1. Rational Method

The most rapid and simplest method for calculating runoff is the Rational Method or Rational Equation, which is used to estimate peak runoff in small drainage basins. This equation uses a runoff coefficient (C) that is taken from a table, like the one published by the American Society of Civil Engineers (1970) and is most suited for watersheds with a drainage area less than 250 acres. The Rational Equation shows that if it rains long enough, the peak discharge from the drainage area will be the average rate of rainfall times the drainage basin area, which is then reduced by multiplying by the runoff coefficient. The time of concentration is the length of time that it takes water to flow from the beginning of the watershed to the point where runoff (discharge) occurs (Fetter, 1994). The Rational equation is:

$$Q_p = C_i A, \text{ where}$$

Q_p = the peak runoff rate in cubic feet per second.

C = the runoff coefficient

i = the average rainfall intensity in inches/hour, and

A = the size of the drainage in acres.

The Rational Method has evolved through time with the use of computer models. The Natural Resources Conservation Service (NRCS) has developed two computer models that are based on the Rational Method: WinTR55 and WinTR20 (USDA, 2009a and 2009b). These models have been used extensively to design small farm ponds and even large flood control reservoirs. Since it is better to build a dam that is slightly too large rather than one that is too small, these models often give conservatively high estimates of runoff.

2. HEC-HMS

The USACE Hydrologic Engineering Center has developed a more sophisticated and complex model called the Hydrologic Modeling System (HEC-HMS). This model simulates precipitation and runoff processes from a wide range of dendritic watersheds, including small and large watersheds, as well as rural and urban conditions. More information and a free download of the software can be found at the HEC-HMS website (www.hec.usace.army.mil/software/hec-hms). However, only experienced hydrologists should use the model.

3. USGS Regional Regression Equations

The United States Geological Survey (USGS) uses their network of gauging stations to provide “regional regression equations” that typically estimate discharge for the 2-, 5-,

10-, 25-, 50- and 100-year flood events. These empirical relationships are often developed for each physiographic region and stratified by rural and urban basins. The results are published in reports, often by state, that can be obtained from the USGS website (water.usgs.gov/software/NFF). Since the return interval for the bankfull discharge is less than the 2-year return interval, regional regression equations from the 1-to 2-year range are needed for stream restoration applications. The USGS in West Virginia has prepared regional regression equations from the 1.0- to 3.0-year range. In addition, they created equations in 0.1-year increments, from the 1.0- to 2-year return interval, e.g., 1.1, 1.2, etc. (Wiley et al., 2002). Ideally, more curves for these lower return intervals will be developed for other regions.

Design Standard

The precipitation/runoff relationship is an important variable in determining channel size and is a vital part of the design process. It was mentioned that the discharge produced by the watershed is often an independent variable in the natural channel design, with the exception of watershed scale projects that might reduce runoff through storm-water BMPs. Therefore, there isn't a performance standard associated with this parameter. A natural channel should carry the appropriate amount of water to maintain dynamic equilibrium and appropriate streambed formations. However, channels that are designed to carry larger storm events, such as the 100-year event, would not function as a natural channel. This type of performance can be assessed below in the Hydraulic Chapter under Floodplain Connectivity.

6.3 » PARAMETER: FLOOD FREQUENCY

Description

Flooding is the periodic, natural occurrence of high flows that exceed the depth of the channel. Flood frequency defines the magnitude and frequency of a given flood and is often analyzed as part of the precipitation/runoff analysis described above. However, these parameters are sometimes assessed for different reasons because "flooding" is defined differently by different disciplines. For example, the geomorphologist defines flooding as the flow that leaves the channel and spreads onto a floodplain that was built by a meandering river, sometimes called a geomorphic floodplain. A traditional water resources engineer might define flooding as the flow that would impact personal property, such as a home. In both cases, flood frequency can be used to predict the probability that a flow will reach a certain elevation (active floodplain or house) within a given timeframe. The geomorphologist typically associates the flood frequency of the active floodplain as the discharge with a 1.5-year return interval (on average). The water resources engineer typically delineates floodplains by the elevation of the 100-year return interval discharge. These two return intervals can also be expressed as an exceedence probability, which is simply the reciprocal of the return interval. Therefore, in the case of the 1.5- and 100-year return intervals, the exceedence probabilities are 67% and 1%, respectively.

While the smaller floods are important for channel formation and maintenance, large

floods are important geomorphic agents as well. They are important in developed areas because large floods can damage homes, roads and other structures. For stream restoration projects, it is typically most important to know the flood frequency of the bankfull discharge and the 100-year flood event. It is important to know the frequency of bankfull to help ensure that the channel is not carrying more water than is necessary to maintain dynamic equilibrium. In addition, many stream restoration projects are located in Federal Emergency Management Agency (FEMA) regulated floodplains. In these cases, a no-rise certification is required to show that the project is not increasing the 100-year flood elevation. If the project is designed to increase flooding, and it is acceptable to the landowner, a Letter of Map Revision will be required. More information about working in FEMA regulated floodplains can be found at: www.msc.fema.gov.

Measurement Method

1. Bulletin 17b

The standard for estimating flood frequency in the United States is published by USGS (1981) in Bulletin 17b (water.usgs.gov/osw/bulletin17b/bulletin_17B.html). The most common method for estimating flood frequency is the Log-Pearson Type III distribution, which is also described in the bulletin. This method uses the annual peak discharge over many years to calculate the probability of occurrence. The technique is complex and should be performed by experienced hydrologists. However, for most regions of the United States, flood frequency analysis has already been completed and can be downloaded by state from the USGS website.

Some areas of the country are starting to use partial duration analysis to determine the flood frequency of bankfull. This technique is often preferred over Log Pearson because it uses more data points per year than the single peak discharge used by Log Pearson. Partial duration analysis sets a discharge of interest and then includes all the discharges that exceed that value. Therefore, gauge stations with continuous data are required for this analysis.

Design Standard

Flood frequency analysis is often performed in conjunction with the precipitation/runoff analysis. For flood control projects, a flood discharge with a certain return interval, e.g., the 100-year or 1% probability storm event, is used as the design discharge. A channel size is then designed to carry the 100-year discharge. In natural channel design, however, the channel is sized to carry the bankfull discharge. Methods to determine the bankfull discharge are described above, but the return interval for bankfull is only used as a guide. As mentioned before, the average is 1.5 years and the range is from 1 to 2 years. This range can be used as a guide to develop performance standards, along with other parameters like floodplain connectivity. Therefore, the specific performance ranges for Functioning, Functioning-at-Risk and Not Functioning are described in the Hydraulics Chapter.

6.4 » PARAMETER: FLOW DURATION

Description

Flow duration is the percentage of time that a discharge is above or below a given value. It is often expressed as a flow duration curve that plots discharge on the y-axis and probability (percent of time) on the x-axis. In some parts of the country, especially the West, improving flow duration is an important stream restoration goal. It is also an important functional goal for stream restoration after landscape alterations, such as surface mining through streams.

When flows are critical to maintain a particular species of fish, mussel or macroinvertebrate, flow duration curves can allow one to denote the percent of time a river will exceed that critical value. Alternatively, flow duration curves can be used to determine the discharge that occurs a certain percentage of time. Flow duration can also be generalized to focus on the simple presence versus absence of flow over time — in other words, perennial, intermittent or ephemeral streams. For most projects perennial, intermittent or ephemeral flow will be an independent variable. For more specific information on the importance of flow duration, see Dahm et al. (2003), Humphries and Baldwin (2003), and Stromberg et al. (2007).

Measurement Method

1. Flow Duration Curve

Long-term records from gauge stations are needed in order to develop flow duration curves. From the historical records, the data are ranked in order from highest to lowest. The probability that a discharge can be equaled or exceeded can be calculated as follows:

$P = 100 M / (n+1)$, where

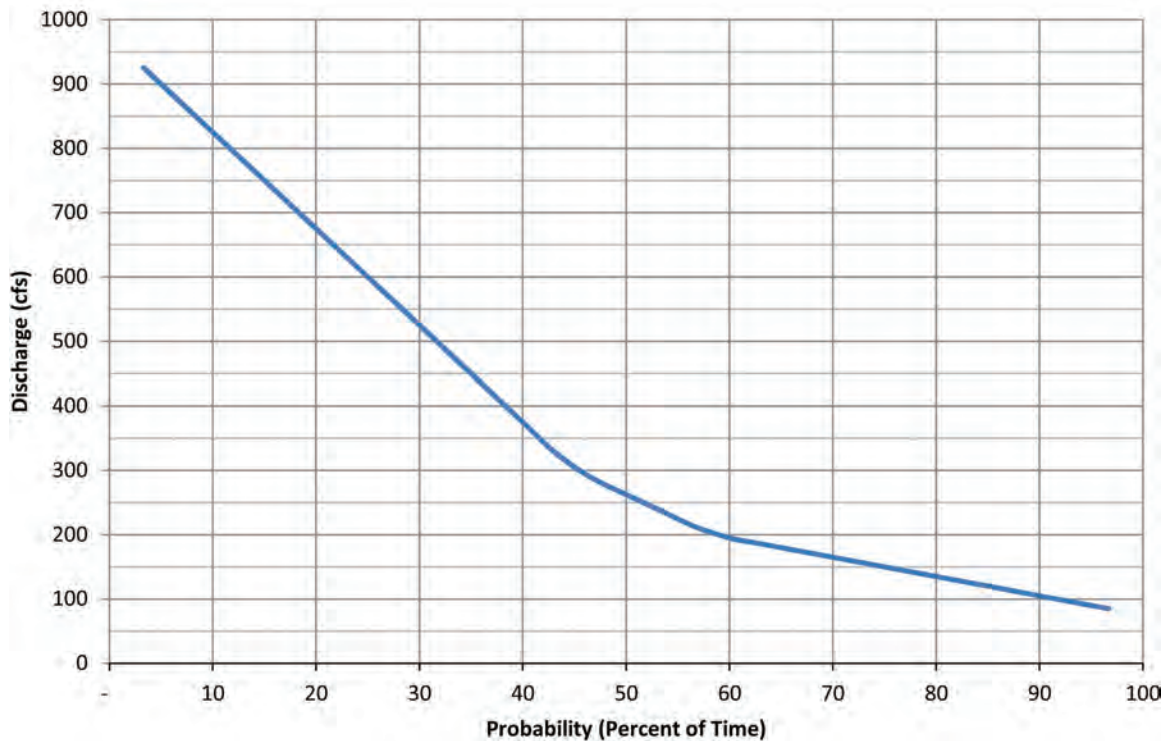
P = the probability that a flow will be equaled or exceeded (% of time)

M = the ranked position of the peak discharge values (dimensionless)

n = the number of peak discharge values in the record (dimensionless).

The discharge and corresponding probability are then plotted on probability paper. A step-by-step example of how to create a flow duration curve is provided by Watson and Burnett (1993). An example of a flow duration curve is shown in Figure 6.3. If gauge data are not available, computer models like HEC-HMS can be used to predict a flow duration curve using information from the closest gauge.

FIGURE 6.3 FLOW DURATION CURVE EXAMPLE



Source: Adapted from original graph by Michael Baker Corporation

Flow duration can also be directly measured at the project site. For perennial streams and large intermittent and ephemeral channels, a gauge station can be established with an automatic stage recorder. These recorders will measure stage and time. A stage/discharge relationship would have to be developed in order to plot discharge. Dingman (2008) provides instructions on how to establish a stream gauge for short-term studies. For this reason, the level of effort can range from moderate (for modeling) to intensive (for measuring flow over time). The level of complexity can also vary; however, it is often more complex to model flow duration than to measure flow duration. A measured flow duration curve is a direct measure of the flow duration function-based parameter; whereas, a modeled curve is an indirect measure (Appendix Ac).

2. Crest Gauge

A simpler and more common approach is to establish a crest gauge at the project site. A crest gauge records the highest elevation of the peak flow, usually without electronic instrumentation. A crest gauge does not provide information about the duration of the peak flow; however, it will provide information about flow occurring between site visits. Crest gauges are most often used in stream restoration projects to determine if bankfull

events occurred between monitoring surveys. Harrelson et al. (1994) provides a simple description of how to build a crest gauge.

3. Monitoring Devices

A monitoring device developed by Flowline Products is being used on small ephemeral and intermittent drainages in the Coastal Plain of North Carolina to document the duration and relative magnitude of flow events. The device is based on the principles of a variable area flow measurement, and consists of a vertical baffle mounted on an axis inside a protective housing. Flow passing through the housing causes the baffle to tilt on its axis, and the degree of tilt is recorded by the internal electronics and logging device. The device is capable of recording flows as low as 0.5 gal/min (Tweedy, 2010, personal communication). Other monitoring devices are also available and can be used for a variety of conditions (Blasch et al., 2002; Adams et al., 2004; Goulsbra et al., 2009; Fritz et al., 2006).

4. Rapid Indicators

Measuring general flow duration rapidly in the field on a non-gauged stream, whether the stream is perennial, intermittent or ephemeral, can be done using indicators of flow duration. Specific indicator-based methods have been developed by the North Carolina Department of the Environment and Natural Resources; EPA Region 10, Oregon Department of State Lands and the Portland Corps District; New Mexico Environment Department; and others that are currently under consideration. Links to select manuals are provided below.

North Carolina Department of Environment and Natural Resources, Division of Water Quality. Raleigh, NC. V.4. portal.ncdenr.org/web/wq/swp/ws/401/waterresources/streamde-terminations)

Oregon Streamflow Duration Assessment Method Interim Version, Public Notice release date, 6 March 2009. www.oregonstatelands.us/DSL/PERMITS/docs/osdam_march_2009.pdf?ga=t

New Mexico Environment Department/Surface of Water Quality Bureau (NMED/SWQB) Hydrology Protocol for the Determination of Ephemeral, Intermittent, and Perennial Waters — DRAFT. Released August 2009. ftp.nmenv.state.nm.us/www/swqb/MAS/Hydrology/NMHydroProtocol-PublicCommentDraft08-2009.pdf

Performance Standards

Performance standards for flow duration will be unique to every stream. Therefore, functional categories are not assigned to this parameter. However, local practitioners can develop performance standards based on flow needs of fish, mussels or other needs. For stream restoration projects on highly manipulated sites, such as surface mining, restoring the general flow duration may be used as a performance standard to help ensure that the suite of functions lost is being replaced.

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Chapter 7

Hydraulics

Hydraulic functions transport water in the channel, on the floodplain and through sediments. Fischenich (2006) describes these functions as surface water storage processes, maintenance of surface and subsurface connections and processes, and the general hydrodynamic balance, which describes the flow conditions in the channel and on the floodplain throughout the year. Here, three broad-level parameters are used to describe the Hydraulic functions. These include floodplain connectivity, flow dynamics and groundwater/surface water exchange. A variety of measurement methods are provided for each parameter, and performance standards are provided when available, as shown in Table 7.1. Appendix Ac includes a list of all the Hydraulic measurement methods along with information about the method's type, level of effort, level of complexity, and whether it is a direct or indirect measure of the function-based parameter. The criteria used to make these determinations are provided in Chapter 4.

Three different methods are provided for measuring floodplain connectivity and respective performance standards. Performance standards are not provided for shear stress and stream power; however, these are important measures of flow dynamics that are used in the sediment transport competency and capacity discussion in Geomorphology (Level 3). Performance standards are also not provided for groundwater/surface water exchange. This parameter and methods for measuring it are included because of its importance to Physicochemical (Level 4) functions and Biology (Level 5) functions. A discussion is provided under Design Standards that illustrates how this parameter can be used in a stream restoration design. Ultimately, as more reference research and project surveys are completed, a better understanding of this parameter will emerge that may allow for development of performance standards.

7.1 » PARAMETER: FLOODPLAIN CONNECTIVITY

Description

Floodplain connectivity describes how often streamflows access the adjacent floodplain. Fischenich (2006) included floodplain connectivity as part of the hydrodynamic character function, which was considered the most important of the 15 functions addressed. In high-functioning alluvial valleys, all flows greater than the bankfull discharge spread across a wide floodplain. In humid environments, streams that are well connected to the floodplain also have relatively high water tables, encouraging the development of riparian wetlands. In these systems, the channel is just deep enough to maintain sediment transport equilibrium and to create diverse bed forms and habitats.

Channelization is the primary impact that has directly disconnected streams from

their adjacent floodplain. Schoof (1980) defines channelization as the widening, deepening and straightening of channels to increase their capacity for transporting flood flows and to decrease flooding on adjacent land. Schoof (1980) estimates that over 200,000 miles of stream channels in the US have been modified over the past 150 years. He also estimates that the primary effects of channelization have included draining of wetlands; reduction in stream length through straightening; clearing of floodplain hardwoods; lowering of groundwater levels; reduction of groundwater recharge from stream flow; increase in erosion and sedimentation; and increase of downstream flooding. In a more recent study, Kroes and Hupp (2010) evaluated the effect of channelization on floodplain deposition and subsidence in a Maryland watershed. They found that the sediment storage function of the river had been dramatically altered by channelization. Finally, channelization has been found to reduce the size, number and species diversity in streams (Schoof, 1980). Indirect impacts, like urbanization and increases to impervious cover, also contribute to channel enlargement and incision through increased runoff. The extra runoff often causes an increase in stream power, which leads to headcuts and incision. The combination of increased runoff and channelization can lead to rapid destabilization and adjustment of stream channels.

TABLE 7.1 HYDRAULIC PARAMETERS, MEASUREMENT METHODS AND AVAILABILITY OF PERFORMANCE STANDARDS

PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD
Floodplain Connectivity	<ol style="list-style-type: none"> 1. Bank Height Ratio 2. Entrenchment Ratio 3. Stage Versus Discharge 	Yes Yes Yes
Flow Dynamics	<ol style="list-style-type: none"> 1. Stream Velocity 2. Shear Stress 3. Stream Power 	Yes No No
Groundwater/Surface Water Exchange	<ol style="list-style-type: none"> 1. Piezometers 2. Tracers 3. Seepage Meters 	No No No

Therefore, reconnecting streams to the floodplain is a major goal when working in watersheds that have channelized/incised streams. Floodplain connectivity is a driving force for many of the geomorphic and ecologic functions (Wohl, 2004; Shields et al., 2010). It is also a parameter that can easily be assessed, modified as part of a design and evaluated through monitoring, making it an excellent parameter for including a performance standard.

Floodplain Connectivity by Stream Type

Floodplains are associated with streams in alluvial valleys. Alluvial valleys are typi-

cally many times wider than the stream channel with longitudinal valley slopes less than 2%. Floodplain material is mostly comprised of alluvium (sand, silt and clay) that is deposited from frequent overbank flooding and long-term channel migration (Bridge, 2003). Rosgen C, E and DA stream types are common in these alluvial valleys, with the C and E stream types common as natural channel design targets. The DA stream type is associated with wetland/swamp systems in coastal plain settings where flows are often braided and diffuse. Restoring DA stream types in coastal plain settings has become a more common restoration approach in recent years (USACE Wilmington District and NCDENR, 2005).

Colluvial valleys do not have wide, well-developed floodplains and are naturally confined between hillslopes. Colluvial valleys have bowl-shaped cross sections and typically have valley slopes greater than 2%. Colluvium is angular and poorly sorted material that eroded from adjacent hill slopes and then deposited on the valley floor or even the channel (Easterbrook, 1999; Leopold et al., 1992). The Rosgen B stream type is often found in colluvial valleys. However, colluvial/confined valleys do exist with valley slopes that are less than 2%. The Rosgen Bc stream type is found in these low-gradient, but confined valleys. Floodplain connectivity, therefore, is limited to a bankfull bench or flood-prone area because the true definition of a floodplain is not relevant for these settings. These features are much narrower than a fully developed floodplain; however, they do dissipate flood energy and provide a flat depositional feature, which allows riparian vegetation to become established.

Rosgen stream types A, G and F do not have floodplains. The A stream type is associated with v-shaped valleys, which typically have longitudinal slopes greater than 4%. They are rarely associated with stream restoration projects; however, they are often impacted by surface mining activities in the Appalachian Mountains. The A stream types do not have a floodplain, but can have small bankfull benches like the B stream type (Rosgen, 1996). When the drainage area for these stream types becomes very small and the channel is ephemeral, there may not be a bankfull discharge that represents channel formation.

The F and G stream types can exist in natural, stable environments like gorges. However, they are most often associated with unstable environments due to channelization and urbanization (Rosgen, 1996). These stream types are very common targets for

Therefore, reconnecting streams to the floodplain is a major goal when working in watersheds that have channelized/incised streams. Floodplain connectivity is a driving force for many of the geomorphic and ecologic functions (Wohl, 2004; Shields et al., 2010). It is also a parameter that can easily be assessed, modified as part of a design and evaluated through monitoring, making it an excellent parameter for including a performance standard.

stream restoration because they are disconnected from the floodplain and have often evolved from C or E stream types through degradation and lateral erosion processes. Therefore, the functional lift of reconnecting the stream to a floodplain is greatest in these scenarios.

D stream types are associated with glacial outwash plains, alluvial fans and other environments where sediment supply exceeds sediment transport capacity (Rosgen, 1996). D stream types in alluvial valleys are sometimes caused by land use changes and can be restored to single-thread channels, often to a C stream type. This is more common in the arid West. However, in many other cases, D stream types are natural (glacial outwash plains and alluvial fans) and should not be altered. Regardless, D stream types are not incised and have access to a very active floodplain.

The descriptions above offer a general discussion of the three most common valley types and their associated stream types. There are many subtle differences and changes to valley morphology based on climate and geology, and a good description of the various valley types can be found in Bridge (2003), Easterbrook (1999) and Rosgen (1996).

Measurement Method

There are simple to moderately complex methods for measuring floodplain connectivity. Simple methods include the bank height ratio and entrenchment ratio, both of which require that the bankfull stage be determined. A more complex method is the use of HEC-RAS, which can show the stage versus discharge relationship for a wide range of return intervals, e.g., from base flow through the 100-year flood event. A brief description of each method is given below.

1. Bank Height Ratio

The bank height ratio (BHR) is a direct measure of channel incision. This ratio is calculated as follows:

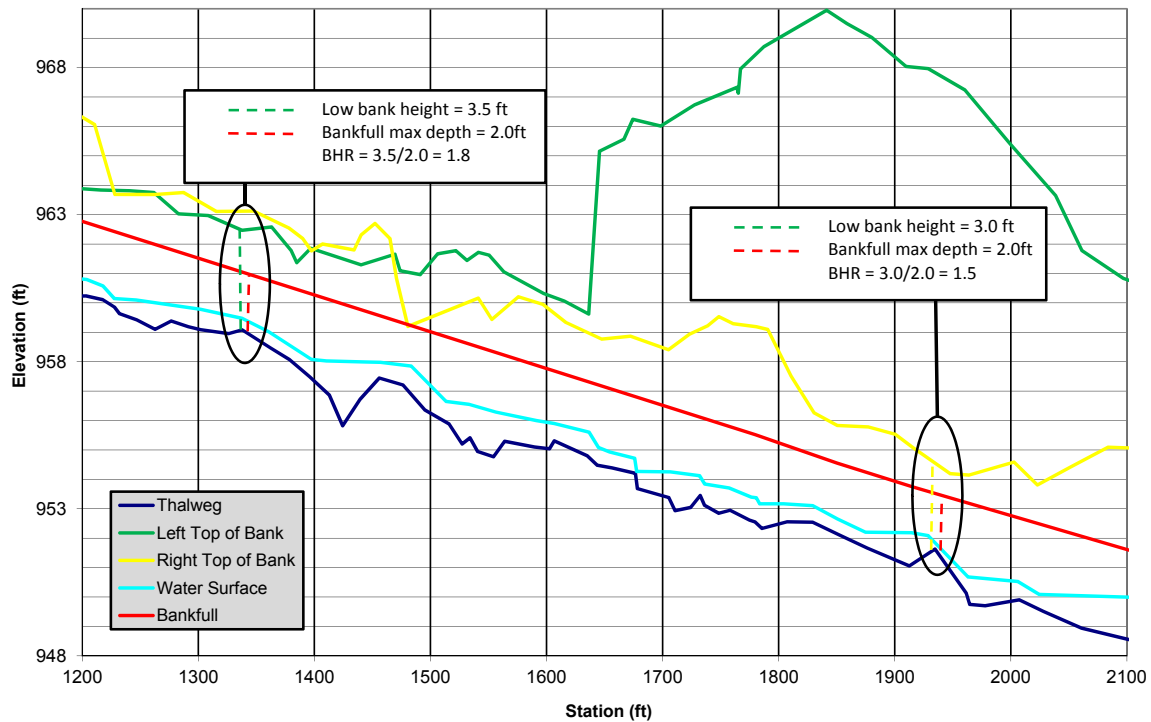
$$\text{BHR} = D_{\text{tob}} / D_{\text{bf}}, \text{ where}$$

D_{tob} = the depth from the top of the lowest bank to the thalweg

D_{bf} = the depth from the bankfull elevation to the thalweg.

A BHR of 1.0 means that all flows greater than bankfull are spreading onto a floodplain (C and E stream types) or bankfull bench/floodprone area (A and B stream types). A BHR of 2.0 means that it takes a stage of two times the bankfull stage to access the floodplain and the stream is highly incised. The bank height ratio can be measured from a cross section or longitudinal profile if the profile includes the stream bed and both banks (left and right) or the lowest profile of the two banks. Generally, it is preferable to measure BHR from riffles along the profile because riffles represent the natural grade control feature for a river. In this application, the BHR is not measured in the pool. An example of measuring the BHR from a longitudinal profile and cross section is shown in Figures 7.1 and 7.2, respectively.

FIGURE 7.1 MEASUREMENT OF BANK HEIGHT RATIO FROM A LONGITUDINAL PROFILE

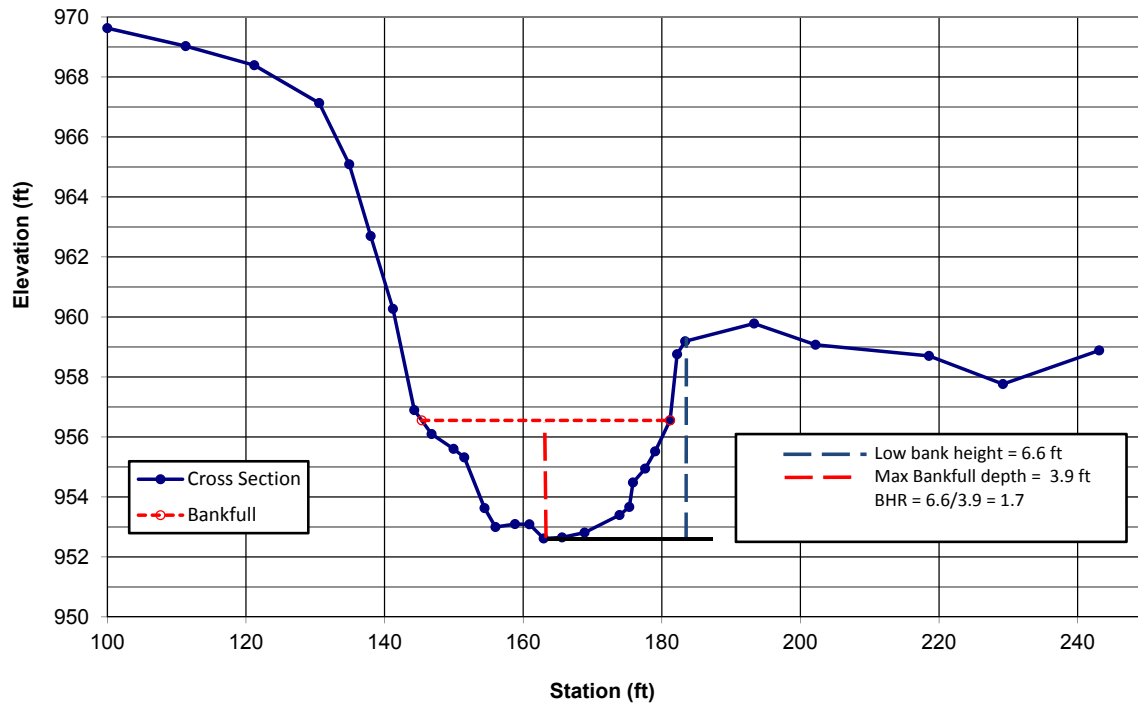


Source: Reproduced with permission from Michael Baker Corporation

It should be noted that the BHR can be measured differently for other purposes. For example, the Bank Erosion Hazard Index, developed by Rosgen (2001), calculates the BHR by measuring the depth near the study bank, rather than the thalweg, and may include measurements from a pool feature.

Measuring the bank height ratio from a profile or cross section is considered a moderate level of effort and moderate level of complexity (see Appendix Ac) because of the time and skill required to make the survey measurements. A rapid and simpler approach is available for assessing the bank height ratio, which is often preferred by regulatory agencies or others who quickly want to determine if a stream (pre- or post-restoration) is incised. A rapid approach is best used if a regional curve is available. If it is, the riffle mean depth from the curve can be used as an estimate for the bankfull max depth. Next, measurements are made along the stream reach from the top of the bank to the bottom edge of the channel, along riffle sections. This measurement is typically made with a pocket rod or standard survey rod. The measurement can quickly be divided by the bankfull depth to get the bank height ratio. If a regional curve is not available, at least one measurement from a bankfull indicator is required, measuring from the indicator to the edge of the water surface.

FIGURE 7.2 MEASUREMENT OF BANK HEIGHT RATIO FROM A CROSS SECTION



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2. Entrenchment Ratio

The entrenchment ratio (ER) is a measure of the floodprone area width in relation to the bankfull width (Rosgen 1994). The floodprone area width is measured at a stage of 2 times the bankfull max depth. Therefore, it is possible to have a stream that is incised, e.g., BHR of 1.8, but not entrenched if the floodplain is wide. The ER is calculated in a riffle cross section as follows:

ER = FW / BW, where

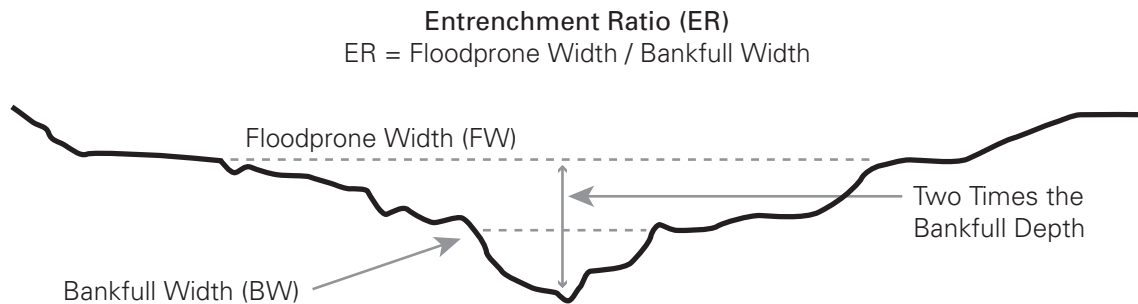
FW = floodprone width, measured at a stage of 2 times the bankfull max depth

BW = bankfull riffle width.

The BHR and ER work well together to quantify floodplain connectivity. For all stream types, a BHR of 1.0 indicates that the stream is not incised and has access to a floodplain or floodprone area. However, the ER will naturally vary by stream type. Streams in v-shaped valleys (A stream types) and colluvial valleys (B stream types) will have lower entrenchment ratios than streams in alluvial valleys (C, E and DA stream types). Therefore a C or E stream type with a bank height ratio of 1.0 and an entrenchment ratio of 10 is not incised and has a wide floodplain that will minimize flood depths, thereby encouraging flood storage, floodplain accretion and other floodplain processes. C or E stream types that have a BHR of 1.0 and an ER of 2.5 are also not incised, but are

more entrenched than the previous example, meaning that flood flows do not have as large a floodplain to dissipate energy and provide wetlands.

FIGURE 7.3 MEASUREMENT OF ENTRENCHMENT RATIO



3. Stage Versus Discharge

HEC-RAS (Hydrologic Engineering Center, River Analysis System) is a one-dimensional stream flow model developed by the USACE and is the most common analytical tool for completing hydraulic analysis associated with stream assessment and restoration projects. Regarding floodplain connectivity, HEC-RAS can be used to predict the stage of various flood return intervals, e.g., bankfull, 2-year, 10-year, etc. A separate analysis of Hydrology is used to determine the discharge for bankfull and the various return interval floods (See Hydrology Chapter). Therefore, HEC-RAS can be used to show if the channel carries the bankfull discharge, the 100-year discharge, or something in between. Obviously, if the channel carries the 100-year discharge, it is very incised; if it carries the bankfull discharge, it is not incised. An example of using HEC-RAS to determine how much water the channel will carry is shown in Figure 7.4. In this example, the channel will carry the 5-year discharge. The bankfull discharge is shown as a dashed line and is between the 1.1- and 1.5-year discharge. The bankfull stage came from the Geomorphic assessment and was entered into HEC-RAS.

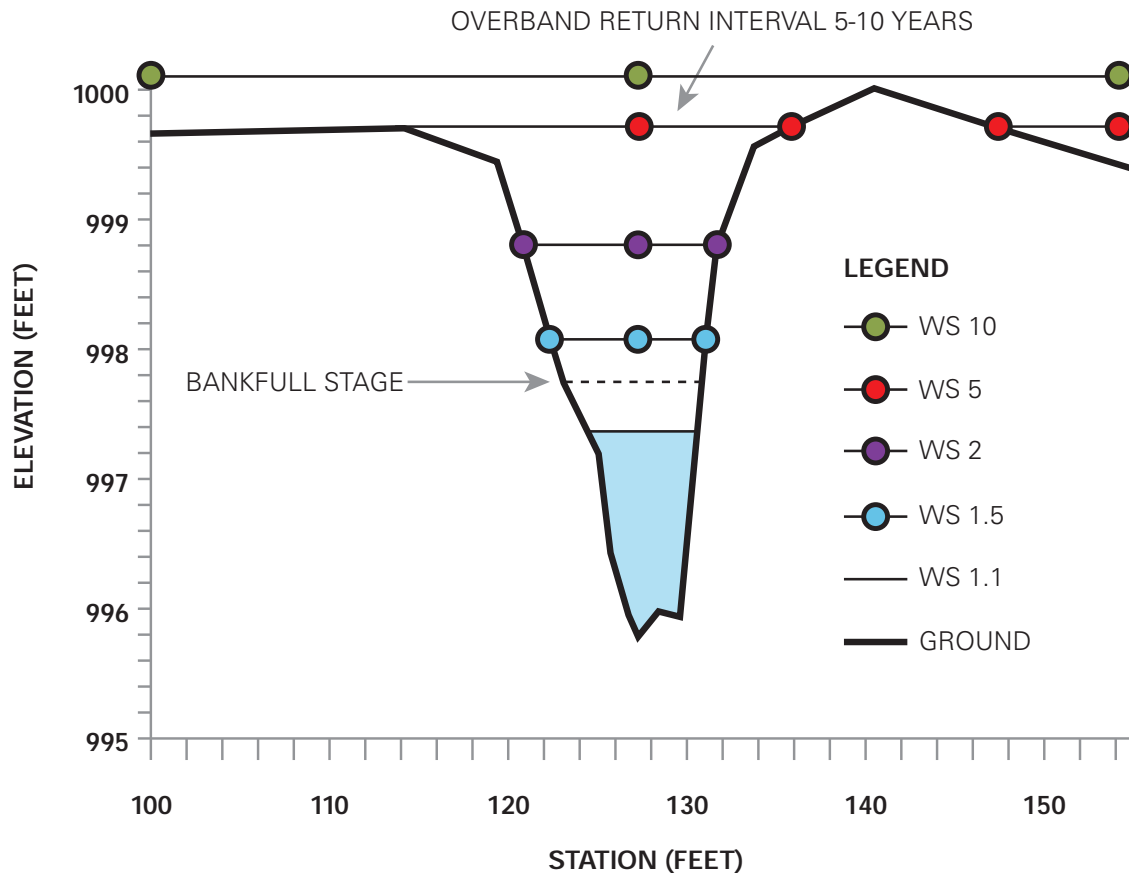
Dunne and Leopold (1978) created a dimensionless rating curve for gauge stations in the Eastern US by plotting the measured flood depth divided by the bankfull depth ($d/dbkf$), versus the measured flood discharge divided by the bankfull discharge ($Q/Qbkf$). This relationship is shown below in Figure 7.5 and includes data from streams with alluvial valleys. Relationships like this can be used to determine if stream restoration projects have channels that are connected to an active floodplain. It does, however, require an estimate of the bankfull discharge and knowledge that the curve represents the hydro-physiographic region of the project. If the bankfull discharge is unknown, then a return interval discharge of 1.5 can be used (as an estimate only) in the denominator. Rosgen (1996) created similar curves by stream type. The G stream type is shown on Figure 7.5 representing streams that are not connected to a floodplain. In the absence of

bank height ratios and entrenchment ratios, these two curves can be used to assess floodplain connectivity. Performance standards related to the use of these curves is provided in the section below.

Performance Standard

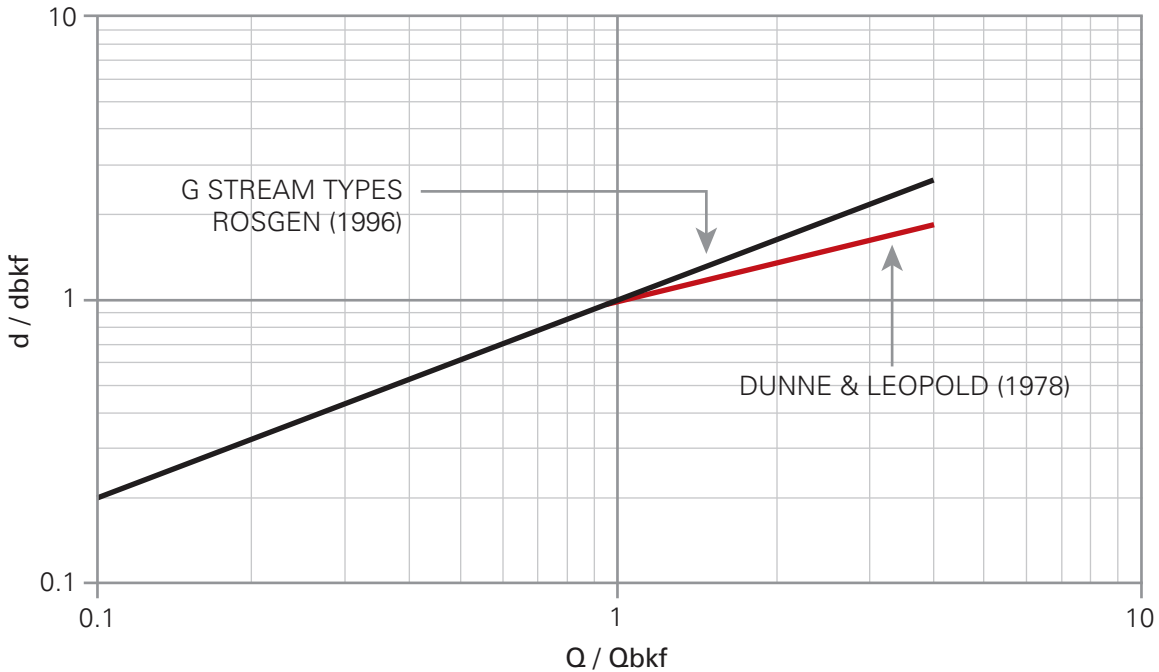
Performance standards for floodplain connectivity metrics are shown in Table 7.2. The BHR performance standards are adapted from Rosgen (2006), which include a graph showing the relationship between BHR and a qualitative stream stability rating using the following categories: stable, slightly incised, moderately incised and deeply incised. These values relate to channel stability; however, to assess floodplain connectivity the values were recategorized as Functioning, Functioning-at-Risk or Not Functioning.

FIGURE 7.4 HYDRAULIC ANALYSIS BY THE HEC-RAS STREAM FLOW MODEL



Source: Adapted from original graph by Michael Baker Corporation

FIGURE 7.5 DIMENSIONLESS RATING CURVE FOR GAUGE STATIONS IN THE EASTERN UNITED STATES



Source: Adapted from Dunne and Leopold (1978), Leopold (1994), and Rosgen (1996)

TABLE 7.2 FLOODPLAIN CONNECTIVITY PERFORMANCE STANDARDS

MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
Bank Height Ratio (BHR)	1.0 to 1.2	1.3 to 1.5	> 1.5
Entrenchment Ratio (ER) for C and E Stream Types	> 2.2	2.0 to 2.2	< 2.0
Entrenchment Ratio (ER) for B and Bc Stream Types	> 1.4	1.2 to 1.4	< 1.2
Dimensionless rating curve*	Project site $Q/Q_{b\text{kf}}$ plots on the curve	Project site $Q/Q_{b\text{kf}}$ plots above the curve	Project site $Q/Q_{b\text{kf}}$ of 2.0 plots above 1.6 for $d/d_{b\text{kf}}$

* See Figure 7.5 for dimensionless rating curve from Dunne and Leopold (1978).

The entrenchment ratio performance standards are also based on Rosgen (2006). The Functioning category represents the minimum value for that stream type, e.g., a 2.2 for C and E stream types. The Functioning-at-Risk category represents the amount that the

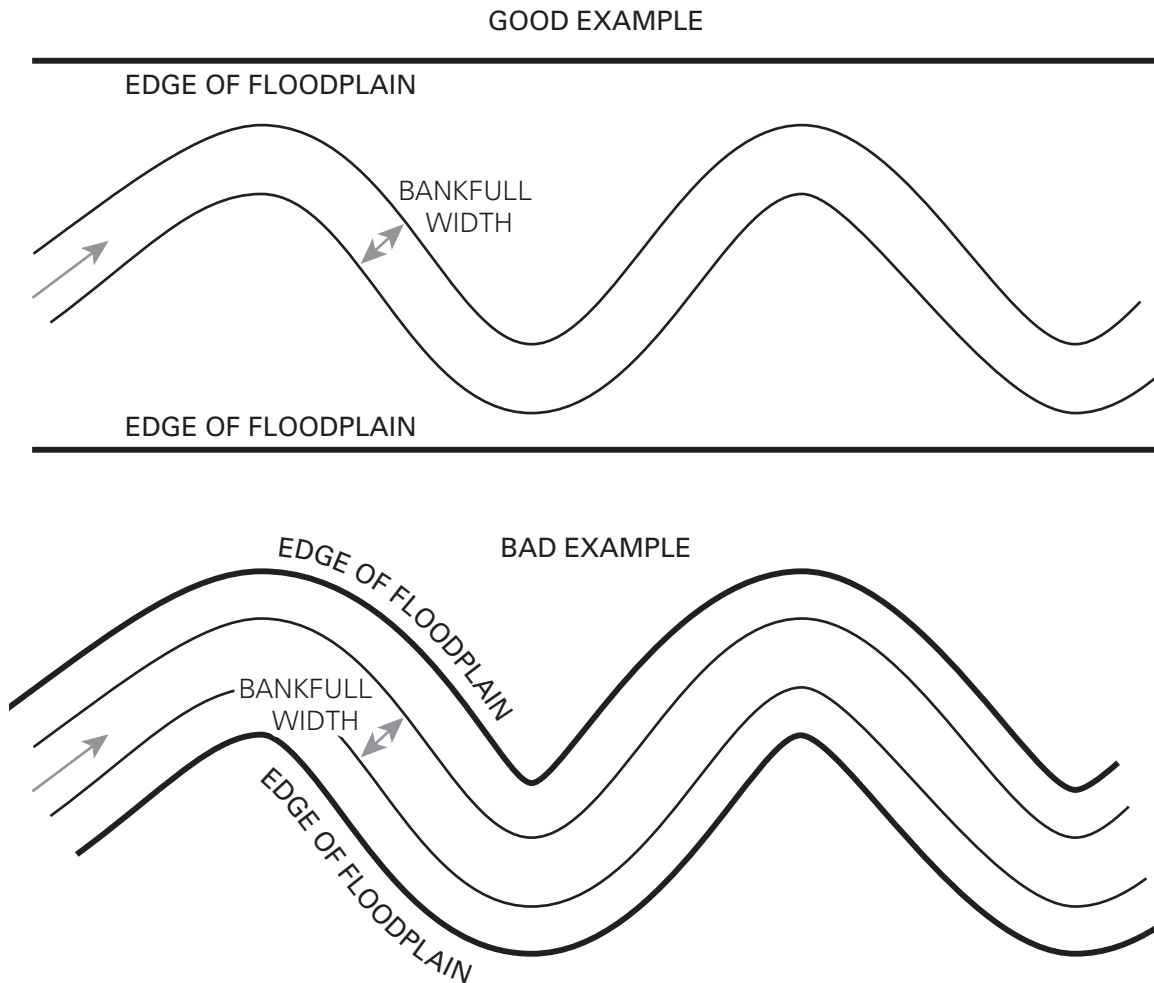
ratio can vary and remain in the same stream type. For example, a C and E stream can have an entrenchment ratio of 2.0 and still be a C or E stream type based on what Rosgen calls the “continuum of physical variables”. However, a decreasing entrenchment ratio is a negative trend because it indicates that the valley is becoming more confined and floodplain processes are diminishing.

Between the BHR and ER, the BHR is the most important for achieving functional lift because it is a direct measure of incision and, therefore, floodplain connectivity. It does not, however, provide information about how far water can spread onto the floodplain. The ER is a nice complement to the BHR because it accounts for the width of the floodplain/valley once floodwaters leave the channel. The ER becomes more critical for restoration projects that include floodplain excavation. It would be extremely rare for this type of project to have an ER of 10, for example. Instead, minimum ER values will be used to lower construction cost and meet landowner constraints. These minimums should not exceed the values listed in 7.2. In addition, an excavated floodplain should be relatively straight with the fall line of the valley and should not simply follow the pattern of the channel using a constant floodplain width to achieve the targeted ER. An example is shown below in Figure 7.6.

It is more difficult to use discharge as a performance standard because the discharge rating curve varies by the shape of the channel (Leopold, 1994) and the degree of incision. However, rating curves from different gauge stations become quite similar when the values are converted to a dimensionless form (Leopold, 1994). If the $d/d_{b_{kbf}}$ versus $Q/Q_{b_{kbf}}$ plots on the curve, then the stream is connected to the floodplain. If data from the project site plot above the curve, it means that stage is increasing at a higher rate than the non-incised streams used to create the curve. This is likely caused by a deeper channel, and the additional discharge is not spreading onto an active floodplain as quickly. If the project site plots near the curve, it may still be functioning similar to reference reach streams, but it is Functioning-at-Risk. As the project site plots further from the curve, the risk of channel incision increases.

Rosgen (1996) shows a dimensionless discharge rating curve stratified by stream type. This relationship shows that the G stream type at a $Q/Q_{b_{kbf}}$ of 2.0 has a d/db_{kbf} of 1.6. The breakpoint for Not Functioning floodplain connectivity was therefore set at a d/db_{kbf} of 1.6 for a Q ratio of 2.0, indicating a potential stream type change of a C or E to a G. Again, it would be easier to use the BHR and ER (and then stream type) to make this determination. However, a practitioner or reviewer could use gauge station data or published dimensionless discharge rating curves and the 1.5-year Q for bankfull to make an estimate of floodplain connectivity performance.

FIGURE 7.6 PROPER VERSUS IMPROPER FLOODPLAIN EXCAVATION DESIGN



7.2 » PARAMETER: FLOW DYNAMICS

Description

The water flowing in a stream channel moves downhill because of gravity and slope. The flow is then retarded by resistance applied by the stream bed and banks. The interaction of flowing water against the stream bed and banks creates dynamic flow conditions, termed here as flow dynamics. The morphology of natural channels is dependent on these flow dynamics. In intermittent and perennial streams, the discharge of groundwater and the overall surface/subsurface interaction creates additional functions, especially as they relate to and support Physicochemical and Biology functions.

There are many resources that describe flow dynamics in stream channels and floodplains. A few include Knighton (1998), Leopold et al. (1992), Fetter (1994) and Bridge

(2003). Flow dynamics have a major role in shaping the geometry of the channel. Therefore, restoration practitioners spend a considerable amount of time determining the proper flow dynamics for a restoration project. Assessing flow dynamics for establishing a baseline functional capacity or determining functional lift could include a wide range of measurements, ranging from surface/subsurface interactions, stage versus discharge relationships, velocity distributions, shear stress or tractive force, and stream power. Many of these metrics relate to the ability of the stream to “do work” by transporting sediment that is delivered to the channel from upstream sources, the stream bed, and streambanks. Sediment transport parameters (sediment transport capacity and competency) are discussed in the Geomorphology Chapter because they describe the Geomorphology function of transporting sediment.

Three important measures of flow dynamics are described here: stream velocity, shear stress and stream power. However, they are also applied in the Geomorphology Chapter for assessing channel stability and sediment transport. These Hydraulic parameters influence channel stability and sediment transport by providing the force and power needed for Geomorphic functions to occur, e.g., transport of organic material and sediment to create diverse bed forms and dynamic equilibrium.

Measurement Method

1. Stream Velocity

Stream velocity is a vector that has magnitude and direction. Knighton (1998) describes stream velocity as one of the most sensitive and variable properties of open-channel flow because it is dependent on a wide range of factors. Knighton (1998) describes the variability in four different ways, including distance from the stream bed, across the stream channel and downstream, as well as with time. It is the character of this variation that is important because of its influence on erosion, sediment transport and deposition. Stream velocity is also important at baseflow and flood flow conditions. Baseflow velocities that are too high prevent upstream fish movement, and high stream velocities during flood flows can cause stream bed and bank erosion if the flow force exceeds the resisting forces. Therefore, stream velocity is a widely used parameter to help assess channel stability, create stable channel designs and help support aquatic life.

The bankfull discharge and other flow magnitudes, e.g., the 100-year discharge, are determined as part of the Hydrology assessment discussed in Chapter 6. The average bankfull velocity is calculated as the bankfull discharge divided by the cross-sectional area, which can be measured during an assessment of the pre- or post-restoration condition. In other words, the bankfull discharge is a design element and will not change after restoration construction, but the cross-sectional area may change after construction, and this change can be positive or negative. Dunne and Leopold (1978) noted that the average bankfull velocity is approximately 4 feet/sec. Published regional curves, however, show bankfull velocities varying by stream type.

Velocity can also be measured in the field; this is easier to do during baseflow conditions than bankfull or flood conditions. Velocity may be measured in the field to assure that

baseflow velocities will allow for fish passage and to measure discharge (discharge = velocity x the cross-sectional area). This may be important for stream restoration projects that include culvert removal or other barriers to fish passage. Dingman (2008) and Harrelson et al. (1994) provide detailed methods on a variety of ways to measure stream velocity and discharge. A single velocity measurement as described above is considered a rapid level of effort with moderate complexity. However, taking velocity measurements for a range of flow conditions to develop a stage versus discharge rating curve requires multiple trips and more expertise and is considered an intensive level of effort and complex (Appendix Ac).

2. Shear Stress

Shear stress is a hydraulic force that is often used to predict sediment entrainment (sediment transport competency). Regarding the Pyramid, shear stress is a Hydraulic parameter (Level 2) that is used to quantify a Geomorphology function (Level 3), the entrainment and transport of bed material. Most stream beds consist of unconsolidated, cohesionless grains of sand and gravel. As flow increases, the force of the water over these particles increases. At some threshold, the particles begin to move. This initial movement is commonly defined as the critical shear stress (τ_{cr}) or mean boundary shear stress (τ_0) (Knighton, 1998). The mean boundary shear stress is calculated as:

$$\tau_0 = \gamma R S, \text{ where}$$

$$\tau_0 = \text{mean boundary shear stress in lbs/ft}^2$$

$$\gamma = \text{the specific weight of water (typically 62.4 lbs/ft}^3)$$

$$R = \text{hydraulic radius in ft}$$

$$S = \text{average channel slope in ft/ft.}$$

There are many ways to calculate critical shear stress, and it is beyond the scope of this document to review them all here. However, Knighton (1998) and Wilcock et al. (2009) provides a description of the different ways to calculate critical shear stress, including a variety of graphs and equations that can be used to predict erosion, transport and deposition. Moreover, Rosgen (2006) provides an application of Andrews (1983 and 1984) equations for estimating the depth needed to maintain bed equilibrium during a bankfull event, and Wohl (2000) provides a description of entrainment processes in mountain rivers. Rosgen (2006) also created a relationship between particles transported at near bankfull flows versus the boundary shear stress. These procedures are described in more detail in the Geomorphology Chapter. Simple calculations of shear stress and its use with existing graphs is considered a moderate level of effort and moderate complexity because sufficient expertise is required to know when to use this method over other methods. The level of effort and complexity becomes intensive if shear stress curves are developed for a certain region, which requires bedload/material samples for a range of flow conditions (Appendix Ac).

3. Stream Power

Stream power is the ability of the stream to do work, where work is defined as the

conversion of potential energy (elevation change) to kinetic energy. Most of the kinetic energy is dissipated through friction from the bed and banks. However, a small portion is available to accomplish geomorphic work like the entrainment and transport of sediment (Bagnold, 1960). Phillips (1989) provides a cross-sectional stream power calculation, which is a physically based measure of sediment transport capacity. Thus, cross-sectional stream power can be written as:

$$\Omega = \gamma QS, \text{ where}$$

Ω = stream power per unit length (Watts/meter)
 γ = specific weight of water (1 g/m^3)
 Q = discharge (m^3/s)
 S = slope (m/m).

Mean stream power is related to competence and can be expressed as:

$$\omega = \gamma RSV = \Omega/W = \tau V \text{ (Lecce, 1997)}$$

ω = unit or mean stream power (W/m^2)
 R = hydraulic radius (m)
 V = velocity (m/s)
 W = width (m).

As a functional assessment tool for stream restoration projects, mean stream power is more useful than cross-sectional stream power. This is because mean stream power is normalized by channel width and can be compared across various streams of different size. Mean stream power is also the product of shear stress and velocity, which were each discussed above. In this regard, mean stream power is probably the most important parameter for describing flow dynamics. It is also a vital input parameter for sediment transport functions, as described in the Geomorphology Chapter. Similar to shear stress, if stream power is calculated and compared to literature values or existing graphs, the level of effort and complexity is moderate. However, if stream power curves (sediment transport rate versus stream power) are developed the level of effort and complexity is complex (Appendix Ac).

Nanson and Croke (1992) used stream power to classify floodplains into three classes: High-energy non-cohesive floodplains with bankfull ω greater than 300 W/m^2 ; medium-energy non-cohesive floodplains with bankfull ω between 10 and 300 W/m^2 ; and low-energy cohesive floodplains with bankfull ω below 10 W/m^2 . To further divide the classes into orders and suborders, nine discriminatory fluvial geomorphic factors are added. These factors include: (1) Valley Confinement, (2) Channel Cutting and Filling, (3) Braid-channel Accretion, (4) Lateral Point Bar Accretion, (5) Overbank Vertical-accretion, (6) Annabranching, (7) Scroll-bar Formation, (8) Counterpoint Accretion and (9) Organic Accumulation. The first six factors are used to divide the classes into orders, and the remaining three are used to divide the floodplains into suborders.

This is one example of how stream power can be used to assess the functional capacity of a potential stream restoration site. For example, there are many low energy floodplains

(ω less than 10 W/m²) in the Piedmont and Coastal Plain regions of the eastern United States. But these floodplains lack many of the processes (factors) described above due to channelization, floodplain aggradation, deforestation and other direct and indirect disturbances. The Nanson and Croke (1992) floodplain classification provides restoration practitioners with a framework of processes that can be incorporated into restoration goals and then quantified during design and monitoring as functional lift. It also provides guidance to help ensure that the right type of stream channel is designed given the valley morphology.

Performance Standard

The measurement methods used to describe flow dynamics include stream velocity, shear stress and stream power. Shear stress and stream power are important input parameters for assessing sediment transport; however, there are other Geomorphology parameters and measurement methods that are better for developing performance standards. Stream velocity can be used as a flow dynamics performance standard, especially for evaluating the appropriate bankfull discharge (and flow area) and for fish passage. Bankfull velocity performance standards should be based on local regional curves stratified by stream type and the bankfull cross-sectional area measured in the field. Example performance standards by stream type are provided below in Table 7.3.

TABLE 7.3 FLOW DYNAMICS PERFORMANCE STANDARDS

MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
Bankfull Velocity for C and E stream types (ft/s)	3 to 6	6 to 7	> 7
Bankfull Velocity for Cc- (ft/s)	< 3	3 to 4	> 5
Bankfull Velocity for B stream types (ft/s)	4 to 6	6 to 7	> 7

Bankfull velocities typically should not exceed the range of velocities provided by gauge sites used to develop regional curves. For C and E stream types with slopes between 0.005 and 0.02 ft/ft, the average bankfull velocity is 4 ft/s (Dunne and Leopold, 1978). However, these values only provide general guidance and are not the best performance standard for stream restoration projects. Values outside of the range shown can indicate a potential problem (usually with stability), but the bank height ratio parameter and other parameters in the Geomorphology Chapter are probably better suited for stream restoration performance standards.

A wide range of velocity performance standards may be applied to projects with fish passage issues and should be based on the fish species and site conditions, e.g., open channel or culvert crossing. Stream assessments and restoration projects often deal with culvert crossings and associated fish passage issues. The FishXing (pronounced “fish crossing”)

software is a free tool that can be used to design culvert crossings for passage. The FishX-ing website includes references and supporting materials that could be used for assessing velocity thresholds for a variety of fish species (www.stream.fs.fed.us/fishxing/index.html).

7.3 » PARAMETER: GROUNDWATER AND SURFACE WATER EXCHANGE

Description

Surface water in streams interacts with groundwater in three basic ways: groundwater discharging into the stream through the stream bed (gaining stream), surface water flowing through the bed and into groundwater (losing stream), or a combination of both (Winter et al., 1998). This document describes the processes of groundwater and surface water exchange as it relates to stream assessments and restoration. An overview of groundwater hydrology is not provided; however, Fetter (1994) and Winter et al. (1998) are good sources for background information.

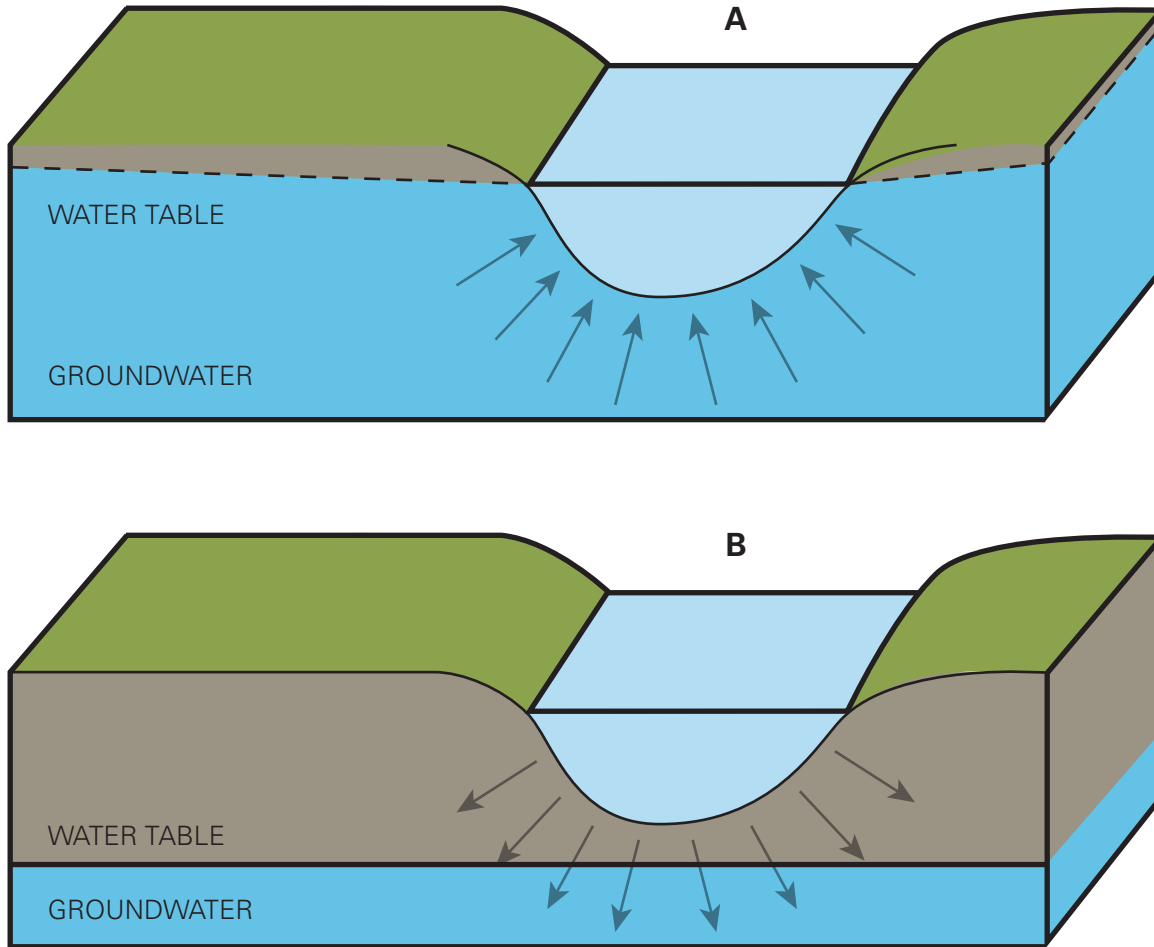
Figure 7.7 shows examples of a gaining and losing stream. Gaining streams are characterized as zones where the water table is higher than the stream bed. Losing streams are the opposite — areas where the water table is below the elevation of the stream bed. Losing streams can be connected to the water table by a continuous zone of saturation or by an unsaturated zone (Fetter, 1994; Winter et al., 1998).

In some environments, stream reaches are almost always gaining or losing. However, in other environments, surface and groundwater exchange is more variable, e.g., headwater streams. Flow direction toward or away from the stream bed can change quickly, based on flood events that cause recharge near the streambank, short-term flood peaks or transpiration of groundwater by riparian vegetation. A very common type of groundwater and surface water interaction during storms is called bank storage, which occurs during a rapid rise in stream stage (depth). As the stage increases, water flows from the channel into the unsaturated portion of the streambank. If the storm does not overtop the streambank and spread onto the floodplain, water stored in the banks (bank storage) typically returns to the channel within a few days or weeks. If the storm does overtop the bank and spread onto the adjacent floodplain, widespread recharge to the water table occurs as water seeps through the unsaturated zone (Winter et al., 1998). The timeframe for this water to return to the channel through groundwater flow may take weeks, months or even years. Depending on the frequency, magnitude and intensity of storms in a given region, the stream and adjacent aquifer may be continuously readjusted based on these processes (Winter et al., 1998). This is another reason that floodplain connectivity is so important. Streams that overtop the streambank frequently (all flows greater than bank-full) have more opportunity to store and slowly return flood flows to the channel. Figure 7.8 illustrates these two processes (bank storage and recharge) as stream stage increases.

The processes described above occur during storm events; however, many gaining streams have reaches that lose water to the aquifer during baseflow conditions. The direction and rate of seepage through the bed is often related to abrupt changes in bed slope and meander bends. This subsurface zone where stream water flows through short segments of the bed and banks is called the hyporheic zone. The hyporheic zone is a

FIGURE 7.7 GAINING AND LOSING STREAM EXAMPLES

(In the illustration, **A** shows gaining stream and **B** shows a losing stream with an unsaturated zone.)



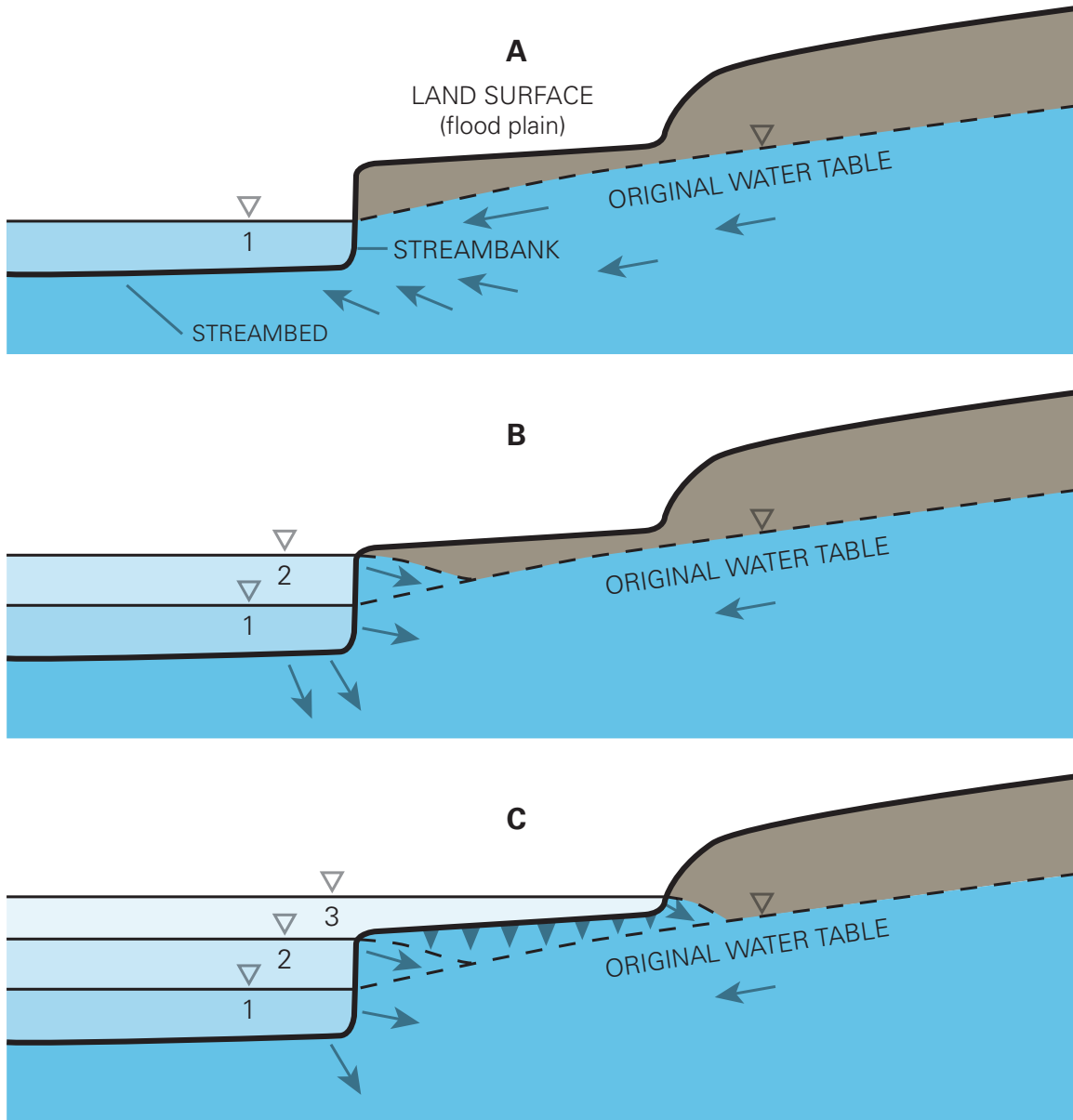
Source: Adapted from Winter et al. (1998)

subsurface area of porous sediments where surface water and groundwater mix, thereby creating an environment that is different from the stream or the groundwater (Figure 7.9).

This unique environment can have a large effect on the types and numbers of organisms (Level 5 – Biology) found in the stream. The importance of the hyporheic zone is increasingly being recognized in stream and watershed assessments. As such, restoration approaches that help to encourage the development of a hyporheic zone are being identified and implemented. These restoration techniques include adding meanders, creating bed form diversity (steep riffles and flat pools), adding gravel layers beneath the ground surface of the floodplain and sometimes step structures like cross vanes. Since these design elements must be included as part of a sediment transport analysis and overall stable geometry, it is included in Pyramid Level 3 (Geomorphology) rather than Level 2 (Hydraulic).

FIGURE 7.8

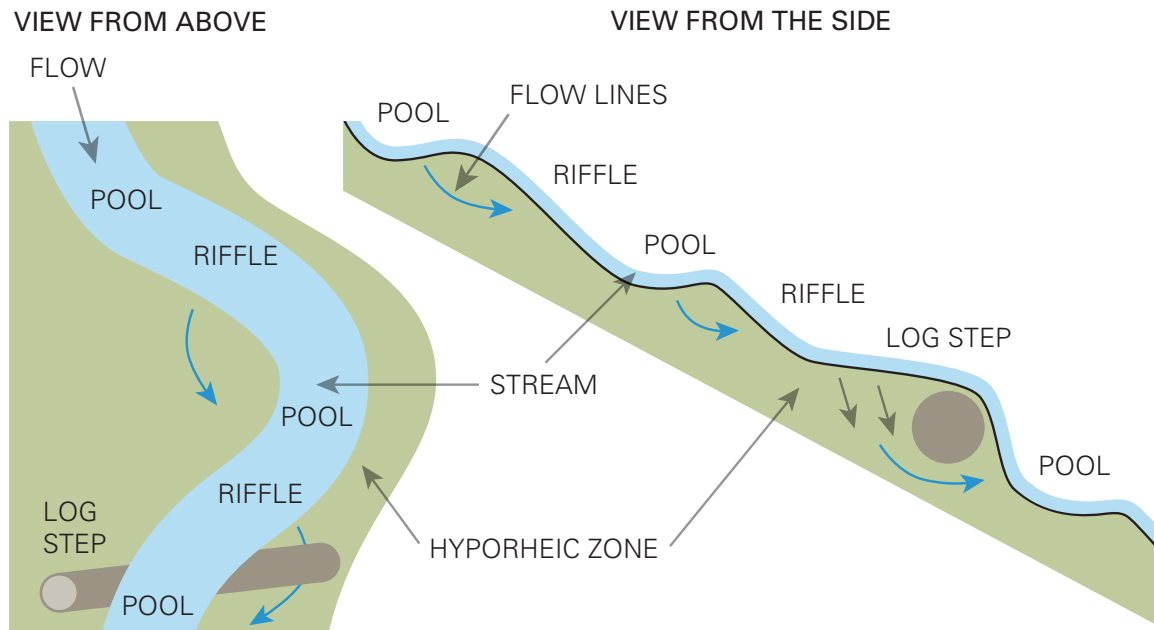
(In the figure, A shows gaining stream, B shows bank storage and C shows groundwater recharge associated with overbank flooding.)



▽ ▽ ▽ SEQUENTIAL STREAM STAGES
 1 2 3
 → APPROXIMATE DIRECTION OF GROUND WATER FLOW
 OR RECHARGE THROUGH THE UNSATURATED ZONE

Source: Adapted from Winter et al. (1998)

FIGURE 7.9 HYPORHEIC ZONE



Source: Adapted from *Waterencyclopedia.com*

Measurement Method

There are many ways to measure groundwater/surface water interactions; however, mapping the extent of the hyporheic zone is challenging. Kalbus et al. (2006) provides a thorough review of methods to measure groundwater discharge into streams, stream recharge of groundwater and the interactions between the two. This document only highlights three methods described by Kalbus et al. (2006), piezometers, tracers and seepage meters, because they are the most likely methods to be used by stream professionals. However, refer to Kalbus et al. (2006) for a more thorough review of methods.

1. Piezometers

A piezometer is a small diameter well with a short screen or section of slotted pipe at the bottom end. It is used to measure hydraulic head (Fetter, 1994) and can usually be installed by hand. As such, it is probably the most common method for measuring the hyporheic zone. Piezometers are typically installed in the stream bed. This type of installation shows if the stream is gaining or losing by comparing the water elevation in the piezometer to the adjacent water elevation of the stream. If the water elevation in the piezometer is lower than the adjacent stream elevation, the stream is losing water to the hyporheic zone and vice versa. Transects of piezometers are installed throughout the stream reach to delineate gaining and losing areas. Additionally, water samples can be collected and the chemistry compared between the stream and the piezometer. This can be compared to results from piezometers installed in the floodplain to delineate the

lateral extent of the hyporheic zone, thus providing the depth and lateral extent.

2. Tracers

Tracers, or dye, can also be used to measure flow velocity in the hyporheic zone. A known concentration of the tracer is injected into the sediments below the stream bed. Water samples are then collected downstream to determine the concentration of the dye. Tracer studies are often used in combination with computer models to estimate the flow dynamics in the stream channel and hyporheic zone.

3. Seepage Meters

Bag-type or automatic seepage meters are also used to measure groundwater/surface water interaction. There have been problems with using the bag-type meter in stream systems, many of which have been overcome by the automatic seepage meter. The automatic meter records velocities using a heat pulse, an ultrasonic device or an electromagnetic flow meter.

Design Standard

The development of a hyporheic zone is critically important to support Physicochemical and Biological processes. There are stream restoration techniques that can be used to support the development of a hyporheic zone. Some examples include adding meanders, creating step-pools or steep gradient riffles, adding bed form complexity, and creating porous subsurface sediments. As stream restoration technologies advance, there is an increase in working with bed sediments, and even loosening sediments that have been previously compacted in the floodplain. However, developing performance standards for groundwater/surface water exchange is difficult. The science is emerging, but currently there are no quantitative standards to say that a hyporheic zone is Functioning, Functioning-at-Risk or Not Functioning. The best opportunity for developing a performance standard would be cases where a reference reach is upstream or downstream of the project. In this case, the design goal could be to have a hyporheic zone that is similar in depth and width to the reference reach, which could be assessed using piezometers. Another option is to use Level 5 parameters like macroinvertebrate communities, since many of these organisms rely on the hyporheic zone as a critical habitat.

Chapter 8

Geomorphology

Level 3 on the Pyramid represents the Geomorphology functions, which transport and store organic matter (wood) and sediment to create diverse bed forms and dynamic equilibrium. These functions include the interaction of flowing water with the stream bed, streambanks and upstream sediment supply. Therefore, the assessment and restoration of Geomorphology functions come after an assessment of the Hydrology (Level 1) and Hydraulic (Level 2) functions, as the Geomorphology functions integrate both of these preceding functions.

The interaction between flowing water and sediment transport creates bed forms like riffles, runs, pools and glides, which provide the critical habitats for macroinvertebrates, fish and other organisms. Streams that are in balance with Hydraulic and Geomorphology functions are said to be in *dynamic equilibrium*. This means that the stream bed is not aggrading nor degrading over time, and that lateral adjustments do not change the cross-sectional area, even though its position on the landscape may change (Hack, 1960).

Table 8.1 provides a list of the parameters included in Level 3, along with methods for measuring the parameters. An indication of whether or not a measurement method includes a performance standard is also provided. A description of each parameter, measurement method and performance standards are provided below. Appendix Ac includes a list of all the Geomorphology measurement methods along with information about the method's type, level of effort, level of complexity, and whether it is a direct or indirect measure of the function-based parameter. The criteria used to make these determinations are provided in Chapter 4.

8.1 » PARAMETER: SEDIMENT TRANSPORT COMPETENCY

Description

The ability of the stream to transport its sediment load can be determined through sediment transport competency and capacity analyses. Sediment transport competency is the ability of a stream to move particles of a given size and is a measurement of force, often expressed in units of pounds per square foot (lbs/ft²). A description of shear stress is provided in the Hydraulics Chapter. Sediment transport competency is a common parameter used to determine the vertical stability of a gravel bed stream. Competency analysis is typically not completed in sand bed channels because all particle sizes are mobile.

Sediment transport competency is used more during the stream restoration design phase than for evaluating performance during the post-restoration monitoring phase. Other parameters, such as bed form diversity, are easier to measure during the monitor-

TABLE 8.1 GEOMORPHOLOGY PARAMETERS, MEASUREMENT METHODS AND AVAILABILITY OF PERFORMANCE STANDARDS (CONT.)

PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD
Channel Evolution	<ol style="list-style-type: none"> 1. Simon Channel Evolution Model 2. Rosgen Stream Type Succession Scenarios 	<p>Yes</p> <p>Yes</p>
Bank Migration/Lateral Stability	<ol style="list-style-type: none"> 1. Meander Width Ratio 2. BEHI / NBS 3. Bank Pins 4. Bank Profiles 5. Cross-Sectional Surveys 6. Bank Stability and Toe Erosion Model 	<p>Yes</p> <p>Yes</p> <p>Yes</p> <p>Yes</p> <p>Yes</p> <p>Yes</p>
Riparian Vegetation	<ol style="list-style-type: none"> 1. Buffer Width 2. Buffer Density 3. Buffer Composition 4. Buffer Age 5. Buffer Growth 6. Canopy Density 7. Proper Functioning Condition (PFC) 8. NRCS Stream Visual Assessment Protocol 9. Rapid Bioassessment Protocol 10. Watershed Assessment of River Stability and Sediment Supply (WARSSS) 11. USFWS Stream Assessment Ranking Protocol (SAR) 	<p>Yes</p> <p>Yes</p> <p>Yes</p> <p>Yes</p> <p>Yes</p> <p>Yes</p> <p>Yes</p> <p>Yes</p> <p>Yes</p> <p>Yes</p> <p>No</p> <p>Yes</p>
Bed Form Diversity	<ol style="list-style-type: none"> 1. Percent Riffle and Pool 2. Facet Slope 3. Pool-to-Pool Spacing 4. Depth Variability 	<p>Yes</p> <p>Yes</p> <p>Yes</p> <p>Yes</p>
Bed Material Characterization	<ol style="list-style-type: none"> 1. Bevenger and King (1995) 2. Riffle Stability Index (RSI) 	<p>Yes</p> <p>Yes</p>
Sediment Transport Competency	<ol style="list-style-type: none"> 1. Shear Stress Curve 2. Required Depth and Slope 3. Spreadsheets and Computer Models 	<p>No</p> <p>No</p> <p>No</p>
Sediment Transport Capacity	<ol style="list-style-type: none"> 1. Computer Models 2. FLOWSED and POWERSED 3. BAGS 	<p>No</p> <p>No</p> <p>No</p>
Large Woody Debris Transport and Storage	<ol style="list-style-type: none"> 1. Wohl et al. (2009) 2. Large Woody Debris Index 	<p>No</p> <p>Yes</p>

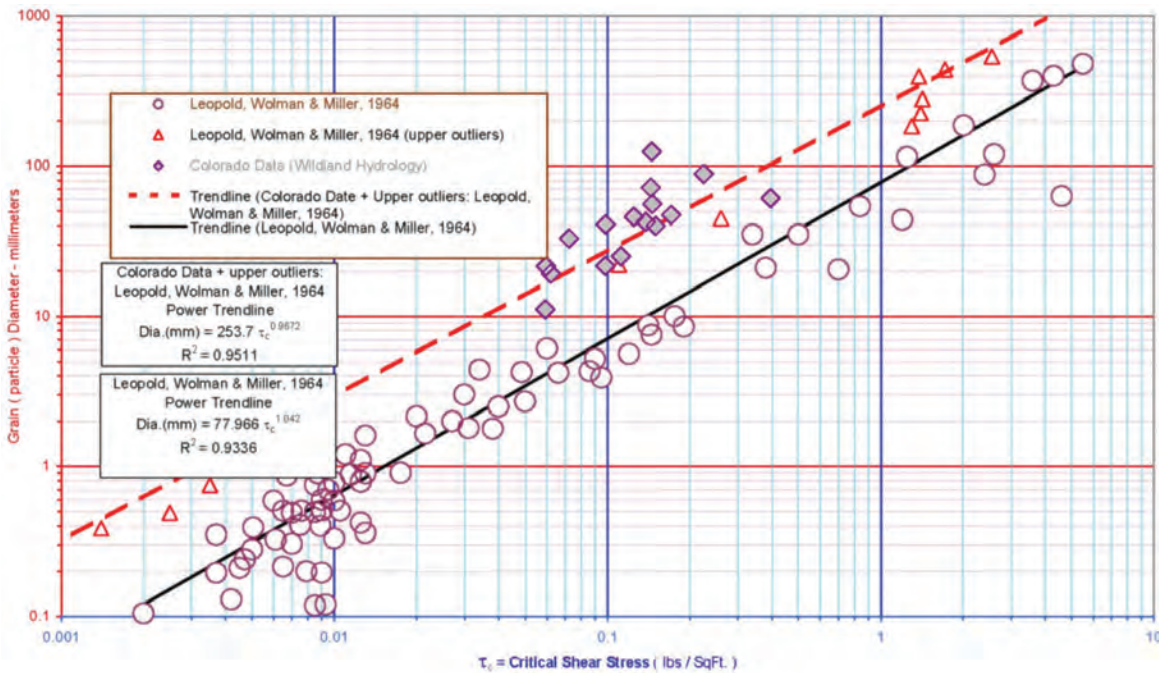
ing phase to determine if sediment transport processes are working properly. For example, if the stream is aggrading, excessive bar development, e.g., mid channel bars, will be obvious. If the stream is degrading, headcuts and the lack of pool features will be obvious. Therefore, the measurement methods described below are typically used to assess reference reach and project reach streams. Design standards are discussed after the measurement methods; however, performance standards are not included for this parameter.

Measurement Methods

1. Shear Stress Curve

There are a variety of methods for assessing sediment transport competency in gravel bed streams, most of which are based on tractive force or shear stress calculations. Rosgen (2006) measured bedload from Colorado Rivers and combined this data set with the high outliers from a Leopold, Wolman and Miller (1964) data set. This form of boundary shear stress is used by Rosgen (2006) to predict particle sizes that may be transported during a bankfull event. It is therefore a rapid assessment tool that does not require detailed modeling or intensive field work, only a cross section, average slope measurement and grain size distribution of the bed material. The result is shown below in Figure 8.1.

FIGURE 8.1 GRAIN SIZE ENTRAINED AS A FUNCTION OF SHEAR STRESS



Source: US EPA Watershed Assessment of River Stability and Sediment Supply (WARSSS) v1.0

The upper line represents data measured in natural rivers at or near the bankfull discharge, along with upper outliers from the Leopold, Wolman and Miller (1964) curve. The upper curve is used more often to assess sediment transport competency in stream restoration projects. However, it is an empirical tool and data from the project reach should be representative of the data used to create the curve (Rosgen, 2009). If it is not, then local curves should be developed in order to use the curve for design or assessment purposes. The development of a local curve requires an intensive level of effort and should only be developed by qualified scientists or engineers (Appendix Ac).

2. Required Depth and Slope

Rosgen (2006) also describes a much more detailed procedure that involves sampling bed material from the riffle pavement (surface layer) and the riffle subpavement, or material from the point bar. The material is sieved and a grain size distribution for the pavement and subpavement or point bar is developed. A series of calculations are then made using equations from Andrews (1984) and Andrews and Erman (1986) to determine the depth and slope required to move the largest particle from the subpavement or bar. From past monitoring, Rosgen has determined that the largest particle from the subpavement or point bar closely matches the largest particle sampled during a bankfull event. The required depth and slope can then be compared to the project reach depth and slope (could be a pre- or post-restoration condition as well). If the required depth and slope is greater than the project depth and slope, then there is a potential for stream bed aggradation because more shear stress is needed to move the bed. If the required depth and slope is less than the project depth and slope, then there is risk of bed degradation because there is more shear stress than is necessary to move the bed, e.g., all particle sizes may be transported rather than the largest size from the sub-pavement or bar sample.

3. Spreadsheets and Computer Models

Several computer models can be used to assess vertical stability, including those ranging from rapid/simple spreadsheet programs like BAGS to one-dimensional models like HEC-RAS, as well as the more sophisticated two-dimensional models. These models typically compute competency and capacity with more emphasis placed on capacity. A description of these techniques is provided below.

Design Standard

Sediment transport competency and capacity are often assessed together. Therefore, design standards for both parameters are discussed in the following section (Parameter: Sediment Transport Capacity).

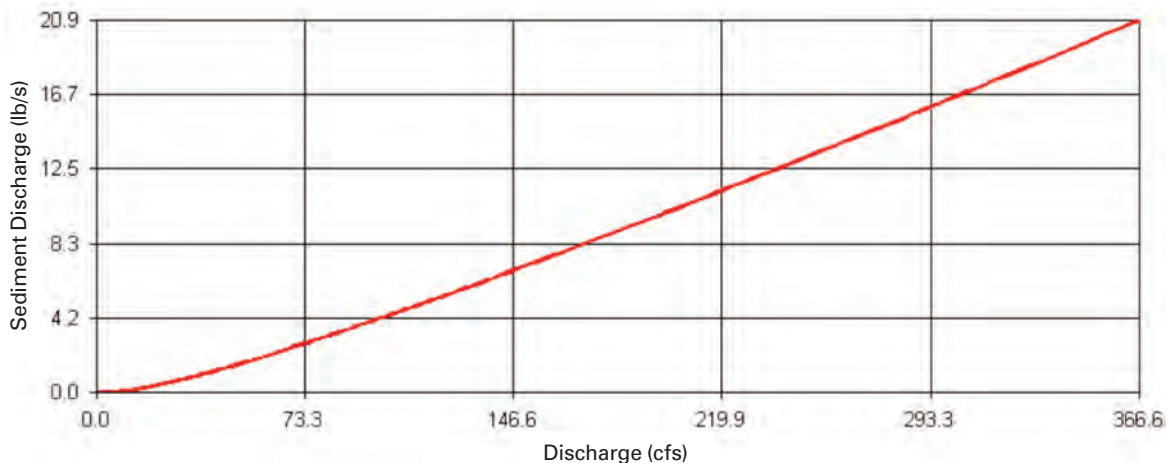
8.2 » PARAMETER: SEDIMENT TRANSPORT CAPACITY

Description

Sediment transport capacity is the ability of a stream to move a quantity of sediment through a riffle cross section. It is typically assessed using stream power, and is often

expressed as units of watts/square meter (W/m^2). A description of stream power is provided in the Hydraulics Chapter. Sediment transport capacity is often shown as a sediment transport rating curve, which provides an estimate of the quantity of total sediment (load) transported through a cross section per unit time. The curve is provided as a sediment transport rate versus discharge or stream power. An example of a sediment transport rating curve is shown below in Figure 8.2.

FIGURE 8.2 A MODELED SEDIMENT RATING CURVE FOR A PROJECT IN NC



Source: Reproduced with permission from Michael Baker Corporation

The total sediment load transported through a cross section can be divided by type of movement into bedload and suspended load fractions. Bedload is generally composed of larger particles, such as coarse sand, gravel and even cobbles or boulders, which are transported by rolling, sliding or hopping (saltating) along the bed. Suspended load is normally composed of fine sand, silt and clay particles transported in the water column.

Measurement Method

As mentioned previously, sediment transport capacity is often characterized by calculating stream power and developing rating curves, such as sediment transport in lbs/sec versus discharge or stream power. A common approach is to calculate the sediment transport capacity of a reach immediately upstream of the project, called the supply reach. Sediment transport capacity is also calculated for the project reach. The two are compared, and if the project reach has a similar transport rate as the supply reach, the project reach is assumed to be in equilibrium. If the project reach is transporting more sediment than the supply reach, there is a risk of bed degradation. Conversely, if the project reach is transporting less sediment than the supply reach, then there is a risk of aggradation. It is preferable that the upstream supply reach is stable, i.e., not aggrading or degrading. However, this approach can be used even if the upstream reach is unstable, as the goal is to transport the load of sediment that is delivered to the project reach, whatever that value may be. The problem is that an unstable supply reach will likely change

significantly with time and, therefore, the sediment supply to the project reach will change. This is one reason that it is preferable to select restoration reaches downstream of stable reaches. Another complicating factor is that a restoration design may have a goal to store sediment rather than have a transport reach. Furthermore, projects with a low sediment supply may not need a quantitative sediment transport analysis. Innovative design approaches like those shown on Figure 6.2 are redefining approaches for assessing sediment transport.

1. Computer Models

There are several computer models that can be used to quantify sediment transport capacity. HEC-RAS Version 4.1 has a sediment transport feature that can easily be run if a hydraulic model has already been developed for the project and bed material data are available. Another option is SAMWin, which is a single cross-section analyzer using a variety of sediment transport capacity equations. The software then predicts a stable cross-sectional geometry based on a Copeland stability curve and other methods (Thomas et al., 2002). More information about SAMWin, as well as a free download of the software and supporting documents, can be found at chl.erdc.usace.army.mil/chl.aspx?p=s&a=SOFTWARE;2.

Two-dimensional models are also becoming more prevalent for assessing channel hydraulics and sediment transport capacity. Two examples of commercially available 2-D models with hydraulic and sediment transport modeling capabilities are provided below.

RiverFLO-2D www.flo-2d.com/products

Mike 21 www.mikebydhi.com

2. FLOWSED and POWERSED

Rosgen (2006) developed an empirical approach to assessing sediment transport capacity. This approach is used to develop dimensionless bedload and suspended rating curves by normalizing the measured transport rates by the bankfull value. Dimensionless rating curves are developed for the project reach and as a reference reach for comparison. Sediment supply often increases in unstable streams, which will cause the curve to shift toward finer sediment sizes. This shift can then be compared to the reference curve to determine if the shift is significantly different.

This approach has been automated and further advanced through the FLOWSED and POWERSED models (Rosgen, 2006). FLOWSED is a model that is used to estimate annual sediment supply/loading, and it is often used to determine functional capacity by comparing results of a project reach to a reference reach, or pre-restoration conditions to post-restoration conditions. FLOWSED is also used to input sediment supply into POWERSED, which is used in conjunction with FLOWSED to determine channel stability. POWERSED includes a hydraulic analysis in order to calculate sediment transport capacity. FLOWSED and POWERSED are included in the RIVERMorph software program (www.rivermorph.com).

3. Bedload Assessment in Gravel-bedded Streams (BAGS)

A simpler spreadsheet-based program called Bedload Assessment in Gravel-bedded Streams (BAGS) was developed by Pitlick et al. (2009). BAGS predicts sediment transport using six different bedload transport equations developed for gravel bed streams. A sediment transport primer by Wilcock et al. (2009), a user manual, and the BAGS program is available from www.stream.fs.fed.us/publications/bags.html. The primer is a good document for those who want to learn more about the fundamentals of sediment transport processes.

Design Standard

Sediment transport competency and capacity are two of the most important design elements for stream restoration projects located in *transport zones*. Transport zones are stream reaches that receive significant sediment supply from upstream and adjacent sources. The project reach must be able to transport this load in order to maintain equilibrium. If a project is located in a reach where there is not significant sediment supply, like a small headwater stream or perhaps an urban channel, sediment transport competency and capacity analyses are less important.

In either case, sediment transport calculations are probably more useful as a design and assessment parameter than for determining post-restoration performance. If sediment transport calculations are wrong and the design is flawed as a result, stability problems will be obvious without the need for recalculating competency and capacity (although calculations may help to understand why a project is not properly transporting the sediment load). Indicators of sediment transport problems include excessive bar development (aggradation) and head-cutting (degradation), among others. Harman and Starr (2011) provide a checklist that can be used to help assess whether a natural channel design included the appropriate sediment transport analyses. The checklist is available for free download at http://water.epa.gov/lawsregs/guidance/wetlands/wetlandsmitigation_index.cfm under Technical Resources for Mitigation or www.stream-mechanics.com.

In addition, Rosgen (2006) provides a comprehensive method for assessing vertical stability using a wide range of quantitative and qualitative methods. Other parameters from the Pyramid, like depth variability, percent riffle and pool, and lateral stability provide better performance standards because they represent the *result* of proper sediment transport. If the channel is in equilibrium, there is a greater probability that the appropriate bed features will form and the streambanks will have low erosion rates (rates that are comparable to reference reaches).

8.3 » PARAMETER: LARGE WOODY DEBRIS TRANSPORT AND STORAGE

Description

In addition to sediment, streams also transport, store and breakdown organic matter. Of course the type of organic matter and the rates of transport, storage and breakdown or decomposition vary greatly across the US, with the greatest rates being in forested headwater streams. A forested riparian buffer delivers many types of organic matter to the

stream, including leaves, large woody debris (LWD), dissolved organic compounds, feces and even dead animals (Richardson et al., 2005). LWD includes logs, limbs and whole trees that are sometimes transported or stored in the channel and oftentimes stored on the floodplain and floodprone area (Wohl, 2000).

The minimum size for organic matter to be classified as LWD is often reported as 10 cm in diameter (Wohl, 2000). Davis et al. (2001) defines LWD as having a 10-cm diameter at one end and is over 1 m in length. There is no maximum size for LWD, and it can include parts of trees (limbs), entire trees or groups of trees. Particulate organic matter (POM — leaves, needles and small pieces of wood) transport can be considered a Geomorphology (Level 3) parameter, at least in terms of recruitment and transport; however, since POM breaks down much faster than LWD, it fits better under organic processing, which is a Physicochemical (Level 4) parameter. The distinction made here is that LWD is a structural control and often included in geomorphology assessments, whereas, the transport and processing of POM is often part of ecological assessments. For this reason, LWD measurements are included in this section and methods for measuring organic processing are included in the Physicochemical Chapter (Level 4).

Large woody debris is most prevalent in mountain streams (Rosgen stream types A and B) and provides an important form of boundary roughness and flow resistance. Additionally, LWD can increase localized bank erosion and, therefore, sediment supply; produce a stepped channel profile where large pieces span the channel width; create sediment and organic matter storage areas; provide cover for fish; and increase substrate diversity (Wohl, 2000). In this role, LWD has a major influence on bed forms, sediment transport and channel stability — clearly a Pyramid Level 3 parameter. It also provides structure that is important for the processing of organic matter (Level 4 – Physicochemical) and supporting macroinvertebrate and fish health (Level 5 – Biology).

Measurement Method

There is an increasing amount of literature about the role and importance of LWD in rivers. Montgomery et al. (2003) provides a good overview of the geomorphic effects of wood in rivers with a global and historical overview. Abbe and Montgomery (1996) describe the role of LWD jams on channel hydraulics and habitat formations in large rivers of the Pacific Northwest. Webster et al. (1999) describes the transport and breakdown of allochthonous material at the Coweeta research forest, a Southeastern US watershed.

1. Wohl LWD Assessment

Wohl et al. (2009) published a recommended list of parameters and methods of measurement to create a more standardized approach to measuring LWD. This list may be more suited for stream assessments that are associated with research projects than those for stream restoration. However, as noted in this document, many of these parameters can be measured rapidly. Unfortunately, there have not been enough studies or assessments completed using this method, and especially on high-quality streams, to create a reference reach database and, therefore, a basis for developing performance standards.

Hopefully, that information will be available in the near future. A list of parameters and measurement methods from Wohl et al. (2009) are provided at stream.fs.fed.us/publications/documentsStream.html. Level I lists metrics that the authors propose should be included in all studies; Level II lists those metrics that are more applicable to a research project.

2. Large Woody Debris Index (LWDI)

While the research continues to evolve, Davis et al. (2001) provides a moderately rapid and simple method of measuring LWD that includes a Large Woody Debris Index (LWDI), making it a useful technique for comparing LWD functionality at a project reach to a reference reach. Two stages of assessment of LWD and debris dams are described by Davis et al. (2001). Stage 1 involves simply counting all LWD pieces and debris dams within a reach and standardizing the count, based on reach length or sample area. In addition to total counts of LWD and debris jams, stage 2 includes the single LWD piece and debris dam size, compared to stream size, its position in the channel and the overall stability of the LWD. The data collected in stages 1 and 2 are used to compute the LWDI. Davis et al. (2001) also provide guidance on how to set up a monitoring program to collect and evaluate the data, which generally include multiple samples that are statistically compared to a reference stream.

Performance Standard

Many restoration projects are beginning to incorporate LWD into their designs. This is most prevalent in the Pacific Northwest, where practitioners are using engineered log jams to restore floodplain connectivity, pool habitat and substrate diversity, as well as reduce streambank erosion (Abbe et al., 2003). Rosgen (2010) is also incorporating more wood into natural channel designs through the use of a toe-wood structure. Harman (2004) shows techniques for using root wads and cover logs to increase wood in the outside of meander bends. In these cases, performance may be measured based on the stability of the structures post-restoration and flows that exceed the bankfull discharge.

To determine the overall performance of LWD on creating bed form diversity, organic matter and nutrient retention, and channel stability, the LWDI index can be used. A Functioning stream would have a LWDI that statistically has the same score as the reference reach. A Not Functioning stream would have statistically significant lower value than the reference stream with no evidence that the stream is trending towards a Functioning condition, e.g., no buffer along the study reach or upstream. A Functioning-at-Risk stream would also be statistically lower than the reference condition; however, the trend is toward a Functioning condition, e.g., a buffer has been planted or is already established and/or a wood supply exists upstream (Table 8.2).

TABLE 8.2 LARGE WOODY DEBRIS PERFORMANCE STANDARDS

MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
Large Woody Debris Index (LWDI)	LWDI of project reach equals LWDI of reference reach	LWDI of project reach does not equal reference reach, but is trending in that direction.	LWDI of project reach does not equal LWDI of reference reach and is not trending in that direction.

8.4 » PARAMETER: CHANNEL EVOLUTION

Description

Channel evolution occurs when a stream system begins to change its morphology from one condition or stream type to a new condition or stream type. Channel evolution can be a negative or positive trend. As described by Leopold (1994), a stream system is a “transporting machine” for water and sediment. An open system, such as a stream, will attempt to work toward two end goals: (1) to perform a minimum amount of work and (2) to expend energy uniformly. A stream system that is in equilibrium is one where these goals are balanced (Leopold, 1994).

Channel evolution can be the result of a channel changing to a more stable or efficient form. This is commonly seen in stream restoration where new channel geometry is altered to a more stable form. Restored channels are typically constructed so that they can improve (evolve) their functional capacity over time. In a meandering stream, this generally corresponds to an evolution from a Rosgen C stream type to an E. An example of this process is shown below in Figures 8.3 and 8.4. Figure 8.3 is a 2002 photo of a riffle, taken a few months after construction and a bankfull event. Note the deposition on the right bank (left side of photo). Figure 8.4 is a photo of the riffle in 2006 after the vegetation has become more established.

The channel evolved from a C stream type with a bankfull width/depth ratio of 14 in 2003 to an E stream type in 2007, with a bankfull width/depth ratio of 9. The cross section in Figure 8.5 (below) represents the riffle. The deposition on the right bank is a natural levee that was formed between the upstream point bar and the riffle section. There was toe erosion along the left bank; however, the riffle evolved in a positive direction as shown by the decrease in bankfull width/depth ratio, while maintaining a BHR near 1.0.

Channel evolution can also be the result of a disruption to the stream or watershed. If a disruption to either the amount of stream power (such as from a change in slope or discharge) or to the work to be done (such as a change in the amount of sediment supply), the stream’s equilibrium may be disturbed, and the stream channel may begin evolving to meet the new conditions. This relationship was first described by Lane (1955). Lane’s diagram states that the sediment size multiplied by the sediment load is proportional to the stream discharge multiplied by the slope (Figure 8.6).

FIGURE 8.3 RESTORED RIFFLE IN 2002



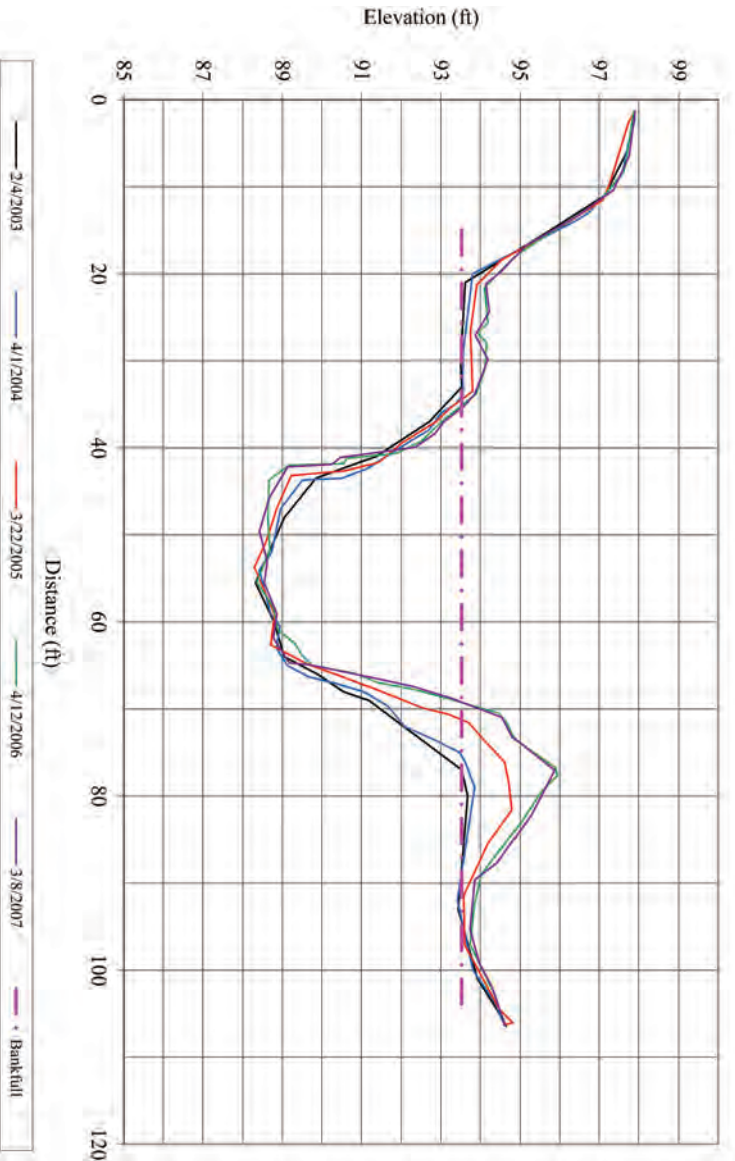
Source: Reproduced with permission from Michael Baker Corporation

FIGURE 8.4 RESTORED RIFFLE IN 2006



Source: Reproduced with permission from Michael Baker Corporation

FIGURE 8.5 EVOLUTION OF THE RIFFLE CROSS SECTION FROM 2003 TO 2007



Source: Reproduced with permission from Michael Baker Corporation and Wetland Hydrology

A common sequence of physical adjustments (channel evolution) has been observed in many streams following disturbance. Disturbance can result from channelization, which is an increase in runoff due to build-out in the watershed, removal of streamside vegetation or other changes that negatively affect stream stability. These disturbances occur in both urban and rural environments. Several models have been used to describe this process of physical adjustment for a stream.

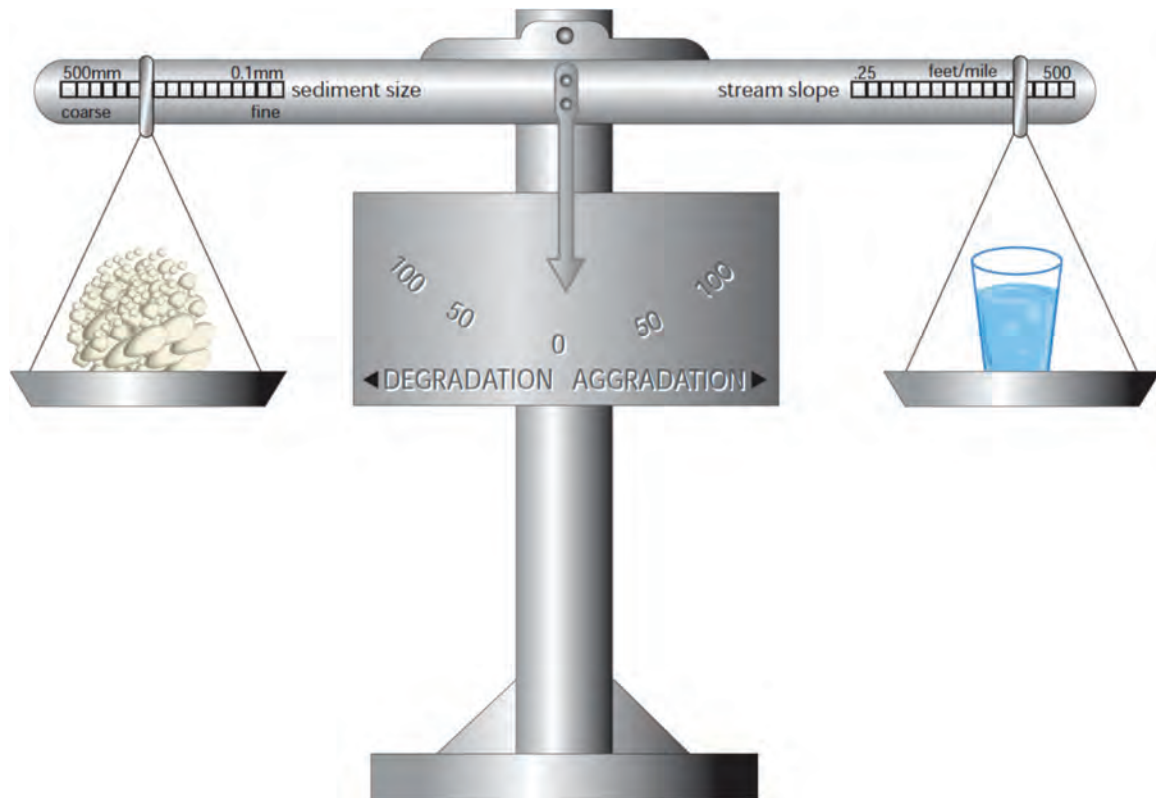
The channel evolutionary stage conveys important information about the pressures on stream systems and the stream channel's response. Stream and river restoration projects often have an end goal of stabilizing the stream system, i.e., bringing the system into equilibrium. In order to prevent or correct stream stability issues the current evolutionary stage of the channel, and the pressures acting upon it must be understood.

Measurement Method

Understanding channel evolution is helpful during geomorphic assessments, restoration goal setting and project evaluation. Channel evolution can be used during the geomorphic assessment phase to determine whether the stream reach is trending towards stability or instability. This determination helps to establish better goals. If the stream is trending towards stability (late stage of evolution), then the restoration goals can be more

FIGURE 8.6 GRAPHIC REPRESENTATION OF LANE'S DIAGRAM

The sediment size and load is shown on the left, and discharge and slope (power) is shown on the right. When one of these parameters changes, there is often a change in streambed elevation. For example, an increase in channel slope from channelization often leads to degradation.



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passive. These passive approaches often include land use management changes or simply re-establishing a wide riparian buffer. If the stream is stable but is showing signs of instability (early stage of channel evolution) like the early signs of a headcut, then the goal may be to simply stabilize the headcut to prevent further upstream damage. Full-scale restoration goals are often needed for streams that have been disturbed and are evolving towards increasingly unstable conditions or reaches that will require many years of adjustment before reaching equilibrium. Channel evolution can then be used after restoration to help show that the stream is moving from a newly constructed condition to a reference condition, e.g., a C evolving to an E.

If the stream is trending towards stability (late stage of evolution), then the restoration goals can be more passive.

Channel evolution can be assessed using Simon's Channel Evolution Model, Rosgen's Stream Type Succession Scenarios or both. Both methods involve assessing the stream in its current condition and determining its evolutionary endpoint.

1. Simon Channel Evolution Model

The Simon (1989) Channel Evolution Model (Figure 8.7) characterizes evolution in six steps, including:

1. Sinuous, pre-modified
2. Channelized
3. Degradation
4. Degradation and widening
5. Aggradation and widening
6. Quasi-equilibrium

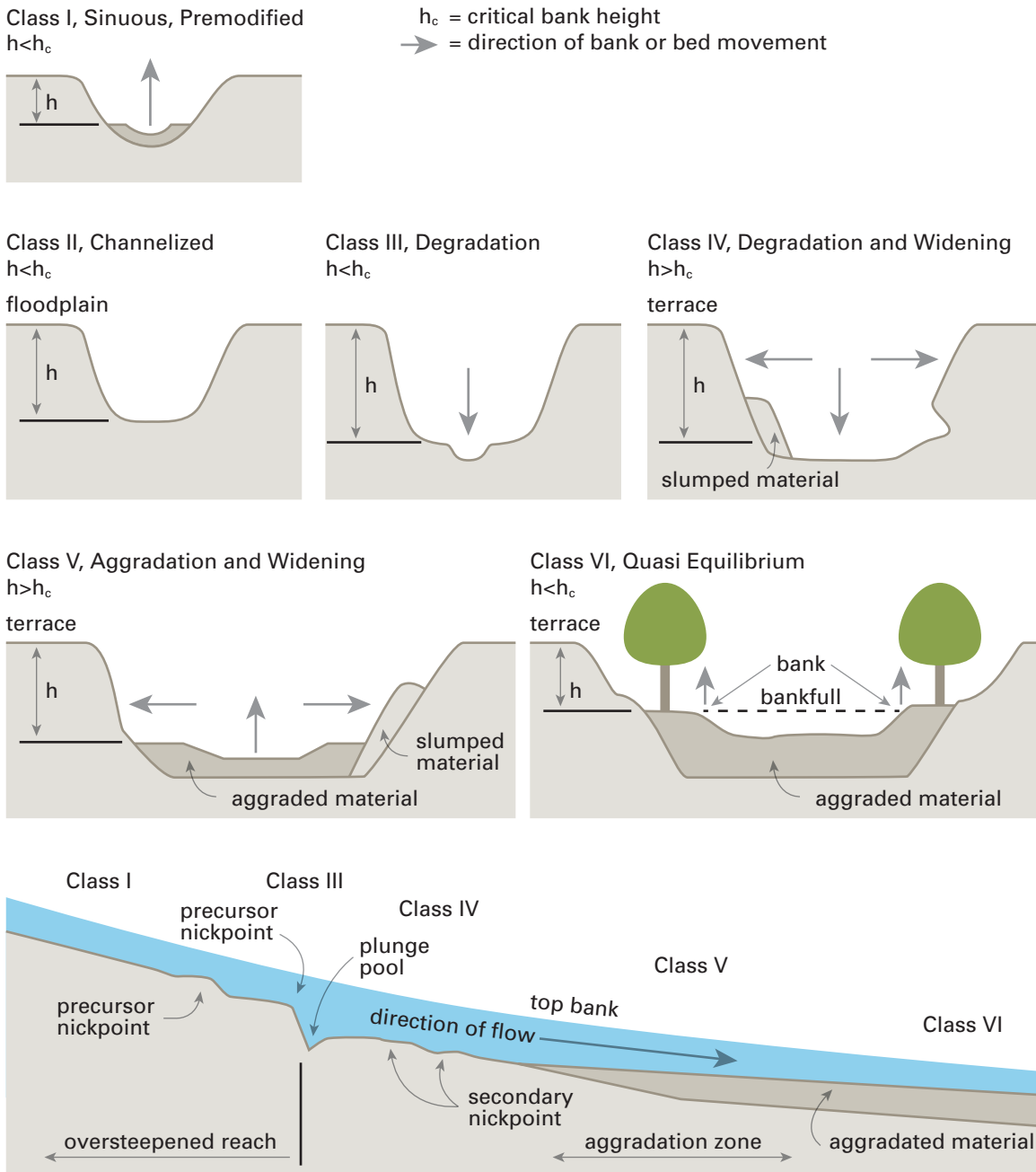
The channel evolution process is initiated once a stable stream that is well connected to its floodplain is disturbed. Disturbance commonly results in an increase in stream power that causes degradation, often referred to as channel incision (Lane, 1955). Incision eventually leads to over-steepening of the banks; and when critical bank heights are exceeded, the banks begin to fail. Incision and widening continue as headcutting moves upstream. Eventually the bed slope is reduced, and sedimentation from bank erosion begins to fill the channel (aggradation). A new, low-flow channel begins to form in the

Full-scale restoration goals are often needed for streams that have been disturbed and are evolving towards increasingly unstable conditions or reaches that will require many years of adjustment before reaching equilibrium.

sediment deposits. By the end of the evolutionary process, a stable stream geometry, similar to those of undisturbed channels, forms in the deposited alluvium. The new channel is at a lower elevation than its original form, with a new floodplain constructed of alluvial material (FISRWG, 1998).

The first step toward determining the channel evolution using this method is to characterize the channel in its current condition. This may involve using similar morphological indicators to determine vertical and lateral stability, as well as reviewing sediment transport calculations, as described in the Rosgen (2006) method. Then an evolutionary stage from Simon's model can be selected. For example, a newly channelized stream corresponds to Stage 2 of the Simon model. If an active headcut is observed in this channelized stream, it indicates vertical instability, which corresponds to Stage 3 of the Simon model. If BHRs are high, indicating incision, the stream may begin to have rotational and slab bank failure from the changes in bank hydrostatic pore pressure caused by the drop in the water table. This will cause the channel to widen, which would indicate that the stream is in Stage 4

FIGURE 8.7 SIMON CHANNEL EVOLUTION MODEL



Source: Adapted from FISRWG(1998) and Simon (1989)

of the Simon model. Stage 4 also corresponds to an increase in width to depth ratios. As the stream continues to widen the slope decreases from down-cutting, the channel loses the capacity to transport the sediment received. Depositional features, such as mid-channel and transverse bars, begin to develop, which force velocity vectors towards stream-banks and cause increased bank erosion or widening. This is Stage 5 of the Simon model.

The level of effort and complexity for using the Simon Channel Evolution Model varies depending on a qualitative versus a quantitative assessment. An experienced practitioner can predict the stage of evolution by simply observing the channel, making the level of effort “rapid” and level of complexity “simple.” If field measurements are taken, the level of effort and complexity increase to moderate (Appendix Ac).

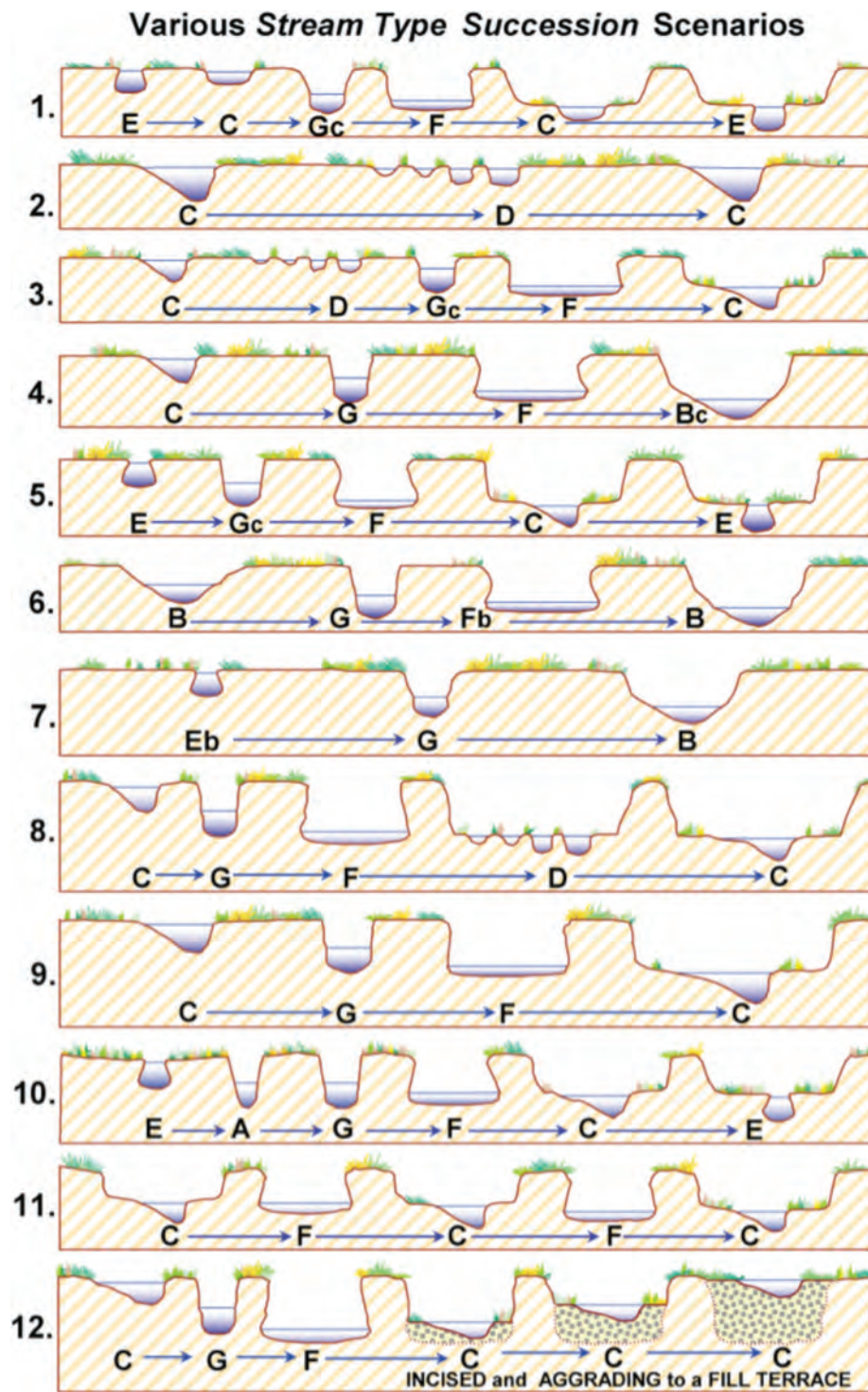
2. Rosgen Stream Type Succession Scenarios

Rosgen (2006) uses changes in stream type to illustrate channel evolution. These changes were measured in streams throughout the US. Nine different stream type succession scenarios are shown in Rosgen (2006). Since that publication, three more scenarios have been added, and all 12 are shown below in Figure 8.8 (Rosgen, 2010, personal communication). Scenario 5 most closely matches the Simon (1989) approach.

The first step toward determining the channel evolution with this method is to classify the channel using the Rosgen (1994) methodology. After determining the stream type, observations should extend to the valley to determine what the naturally forming stream type is for the given valley. Rosgen (1996) provides information regarding which stream types occur naturally in certain valleys. Knowing the naturally occurring, stable stream type provides the potential evolutionary starting and/or end point for the stream.

The next step in determining the channel evolution is to determine if the stream is already at its evolutionary end point, or if it is in one of the stages of evolution. Morphological indicators can give clues as to whether a channel is vertically unstable, laterally unstable or both. These include the presence (or absence) of features such as headcuts and depositional bars; the presence and location of bank erosion; and geomorphic channel measurements, such as bank height ratio, entrenchment ratio and width to depth ratio. These indicators provide insight into whether the channel is aggrading or degrading. These observations are then compared to sediment competency calculations to determine whether the bankfull flows have the force to entrain the sediment delivered by the watershed, or if they have excessive force and may mobilize the entire bed. Rosgen (2006) provides a detailed assessment method, which includes a series of geomorphology-based worksheets used to determine channel stability. After the geomorphic and stability data are gathered, the appropriate evolutionary sequence can be selected from one of the 12 scenarios shown in Figure 8.8. These determinations can be made visually by an experienced practitioner and can, therefore, be completed rapidly. However, they can also be measured, which increases the level of effort and complexity to moderate (Appendix Ac).

FIGURE 8.8 ROSGEN EVOLUTION MODEL BY STREAM TYPE



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Performance Standard

Channel evolution as a performance standard is different than most of the other parameters in that it is a summary condition that integrates several parameters and

Channel evolution as a performance standard is different than most of the other parameters in that it is a summary condition that integrates several parameters and processes. As such, it may be tempting to use channel evolution as the only performance standard in the Hydraulic and Geomorphology categories. This approach is strongly discouraged because stream type alone does not provide stability and functional capacity information.

processes. As such, it may be tempting to use channel evolution as the only performance standard in the Hydraulic and Geomorphology categories, stating for example that a Rosgen C stream type is Functioning and therefore meets the performance standard. This approach is strongly discouraged because stream type alone does not provide stability and functional capacity information. There are many C and E stream types that are Functioning-at-Risk or Not Functioning. Keep in mind that a channel could have a bank height ratio of 1.8, a very incised channel, and still classify as a C or E.

The reason for including channel evolution is to show the current channel condition and how it could change over time. The federal mitigation rule suggests that performance standards be based on data from reference reach streams. One reason for this is to show the natural range of variability that exists in stable, functioning streams. The rule also states that performance standards should show the expected stages of

the aquatic resource development process, in order to allow early identification of potential problems and appropriate adaptive management. Channel evolution can be used along with other parameters to show the expected stages of development in a restoration project. For example, many projects are designed and built as a C stream type. Over time, the channel evolves to an E stream type. Showing this evolution indicates that the stream is trending towards a higher degree of functionality. A restored channel that is built as a C stream type but begins to evolve to a Gc stream type represents a negative trend, one that leads to instability and a loss of function. This project would require immediate attention.

Tables 8.3 and Table 8.4 summarize the various stages for each measurement method and whether they are Functioning, Functioning-at-Risk or Not Functioning. The arrow (→) means that the stream type is changing from the former to the latter. For example, a C→Gc means that the current stream type is a C, and the stream is trending towards a Gc. This table can be used as an aid in performing geomorphic assessments, goal setting and for evaluating stream restoration projects.

TABLE 8.3 PERFORMANCE MEASUREMENT FOR ROSGEN’S STREAM TYPE EVOLUTIONARY STAGES

MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
Rosgen’s Stream Type Succession Scenarios			
1. E→C→G _c →F→C→E	E, C	C→G _c and F→C	G _c , F
2. C→D→C	C	C→D and D→C	D
3. C→D→G _c →F→C	C	C→D and F→C	D, G _c , F
4. C→G→F→B _c	C, B _c	C→G and F→B _c	G, F
5. E→G _c →F→C→E	E, C	E→G _c and F→C	G _c , F
6. B→G→F _b →B	B	B→G and F _b →B	G, F _b
7. E _b →G→B	E _b , B	E _b →G and G→B	G
8. C→G→F→D→C	C	C→G and D→C	G, F, D
9. C→G→F→C	C	C→G and F→C	G, F
10. E→A→G→F→C→E	E	E→A and F→C	A, G, F
11. C→F→C→F→C	First and last C	C→F	F
12. C→G→F→C→C→C	First and last C	C→G and C→C	G, F, Fourth C

TABLE 8.4 PERFORMANCE MEASUREMENT FOR SIMON’S CHANNEL EVOLUTION STAGES

Simon (1989) Channel Evolution Model Stages			
	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
1. Sinuous, pre-modified	✓		
2. Channelized			✓
3. Degradation			✓
4. Degradation and widening			✓
5. Aggradation and widening		✓ *	
6. Quasi-equilibrium	✓		

* Only late Stage 5 of the Simon model, where the stream has begun to construct a new floodplain at a lower elevation, is considered to be Functioning-at-Risk.

In addition to the performance standards provided above, Table 8.5 may be helpful in illustrating the effects of stream type changes on habitat parameters. These parameters are provided by Rosgen and do not directly correspond to parameters on the Pyramid. This table is provided by Rosgen (2010, personal communication) and shows how each

variable (parameter) responds to the change in stream type. An up arrow means that there is an improvement, a down arrow means that there is a functional loss, and a sideways arrow indicates no change. The green shading indicates that these two stream type evolutionary changes are positive or, using Performance Standard terminology, Functioning-at-Risk. Once they evolve to a C or E stream type, they will be Functioning.

TABLE 8.5 THE EFFECTS OF STREAM TYPE CHANGES ON HABITAT PARAMETERS

Variable	C→G	G→F	C→D	F→C	C→E
Instream Cover	↓	↓	↓	↑	↑
Overhead Cover	↓	↓	↓	↑	↑
Substrate Composition	↑	↓	↓	↑	↑
Pool Quality	↓	↓	↓	↑	↑
Holding Cover Velocity	↓	↓	↓	↑	↑
Temperature	→	↑	↑	↓	↓
Oxygen	→	↓	↓	↑	↑
Macro Invertebrates	↓	↓	↓	↑	↑
Spawning Habitat	↓	↓	↓	↑	↑
Diversity	↓	↓	↓	↑	↑
Rearing	↓	↑	↑	↑	↑
IBI Score	↓	↓	↓	↑	↑

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8.5 » PARAMETER: BANK MIGRATION/LATERAL STABILITY

Description

Lateral stream migration commonly occurs on rivers that flow through alluvial valleys. A channel migrates within the floodplain through lateral erosion on the outside of meander bends and subsequent deposition on the interior bend, or point bar. In order to understand bank migration and lateral stability, energy expenditure in a stream system should be addressed first. Streams and rivers are open systems, which have a continual source of potential energy supplied by topographic elevation and precipitation (the hydrologic cycle). The potential energy supplied by the rain and elevation is transformed to kinetic energy as water flows downhill. The kinetic energy carries sediment downstream (sediment transport) and causes some erosion from turbulence and friction along the channel boundary. In an alluvial valley where the boundary conditions (bank materials) are erodible, meanders will form and continue to erode until the stream achieves a plan form, where energy is expended uniformly and the least amount of work possible is accomplished (Leopold, 1994). Once this equilibrium is achieved, a stream may continue to

migrate but will deposit materials in bars to maintain the bankfull cross-sectional area.

Bank migration and lateral stability are as much a function of the bank materials and bank cover as they are the in-stream hydraulic forces acting upon them. This is because bank materials and vegetative cover resist hydraulic forces, such as shear stress. A barren bank composed primarily of sand, for example, is more susceptible to erosion than a densely vegetated clay bank. In addition, some stream types are naturally more susceptible to bank erosion than other stream types. Stream types A and B are less likely to experience extreme bank migration because of their confined valleys and steep vertical profiles, often controlled by bedrock or colluvium. Stream types C and E are more likely to experience bank migration since these stream types are by nature sinuous, meandering stream channels, which actively migrate across floodplains. Stream types F and G are often associated with excessive bank erosion because they are entrenched. Bank erosion within these stream types can be extreme in disturbed systems where the former stream type was a C or E (see section on Channel Evolution). However, F and G stream types associated with bedrock-controlled gorges may be stable. Rosgen (1994) provides a table (Table 8.6) showing the sensitivity to lateral adjustment and recovery potential. In this example, recovery potential means the ability of the stream to return to a laterally stable condition without human intervention.

TABLE 8.6 Rosgen (1994)

Illustrates the sensitivity to disturbance, recovery potential, typical sediment supply conditions, streambank erosion potential and the influence of bank vegetation on stability for a wide range of stream types.

Stream Type	Sensitivity to disturbance ^a	Recovery potential ^b	Sediment supply ^c	Streambank erosion potential	Vegetation controlling influence ^d
A1	Very low	Excellent	Very low	Very low	Negligible
A2	Very low	Excellent	Very low	Very low	Negligible
A3	Very high	Very poor	Very high	Very high	Negligible
A4	Extreme	Very poor	Very high	Very high	Negligible
A5	Extreme	Very poor	Very high	Very high	Negligible
A6	High	Poor	High	High	Negligible
B1	Very low	Excellent	Very low	Very low	Negligible
B2	Very low	Excellent	Very low	Very low	Negligible
B3	Low	Excellent	Low	Low	Moderate
B4	Moderate	Excellent	Moderate	Low	Moderate
B5	Moderate	Excellent	Moderate	Moderate	Moderate
B6	Moderate	Excellent	Moderate	Low	Moderate
C1	Low	Very good	Very low	Low	Moderate
C2	Low	Very good	Low	Low	Moderate
C3	Moderate	Good	Moderate	Moderate	Very high
C4	Very high	Good	High	Very high	Very high
C5	Very high	Fair	Very high	Very high	Very high
C6	Very high	Good	High	High	Very high

TABLE 8.6 Rosgen (1994) (CONT.)

Illustrates the sensitivity to disturbance, recovery potential, typical sediment supply conditions, streambank erosion potential and the influence of bank vegetation on stability for a wide range of stream types.

Stream Type	Sensitivity to disturbance ^a	Recovery potential ^b	Sediment supply ^c	Streambank erosion potential	Vegetation controlling influence ^d
D3	Very high	Poor	Very high	Very high	Moderate
D4	Very high	Poor	Very high	Very high	Moderate
D5	Very high	Poor	Very high	Very high	Moderate
D6	High	Poor	High	High	Moderate
Da4	Moderate	Good	Very low	Low	Very high
DA5	Moderate	Good	Low	Low	Very high
DA6	Moderate	Good	Very low	Very low	Very high
E3	High	Good	Low	Moderate	Very high
E4	Very high	Good	Moderate	High	Very high
E5	Very high	Good	Moderate	High	Very high
E6	Very high	Good	Low	Moderate	Very high
F1	Low	Fair	Low	Moderate	Low
F2	Low	Fair	Moderate	Moderate	Low
F3	Moderate	Poor	Very high	Very high	Moderate
F4	Extreme	Poor	Very high	Very high	Moderate
F5	Very high	Poor	Very high	Very high	Moderate
F6	Very high	Fair	High	Very high	Moderate
G1	Low	Good	Low	Low	Low
G2	Moderate	Fair	Moderate	Moderate	Low
G3	Very high	Poor	Very high	Very high	High
G4	Extreme	Very poor	Very high	Very high	High
G5	Extreme	Very poor	Very high	Very high	High
G6	Very high	Poor	High	High	High

a Includes increases in streamflow magnitude and timing and/or sediment increases.

b Assumes natural recovery once cause of instability is corrected.

c Includes suspended and bedload from channel derived sources and/or from stream adjacent slopes.

d Vegetation that influences width/depth ratio-stability.

Measurement Method

Bank migration can be measured a variety of ways, ranging from rapid and simple methods to intensive and complex. This document provides examples from simple interpretations of aerial photographs to complex computer models. These measurement methods are listed in progressive order, from simple to complex.

1. Meander Width Ratio

Meander width ratio is the ratio of stream belt width divided by stream bankfull width. The belt width is the distance from the apex of one meander bend to the next meander bend, measured perpendicular to the fall line of the valley (Figure 8.9). To compare belt widths between different size streams, the belt width is divided by the bankfull width to create a dimensionless ratio. The minimum meander width ratio for meandering streams (C and E stream types) is between 3.0 and 3.5; this ratio is required to create a sinuosity of at least 1.2, the most common break point between meandering and non-meandering streams (Rosgen, 1996; Leopold and Wolman, 1957). If a straightened stream is eroding on both banks and readjusting its pattern, the bankfull width (measured from the aerial) can be multiplied by 3.5 (conservatively) to estimate the amount of lateral erosion that will likely occur.

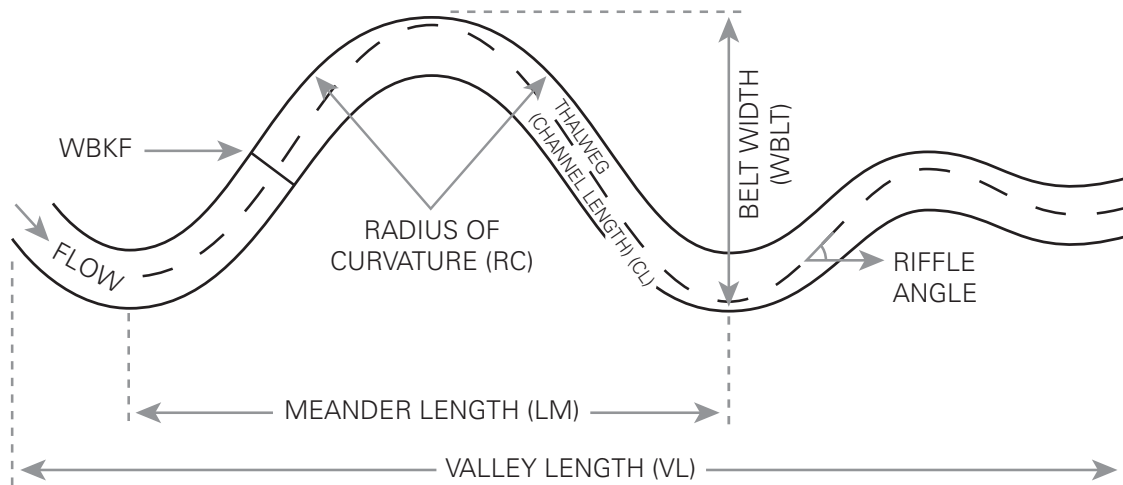
Meander width measurements can rapidly be taken from existing engineering plans, topographic maps and aerial photographs. Aerial photography, unlike other methods providing information about lateral stability and bank erosion on a local, short-term scale, can be used to determine lateral stability over a much longer time frame and over great distances. Historic aerial photography can be overlaid with current photography to determine the degree of lateral migration that has occurred between the dates of the photographs. Digital orthophotos can usually be purchased from local or state governments and are preferred over some free Web services that do not provide geo-corrected photographs.

Using aerial photography to determine lateral stability has its benefits. For relatively low cost and time expenditure, aerial photography affords long-term views of the stream channel position in the floodplain. It can also provide information about whether the channel migrated rapidly or slowly in the past, and whether a local or watershed disturbance, such as deforestation, is correlated to the channel migration changes. A limitation to aerial photography is that it only provides plan view information, i.e., it is not possible to calculate the volume of eroded sediment without a field measurement of the bank height or more advanced techniques for reading aerial photos. Aerial photograph analysis combined with reference reach surveys can be used to determine the ultimate belt width of an unstable C or E stream type.

2. BEHI/NBS

Rosgen's Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) rating methods can be used to estimate the annual amount of lateral erosion/migration. These methods involve collecting relatively simple measurements and visual observations of streambanks, including bank cover, depth of root mass, channel composition and bank slope; then a BEHI risk rating is assigned, from very low to extreme. Observations of channel flow characteristics, including water-surface slope, direction of velocity vectors and other methods, are used to assess the NBS risk rating, which can range from very low to extreme. These ratings can be used with a streambank erodibility rating curve, appropriate for the area, to derive a predicted annual linear footage of bank erosion per year. A detailed description of this method is in Rosgen (2009). The BEHI/NBS assess-

FIGURE 8.9 PATTERN MEASUREMENTS AND RATIOS, INCLUDING THE MEANDER WIDTH



CHANNEL PATTERN CALCULATIONS
RADIUS OF CURVATURE / RIFFLE WIDTH (RC / WBKF)
MEANDER LENGTH / RIFFLE WIDTH (LM / WBKF)
MEANDER WIDTH RATIO (MWR = WBKT / WBKF)
SINUOSITY (K) = CHANNEL LENGTH (CL) / VALLEY LENGTH (VL)

ment can be completed with a moderate level of effort if the practitioner is not quantitatively measuring every bank, but rather makes qualitative predictions with periodic measurements for calibration. If the practitioner is using bank pins and cross sections (see below) to develop BEHI/NBS curves, the level of effort increases to intensive (Appendix Ac).

3. Bank Pins

Another method for measuring lateral stability or bank erosion/migration is through the installation of bank pins. Bank pins are usually long steel rods (rebar) installed flush with the streambank. The pins are installed at known intervals from the toe of the bank to the top of the bank. Each time the site is visited, the length of exposed rebar is measured and can be combined with the distance between pins to provide a square-footage of bank material lost.

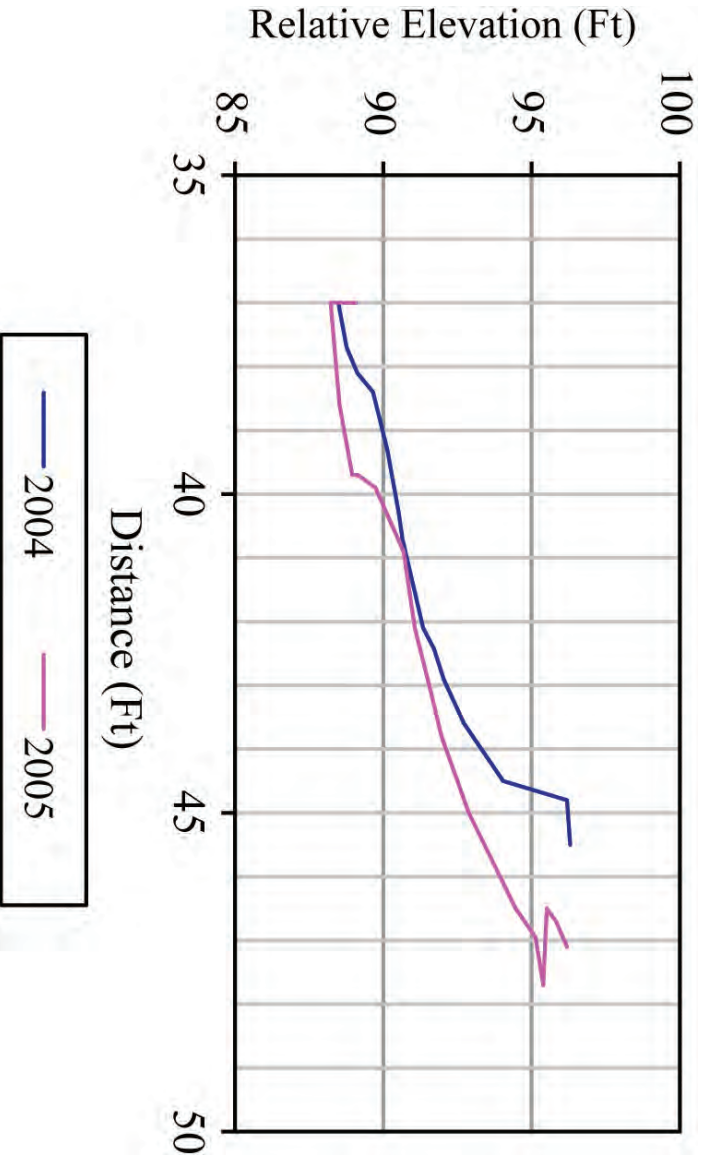
Using bank pins to perform annual monitoring of bank erosion is beneficial due to the relatively low cost and time required. Unfortunately, this method provides information about the eroding bank only and fails to capture information about developing bars (if any). Although visual observations of developing bars can be made, it is difficult to determine whether the erosion and deposition are balanced, and whether the channel is maintaining dimension, despite erosion. More information about banks pins can be found in Harrelson et al. (1994).

4. Bank Profiles

Bank profiles provide detailed information about lateral stability and bank erosion at a particular bank. These profiles involve installing permanent cross-section markers, as discussed in Cross-Sectional Surveys (below), as well as a permanent toe pin marker. The toe pin should be installed at the base of the study bank to ensure that the bank profile is taken in the same location each time. Surveys of the bank are conducted each time the site is visited. Detailed instructions about performing bank profiles are provided by Rosgen (2009).

One benefit to conducting a bank profile survey, as opposed to installing and measuring bank pins, is that a survey captures more detailed information about the bank, allowing for a more precise measurement of bank material lost due to erosion. A bank profile also causes virtually no disturbance to the bank, as opposed to bank pins that require hammering rods into the bank. Some researchers believe that bank pin installation compromises the integrity of the bank, resulting in more erosion than would typically occur if the bank were undisturbed.

FIGURE 8.10 OVERLAY OF TWO BANK PROFILES FROM WATTS BRANCH



Surveys were taken near the same date, one year apart. Note that the 2005 profile shows an overhang at the top of the bank. Overhangs and undercutts are easier to measure with a bank profile than a cross section.

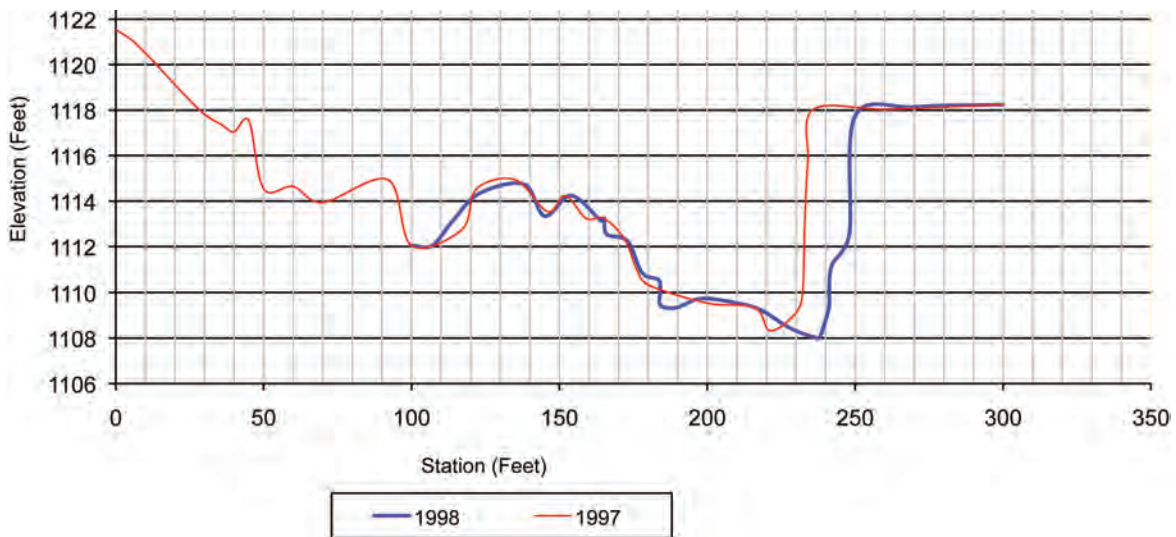
Source: Reproduced with permission from US Fish and Wildlife Service

An example of two bank profiles measured at the same location and overlaid with each other is shown in Figure 8.10. The figure shows a lateral erosion rate of 1.4 feet, which was calculated as the difference in area between the two curves, divided by the bank height. To measure the total amount of bank erosion in ft^3/year , the lateral erosion rate can be multiplied by the bank height and length that is representative of the profile.

5. Cross-Sectional Surveys

Lateral stability and bank erosion/migration can also be measured and monitored through cross-sectional surveys. Cross sections should be defined through installation of permanent markers denoting the beginning and end point of the survey to ensure the section is repeated in the same place each time. Cross sections from year to year can be overlaid and the distance of bank migration can be measured. Unlike bank pins and bank profiles, cross sections provide information about the channel bed and the opposite bank, so deposition or erosion across the entire section can be observed. This can be very useful in helping determine whether lateral erosion is a result of a stable but active and dynamic channel, or if it is the result of a stream out of equilibrium. Also useful is the ability to determine if there has been a change in cross-sectional area, width or depth, as a result of lateral erosion and/or deposition within the section. This provides insight into whether the bank migration is a result of natural migratory processes, or whether it is a result of stream disequilibrium. Detailed information on performing cross-sectional surveys can be found in Harrelson et al. (1994) and Rosgen (2009). An example of two cross sections measured at the same location one year apart is shown below in Figure 8.11. The overlay shows that the right streambank has laterally eroded 15 feet. The point bar location has remained the same, indicating that the bankfull channel width and cross-sectional area is increasing.

FIGURE 8.11 CROSS-SECTIONAL SURVEYS OF AN ERODING STREAMBANK



Source: NC State University, Stream Restoration Program

6. Bank Stability and Toe Erosion Model

Andrew Simon and Eddy Langendoen (2006) developed a computer model that can be used to estimate the potential for bank failure — or lateral instability — from horizontal layer, vertical slice with tension crack, or cantilever failures. The model requires detailed input information about the streambank, including the various soil layers and profile, the water table and stream level, the bank profile, and vegetation present on the bank. The model outputs a factor of safety that corresponds to the potential for bank failure. Due to the amount of data that needs to be collected and entered into the model, this is one of the more complex methods of predicting lateral stability.

Performance Standards

Thresholds for determining whether a stream is Functioning from a bank migration or lateral stability standpoint should be considered with stream channel type and channel evolutionary stage in mind. In general, it is good to compare what is observed in the field with what is known about stable reference reach conditions. There are several different methods for measuring lateral instability; therefore, the performance standards for each are broken down by measurement method. The performance standards provided below are most applicable to Bc, C, E, F and Gc stream types.

1. Meander Width Ratio (MWR)

The Meander Width Ratio (MWR), described above, can be used to determine whether a stream channel is Functioning from a lateral stability perspective. Each stream type has an accepted range of MWRs, as determined from reference reach surveys. MWRs determined from aerial photography can then be compared to known ranges for stable reference reach streams to establish whether the stream is Functioning. Typical ratios for C and E stream types are shown in Table 8.7.

A minimum MWR of 3.0 to 3.5 is critical for stream restoration projects that include new channel construction. If a C or E stream type is designed and constructed with a MWR below 3.0, there is a high risk of bank erosion and reach wide instability. In these cases, the restoration practitioner is trying to force a meandering channel in a confined corridor. Confinement is usually caused by land availability rather than geologic controls. These streams typically have sinuosity less than 1.2 and do not classify as meandering streams. The result is that the stream begins to straighten through bank erosion that extends from the outside of the meander bend downstream to the next point bar. A range of 3.0 to 3.5 is used in the Functioning-at-Risk category because a sinuosity of 1.2 can typically be achieved with this range. For example, W/D ratios less than 12 can often

A minimum MWR of 3.0 to 3.5 is critical for stream restoration projects that include new channel construction. If a C or E stream type is designed and constructed with a MWR below 3.0, there is a high risk of bank erosion and reach wide instability.

achieve the minimum sinuosity of 1.2 with a MWR of 3.0. Higher W/D ratio streams need a MWR of 3.5. Generally, higher MWRs lead to higher functionality (longer riffles and more stream length), as long as the sinuosity does not lower the slope to a point where the channel aggrades.

2. Lateral Erosion (BEHI/NBS)

BEHI and NBS scores can be used to determine thresholds for Functioning, Functioning-at-Risk and Not Functioning. However, a reach wide assessment of bank erosion should be conducted to determine overall functionality from a bank stability perspective. For example, a large tree could fall into a stream creating an unstable bank, perhaps with a high BEHI score and an Extreme NBS score; this would cause the bank to fall into the Not Functioning category. But if the buffer width is sufficient and the banks are well vegetated upstream and downstream of the unstable bank, it is unlikely that the bank erosion will worsen. It will likely heal over time because the overall reach is stable and Functioning. If the buffer is not well established, it is possible that the bank will erode for a long time before it becomes stable and could lead to pattern adjustment and instability for a longer portion of the reach.

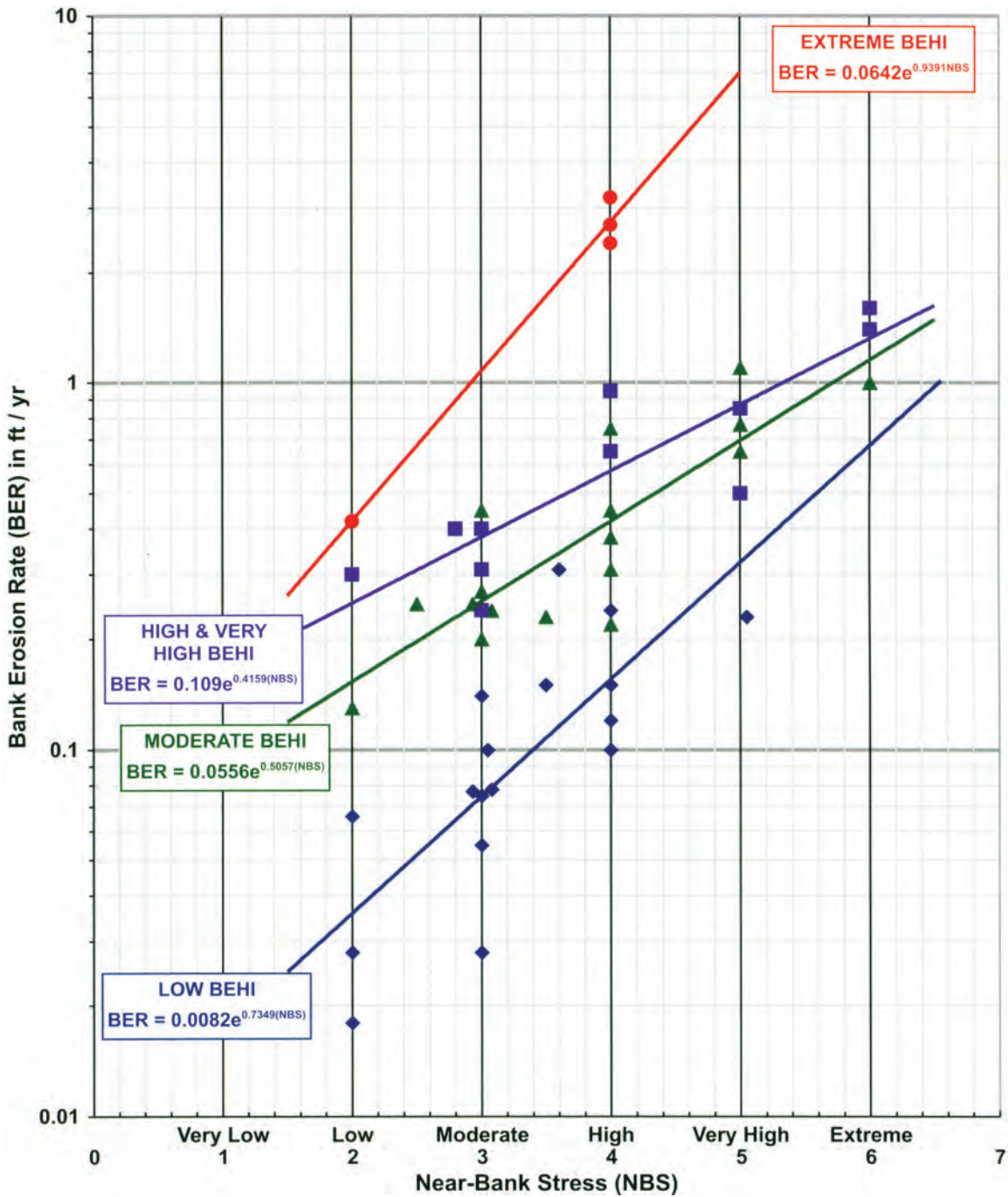
The thresholds shown in Table 8.7 came from a review of the erosion rate curve provided by Rosgen (2001). This curve was developed in Colorado (Figure 8.12), so these ranges could be modified based on locally developed curves. The Rivermorph software package provides erosion rate curves for other parts of the US.

Table 8.7 shows the BEHI categories/curves as rows and the NBS rating in the individual columns for Functioning, Functioning-at-Risk and Not Functioning. The Colorado erosion rate curve shown in Figure 8.12 was used as a guide to determine the level of functionality. In general, if the curve predicted below 0.1 ft/year, a Functioning category is shown. If the erosion rate fell between 0.1 and 0.5 ft/yr, a Functioning-at-Risk category was shown. Not Functioning categories were assigned to curves that predicted above 0.5 ft/yr. This curve was only used as a guide, however, as some curves deviate from this range based on the slope of the curve and its relationship to other curves. Again, these classifications can be modified based on locally generated curves and their comparison to reference reach data.

3. Lateral Erosion (Bank Profile)

Bank profiles provide an actual measurement of erosion in feet/year. Therefore, performance standards can be created based on those measurements as long as several years of data are available that represent varying weather conditions, including bankfull events. The performance standards should be developed from reference streams for the Functioning category, moderately eroding streambanks for Functioning-at-Risk, and highly eroding for Not Functioning. These values are then compared to the erosion rates from project streams, providing an estimate of functional capacity. Typical values for Functioning, Functioning-at-Risk and Not Functioning are provided in Table 8.7. These values are based on the Colorado erosion rate curve shown in Figure 8.12 and data collected by the

FIGURE 8.12 EROSION RATE CURVES BASED ON BEHI AND NBS SCORES IN COLORADO



Source: Reproduced with permission from Wildland Hydrology

authors in North Carolina streams. They are typical values and can be adjusted based on local site conditions.

It should also be noted that these values came from an assessment of a short length of streambank and are not representative of the overall reach length. Many reference reach streams that would be considered laterally stable will have varying levels of bank erosion. Most of the streambanks will be stable with erosion rates similar to what is shown in Table 8.7; however, there may be short sections that have higher erosion rates. If the erosion is localized and will not lead to further instability or reach wide instability, the overall reach should still be considered Functioning.

4. Lateral Erosion (Cross Sections)

Cross-sectional data can give a broader perspective of functionality than the bank profiles, and they are often used together to assess lateral erosion and instability. Cross-sectional data can be used to calculate bankfull cross sectional, area, width and mean depth. From these data, the bankfull width/depth ratio can be calculated as the bankfull width divided by mean depth (W/D). Increases in the W/D ratio are often associated with accelerated bank erosion rates and bed aggradation (Rosgen, 2006). This information is not provided by the bank profile. Rosgen (2009) developed a comparison of project W/D ratios to reference reach W/D_{ref} by simply dividing the W/D by the W/D_{ref}. As the ratio increases, the risk of bank erosion and bed aggradation increases. These values are shown below in Table 8.7 and are used to determine functionality. The values are most applicable to C stream types in Western states. In the Southeastern US, the values can likely be increased slightly because most streams in alluvial valleys are E stream types. It will take bigger changes in the W/D before bank erosion leads to aggradation.

5. Bank Stability and Toe Erosion Model

Simon and Langendoen's (2006) model calculates a Factor of Safety (Fs) value to determine the lateral stability of a bank. The Factor of Safety can be used to establish the functionality for the bank; however, the previous comments still apply. The overall reach should be assessed to determine if the bank erosion is simply a localized problem or symptomatic of a larger, system-wide problem.

TABLE 8.7 LATERAL STABILITY PERFORMANCE STANDARDS

MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
Meander Width Ratio for C and E stream types	≥ 3.5 (based on reference reach surveys)	3.0 to 3.5 as long as sinuosity is ≥ 1.2	< than 3.0
Lateral Erosion rate – Low BEHI Curve	Very low to Moderate NBS	Moderate to Very High NBS	Extreme NBS
Lateral Erosion rate – Moderate BEHI Curve	Very low to Low NBS	Low to High NBS	High to Extreme NBS
Lateral Erosion rate – High and Very High BEHI Curve	N/A	Low to Moderate NBS	Moderate to Extreme NBS
Lateral Erosion rate – Extreme BEHI Curve	N/A	Low NBS	Low to Extreme NBS
Lateral Erosion Rate (Bank Pins and Bank Profiles)	Erosion rate is similar to reference reach values, generally < 0.1 ft/yr	0.1 to 0.5 ft/yr	> 0.5 ft/yr
Lateral Erosion Rate Potential for C4 streams (W/Dproj / W/Dref*)	1.0 to 1.2	1.2 to 1.4	= > 1.4
Bank Stability and Toe Erosion Model	Fs > 1.3	1.0 < Fs > 1.3	Fs < 1.0

* W/D_{proj} = Bankfull width divided by bankfull mean depth from the project reach
 W/D_{ref} = Bankfull width divided by bankfull mean depth from the reference reach

8.6 » PARAMETER: RIPARIAN VEGETATION

Description

The lateral migration parameters discussed above primarily focus on maintaining streambank stability and do not evaluate the overall condition of the riparian buffer. The BEHI/NBS method for predicting streambank erosion, for example, does include assessments of streambank vegetation, but is only for the purpose of providing bank stability. Riparian buffers or zones are the vegetated region adjacent to streams and wetlands that are critical to providing channel stability, cover/shade, wood recruitment to the channel, and a source of carbon (Sweeney, 1993; Hession et al., 2000; Sweeney et al., 2004; Hoffman, 2006; Sweeney and Blaine, 2007). Therefore, the restoration of riparian vegetation as part of a Level-3 assessment and design approach provides the vegetative structure to support many of the Level 3, 4 and 5 functions.

Research has shown that a well-managed restored buffer can trap and/or convert up to 75% of nitrogen and 70% of phosphorus from nonpoint source runoff, if the source is from land uses that are adjacent to the stream corridor (Orzetti et al., 2010; Claussen et al., 2000; Lee et al., 2003; Schoonover and Williard, 2005). Additional research has shown 50% to 80% reductions in sediment loads from adjacent nonpoint source pollution (Orzetti et al., 2010; Cooper et al., 1987; Daniels and Gilliam, 1996; Lowrance and Sheridan, 2005; Schoonover and Williard, 2005; Tomer et al., 2007). Orzetti et al. (2010) went on to show that habitat, water quality and benthic macroinvertebrate parameters improved with the age of the restored buffer. In their study of 30 streams in the Piedmont of Maryland and Virginia, habitat scores (measured using EPA Rapid Bioassessment Protocols) stabilized between 10 and 15 years after restoration. In addition to habitat improvements, the study showed improvements to water quality and macroinvertebrate communities within 5-10 years post-restoration, leading to conditions similar to mature buffers within 10-15 years post-restoration. Mayer et al. (2005) provides a broader review of the science and regulation of riparian buffers. This literature review focused primarily on research related to nitrogen removal by riparian buffers. The study found that buffers greater than 150 feet wide more consistently removed significant portions of nitrogen entering the riparian zone. The study also found that in order to maintain buffer effectiveness, buffer integrity should be protected against soil compaction, loss of vegetation and stream incision. Stream incision is a key point because a lot of the denitrification occurs through subsurface flow interacting with the root zone of the buffer. If the stream becomes incised and the water table drops, the subsurface flow essentially bypasses the buffer, not allowing denitrification to occur. The assessment of stream incision is part of the Level 2 assessment of Hydraulic functions and the floodplain connectivity parameter.

It is important to note that buffer composition, density and function vary across the country based on climatic and geologic differences. Many of the studies listed above focus on hardwood forests in the Eastern US; however, bottomland hardwoods would not be expected in prairie lands of the Great Plains and Midwest, or arid areas of the Southwest. Reference reach analyses should be completed to determine the functional capacity for a given region. Nevertheless, riparian buffers are important for providing channel stability and supporting Level 4 and 5 functions, regardless of their setting.

For stream assessments and restoration projects, it is also important to identify the potential impacts from land use and other stressors that may exist within and surrounding the riparian buffer area. Watershed disturbances, including livestock grazing, agriculture and urbanization may have affected the soils and hydrology of the buffer and may continue to be a challenge after restoration. Soil compaction and loss of soil fertility can hinder riparian vegetation establishment and growth along with lowered water table elevations. Land disturbance activities also increase the potential for invasive species populations to affect the native vegetation and limit the riparian buffer function. Herbivory and beaver activities can also add pressure on riparian vegetation during establishment and growth in certain watersheds. Although impacts and stressors may be difficult to control outside the buffer area, stream restoration design should always consider these

factors when selecting vegetative species, specifying methods to improve soil conditions and by attempting to reconnect the groundwater table to the riparian buffer root zone. Vegetation maintenance plans are desirable that address these impacts and stressors for the estimated duration of buffer function development.

Overall benefits provided by riparian buffers include:

1. Shade cover, which reduces both air and water temperature fluctuations due to sun exposure within the riparian zone (Barton et al., 1985);
2. Organic matter contributions, including leaf litter that supports macrobenthos food webs and woody debris that creates more diverse bed form and additional organic matter (Dolloff and Warren 2003, Quinn et al., 2007, Opperman et al., 2004);
3. Dissipation of energy and capturing of sediment from upslope overland flow and floodwater (Magette et al., 1989);
4. Nutrient uptake by roots of the riparian vegetation from groundwater moving downslope, acting as a sink to limit what reaches the stream (Lowrance et al., 1984);
5. Stabilization of the streambank by roots that extend throughout the bank (Wynn et al., 2004); and
6. Landscape connectivity for animals traveling along the stream corridor, connecting patches of riparian habitats across the landscape (Fisher et al., 1998).

These are just some of the key benefits that a functioning riparian zone provides; more details can be found in Knight and Bottorff (1984), and Naiman and Decamps (1997).

Measurement Method

Riparian buffers are often assessed by measuring the width, vegetation density, vegetation composition, age-class distribution, and growth and canopy density. Air and water temperature may also be included as a method for assessing buffer functionality, but these measurements are made as part of the Physicochemical assessment (Level 4). Methods for measuring each of these parameters are described below. In addition, rapid methods called the Proper Functioning Condition (PFC), EPA Rapid Bioassessment Protocol (RBP), NRCS Rapid Visual Assessment Protocol (RVAP), and USFWS Stream Assessment Ranking (SAR) are described that can be used to determine the overall functionality of the riparian corridor.

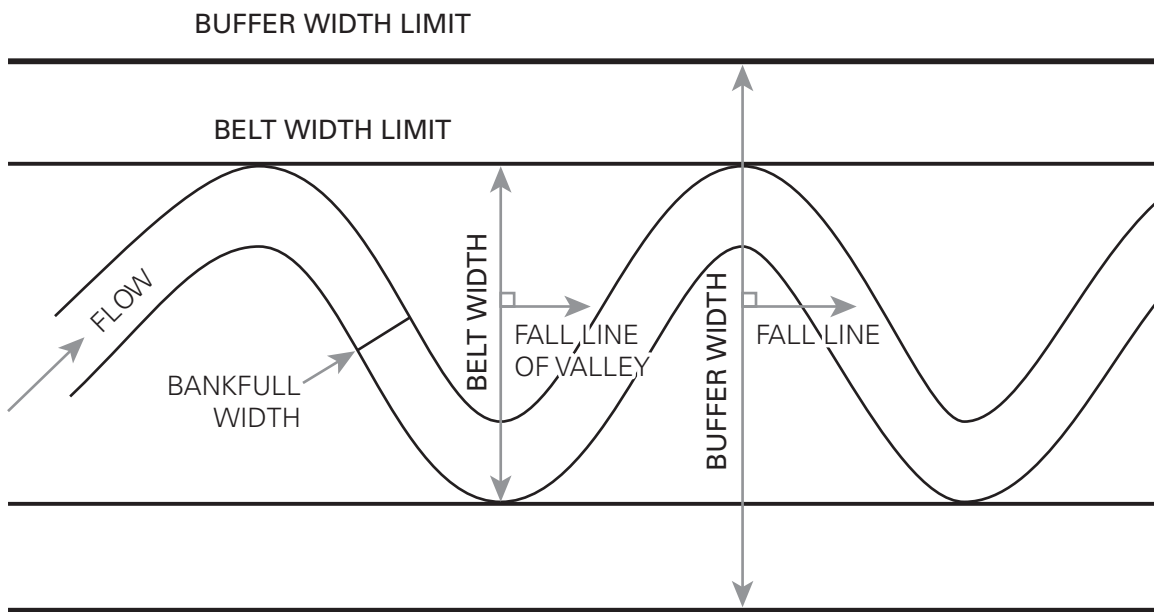
1. Buffer Width

Buffer width is measured from the top of the streambank (bankfull for restored reaches), perpendicular to the fall line of the valley and moving away from the channel. Buffer width is sometimes expressed as an average width or a minimum width. An average width is often used in meandering streams to keep the riparian corridor relatively straight. The average width includes shorter distances at the meander bends and longer distances from the point bar. Each measurement is added together and divided by the total to get the average. The minimum width approach creates a buffer that meanders

with the channel and can be a challenge for establishing conservation easements or fencing requirements.

An alternative approach for meandering streams is to measure the buffer width from the belt width, rather than the top of the bank. The belt width is the distance from one meander bend to the next, measured perpendicular to the fall line of the valley. In this case, a best-fit belt width would be used to establish a straight corridor. The riparian buffer width would be added to the belt width (Figure 8.13).

FIGURE 8.13 BUFFER WIDTH MEASURED FROM BELT WIDTH



NOTE
The buffer width limit is established as a parallel line to the belt width.
The minimum belt width is 3.5 times the bankfull width.
The minimum width from the belt width limit to the buffer width limit is 15 feet.

2. Buffer Density

Buffer density is defined as the number of stems per unit area, e.g., stems/acre. Density is typically measured by establishing rectangular monitoring plots within the riparian corridor. The total area of the plots should be statistically representative of the entire buffer and should be well distributed throughout the buffer. Plots are surveyed annually and include the total number of trees (stems) within the plot. The level of effort varies from moderate to intensive depending on how the results are used. If the results are

compared to a reference condition so that additional measurements are not required, the level of effort is moderate. If measurements are made annually and compared against each other, then the level of effort is intensive (Appendix Ac).

3. Buffer Composition

In conjunction with determining the planted stems surviving year to year, the same plot should be used to determine how species change within the plot. All trees that begin growing in the plot should be identified and counted each year. A size should be determined above which the volunteer stems will be counted, in order to avoid the many individuals that can start each year but will die before the next sample period. This data should be expressed as total stems per area, percent planted and percent volunteer. This data should also indicate if undesirable species are developing, such as exotic species. Exotic species should be removed and not allowed to continue growing until the next growing season. Like buffer density, the level of effort varies from moderate to intensive depending on how the results are used. If the results are compared to a reference condition so that additional measurements are not required, the level of effort is moderate. If measurements are made annually and compared against each other, then the level of effort is intensive (Appendix Ac).

4. Buffer Age

The age-class distribution of vegetative cover should be evaluated to determine the opportunity for recruitment, maintenance and recovery following flooding or other disturbance. A diverse age-class distribution may also limit invasive species establishment and their ability to out-compete native species. This distribution is particularly important for shrub and tree species. Although recently established riparian buffers associated with restoration projects will have minimal age-class distributions initially, the riparian buffer should develop this characteristic over time to more resemble a reference condition for the particular vegetative species established. The age of vegetative cover can be recorded within similar monitoring plots used to determine buffer density and species composition. Buffer age and growth (below) are almost always measured periodically (typically annually) and compared to previous measurements. Therefore, the level of effort is intensive (Appendix Ac).

5. Buffer Growth

Buffer growth can be sampled by measuring stem diameter and height using the methods of Lee et al. (2008). For stems less than 1.37 m in height, measure height (in cm) and ddh (diameter at one decimeter height above the ground) to the nearest mm of the thickest stem. For stems between 1.37 and 2.5 m in height, ddh and height are measured as above, and stem DBH (Diameter at Breast Height or 1.37 m above the ground) is also measured. For stems in excess of 2.5 m in height, DBH and height are measured, but not ddh. These measurements can be used to express the basal area of woody stems that are maturing within the riparian zone.

6. Canopy Density

The angular canopy density, which is an index of cover or shading by the foliage of riparian trees, can be measured using a densiometer. The densiometer consists of a convex mirror divided into grids that allows a visual estimate of the percent of the stream or soil shaded by surrounding vegetation. The canopy density should be taken at the same location and same height above ground each year, and multiple sample locations should be used to provide an estimate of the entire restored riparian zone. The density of the canopy should become greater each year, after about year five when trees begin to get large enough to shade the stream and riparian zone. The level of effort varies from moderate to intensive depending on how the results are used. If the results are compared to a reference condition so that additional measurements are not required, the level of effort is moderate. If measurements are made annually and compared against each other, then the level of effort is intensive (Appendix Ac).

7. Proper Functioning Condition (PFC)

The Bureau of Land Management, with the assistance of other federal agencies, developed a quantitative rapid assessment method for evaluating proper functioning condition for lotic areas. The document was prepared by Prichard et al. (1998) and is available online at ftp.blm.gov/pub/nstc/techrefs/Final1737-15.pdf. Proper Functioning Condition (PFC) is both an assessment methodology and a condition that describes riparian-wetland areas. As an assessment methodology, PFC evaluates hydrology, vegetation and erosion/deposition processes. A checklist is used to assess these functions and to determine the overall health of the streambanks and riparian-wetland area. Therefore, PFC can be used to assess lateral stability (Geomorphology functions), as well as the overall health of the riparian corridor (Biology functions). As a condition, PFC describes how well the physical processes are functioning in order to provide stability and habitat. A stream corridor that is in a Proper Functioning Condition will remain stable during high flow events. This resiliency allows an area to produce desired conditions over time, such as fish habitat, neo-tropical bird habitat or forage. Riparian-wetland areas that are not functioning properly cannot sustain these conditions.

PFC is less quantitative than bank profiles, cross sections or the bank stability toe erosion model. However, it is the only method described here that assesses the stream channel and the riparian buffer to determine bank stability. As such, it is more than a bank stability assessment. According to the manual, a riparian-wetland area is functioning properly when there is adequate vegetation, landforms or woody debris to:

- Dissipate stream energy associated with high flows;
- Filter sediment, capture bedload and aid in floodplain development;
- Improve floodwater retention and groundwater recharge;
- Develop root masses that stabilize streambanks;
- Develop diverse channel characteristics to provide habitat; and
- Support greater biodiversity.

8. NRCS Rapid Visual Assessment Protocol

The NRCS Stream Visual Assessment Protocol (SVAP) is another rapid assessment method that includes the riparian zone as a variable in an overall stream health evaluation. This protocol can be found at www.nrcs.usda.gov/technical/ecs/aquatic/svapfnl.pdf. The SVAP riparian zone assessment is based on the natural vegetation width, its function as a surface flow filter and its potential for vegetative regeneration.

9. The EPA Rapid Bioassessment Protocol (RBP)

The EPA Rapid Bioassessment Protocol (RBP, Barbour et al., 1999) includes riparian areas as part of Habitat Assessment and Physicochemical Parameters (Chapter 5 of the RBP manual). This method includes an index for rating natural vegetation buffer function based on buffer width on each side of the stream, and based on human impacts to the buffer function (Barton et al., 1985).

10. USFWS Stream Assessment Ranking (SAR)

The USFWS Stream Assessment Ranking (SAR) is a component of the US 301 Environmental Stewardship Study, which is a green infrastructure study. The stream assessment component consists of a GIS-based stream stability assessment method and a rapid stream habitat and stability assessment method. It also includes restoration feasibility protocols. The rapid assessment protocols have both office and field components. The office component requires the use of a regional curve to determine bankfull channel width, depth, and cross-sectional area based on the drainage area of the proposed project site. This information is required for the field assessment portion of the protocol since several of the assessment parameters evaluate bankfull channel conditions. The field component of the protocol contains four sections: stream stability assessment; restoration potential, cost and feasibility; existing riparian/instream habitat assessment; and proposed riparian/instream habitat assessment. The stream stability assessment section consists of four parts: lateral stability, vertical stability, stability trend and stream classification. The parameters of the restoration potential, cost and feasibility include construction access, constraints, potential success/risk, and restoration potential description. The existing and proposed riparian/instream habitat assessments consist of the same assessment parameters to allow for comparison between the existing site condition and the proposed site condition, based on the potential restoration solution. The parameters of the riparian/instream habitat assessment include instream cover, epifaunal substrate, velocity/depth regimes, shading, water appearance, nutrient enrichment, riparian vegetation, riparian zone, and sediment supply potential.

11. Watershed Assessment of River Stability and Sediment Supply (WARSSS)

The Rosgen (2009) Watershed Assessment of River Stability and Sediment Supply (WARSSS) includes assessment of riparian vegetation in the Prediction Level Assessment (PLA) Index as part of its overall channel stability analysis procedure. The existing riparian vegetation composition and density along the impacted reach is compared to the

potential vegetation that would be present along a reference reach. The riparian buffer species composition and density are used to interpret the potential for streambank erosion and channel instability. The assessment is a qualitative description recorded using worksheets (See Worksheet 14 and 15, water.epa.gov/scitech/datait/tools/warsss/pla_box07.cfm) and should be performed by a trained biologist. There are no performance standards developed for this assessment at this time.

Performance Standard

1. Buffer Width

There are several performance standards established for buffer width measurements. Two standards are listed in Table 8.8. The average width performance standard for C and E stream types is based on the literature review by Mayer et al. (2005). This research primarily focuses on the effects of buffer width and other parameters on reducing nitrogen. The results showed that while some buffers with widths less than 45 feet did remove nitrogen, buffers that were wider than 150 feet more consistently removed nitrogen. The results also showed that, in general, buffers were effective as nitrogen filters with widths between 30 and 150 feet. Buffer widths for A and B stream types can probably be narrower given that their valleys are narrower; however, the literature does not provide recommendations on buffer widths for these stream types. The second standard is the buffer width to meander belt width as shown in Figure 8.13. This is a new approach that is being introduced in this document for those who want to create a straight riparian corridor with easy to manage conservation easements (if required). A minimum meander width ratio of 3.5 is used because this is typically the minimum average value required to yield a sinuosity of 1.2, the break between meandering and non-meandering streams. The additional 15 feet has more to do with constructability issues for restoration projects that include excavated floodplains. This width and the meander width ratio can be increased if necessary to meet other project goals; however, they should not be decreased to meet a Functioning performance standard.

2. Buffer Density, Composition, Age, Growth and Canopy Density

Other measurement parameters, including buffer density, species composition, age-class distribution, growth, and canopy density do not have published performance standards established at this time. A suitable reference reach from the same region and at the same successional stage, however, can be used to compare riparian buffer function. Performance decisions should be made by a trained biologist or botanist with experience in the region. For this framework, a Functioning riparian buffer would have a measurement method result similar to the reference reach. A Functioning-at-Risk would have a measurement method result that is not functioning at the level of the reference buffer, but has existing potential for this to occur over time or with minimal additional maintenance. Maintenance may include additional plantings, soil amendment or invasive species control. Not Functioning would designate a riparian buffer that does not resemble the reference buffer and that does not have reasonable potential to develop riparian function

over time without significant restoration efforts. These buffers may have limited establishment of intended vegetative species due to environmental conditions (drought, poor soils, disease or flooding) occurring after planting, or they may be inundated with invasive species encroaching from the surrounding landscape. A Not Functioning buffer determined by reference reach parameters may need to be completely re-established with more frequent maintenance to function properly.

3. Rapid Assessment Methods

The rapid assessment methods described above all have associated performance standards with the exception of the WARSSS method. The performance standards have been recategorized as Functioning, Functioning-at-Risk or Not Functioning. The Proper Functioning Condition (PFC) method components for Functioning are listed above in an order relative to how processes work to achieve a proper Functioning condition. If the riparian-wetland is not in PFC, it is placed into one of three categories (two for this document: Functioning-at-Risk and Not Functioning). The PFC manual uses the term Functional-at-Risk, which is defined as being functional but with an existing soil, water or vegetation attribute that makes them susceptible to impairment. Nonfunctional or Not Functioning means that the riparian-wetland area clearly does not provide adequate vegetation, landform or woody debris to dissipate stream energy associated with high flows, and thus is not reducing erosion or improving water quality. The PFC manual adds a third category, called Unknown, which means that the riparian-wetland manager lacks sufficient information to make a functional determination.

The NRCS Stream Visual Assessment Protocol (SVAP) score ranges from 1 (Not Functioning) to 10 (Functioning) based on natural vegetation riparian buffer width and coverage. The EPA Rapid Bioassessment Protocol (RBP) index values range from optimal (10) to poor (0) based on riparian buffer widths on each side of the stream. The USFWS Stream Assessment Ranking (SAR) scores each assessment parameter with a numerical range of 1 to 10, with 10 being the best score. Since the assessment protocol has four separate sections, a variety of scoring combinations can be created for ranking purposes. Each of the assessment section scores can be used individually or tallied together for ranking and prioritization purposes.

8.7 » PARAMETER: BED FORM DIVERSITY

Description

Natural streams rarely have flat uniform beds (Knighton, 1998). Instead, the hydraulic and sediment transport processes described above shape the stream bed into myriad forms, depending on channel slope, type of bed material (sand, gravel, cobble, boulder, bedrock) and other factors. These bed forms are symptomatic of local variations in the sediment transport rate and represent vertical fluctuations in the stream bed (Knighton, 1998), dissipating energy and creating habitat diversity. These vertical fluctuations are essentially a form of meandering, but in the vertical direction rather than horizontal (like sinuosity).

TABLE 8.8 RIPARIAN BUFFER PERFORMANCE PARAMETERS

MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
Average Buffer Width (Ft) from Top of Bank C and E Stream Types	> 150 ft	30 to 150 ft	< 30 ft
Buffer Width (Ft) from Meander Belt Width	Meander belt width at least 3.5 times the bankfull width plus ≥ 15 feet from outside meander bend	Meander belt width at least 3.5 times the bankfull width plus 10 to 15 feet from outside meander bend	Meander belt width ≤ 3.5 times the bankfull width and/or ≤ 10 feet from outside meander bend
Buffer Density (Stems/ac) Buffer Composition Buffer Age Buffer Growth Canopy Density	Parameter is similar to reference reach condition, with no additional maintenance required.	Parameter deviates from reference reach condition, limiting function; but the potential exists for full functionality over time or with moderate additional maintenance.	Significantly less functional than reference reach condition; little or no potential to improve without significant restoration efforts
Proper Functioning Condition (PFC)	Proper Functioning Condition	Functional-at-Risk	Nonfunctional
NRCS Stream Visual Assessment Protocol (SVAP)	Natural vegetation extends at least one to two active channel widths on each side; or if less than one width, covers entire floodplain (8-10)	Natural vegetation extends at least one-half to one-third active channel widths on each side, or filtering function moderately compromised (3-5)	Natural vegetation less than a third of the active channel width on each side, or lack of regeneration, or filtering function severely compromised (1)
EPA Rapid Bioassessment Protocol (RBP) Habitat Assessment	Width of riparian zone > 18 meters on each side; human activities have not impacted zone (Optimal, 9-10)	Width of riparian zone 12-18 meters on each side; human activities have impacted zone only minimally (Sub-Optimal, 6-8); width of riparian zone 6-12 meters on each side; human activities have impacted zone a great deal (Marginal, 3-5)	Width of riparian zone <6 meters on each side; little or no riparian vegetation due to human activity (Poor, 0-2)

TABLE 8.8 RIPARIAN BUFFER PERFORMANCE PARAMETERS (CONT.)

MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
USFWS Stream Assessment Ranking (SAR)	All three zones of vegetation exist; runoff is primarily sheet flow; hillslopes < 10%; hillslopes >200 ft from stream; ponding or wetland areas and litter or debris jams are well represented.	Only Zone 2 of vegetation is well represented; runoff is equally sheet and concentrated flow (moderate gully and rill erosion); hillslopes 20-40%; hillslopes 50-100 ft from stream; ponding or wetland areas and litter or debris jams are minimally represented.	No zones of vegetation well represented; runoff is primarily concentrated flow (extensive gully and rill erosion); hillslopes >40%; hillslopes <50 ft from stream; ponding or wetland areas and litter or debris jams are not well represented or completely absent.

Numerous classifications of bed form exist, many of which are described in Knighton (1998). At a broad level, bed form diversity can be grouped into three categories: sand bed forms (ripple, dunes and antidunes), gravel/cobble bed forms (riffle, run, pool and glide) and step-pool channels. These different bed forms are important because they provide the environmental conditions that a variety of aquatic organisms need for survival. For example, macroinvertebrates often colonize in riffle habitats and fish tend to stay in pools. Without the diversity of riffles and pools, there is also a loss of diversity in macroinvertebrates and fish. A brief description of each bed form category is described below.

Sand Bed Forms

While gravel bed streams have riffle-pool sequences, with riffles composed of gravel-size particles, sand bed channels are characterized by median bed material sizes less than 2 mm in diameter (Bunte and Abt, 2001). Bed material features called ripples, dunes, planebeds and antidunes characterize the sand bed form. Although sand bed streams technically do not have riffles, the term is often used to describe the crossover reach between pools. (“Riffle” is used in this document as an equivalent to crossover.) The size, stage and variation of sand bed forms are created by changes in unit stream power, as described below. These bed forms are symptomatic of local variations in the sediment transport rate and cause minor to major variations in aggradation and degradation (Gomez, 1991). Sand bed forms can be divided between low-flow regimes and high-flow regimes, with a transitional zone between the two (Figure 8.14).

Ripples occur at low flows where the unit stream power is just high enough to entrain sand size particles. This entrainment creates small wavelets from random sediment accumulations that are triangular in profile, with gentle upstream and steep downstream

slopes. The ripple dimensions are independent of flow depth, and their heights are less than 0.02 meters.

As unit stream power increases, dunes eventually replace ripples. Dunes are the most common type of sand bed form and have a larger height and wavelength than ripples. Unlike ripples, dune height and wavelength are proportional to flow depth. The movement of dunes is the major cause of variability in bedload transport rates in sand bed streams. Dunes are eventually washed out to leave an upper-flow plane bed characterized by intense bedload transport. This plane bed prevents the patterns of erosion and deposition required for dune development. This stage of bed form development is the transitional flow regime between the low-flow features and the high-flow regime features (Knighton, 1998).

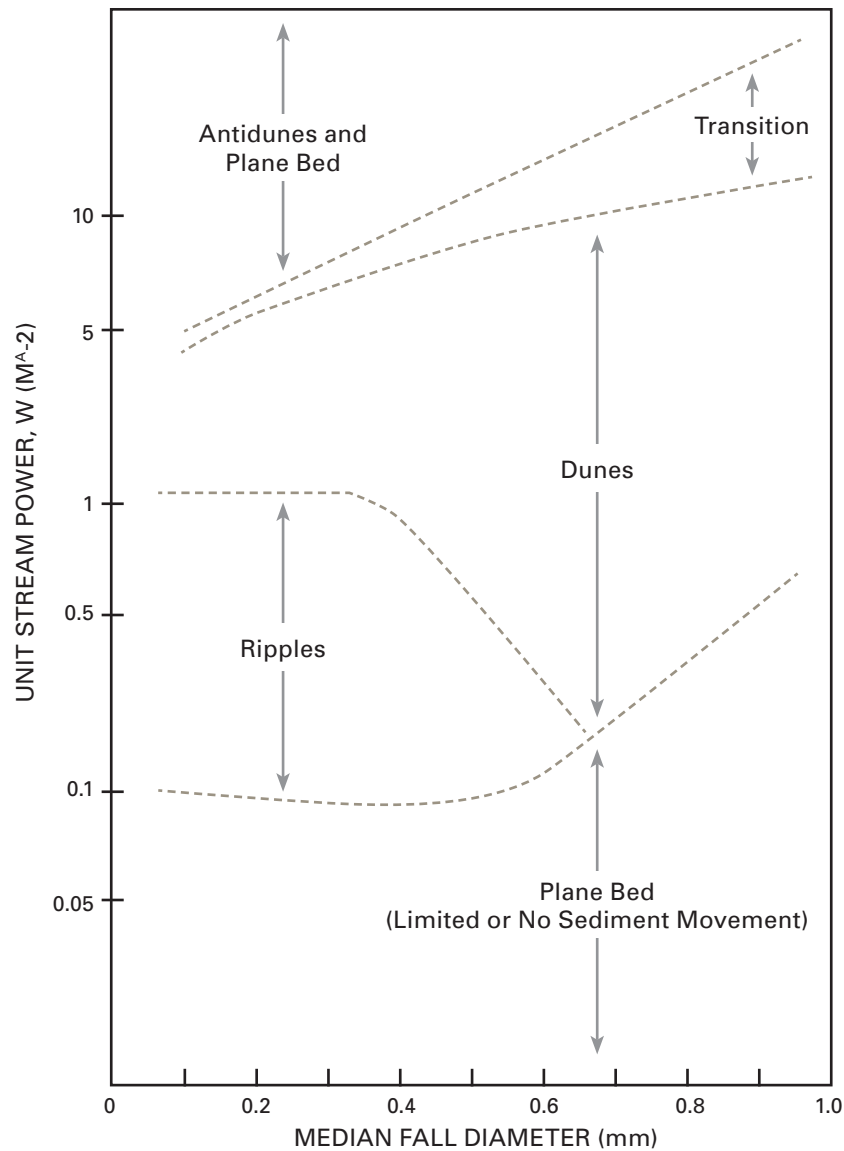
As flow continues to increase, standing waves develop at the water surface, and the bed develops a train of sediment waves (antidunes) that mirror the surface forms. Antidunes migrate upstream by way of scour on the downstream face and deposition on the upstream face, a process that is opposite of ripples and dunes. Antidunes can also move downstream or remain stationary for short periods (Knighton, 1998).

Gravel/Cobble Bed Forms

Meandering gravel bed streams in alluvial valleys have sequences of riffles, runs, pools and glides that help maintain channel slope, bed stability and habitat diversity (Figure 8.15). The riffle is a bed feature composed of gravel or larger-size particles. During low-flow periods, the water depth at a riffle is relatively shallow, and the slope is steeper than the average slope of the channel, so water moves faster over riffles. Riffles control the stream bed elevation and are usually found between meander bends. Runs are a transitional bed form between the riffle and the pool. The pool is located along the outside of a meander bend and is much deeper than the riffle. The slope of the pool is also much flatter than the riffle. Pools can also be found in riffle settings if scour is created by a flow obstruction, like a boulder or large woody debris, further improving the overall diversity. The inside of the meander bend is a depositional feature called a point bar. A glide is the transitional bed form between the pool and the next riffle and is the only bed form that slopes uphill (i.e., if a person was walking through the pool in a downstream direction, he/she would have to walk uphill to reach the next riffle). The glide serves as a spawning area for many species of fish because oxygen is forced up through the sediments, as the water from the deep pool is forced up through the gravel to reach the riffle.

As stage increases, water and sediment transport character changes as they travel over riffles and through pools. At low flows, pools are depositional features, and riffles are scour features. At high flows, the water surface becomes more uniform, i.e., the water surface slope increases at a faster rate over the pools than the riffles. The pools, therefore, have a slope that is similar to the riffle but a much greater depth. This means that the shear stress is greater in the pool than the riffle. With a relative increase in shear stress, pools scour; a decrease in shear stress occurs over the riffle during the falling limb of the hydrograph, causing bed material deposits (Knighton, 1998).

FIGURE 8.14 SAND BED FORMS (after Knighton, 1998)



Source: Adapted from Knighton (1998)

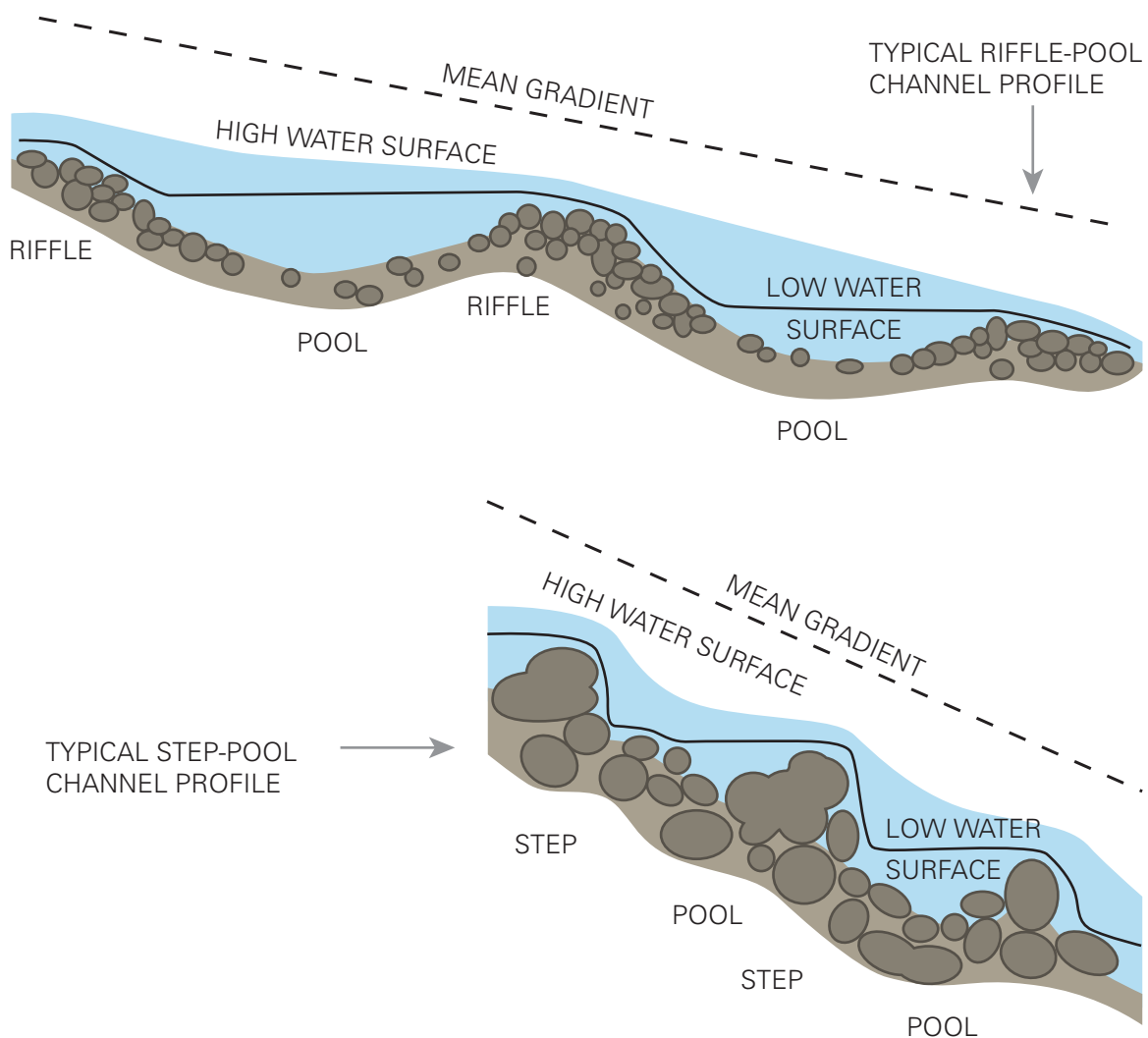
Step-Pool Channels

A step-pool bed profile is characteristic of steep streams formed within colluvial valleys, with valley slopes typically greater than 2% or 3% (Wohl, 2000). Steep mountain streams demonstrate step-pool morphology as a result of episodic sediment transport mechanisms. Because of the high energy associated with the steep channel slope, the substrate in step-pool streams contains significantly larger particles than streams in

flatter alluvial valleys. Steps form from accumulations of boulders and cobbles that span the channel, resulting in a backwater pool upstream and a plunge pool downstream. Smaller particles collect in the interstices of steps, creating stable, interlocking structures (Knighton, 1998). An example is shown in Figure 8.15.

In contrast to meandering streams that dissipate energy through meander bends, step-pool streams dissipate energy through drops and turbulence. Step-pool streams have relatively low sinuosity, and pattern variations commonly result from debris jams, topographic features and bedrock outcrops.

FIGURE 8.15 TYPICAL RIFFLE-POOL AND STEP-POOL PROFILES



Source: Adapted from Knighton (1998)

Measurement Method

Bed form diversity is relatively simple to assess. A longitudinal profile of a stream channel provides detailed information about the bed form and can be used to quantify diversity (Harrelson et al., 1994). Parameters that quantify bed form diversity include: percent riffle and pool, facet slope, pool-to-pool spacing and depth variability. A description of each parameter is provided below.

1. Percent Riffle and Pool

This parameter measures the percentage of riffles and pools for a stream reach. Runs and glides, although important habitat features, are included under the riffle and pool percentage, respectively. The percentages can be determined by comparing the thalweg profile to the water-surface profile, and measuring the length of the feature from the stationing. This approach requires a moderate level of effort and complexity because a profile must be surveyed to collect the data. A rapid approach can be used where the feature lengths are simply measured using a tape, rather than taken from the profile (Appendix Ac). The facet length (riffle or pool) is then divided by the total reach length to calculate the percentage.

Riffles are identified on the profile as the sections of channel that are steeper than the average channel slope. The water surface over the riffle should also be steeper than the average slope. Beware of channel blockages, such as beaver dams, that create flat water-surface slopes (backwater) over previously established riffles. An example is shown at station 760 on the profile in Figure 8.16. The upstream riffles have been “drowned out” to station 550 and are now classified as a pool.

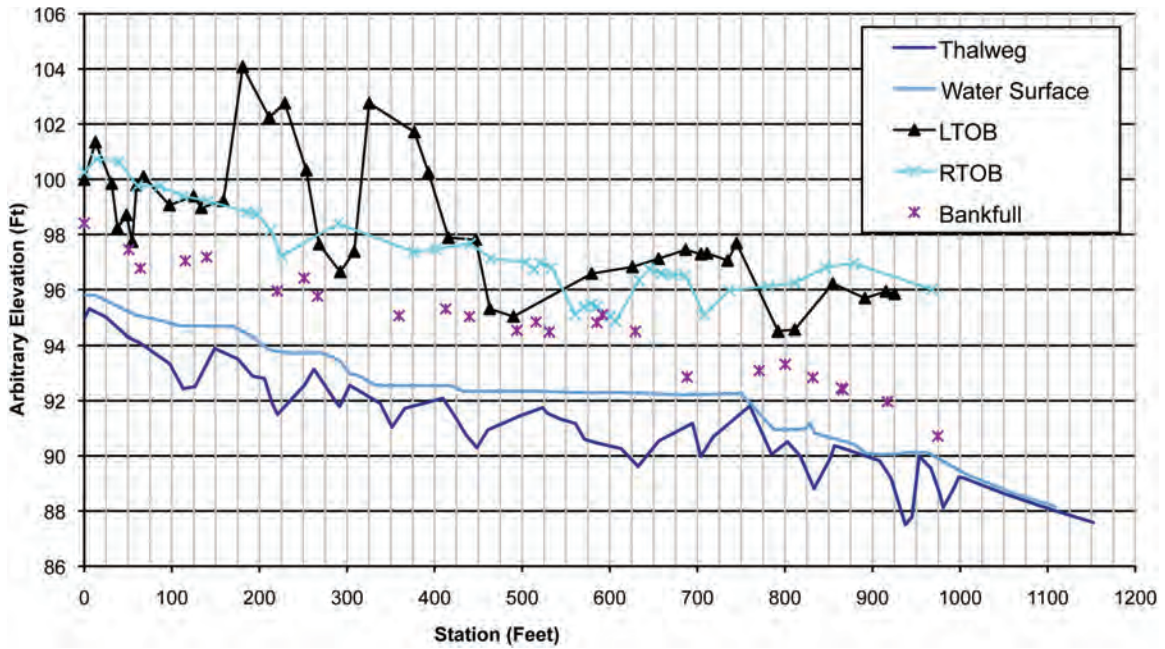
After the riffles and pools have been identified on the longitudinal profile, they can be plotted on the plan view as shown of Figure 8.17. The location of the riffles and pools can now be compared with the meander geometry. Ideally for C and E stream types, the pools will be located at meander bends, and the riffles will be between meander bends. Figure 8.17 shows a riffle at station 2+00, which is the outside of an eroding meander bend. The erosion is partly caused by the steep slope and, therefore, high shear stress associated with the riffle. Pools that are located in meander bends help dissipate energy by having a lower slope, among other things, such as a greater cross-sectional area and depth.

Figures 8.16 and 8.17 show that overall the stream reach has 43% riffle and 57% pool bed forms. Rosgen C and E reference reach streams in the Southeastern US generally have riffle-pool percentages from 60:40 to 80:20, so more riffle bed form than pool. In this example, the bed form is predominately pool because of the beaver dam. The riffles that are present are in unstable locations (meander bend) or very short; the longest riffle is near the end of the reach. The determination of whether a bed form was a riffle or pool was made from an analysis of the bed and water-surface profile (Figure 8.17).

2. Facet Slope

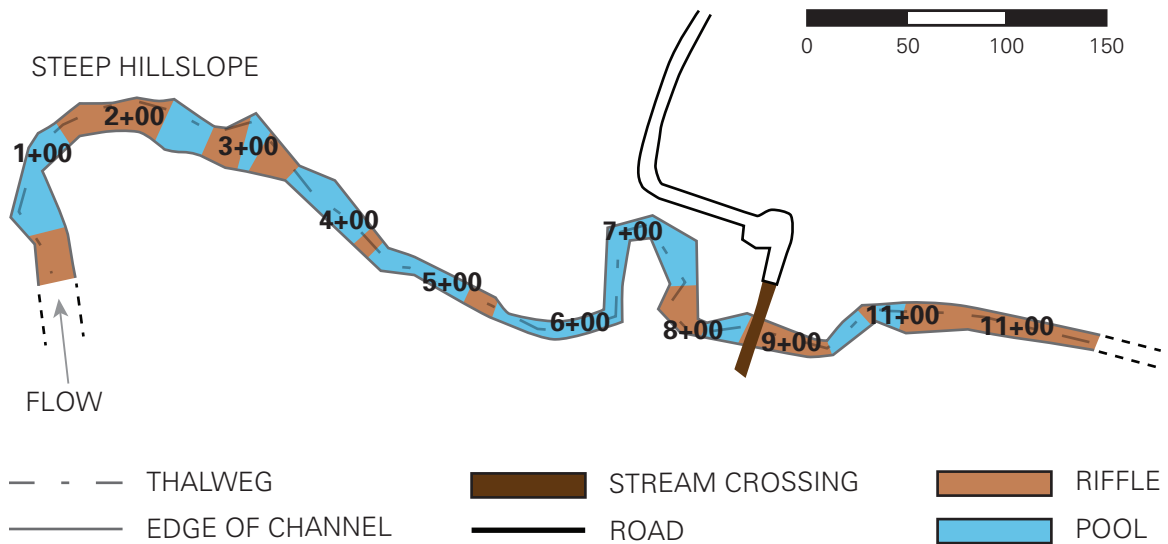
Facet or feature slopes help to identify riffles and pools as described above. In addition, facet slopes can be used to measure the quality and stability of the bed form, e.g., steep

FIGURE 8.16 EXISTING (PRE-RESTORATION) LONGITUDINAL PROFILE SHOWING THALWEG, WATER SURFACE, BANKFULL STAGE, LEFT TOP OF BANK (LTOB) AND RIGHT TOP OF BANK (RTOB)



Source: Adapted from original graph by Michael Baker Corporation

FIGURE 8.17 PLAN VIEW MAP SHOWING RIFFLES IN BROWN AND POOLS IN BLUE



Source: Adapted from original graph by Michael Baker Corporation

riffles are often comprised of coarser bed material because the finer sediments are transported downstream. However, if the riffle gets too steep, larger particles will be transported and the riffle could degrade. Riffle slope stability can be assessed with competency equations by comparing the riffle slope ratio to reference reach ratios. The riffle slope ratio is the riffle slope divided by the average channel slope (Rosgen, 2009). Pool slopes are also important descriptors of quality and stability and should be much flatter than the overall water surface slope to minimize erosional forces acting on the outside bank. However, if the pool slope is zero, the pool does tend to fill and stagnate at low-flow stages.

3. Pool-to-Pool Spacing

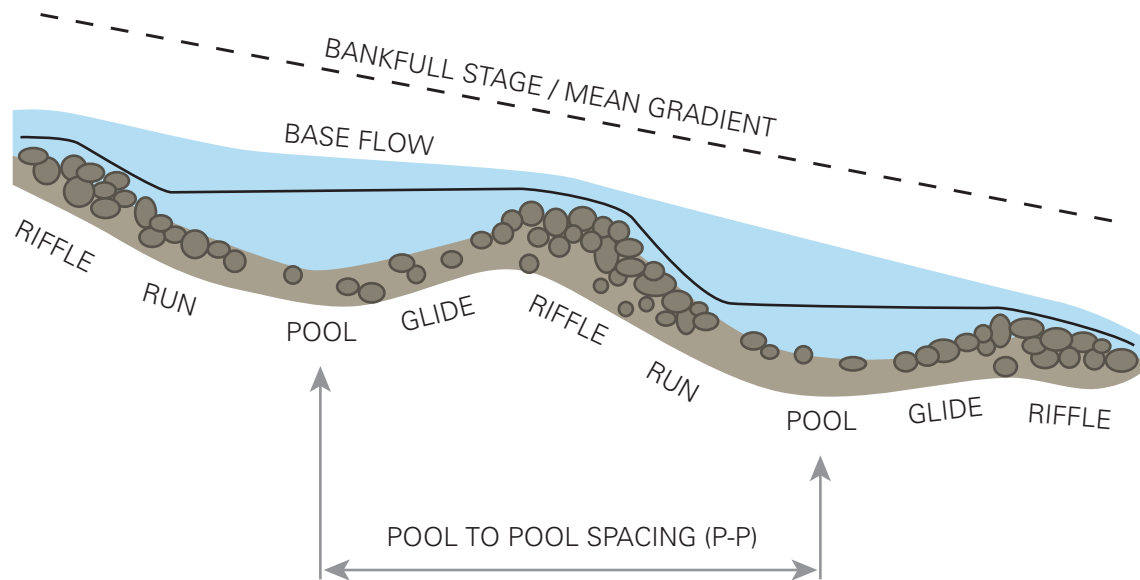
Pool-to-pool spacing measures the frequency of pools in the stream reach and is the distance measured along the stream centerline or thalweg, between the deepest point of two pools. It is most often measured from the longitudinal profile; however, it can be estimated rapidly by simply using a tape. A rapid approach may be used by regulatory agencies to estimate the pool-to-pool spacing of a restored reach. The value is often converted into a dimensionless ratio by dividing the result by the bankfull riffle width. Dimensionless ratios can then be compared to known reference reach ratios of the same channel type to determine if the spacing is within the normal range.

For C and E stream types, stability problems often occur when the pool-to-pool spacing becomes too low. Monitoring studies in North Carolina showed that severe bank erosion occurred when the pool-to-pool spacing ratio was less than 3.0 to 3.5. In these cases, erosion was observed from the outside meander bend to the downstream point bar. For streams in colluvial valleys (B stream type), it is the opposite. Generally, closer pool-to-pool spacing leads to more stable and diverse bed forms. Pool-to-pool spacing ratios greater than 5 often have minor to major headcut problems, especially in areas where the channel was reconstructed (Harman and Starr, 2008). (See Figure 8.18.)

4. Depth Variability

Depth variability can be assessed by measuring the bankfull pool depth at each pool along the stream reach, and then dividing these depths by a representative mean riffle bankfull depth. For this assessment, the pool depths can be measured from the longitudinal profile. The bankfull riffle mean depth can be measured at a representative riffle cross section. The mean depth is then calculated as the cross-sectional area divided by the bankfull width. This dimensionless ratio is referred to as the Pool Max Depth Ratio (Rosgen, 2009). When looking at a stream reach, the variability between Pool Max Depth Ratios provides information on how the stream is processing sediment. If all the ratios are near the same value, it indicates that the pools are all the same depth and are likely filling with sediment. However, this does vary by geologic setting and stream type. It is most desirable to have a range of Pool Max Depth ratios, as it indicates a wide variety of pool depths and high pool habitat diversity.

FIGURE 8.18 TYPICAL POOL-TO-POOL SPACING MEASUREMENTS



$$\text{POOL TO POOL SPACING RATIO} = \text{pool to pool spacing (P-P)} / \text{bankfull riffle width}$$

Source: Reproduced with permission from Michael Baker Corporation

Performance Standard

Performance standards for determining whether a stream is Functioning from a bed form diversity standpoint should be considered with stream channel type and expected habitat diversity in mind. In general, it is good to compare what is observed in the field with what is known about stable, reference reach channel conditions.

1. Percent Riffle and Pool

Reference reach streams in alluvial valleys, like C and E stream types, typically have more riffles than pools. It is generally agreed that having more riffles than pools is one important factor to support healthy fish populations; however, it is difficult to find literature that provides guidance on ideal percentages for riffles and pools. In NC, projects that had 60-70% riffle and 30-40% pool seemed to be preferred over streams that were riffle or pool dominated. As the percentage increased to 70-80% riffle, the quality of fish habitat was diminished due to a lack of pool habitat. Streams with greater than 80% riffle often resemble the bed form of a channelized stream.

A stream reach dominated by pool bed forms in C and E stream types also lacks the necessary diversity for varied aquatic species, especially macroinvertebrates. If 60-70% of the reach is riffle (Functioning), then 30-40% of the reach should be pool. As the percentage of pools increase, bed form diversity goes down (Table 8.9). Once the reach exceeds 50% it is unlikely that the bed form diversity is comparable to high-quality C and E

reference reach streams. This can be a problem in older stream restoration projects where cross vanes were installed at the head of the riffle. The intent was to keep the upstream pool slope fairly flat, which it does. However, the cross vane also creates a pool downstream of the structure, which in this case is the riffle. The result is that a scour pool replaces part of the riffle length, and depending on the meander geometry, this can create too much pool length and not enough riffle length. There is very little data in the literature to provide riffle and pool length percentages for B type channels. However, there is information on pool-to-pool spacing and substrate quality, so performance standards are discussed in the following sections.

The percent riffle and pool is the most subjective measurement method provided in this document. If this method is used as a performance method, it should be used in conjunction with another method that better defines bed form complexity, like LWD measurement methods, pool-to-pool spacing ratios or slope ratios.

2. Pool-to-Pool Spacing Ratios

The performance measures for pool-to-pool spacing are shown below in Table 8.9. Separate ratios are shown for watershed drainage areas below and above 10 square miles. Results from past projects show that severe bank erosion occurs when the pool-to-pool spacing ratio is less than 3.0. This problem is related to the MWR problem (discussed under lateral stability) and often occurs when practitioners force a meandering stream into a confined setting. This problem may also show up in the percent riffle-pool measure, e.g., there may be more pool length than riffle length. Projects in drainage areas below 10 square miles tend to be more stable and have better bed form diversity if the pool-to-pool spacing ratio is between 3.5 and 5.0. However, for larger streams, the ratio increases to between 5.0 and 7.0 (Langbein and Leopold, 1966; Gregory et al., 1994). But as the ratio decreases, the same problem can exist in these larger streams.

The spacing of pools is inversely related to slope, i.e., as slope increases, pool-to-pool spacing decreases. Whittaker (1987) and Chin (1989) report an average pool-to-pool spacing of 2 to 3 times the channel width for stream slopes between 3% and 5%. Grant et al. (1990) reported pool-to-pool spacing of 2 to 4 times the channel width for two Oregon streams. These ranges can be more variable based on the presence of bedrock outcrops and large boulders. The Functioning category shown in Table 8.9 uses a value of less than 4, which is the higher end of the range between these two studies. A minimum number was not provided because a lower spacing typically does not lead to stability problems or a decrease in functionality. As the spacing increases in these moderately steep channels, the risk of bed instability increases and functionality decreases.

3. Depth Variability

Depth variability is assessed by measuring the Pool Max Depth Ratio. Performance measures are shown below for gravel bed C and E streams (C4 and E4) and gravel bed B streams (B4). When the ratio is above 1.5 for B4, C4 and E4 stream types, the pools are typically well formed and Functioning. This ratio is less variable in gravel and cobble bed

These ratios are based on reference reach streams in NC and may need to be adjusted based on local reference reach conditions.

streams than streams with sand beds. Pool depth in sand bed channels (C5 and E5) fluctuate more because the sand is mobilized from the riffle (crossover) sections during lower flows. As a result, the pools may fill in more during low-flow periods and scour during bankfull events. A ratio of 1.2 is used

to indicate a Functioning C5 or E5 stream type. Like the C4 and E4 stream types, as the ratio decreases, bed form diversity decreases. These ratios are based on reference reach streams in NC and may need to be adjusted based on local reference reach conditions.

TABLE 8.9 BED FORM DIVERSITY PERFORMANCE PARAMETERS

MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
Perennial Streams in Alluvial Valleys (C, E)			
Percent Riffle	60 to 70	70 to 80 40 to 60	> 80 < 40
Pool-to-Pool Spacing Ratio (Watersheds < 10 mi ²)	4 to 5	3 to 4 and 5 to 7	< 3 and > 7
Pool-to-Pool Spacing Ratio (Watersheds > 10 mi ²)	5-7	3.5-5.0 and 7 to 8	< 3.5 and > 8
Depth Variability – Gravel Bed Streams (Pool Max Depth Ratio)	> 1.5	1.2 to 1.5	< 1.2
Depth Variability – Sand Bed Streams (Pool Max Depth Ratio)	> 1.2	1.1 to 1.2	< 1.1
Moderate Gradient Perennial Streams in Colluvial Valleys			
Pool-to-Pool Spacing Ratio (Slope between 3 and 5%)	0.5 to 4	4 to 6	>6
Depth Variability (Pool Max Depth Ratio)	> 1.5	1.2 to 1.5	< 1.2

8.8 » PARAMETER: BED MATERIAL CHARACTERIZATION

Description

Bed material (substrate) characterization is an important parameter in function-based assessments and stream restoration designs in gravel bed streams. The composition of the stream bed influences the character of the bed forms, sediment transport, macroinvertebrate habitat and fish habitat (Harrelson et al., 1994). The influence of substrate on chan-

Chapter 8: Geomorphology, Bed Material Characterization

nel form and process varies by stream type. For example, large boulders and cobbles create step-pool bed morphology in steep gradient A and B stream types. Gravel bed material creates riffle-pool sequences in lower gradient C and E stream types, and sand bed material creates ripples and dunes in low gradient C, E and DA stream types.

Characterizing the bed material for the purpose of showing functional lift associated with a stream restoration project is most appropriate in gravel bed streams. The goal for these projects is to show that the bed coarsens after restoration; this implies that the stream bed has excessive fine-grained sediments (sand) prior to restoration, which is typically caused by streambank erosion. Restoration techniques are used to minimize streambank erosion and thereby decrease the supply of the fine-grained sediments. Other restoration techniques, like reconnecting the stream to the floodplain and creating the appropriate geometry, can improve sediment transport processes, which may transport the finer-grained material out of the project reach.

An example of this type of project is shown below in Figure 8.19. Prior to restoration, the project reach was channelized and had eroding streambanks that were comprised mostly of sand. Streambanks were also eroding upstream of the project reach. The restoration project created a meandering C/E stream type with a bank height ratio of 1.0 (well connected to the floodplain). The photo was taken during the first year after construction and soon after a winter flood event. Sandy material from upstream bank erosion deposited on the point bar and floodplain; however, the riffle remained coarse and the pool maintained a depth that was much deeper than the riffle.

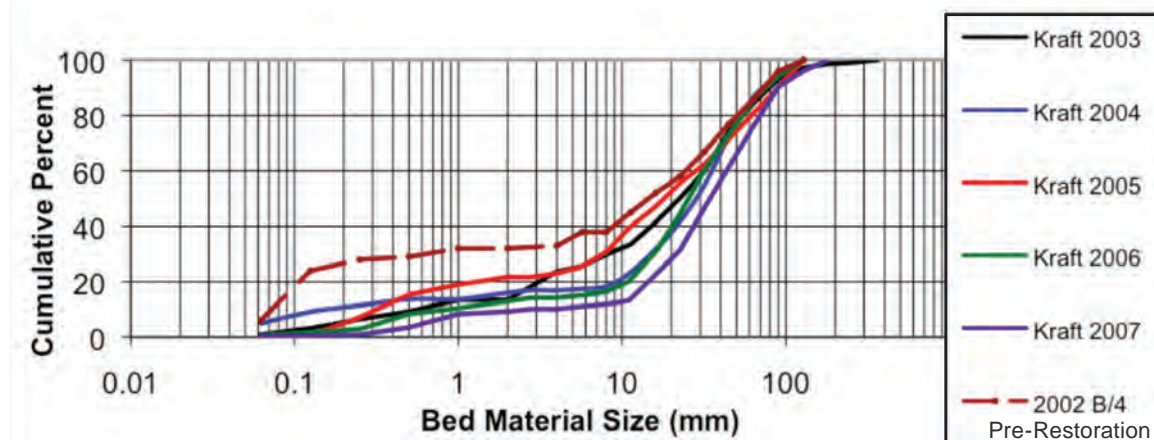
FIGURE 8.19 SOUTH FORK MITCHELL RIVER, KRAFT STREAM RESTORATION PROJECT



Source: Reproduced with permission from Michael Baker Corporation

The bed material was characterized before restoration and for five years after restoration. Figure 8.20 shows the grain size distributions prior to restoration and for five years post-restoration. The x-axis is the size class of the bed material samples in millimeters, and the y-axis is the cumulative percent. The median particle size is where 50 on the y-axis intercepts the line. This value is called the D50, meaning that half of the values are larger and half are smaller than this value. The D84 means that 84% of the values are smaller than this value. Figure 8.20 shows that in general, the bed material coarsened after restoration when compared to the 2002 pre-restoration curve. The suite of curves also shows that there was more variability in the finer-grained sediments (less than the D50) than there was in the coarser grained sediments (greater than the D50). This is common because smaller particles are much more mobile than large particles. The curves also show periodic coarsening and fining during the monitoring years. This is shown more clearly in Figure 8.21.

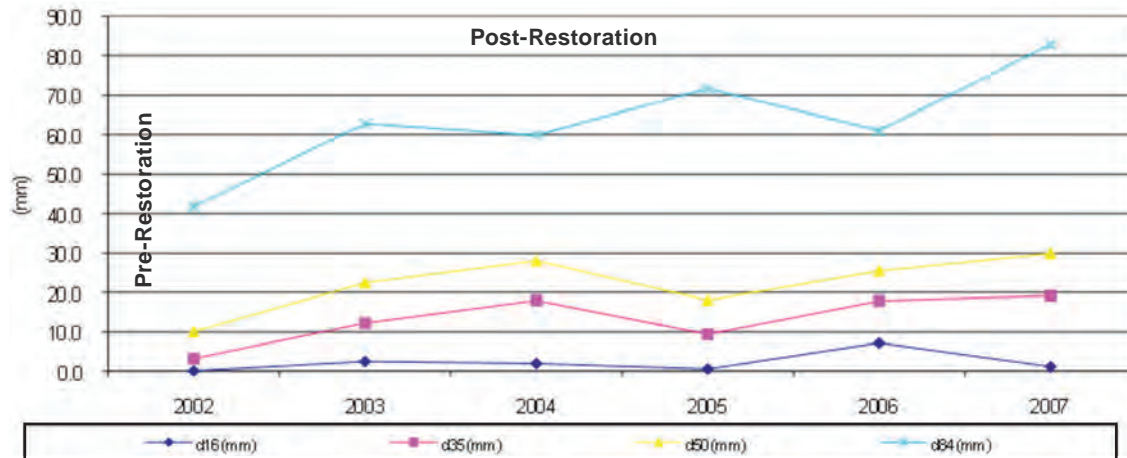
FIGURE 8.20 BED MATERIAL CHARACTERIZATION OF THE KRAFT STREAM RESTORATION PROJECT 2002-2007



Source: Adapted from original graph by Michael Baker Corporation

Figure 8.21 shows how the D16, D35, D50 and D84 change from the pre-restoration condition in 2002 through the last year of monitoring in 2007. The D16, which is a fine sand, changes very little between the monitoring years. This is due to the large amount of sand that is in the channel from upstream bank erosion. This material is easily transported and is mobilized in most storm events. The D35, D50 and D84 all coarsen after restoration with the D35 and D50 changing from sand-size to gravel-size particles. Interestingly, the dip in 2005 occurred during the same year as the remnants from hurricane Francis moved through the area, causing the largest flood of the monitoring period. The bed did shift towards finer-grained sediments that year, but still remained coarser than the pre-restoration condition. The bed material then rebounded in 2006 and was the coarsest of the monitoring period in 2007.

FIGURE 8.21 BED MATERIAL CHARACTERIZATION OF D16, D35, D50 AND D84 PRIOR TO RESTORATION AND FOR FIVE YEARS POST-RESTORATION



Source: Adapted from original graph by Michael Baker Corporation

The point of showing these graphs is to illustrate that under the correct conditions, stream restoration projects can show an improvement (coarsening) due to restoration activities, even if the upstream watershed is not pristine. The best cases for showing improvement are stream reaches that have gravel and cobble in the bed material, but with sandy material being supplied by bank erosion. Projects that are the least likely to show improvement are sand bed streams that do not have gravel and/or cobble sources of bed material.

Measurement Method

The most common method for measuring bed material or substrate is the Wolman (1954) pebble count procedure. The two measurement methods described below use the pebble count method for sampling the bed material. Based on project goals, however, there are many ways that the pebble count procedure can be implemented. Bunte and Abt (2001) provide a comprehensive manual on sampling and analyzing surface and subsurface particles. This manual is available online at www.stream.fs.fed.us/publications/documents/Stream.html. The level of effort for these two methods is moderate if the values are compared to existing reference reach data sets and can become intensive if the reference data sets need to be developed (Appendix Ac).

1. Size Class Pebble Count Analyzer

Potyondy and Bunte (2007) and Bevenger and King (1995) provide spreadsheet tools and instructions for managing pebble count data. These spreadsheets are useful for stream restoration monitoring projects because they can be used to compare a project reach to a reference reach/watershed. The spreadsheet includes statistical applications

that can be used to determine if select sediment size classes from the project reach are statistically different than the reference reach. (Spreadsheets are available at www.stream.fs.fed.us/publications/software.html.)

2. Riffle Stability Index (RSI)

Kappesser (2002) developed a Riffle Stability Index (RSI) to estimate the degree of increased sediment supply to riffles in streams with gradients between 2% and 4%. Kappesser states that the RSI can be used where sediment supply from headwater activities is depositing materials on riffles and filling pools, and reflects qualitative differences between reference watersheds and managed watersheds.

Performance Standard

Performance parameters for substrate distributions are shown below in Table 8.10. The Size Class Pebble Count Analyzer developed by Potyondy and Bunte (2007) and Bevenger and King (2005) can be used in low- and high-gradient channels. Using this method, a Functioning stream is defined as one where select bed material classes are not statistically different than the reference reach or watershed. A Not Functioning stream is where the project stream is statistically finer than the reference reach/watershed. One issue with this method is that there is no guidance or data to suggest an appropriate range for Functioning-at-Risk, so this would need to be determined by the user.

The RSI is recommended for B3 and F3b channels because the method provides scores for Functioning, Functioning-at-Risk and Not Functioning (although the terminology differs). Kappesser (2002) stated that riffles from Idaho and Virginia scoring less than 70 were indicative of watersheds in good condition (Functioning). Values between 70 and 85 indicated watersheds in fair condition (Functioning-at-Risk), and values greater than 85 indicated poor conditions (Not Functioning).

TABLE 8.10 BED MATERIAL CHARACTERIZATION PERFORMANCE PARAMETERS

MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
Size Class Pebble Count Analyzer	Project Reach is not statistically different than reference reach	N/A	Project Reach is statistically different (finer) than reference reach
Riffle Stability Index (RSI) for Rosgen B3 and F3b	< 70	70 to 85	> 85

Chapter 9

Physicochemical

The Physicochemical functions of a stream are determining factors of aquatic ecosystem health. Many lotic organisms are affected by even small changes in water chemistry and habitat. Physicochemical functions include the interaction of physical and chemical processes to create the basic water quality of the stream (including temperature, dissolved oxygen, conductivity, pH and turbidity), as well as to facilitate nutrient and organic carbon processes. The parameters used to describe Physicochemical functions are included in Level 4 of the Pyramid. These parameters provide both direct and indirect indications of stream condition and its ability to support biological communities (Level 5). Understanding what is expected for these parameters in a project stream, based on the reference condition and what the stream actually demonstrates, will provide a comprehensive Physicochemical stream assessment. Determination of the reference condition using data from reference streams that support desired biological communities is important. Before beginning an assessment, a review of Total Maximum Daily Load (TMDL) values determined based on water quality standards, as well as review of specific watershed plans, can determine what Physicochemical constituents are of concern for the stream. These resources can identify what is being measured and what approaches are currently being applied to monitor Physicochemical parameters and to improve water quality.

Measurement of Physicochemical functions also requires an understanding of what influential variables are present that cannot be affected by restoration at the reach scale. These variables include external discharges from upstream, point source and non-point source contributions, and the effects of land-use changes in the watershed. These variables highlight the need for preliminary considerations of site selection and reach length if the goal is to improve stream Physicochemical function. Climate factors will also have a significant effect on Physicochemical functions, but these environmental variables cannot be controlled at any scale. Some of these variables that are beyond the scope of the restoration plan can be differentiated from variables that are controllable through comparisons with upstream, downstream and reference stream conditions. The ability to evaluate the actual effects of stream restoration within a reach with statistical confidence should be considered by performance standards.

Table 9.1 provides a list of the Physicochemical parameters included in this chapter, along with their associated measurement methods and availability of performance standards. Although there are many additional parameters that can determine Physicochemical function, e.g., alkalinity, pollutants and metals; however, those included in this chapter are considered the most common and the most important parameters for assessment and restoration. Appendix Ac includes a list of all the example Physicochemical

measurement methods along with information about the method's type, level of effort, level of complexity, and whether it is a direct or indirect measure of the function-based parameter. The criteria used to make these determinations are provided in Chapter 4.

TABLE 9.1 PHYSICOCHEMICAL PARAMETERS, MEASUREMENT METHODS AND AVAILABILITY OF PERFORMANCE STANDARDS

PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD
Water Quality	1. Temperature 2. Dissolved Oxygen 3. Conductivity 4. pH 5. Turbidity	Yes Yes Yes Yes Yes
Nutrients	1. Field test kits using reagents reactions 2. Laboratory analysis	Yes Yes
Organic Carbon	1. Laboratory analysis	Yes

9.1 » PARAMETER: WATER QUALITY

Description

Temperature

Temperature is a physical property that indicates the relative hotness or coldness of water. Stream temperature can influence several other Physicochemical parameters directly, including dissolved oxygen (DO) concentrations, conductivity and pH (USGS, 2010). As temperature increases, DO held in the water column is reduced based on changes in solubility of gases with temperature. Warm water holds less DO than cold water (Mortimer, 1981). As temperature increases, conductivity increases as more molecules become dissolved and release ions into solution. These ions can also have an effect on pH, which is a measure of hydrogen and hydroxide ions in the water column (Stumm and Morgan, 1996). Biological functions within streams are also affected by temperature, which regulates lifecycles, spatial distribution and metabolism of all trophic levels. Temperature cues control the lifecycles of most stream organisms, signaling activities such as reproduction by microbial communities, emergence by macroinvertebrates, and spawning by fish (Hynes 1970). Stream temperature can be highly variable within a short distance between microhabitats, such as temperature differences between warmer back-water depositional areas and the main channel (Hauer and Hill, 2006). Warmer stream temperatures increase the rate of metabolic processes, such as photosynthesis and respiration, while most aquatic organisms reduce their metabolic processes during colder months (Hynes, 1970). Fishery managers have long recognized the importance of temperature to fish distribution and have separated lotic systems into warm-water streams

and cold-water streams to describe habitat (Moyle and Cech, 1982).

Stream temperatures are influenced by climate, streamflow and depth, sunlight exposure and the riparian canopy. Air temperature above the water surface affects stream temperature through heat transfer. Daily and seasonal stream temperatures fluctuate with air temperatures over the same time period, although the stream has less fluctuation due to the higher latent heat of water (Hauer and Hill, 2006). Precipitation and watershed runoff influence stream temperatures when there is a great enough temperature difference between watershed runoff and streamflow, and when there is a large enough volume of runoff entering streamflow. The same effect occurs with point-source discharges from power plants and industrial processes, and with hyporheic groundwater inputs through the streambed and banks (USEPA, 1997b).

Groundwater tends to be cooler than ambient water temperatures in summer months and warmer in winter months, due to the influences of soil temperature (Smith, 2005). Streamflow can affect temperature through turbulence, mixing surface and subsurface waters for a more even temperature distribution in running water compared to stagnant water. Shallow flow depth in small streams has less variation compared to deeper, larger streams where a temperature gradient can occur between surface and subsurface water (Hynes, 1970). Temperature generally decreases as depth increases due to less sunlight and atmospheric influence (Wetzel, 2001). Exceptions do occur, however, such as when surface water temperatures drop below freezing and act as an insulating layer that keeps deeper waters warm (Hynes, 1970). Sunlight can be the most influential factor for stream temperature, particularly in open waters (Hauer and Hill, 2006). Effects of sunlight are primarily dependent on the presence and relative density of a riparian canopy. A dense, tall canopy will filter more sunlight, diminishing the rise in temperature caused by solar radiation and reducing variability in stream temperatures over time (Allan and Castillo, 2007). Exposure to sunlight is also dependent on geographic latitude and variations throughout the day and the seasons.

Stream temperatures that are significantly different from ambient temperatures measured within reference streams should be regulated to maintain healthy biological communities. Even though temperatures of external flow contributions from watershed runoff and point-source discharges generally cannot be controlled, they should be considered to determine their impact and potential incorporation into a restoration plan. Stream restoration techniques can help regulate temperatures by providing adequate baseflow and flow duration (Level 1), since flowing water is well mixed with less temperature fluctuation. There are several methods that can be used to improve groundwater exchange through the hyporheic zone and streambanks to help regulate temperatures. Floodplain connectivity described in Level 2 will slowly recharge groundwater for a more consistent discharge through the hyporheic zone (Winter et al., 1998). Lateral stream stability, the riparian buffer and the degree of bed form diversity are all Level 3 parameters that can be used to regulate temperature. Creating a stable channel that carries its sediment and water effectively will help maintain consistent baseflow. Riparian buffers and large woody debris (LWD) within the channel can maintain consistent and generally

cooler temperatures over time by providing shade (Figure 9.1). Changes to the stream channel that improve bed form diversity, including deep pools, will help regulate temperatures in various biological habitats.

Ambient water temperatures with less fluctuation occur in lotic systems when the following conditions are present:

- Minimal variability between watershed runoff temperatures and stream temperatures;
- Adequate baseflow to provide mixing to prevent stagnant water;
- Floodplain connectivity to support hyporheic groundwater recharge for more consistent temperatures;
- Established riparian buffer to provide shade to help keep the water cool on hot sunny days and provide thermal regulation with less fluctuation over time; and
- Bed form diversity, as deep pools offer cooler waters for fish habitat, cover features (such as logs, rocks and undercut streambanks) and provide shade for cooler temperatures.

FIGURE 9.1 OVERHANGING VEGETATION PROVIDES SHADE IN NEWLY RESTORED STREAMS



Figure 9.1a Restoration site immediately after construction.



Figure 9.1b Same restoration site seven years after construction with overhanging vegetation that provides shade and reduces temperature variation.

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Dissolved Oxygen

Oxygen dissolved in the water column is required by stream biota to sustain life. The amount of dissolved oxygen (DO) significantly affects biological respiration rates, as well as the solubility of other chemical constituents like inorganic nutrients. In lotic systems, these effects become important in the substrate hyporheic zone where exchange of DO from surface waters to subsurface waters maintains microbial communities and provides habitat for stream biota (Wetzel, 2001).

Oxygen enters the water column primarily through diffusion from the atmosphere. Streamflow creates turbulence, which leads to additional entrainment of oxygen from the atmosphere (USEPA, 1997b). Turbulence is increased by rough channel beds (Hynes,

1970) and structures, such as rocks and large woody debris that rise above the water surface, creating eddies and mixing (Gordon et al., 2004). The water column is considered saturated when DO concentrations are in equilibrium with oxygen in the atmosphere. The amount of DO is also influenced by temperature, altitude and salinity. DO is more soluble in colder water than warmer water. In larger rivers, temperature may play a greater role than diffusion in influencing DO levels, due to smaller surface area relative to volume and less turbulence. Small streams with turbulent flow, however, can maintain DO concentrations near saturation, regardless of daily and seasonal temperature changes (Allan and Castillo, 2007). Streams at higher altitudes generally have higher DO concentrations than those at lower elevations due to differences in atmospheric pressure (USEPA, 1997b); and DO concentrations decline as salinity increases (Wetzel, 2001).

Oxygen is both produced and consumed within the lotic system through biological and chemical processes. Primary producers such as phytoplankton, algae and aquatic plants (macrophytes) release oxygen during photosynthesis, a process that produces organic material using inorganic carbon (CO_2) and energy from sunlight. Aquatic organisms, from microbes to fish, consume oxygen during the process of respiration when they metabolize the organic materials. In larger, slow-moving rivers with ample sunlight exposure, photosynthetic activity can be high enough to elevate DO levels during day while subsiding overnight. Without these biological processes, the effects of daily temperature changes and reduced diffusion rates would cause the opposite trend in rivers (Allan and Castillo, 2007). Dissolved oxygen concentrations can also be affected by availability of dissolved organic matter, whether through direct chemical reactions or through indirect stimulation of microbial respiration (Wetzel, 2001).

In natural streams, there is a balance between the rate of oxygen supply from diffusion, entrainment and photosynthesis, and the rate of oxygen consumption through biological metabolism and abiotic chemical reactions (Wetzel, 2001). This balance ensures that oxygen production is greater than consumption, and sufficient oxygen is available to support life at all trophic levels. Pollutants, such as excess nutrients and organic waste contributed from surface runoff and point-source discharges, can alter this balance and create conditions where more oxygen is consumed. One popular example is the *algal bloom* (when algal production increases as a result of excess nutrient loading), also referred to as eutrophication. Even though algal photosynthesis produces oxygen, microbial respiration rates increase DO consumption to a greater extent during decomposition of the algal biomass and its waste products (Carpenter et al., 1998). Drastic oxygen depletion may occur, causing anaerobic conditions within the water column that harm other organisms, e.g., fish kills (Hynes, 1960).

DO concentrations in impaired streams can be improved through removing sources of excess nutrients and organic pollutants in watershed discharges that influence stream-flow. On a reach scale, stream restoration techniques can improve DO concentrations using channel modifications that enhance flow dynamics described in Level 2. Narrowing a channel that has been over-widened and increasing channel slope can maintain base-flows for better oxygen diffusion rates. Removal of stream impoundments, such as dams,

will restore flowing water and prevent the increase in temperature that occurs behind the obstruction. In-stream structures used to improve Geomorphology function can increase streamflow turbulence, including boulder clusters and cross vanes (Fischenich and Seal, 1999). (See Figure 9.2.) Riparian buffer establishment will indirectly improve DO concentrations by reducing stream temperature through shading.

Higher concentrations of DO occur in stream systems when the following conditions are present:

- Excess nutrient and organic pollutant loads are controlled, maintaining a balanced biological system in which respiration does not consume more dissolved oxygen than is produced;
- Flowing water, which contains more oxygen than stagnant water through entrainment and mixing;
- In-stream structures, breaking the water surface to create turbulence and mixing; and
- Established riparian buffer, which provides shade for cooler water temperatures to increase the solubility of oxygen in the water column.

FIGURE 9.2 FLOW TURBULENCE CREATED FROM ROCK CROSS VANE STRUCTURE



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Conductivity

Conductivity is the measure of water's ability to conduct electrical current through dissolved ions. Inorganic compounds are good conductors, while organic compounds are poor conductors. This makes conductivity a good estimate of the total inorganic dissolved solids present in the water column (Eaton et al., 2005). Some of the more common inorganic dissolved ions include anions such as chloride, nitrate, sulfate and phosphate, and cations such as sodium, magnesium, calcium, potassium and aluminum. Conductivity is

primarily used as a baseline chemical indicator of stream health and is a good screening tool for stream restoration projects. Conductivity can be used to measure changes in discharge characteristics, external flow contributions, pollutant load and other factors affecting the chemical composition of streamflow (USEPA, 1997b).

The amount of conductivity depends to a greater extent on the concentration of charged ions rather than the types of ions present. This characteristic makes it a good measure of total dissolved solids across aquatic resources (Allan and Castillo, 2007). Conductivity is significantly influenced by temperature. Higher temperatures cause more ions to be released into solution, increasing conductivity. The effects of temperature can be accounted for by comparing the conductivity at the standard temperature of 25°C, which is referred to as specific conductance (USGS, 2010). Conductivity is also influenced by external factors, including geology, soils and climate. Dissolved ion concentrations are much higher in streams flowing through sedimentary rock that is more easily weathered compared to igneous and metamorphic rock (Allan and Castillo, 2007). Streams flowing through clay and silt soils tend to have higher conductivity than inert sandy soils due to the presence of charged molecules in clays and silts (Essington, 2005). Precipitation and runoff characteristics can influence stream conductivity. In temperate climates, precipitation events can dilute the dissolved ion concentrations in surface waters. In some cases, however, more precipitation can increase conductivity if rainwater has a higher concentration of dissolved solids compared to the receiving stream water. Arid climates have surface waters with high conductivity due to less rainfall. Salts accumulate in soils with little precipitation and high evaporation, readily dissolving in surface water runoff and groundwater (Walling, 1984; Allan and Castillo, 2007).

Conductivity measurements comparable to reference stream conditions are maintained in stream systems when the following conditions are present:

- Low pollutant loads in watershed runoff and point-source discharges, which eliminates direct impact of flows with higher conductivities than those inherent in the receiving stream; and
- Established riparian buffer, which provides shade to stabilize temperatures, allows filtration of surface-runoff contaminants, and decreases evaporation that can concentrate dissolved ions.

pH

Measurements of pH indicate the relative acidity or alkalinity of water. The pH scale (0–14) measures the logarithmic concentration of hydrogen (H⁺) and hydroxide (OH⁻) ions that compose the water (H₂O) molecule. The pH is 7.0, or neutral, when both ions are in equilibrium, such as in pure water. Streamwater contains dissolved ions that interact with these water ions to alter the equilibrium. When the pH drops below 7.0, the water is considered acidic; when the pH is above 7.0, water is considered alkaline (USEPA, 1997b). Stream pH can have a significant effect on biological communities, which prefer pH values in the 6.5 to 8.0 range. Diversity can be reduced in streams with pH outside

this range, favoring only certain species that can tolerate more extreme pH conditions (Hynes, 1970). Like conductivity, pH is a good screening tool for stream restoration projects. At low pH values, ions from metals and toxic compounds can be released into the water column and negatively impact biological communities (Allan and Castillo, 2007).

Stream pH can be influenced by chemical reactions and dissolved constituents present in the water. In natural streams, H⁺ and OH⁻ ions are typically produced during the dissociation or hydrolysis of carbon compounds (Wetzel, 2001). Conductivity can be altered by changes in pH, and vice versa, due to the interaction between water ions and dissolved ions present in the water column. The effects of temperature on stream pH are similar to those experienced by conductivity (Stumm and Morgan, 1996).

The pH of streams can be controlled by precipitation and runoff, as well as by soils and geology. Precipitation typically has an average pH of 5.6 due to the dissolved ions captured in the atmosphere. An increase in atmospheric pollution from anthropogenic sources can create acid rain, with even lower pH values (USEPA, 2008). Watershed runoff can increase the acidity of streamflow, depending on the amount of precipitation, runoff volume and contaminants carried from the surface. Streams that flow through soils with high organic acid content, such as wetlands and swamps, generally have inherently lower pH values. Streams that flow through soils with high carbonate and hydroxide content, such as those derived from limestone, have higher pH values due to the buffering capacity provided when binding with hydrogen ions of acids occurs. Weathering of sedimentary rock produces alkaline soils, while soils derived from igneous rock are low in alkalinity (Wetzel, 2001). The effects of groundwater inputs on stream pH are similar to conductivity, due to the relationship between groundwater and surrounding soil chemistry.

Stream pH values comparable to reference conditions are maintained in stream systems when the following conditions are present:

- Low pollutant loads in watershed runoff and point-source discharges, which eliminates direct impact of flows with higher conductivities than those inherent in the receiving stream; and
- Established riparian buffer, which provides shade to stabilize temperatures, allows filtration of acid rain and surface runoff contaminants, and decreases evaporation that can concentrate dissolved ions.

Turbidity

Turbidity is a measure of water clarity based on how much light passes through the water column (USEPA, 1997b). Turbid water appears colored or cloudy due to suspended and dissolved materials, including soil particles, organic matter, plankton and dyes (USGS, 2010). Turbidity influences other Physicochemical parameters and significantly impacts biological communities. When the water is turbid, temperatures increase due to higher absorption of heat by the suspended particles. Dissolved oxygen can be reduced as a result of increased temperatures and reduced photosynthetic activity when light penetration is impeded. Biological lifecycles and habitats are negatively affected by high

turbidity. In the water column, suspended materials can reduce visibility needed for feeding activities and disrupt respiration, such as clogging of fish gills. As the fine particles settle, they blanket the stream bottom covering substrates used for habitat, and they fill interstitial spaces of the hyporheic zone where oxygen exchange occurs. High turbidity for extended lengths of time will reduce reproduction and development of aquatic organisms (Hynes, 1960; USEPA, 1997b).

Natural causes of turbidity are observed in streams with high plankton productivity, as well as in streams that flow through organic soils with dissolved humic acids (Hynes, 1970). Turbidity can also be caused by watershed runoff, flow dynamics and channel instability. Fine sediment particles, such as clays, silts and fine sands derived from anthropogenic activities, are common causes of turbidity, particularly in disturbed watersheds and unstable stream channels (Whipple et al., 1981). These particles are entrained in stormwater runoff over bare soils during development of the watershed or with agricultural activities (Wolman and Schick, 1967; USEPA, 2003a). Developed watersheds with impervious surfaces deliver larger volumes of runoff at a faster rate, accelerating streambank erosion as the channel becomes increasingly unstable. Studies have shown that turbidity can remain elevated long after a storm event has ended in disturbed watersheds due to channel instability (Hammer, 1972; Whipple et al., 1981). Fine sediment particles can also have adsorbed nutrients that enrich the streamwater. The excess nutrients increase microbial productivity and biomass to perpetuate the turbidity problem. Fine sediment particles may also carry pollutants that are detrimental to aquatic life, such as pesticides and metals (Hynes, 1960).

Stream restoration projects can include several methods to control turbidity. Stabilizing the watershed and treating turbid stormwater runoff are desired practices in coordination with a reach-scale restoration project. Designing a channel with floodplain connectivity will provide for sediment deposition outside of the main channel and reduce shear stress during large storm events. Creating a stable channel that can convey the water and sediment delivered from the watershed effectively and protecting streambanks from shear stress will prevent channel erosion as a source of fine sediments in the water column. Establishing a riparian buffer will significantly reduce fine sediment in runoff, while increasing infiltration for reduced runoff volume.

Low turbidity concentrations occur in stream systems when the following conditions are present:

- Watershed stability, which prevents entrainment of fine sediments and associated nutrients from exposed watershed soils;
- Floodplain connectivity, which promotes sediment deposition on the floodplain and not within the channel, provides energy dissipation, and reduces channel erosion during large storm events.
- Channel stability, reducing stream bed and streambank erosion; and
- Established riparian buffer, which slows runoff rates for deposition of fine sediments and associated pollutants, and provides streambank stability for less erosion.

Measurement Method

In order to measure basic water quality parameters effectively, a stream monitoring plan must be developed that considers the significant spatial and temporal variability of the parameters, as well as fluctuations caused by flow conditions. Collecting individual (discrete) samples provides information about the parameter at one point in time, which may yield limited information in lotic systems with such dynamic variability. Continuous monitoring is recommended in order to better capture variability and allow for comparison over time and between the target reach and reference reach. In order to demonstrate whether significant changes have occurred over time, the number of samples and frequency of collection are important for statistical analyses of results. The level of effort for water quality parameters is rapid for discrete samples, but is considered intensive for continuous monitoring used to capture high variability. The level of complexity for all the water quality measurement methods is considered simple to moderate, depending on the instruments used and the statistical detail or level of expertise required for analyses to determine deviation from the reference condition and species requirements (Appendix Ac).

When measuring basic water quality parameters to determine Physicochemical function of a restored stream, it is imperative to identify influential variables that cannot be affected by restoration at the reach scale. External discharges from upstream, point-source and non-point-source contributions, and the effects of land-use changes in the watershed are all variables that may not be included in a reach-scale project. In order to fully restore these water quality parameters, a watershed scale effort may be required along with the presence of a healthy upstream watershed. These variables demonstrate that site selection and reach length must be considered during the planning stage of a stream restoration project. Climate, geology and soils can also have a significant effect on basic water quality but cannot be controlled at any scale. Environmental variables that are beyond the scope of the restoration plan can be differentiated from variables that are controllable through comparisons with upstream, downstream and reference stream conditions.

The measurement methods listed below are brief summaries for each basic water quality parameter. All measurement methods are considered direct assessments of water quality parameters for Physicochemical function (Appendix Ac). Details for each method can be found in the associated references, as well as outlined in the Standard Methods for the Examination of Water and Wastewater (Eaton et al., 2005). There are many resources to assist with deriving a monitoring plan, including those published by state environmental agencies and federal agencies, such as the USEPA (1997b) guide, *Volunteer Stream Monitoring: A Methods Manual*. Recommended references for methods and sampling plans include *Methods in Stream Ecology* (Hauer and Lamberti, 2006) and *Limnological Analyses* (Wetzel and Likens, 2000).

1. Temperature

Temperature is typically recorded in degrees Celsius for metric units and degrees Fahrenheit for English units. Temperature can be measured using a standard liquid-in-glass thermometer, electronic thermistor or thermocoupler in-situ (Hauer and Hill 2006).

Temperature sensors are commonly included with meters and probes that measure other parameters, including dissolved oxygen, conductivity and pH; therefore, a separate device may not be needed (USGS, 2010). Calibration of all devices with a NIST-certified thermometer is recommended (Eaton et al., 2005).

Temperature can be one of the most variable stream parameters to measure. This variability should be captured to the fullest extent possible, considering how many Physicochemical parameters and Biological (Level 5) functions are affected by changes in temperature.

External factors that affect temperature should also be taken into account during monitoring. Air temperature and precipitation should be measured, and sampling locations should be selected with the understanding that riparian canopy and external discharges, especially from groundwater seepage, can significantly influence water temperature. Therefore, the purpose of the sampling should be determined before the temperature sensors are deployed. Localized influences on temperature, like groundwater seepage, should be avoided if the goal is to determine a well-mixed, average temperature. Alternatively, sensors may be deployed in areas with groundwater seepage if the influence of groundwater and surface water exchange need to be determined.

2. Dissolved oxygen

Dissolved oxygen (DO) is measured as a concentration (mg/L) or as a percentage of the amount required for complete saturation of the water column. Saturation is based on the total amount of oxygen that can be dissolved in pure water at a specific atmospheric pressure and water temperature. Reference tables are available to determine what these DO concentrations should be (Mortimer, 1981; Eaton et al., 2005). DO should be measured in-situ or immediately after sample collection to avoid changes in concentrations associated with microbial processes and temperature. For in-stream measurements, a probe and meter combination can be used. The most common DO probes have selectively permeable membranes or optical sensors to detect DO within the water column. When using a probe and meter, temperature and barometric pressure should also be measured to adjust DO measurements to environmental conditions (USGS, 2010). In order to measure DO concentrations using water samples, the method must immediately stabilize DO in the water column. A common method is the Winkler titration that uses reagents added in the field prior to titration (Hauer and Hill, 2006). Although the Winkler method is typically not as accurate as a meter and probe combination, it is generally more economical.

Due to the variability of DO along the stream length and its requirement by many organisms, the sampling protocol should include measurements from different stream features, e.g., pool, riffle, upstream and downstream of an impoundment, stream areas with different riparian cover densities, and near areas where significant external flow contributions are suspected, e.g., groundwater seeps and springs, stormwater, point sources).

3. Conductivity

Conductivity is commonly measured with a probe and meter combination that measures resistance by dissolved ions to an electric charge in units of milliSiemens (mS)/cm

or milli-ohms (mhos)/cm (USEPA, 1997b; Eaton et al., 2005). A temperature sensor is most always included with the conductivity probe and meter due to the relationship between the two parameters. Specific conductance is a measure of conductivity that has been normalized to unit length at the standard temperature of 25 °C (USGS, 2010). Conductivity measurements indicate the amount of total dissolved solids (TDS) within the water column. Actual TDS can be calculated by multiplying the conductivity reading by an empirically determined factor between 0.55 and 0.9 (Eaton et al., 2005). Conductivity measurements also provide useful baseline data that can indicate changes in water quality over time, particularly due to additions of external discharges and pollutants.

4. pH

The pH value can be collected in the field or laboratory using a color treatment test or using a pH probe and meter combination. Samples collected should be evaluated within two hours due to the effects of CO₂ exchange with air on pH; therefore, field measurements are generally easier and more accurate. For the color treatment test, reagents are added to the sample causing coloration of the water. The color and its intensity are compared to a standard color chart to determine the estimated pH unit. For a more accurate measurement, a pH meter and probe can be used (USEPA, 1997b). The pH meter measures hydrogen ion activity as a function of electric potential generated between a glass pH electrode and a reference electrode. Results are reported by the meter in pH units or millivolts. Temperature should also be measured by the probe to compensate pH measurements for water temperature (USGS, 2010).

5. Turbidity

Turbidity can be measured directly using a turbidity meter and probe in the field or by laboratory analysis. The meter uses a light source and a photoelectric cell to measure light intensity that is scattered and absorbed by suspended and dissolved particles in water. Without turbidity, light would be transmitted in straight lines through a sample. The most common unit is the Nephelometric turbidity unit (NTU), and most meters measure a range from 0 to 1000 NTU (USEPA, 1997b and USGS, 2010). Turbidity can be measured indirectly using a Secchi disk in deep, slow-moving rivers (Wetzel and Likens, 2000) or using a transparency tube (USEPA, 1997b).

Turbidity is highly dependent on streamflow with typical increases as stage rises during storm events that entrain excess sediments during surface runoff and within the channel. Measurements taken during or immediately after rain events or snowmelt will result in higher turbidity readings. It is recommended that streamflow measurements be recorded over time, along with continuous monitoring of turbidity, to capture changes during storm events. Baseflow samples alone will not yield information about turbidity levels and their potential impacts on the biological community.

Performance Standard

Since external factors such as upstream discharges, point-source discharges and watershed land use changes cannot always be controlled, it is important to measure basic water quality parameters within the proposed restoration reach prior to construction, as well as within the reference stream(s). Measurements should also be taken upstream and downstream of the restored reach to determine what is coming into and exiting the restored reach. These locations will provide baseline measurements of existing and reference conditions for each parameter for comparison of post-restoration performance.

Existing condition and reference stream measurements along with water quality standards should be used when assessing the functionality of stream chemistry. To determine whether or not an aquatic system is meeting its pre-determined designated use, regulators use water quality standards. The designated uses are determined by taking into consideration the desired use and value of a stream for public water supply, protection of fish, shellfish and wildlife, and for recreational, agricultural, industrial and navigational purposes (USEPA, 2011). Streams meeting these standards are only meeting the minimal requirements determined for the use by the state in which the system is located. Water quality standards vary depending upon specific state regulations; therefore, it is recommended that monitoring programs use their state's standards as the minimum requirements for stream assessment. The EPA has compiled a database of each state's water quality standards on their website (www.epa.gov/waterscience/standards/wqslibrary; USEPA, 2007). EPA has also compiled water quality monitoring information from across the country. This data set is available at www.epa.gov/storet.

Reference conditions and certain species requirements may exceed the water quality standards, depending on the designated use. An example in the East would be restoring a stream for native brook trout, which would have higher water quality standards than restoring a stream for recreational fishing of rainbow trout, due to species requirements. Both measurements from reference streams and appropriate water quality standards for the desired use are, therefore, the best assessments to determine if the project reach is Functioning. Measurements that only meet the minimum water quality standards, but are not representative of the reference stream conditions and are limiting to certain species, are considered Functioning-at-Risk; those not meeting minimum water quality standards, not representative of the reference conditions, and not supporting species requirements should be considered Not Functioning. For parameters that do not have water quality standards, reference conditions and species requirements are used to determine performance level (Table 9.2). Turbidity may or may not have regulated water quality standards, depending on the location; therefore, turbidity is listed in both categories in the table.

TABLE 9.2 BASIC WATER QUALITY PERFORMANCE STANDARDS

MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
Temperature	Meets water quality standards for designated use	Meets water quality standards for designated use	Does not meet water quality standards for designated use
DO		Is not representative of reference stream conditions and does not support species requirements	Is not representative of reference stream conditions and does not support species requirements
Turbidity	Representative of reference stream conditions and meets species requirements		
Conductivity	Representative of reference stream conditions and meets species requirements	Is not representative of reference stream conditions <i>or</i>	Statistically different than reference stream conditions and
pH		Does not support species requirements	Does not support species requirements
Turbidity			

9.2 » PARAMETER: NUTRIENTS

Description

Nutrients are chemical elements required by all organisms to live and grow. The most important nutrients found in both aquatic and terrestrial ecosystems are nitrogen and phosphorus due to their influence on growth (Allan and Castillo, 2007). Nitrogen is found in dissolved inorganic form primarily as nitrate (NO_3^-) and ammonium (NH_4^+) ions, and as organic nitrogen. Nitrogen enters the stream through precipitation, atmospheric deposition and diffusion, in situ nitrogen fixation, groundwater, and surface runoff. Phosphorus is present as inorganic phosphate (PO_4^{3-}) and as organic phosphorus (USEPA, 1997b). Both inorganic and organic phosphorus can be dissolved in water or suspended in the water column as living biomass or attached to solid particles within the sediments (USEPA, 1997b; Allan and Castillo, 2007). Phosphorus enters the stream mainly through weathering of soils and rock and adsorbed to soil in surface runoff (Hynes, 1970).

In natural streams, most nutrients are stored within the biomass of the biological community. Nutrient uptake by living organisms is in equilibrium with nutrient release during excretion and decomposition of dead organic matter. Dissolved inorganic forms of nitrogen (NO_3^- and NH_4^+) and phosphorus (PO_4^{3-}) are present in very low concentrations (Hynes, 1970; Maybeck 1982). Dissolved nutrients move downstream, continuously cycling between abiotic and biotic forms, and between inorganic and organic forms, in a process known as nutrient spiraling. Dissolved inorganic nutrients are assimilated by

living organisms, bound to sediments or chemically transformed, moving from the water column to sediments and then released again for downstream transport (Stream Solute Workshop, 1990; Newbold, 1992). Nutrient cycling can help maintain water quality by sequestering nutrients within the biological community and substrates, reducing downstream nutrient loads. The nutrient spiraling equilibrium can be significantly disrupted, however, by excess nutrient inputs. Details of nutrient spiraling can be found in Stream Solute Workshop (1990) and Webster and Valett (2006).

Excess nutrients are contributed from anthropogenic sources such as fertilizers, animal waste and sewage from agricultural runoff, urban runoff and direct point-source discharges (Figure 9.3; USEPA, 2000). Nitrogen is also added from atmospheric pollutants through precipitation, commonly referred to as acid rain (USEPA, 2008). Excess nutrients in the stream can over-stimulate microbial productivity causing eutrophication (Figure 9.4; USEPA, 2000). Excess nutrients from nonpoint sources are one of the leading causes of stream impairment in the nation (Carpenter et al., 1998; Allan, 2004; USEPA, 2009). There are several processes that can naturally remove excess nutrients from the water column. Nitrogen can be assimilated into biomass, removed through denitrification, adsorbed to sediments and volatilized (Bernot and Dodds, 2005). Phosphorus is removed from the water column by assimilation and adsorption to sediments (USEPA, 1997b). Nutrient storage processes can be temporary, however, so the most effective way to reduce excess nutrients in streams is to control the sources from the watershed.

Stream restoration projects can include several techniques to reduce excess nutrients. Establishing floodplain connectivity is important for deposition of nutrient-laden sediments outside the channel, and for providing a healthy riparian buffer that can store nutrients. A riparian buffer can remove nutrients if the root zone is in contact with the groundwater table to facilitate denitrification. In-stream modifications that restore incised channels to proper geomorphic dimensions will connect the riparian buffer to the groundwater table. Channel modifications that increase stream length and residence time will promote nutrient uptake by the biological community and denitrification (Gucker and Pusch, 2006). (See Figure 9.5.) Channel stability will also reduce nutrients in the water column by conveying water and sediments effectively, by preventing sediment inputs from streambank erosion, and by maintaining a healthy hyporheic zone where microbial processes can sequester nutrients (Hendricks, 1993).

Removal of excess nutrients occurs in stream systems when the following conditions are present:

- Nonpoint sources of excess nutrients are controlled;
- Floodplain connectivity facilitates sediment deposition, provides sediment storage, and establishes the water table to be in contact with the root zone of the riparian buffer, which is required for denitrification to occur;
- Established riparian buffer, which slows runoff rates and facilitates sediment deposition with associated nutrients, stabilizes streambanks and provides nutrient uptake by riparian vegetation;

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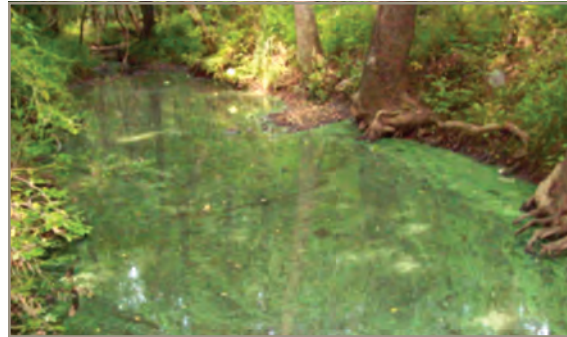
- Meandering channel increasing stream length, which decreases stream velocity and increases hydrologic residence times (required processes for nutrient processing);
- Channel stability, which reduces streambank erosion and fine sediment inputs; and
- Healthy hyporheic zones, promoting habitat for the microbial community that processes nutrients.

FIGURE 9.3 SOURCE OF LATERAL RUN-OFF FROM GOLF COURSE



Source: Reproduced with permission from Michael Baker Corporation

FIGURE 9.4 AREA OF NUTRIENT ENRICHMENT DOWNSTREAM OF GOLF COURSE



Source: Reproduced with permission from Michael Baker Corporation

FIGURE 9.5 RESTORED MEANDERING CHANNEL



Source: Reproduced with permission from Michael Baker Corporation

Restored meandering channel that is well connected to the floodplain. The water table is in contact with the newly established stream buffer. The meandering channel with diverse bed forms and complexity increase the hydrologic residence times. Together, these elements support nutrient processing.

Measurement Method

Chemical measurements for nutrients can be conducted in the field or in a laboratory, dependent upon the measurement method used and the desired accuracy of results. Field test kits are available for the rapid and simple assessment of many nutrient forms, usually containing reagents and a color wheel/colorimeter to determine concentrations. Many of the nutrient tests performed in the laboratory use specialized analytical equipment and complex chemical reactions for better accuracy. For details on these analytical methods, refer to Eaton et al., (2005). The level of effort for nutrient measurements ranges from rapid to intensive, depending on the instrument used and the number of samples required to capture variability and to determine deviation from reference conditions. The level of complexity is considered simple when using field test kits, but complex when laboratory analysis is required (Appendix Ac).

Nitrogen concentrations (mg/L) can be measured by analyzing water samples for inorganic forms, including nitrate (NO_3^-) and ammonia (NH_3). Nitrite (NO_2^-) is an intermediate inorganic form produced during denitrification (NO_3^- to nitrogen gas) and nitrification (NH_3 to NO_3^-). However, it is generally not measured due to its very minute concentrations at any given time. Nitrate is important to quantify because it is readily produced by oxidation of ammonia (nitrification), readily dissolved in water and leached from soils, and an essential nutrient for primary producers (Wetzel, 2001; Eaton et al., 2005). Nitrate can be analyzed in the field with an electrode and meter combination; however, this method is currently unable to detect quantities of less than 1 mg/L. Nitrate can also be quantified using the cadmium reduction method in which NO_3^- reacts with cadmium ions to produce a color reaction that can then be interpreted for concentration. Ammonia concentrations are generally low in natural streams, since ammonia does not readily leach from soils and is rapidly converted to NO_3^- for biological assimilation. Ammonia can be analyzed in the field with an electrode and meter combination or using a salicylate reagent method (USEPA, 1997b; Eaton et al., 2005). Other common nitrogen quantities that can be measured are briefly described to assist with parameter selection. These quantities can be combined with nitrate and ammonia tests in various ways to estimate individual nitrogen components, including organic N concentrations. Total nitrogen (TN) is the sum of all nitrogen forms, inorganic and organic. It can be quantified in the laboratory using a persulfate digestion method. Total Kjeldahl nitrogen (TKN) is named for the method used and is the sum of organic N and ammonia concentrations (Wetzel and Likens, 2000; Eaton et al., 2005).

Phosphorus concentrations (mg/L) can be measured by analyzing water samples for (ortho)phosphate (PO_4) using the ascorbic acid method. To determine total phosphorus (TP) concentrations (organic and inorganic), the sample is first digested with an acidic solution containing a strong oxidizer that first converts all forms to phosphate (PO_4) in preparation for the ascorbic acid test. These two values allow for determination of organic P. The dissolved phosphorus portion can be determined in water samples by filtering out the phosphorus associated with suspended particles first, then using the above phosphate and TP methods. An important form to measure is the soluble reactive phosphorus

(SRP), which is the soluble inorganic PO_4 fraction available for biological assimilation. It is determined by subtracting the filtered PO_4 concentration from the original PO_4 concentration (Wetzel and Likens, 2000; Eaton et al., 2005).

When measuring nutrients within a stream reach, the process of nutrient spiraling should be accounted for since nutrients are being continuously cycled between inorganic and organic states, and between the biological community, substrate and the water column (Newbold, 1992). Adequate upstream and downstream sampling before restoration activities occur is recommended in order to get a good baseline survey of nutrient concentrations entering and exiting the reach. Nutrient cycling can also result in significant nutrient storage within microbial biomass and bottom sediment over long periods of time. Stored nutrients can be reintroduced into the water column under certain stream conditions, causing persistent nutrient release long after the pollutant source has been removed. It is recommended that post-restoration monitoring occurs over a sufficient time period to evaluate whether nutrient reductions have been achieved (USEPA, 2000). Nutrient processing methods are not discussed due to their relative complexity compared to water sample analyses. But these methods are recommended if a more detailed assessment is allowed by time and funding. Resources for these processing methods include Newbold et al. (1981), Payn et al. (2005), and Hauer and Lamberti (2006).

External discharges entering the stream reach of interest along with watershed activities affect nutrient concentrations and must be accounted for in nutrient monitoring plans. Nutrients should be measured within the proposed project reach before and after restoration. Baseline sampling should also occur upstream and downstream of the project reach and within the reference reach for comparisons over space and time. It is recommended that nutrient monitoring extend far enough downstream to observe nutrient cycling effects. This distance would be dependent on the nutrient load, the availability of nutrient sinks and flow rate. A nutrient with/without tracer release study can be used to determine specific distances. It is recommended that nutrient monitoring also occur for an extended period of time after restoration to observe the effects of nutrient storage. Comparisons between existing condition and reference reach measurements along with state water quality standards should be used when assessing nutrient loads.

Performance Standard

Performance standards for nutrients are similar to basic water quality parameters. Due to the predominance of excess nutrients in aquatic systems, the nutrient parameters are evaluated based on amount of eutrophication versus biological limitations. Both measurements from reference streams to establish reference condition and appropriate water quality standards for the desired use can be used to determine whether a project stream is Functioning. It is assumed in this performance standard that the reference stream condition will meet species requirements to qualify as a suitable comparison reach. Measurements that only meet the minimum water quality standards, but are not representative of the reference stream condition and are limiting to certain species, are considered Functioning-at-Risk; those not meeting minimum water quality standards, not

representative of the reference stream condition and not supporting species requirements should be considered Not Functioning. For nutrients that do not have water quality standards, reference conditions and species requirements are used to determine performance level (Table 9.3).

TABLE 9.3 NUTRIENT PERFORMANCE STANDARDS

MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
Field Test Kits and Laboratory Analysis	Meets water quality standards for designated use	Meets water quality standards for designated use	Does not meet water quality standards for designated use
	Representative of reference stream conditions	Is not representative of reference stream conditions	Is not representative of reference stream conditions
	Does not cause eutrophication	Does not cause eutrophication	Causes eutrophication

9.3 » PARAMETER: ORGANIC CARBON

Description

Energy is made available in lotic ecosystems through metabolism of organic carbon. The majority of organic carbon is added from outside the stream channel, referred to as allochthonous. This material is contributed from riparian vegetation and soil organic matter. The remainder of organic carbon is generated within the stream channel, referred to as autochthonous. This material is contributed from organic processing, particularly through photosynthesis by macrophytes and algae (Allan and Castillo, 2007). The largest proportion of OC is non-living (detritus) and not associated with living biomass (Wetzel, 2001). Organic carbon availability significantly influences the biological community in streams. Small streams with dense canopies and limited photosynthesis rely mostly on microbial uptake and decomposition of OC for energy transfer to higher trophic levels. In larger rivers microbial metabolism is still important, even with additional photosynthesis opportunity due to turbidity, depth, downstream transport of OC and floodplain inputs (Vannote et al., 1980).

Organic carbon can either be in dissolved (DOC) or particulate form (POC), and generally composes half of organic matter (OM) on a weight basis (Allan and Castillo, 2007). Due to this consistent relationship between the two organic forms, these terms are commonly used interchangeably in the literature. Dissolved organic carbon (DOC) is commonly the largest pool available to the biological community on an annual basis, and the ratio of DOC:POC is greater than 1 in most streams (Maybeck, 1982; Webster and Meyer, 1997). DOC is composed primarily of humic materials derived from organic

matter in soils and contributed through groundwater to the stream. Within the stream, DOC is assimilated by the microbial community or produced by microbial processing of larger particulate organic materials within the substrate hyporheic zone. DOC can also be transformed by abiotic processes such as precipitation, flocculation, and adsorption to soil particles, and direct mineralization by sunlight. DOC is processed rapidly, generally within days (Wetzel, 2001). Particulate organic carbon (POC) is commonly referred to in the context of organic matter, and is divided into fine particulate organic matter (FPOM) and coarse particulate organic matter (CPOM). FPOM is generally between 0.5 μ m and 1mm and is derived from the decomposition of CPOM in the form of plant litter and woody debris (Wetzel, 2001). It can be found floating in the water column (seston) or within the bottom sediments (Wallace et al., 2006). CPOM is anything greater than 1mm, providing an important fixed carbon source to streams (Lamberti and Gregory, 2006; See Level 3, Organic Matter Transport). Particulate forms of organic matter are generally processed over weeks (FPOM) to years (CPOM) by microbial decomposition or direct consumption by higher trophic levels, including macroinvertebrates and fish. The amount of POC available in the stream is dependent on the amount of riparian vegetation present, watershed runoff characteristics and streamflows (Wetzel, 2001).

Organic carbon processing occurs in a similar pattern as that of nutrients, through carbon spiraling moving downstream (Newbold et al., 1982). Organic carbon is assimilated by living organisms, adsorbed to bottom sediments, or abiotically transformed in a cyclical pattern. Biological metabolism either transfers organic carbon up the food chain during consumption, or remineralizes it to inorganic carbon dioxide gas (CO₂) that is released into the water column. These processes can be complex, and details can be found in Newbold et al. (1982), Thurman (1985) and Webster and Benfield (1986). Organic matter budgets can be created for streams to quantify organic carbon pools and their availability (Cummins et al., 1983; Webster and Meyer, 1997). Due to the importance of organic carbon in lotic systems, stream restoration practitioners should always consider how to enhance organic carbon availability within their projects. The establishment of lateral connectivity between the stream and riparian zone can provide significant OC sources (Gregory et al., 1991; Lake et al., 2007). A riparian buffer contributes both DOM and POM directly from vegetation and watershed surface runoff, and indirectly by enhanced infiltration through the soil to groundwater (Figure 9.6). Floodplain connectivity exposes streamflow to OM sources in the riparian areas and prevents excessive removal of POM by hydraulic scouring during large flow events. Designing a stable channel that can maintain a healthy hyporheic zone with adequate groundwater interaction and oxygen availability is essential for organic processing and has been well documented (Stanford and Ward, 1988; Kasahara and Hill, 2006; Kasahara, 2007; Boulton et al., 2010). Restoring a meandering pattern with deep pools and installing structures, such as root wads, large woody debris (LWD) and cross vanes, will enhance retention of organic materials (James and Henderson, 2005). (See Figure 9.7.)

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Organic carbon availability and processing occurs when the following conditions are present:

- Established riparian buffer, which contributes OC directly through vegetation and indirectly through infiltration to groundwater;
- Floodplain connectivity, providing access to riparian vegetation and organic matter and reducing stream velocities during high flows;
- Healthy hyporheic zones, which promote habitat for the microbial community that processes OC and provides a groundwater interface for DOC contributions; and
- Channel meandering and in-stream structures, which create opportunities for OM storage in deep pools and increase POM retention.

FIGURE 9.6 RIPARIAN BUFFERS PROVIDE ALLOCHTHONOUS MATERIAL



Source: Reproduced with permission from Michael Baker Corporation

Figure 9.6 is an urban stream restoration project six years after construction. The photo was taken in the Fall and shows leaves falling from the riparian buffer into the stream channel.

FIGURE 9.7 ROOT WADS AND MEANDER BENDS HELP RETAIN ORGANIC MATERIAL



Source: Reproduced with permission from Michael Baker Corporation

Measurement Method

The relative amount of organic carbon in a water sample (mg/L) is determined using laboratory analyses. These methods are considered intensive for the level of effort and complex for the level of complexity, due to the different samples that must be collected to evaluate the different forms of organic carbon, due to the equipment required, and due to the level of expertise needed to interpret the measurement results in comparison to the reference condition (Appendix Ac).

Filtration is generally used to separate out the CPOM portion (1mm), the FPOM (0.45 μ m) and the dissolved fraction (DOC). The dissolved portion is then quantified using a total organic carbon (TOC) analyzer after removing the inorganic carbon fraction (CO_2 , bicarbonate and carbonates). The analysis method uses high temperature combustion or UV/persulfate oxidation. POC concentrations (mg/L) in each size class are determined by placing the filtered portion from the water sample into a high temperature oven (550 °C) and quantifying mass lost upon combustion (Wetzel and Likens, 2000; Eaton et al., 2005).

Measurement methods of organic carbon associated with substrates and bottom sediments, primarily DOC and FPOC, are not described in this section. These measurements, along with inorganic carbon (CO_2) methods, are described in Level 5: Microbial Communities. Specific methods of measuring organic carbon can also be found in Wetzel and Likens (2001), Eaton et al., (2005), and Hauer and Lamberti (2006). Retention of CPOM, particularly leaves and small woody debris, can be estimated using methods described in Ehrman and Lamberti (1992) and James and Henderson (2005). In general,

the retention and release of CPOM is modeled by using a log proportional linear regression equation that compares the amount of CPOM remaining in the system to the distance it has traveled within the system.

Similar to nutrient measurement methods, external discharges entering the stream reach of interest along with watershed activities should be considered due to their effects on OC quantities. OC concentrations should be measured within the proposed project reach before and after restoration. Baseline sampling is recommended both upstream and downstream of the project reach and within the reference stream(s), in order to adequately compare measurements spatially and temporally. It is recommended that OC monitoring extend far enough downstream and over an extended period of time after restoration to observe OC spiraling effects, particularly the storage component. Specific measurements of OC spiraling are complex and not covered in this section (see references above). All measurements should be compared to reference conditions for effective evaluation.

Performance Standard

There are no published performance standards for organic carbon concentrations and for organic processing in streams. The best evaluation of organic carbon concentrations is by comparison of quantities with reference reach conditions (Table 9.4). Measurements that meet reference stream conditions are indicative of a Functioning stream reach. Measurements where results do not meet reference stream conditions could be considered Functioning-at-Risk. Measurements of OC concentrations that do not meet reference stream conditions could be considered Not Functioning. A threshold can be determined based on biological species biomass and OC processing found in the reference stream. Suggested performance standards for OC processing are not covered in this section, but they can be found in Level 5 (Biology) due to the dependence of biological metabolism on OC concentrations. Species biomass and assemblage measurements, particularly those of the microbial and benthic macroinvertebrate communities, can be incorporated into evaluations of effective OC concentrations, if desired.

TABLE 9.4 ORGANIC CARBON PERFORMANCE STANDARDS

MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
Laboratory Analysis	Meet reference stream conditions	Do not meet reference stream conditions	Do not meet reference stream conditions and is below a threshold determined for adequate organic processing.

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Chapter 10

Biology

Biology functions are at the top of the Stream Functions Pyramid. These functions include processes that support the life histories of aquatic and riparian plants and animals. The ability of the lotic system to support biological processes is dependent upon the Hydrology, Hydraulic, Geomorphology and Physicochemical functions as described previously. Stream biological communities have a highly interconnected trophic structure starting from primary producers and moving up the food chain to fish. When habitat degradation occurs due to functional loss in the lower levels, and when valuable energy resources are removed, the trophic structure is disrupted and biological assemblages lose diversity and abundance.

The Biology function-based parameters include microbial communities, macrophyte communities, benthic macroinvertebrate communities, fish communities and landscape connectivity. A variety of measurement methods are provided for each parameter. The parameters, measurement method and indication of whether or not a performance standard is provided are shown below in Table 10.1. Scientists have researched the detailed and complex effects of stream condition on biological function and have developed biological indices that integrate ecosystem dynamics into simple, rapid assessments of stream condition. Biological indices are commonly used to assess water quality, but some have been developed to evaluate overall stream condition. Some of these indices are provided below and are included in the Biology category even though they also include parameters from the lower levels, as their purpose is to provide an overall assessment of biological condition. Appendix Ac includes a list of all the Biological measurement methods along with information about the method's type, level of effort, level of complexity, and whether it is a direct or indirect measure of the function-based parameter. The criteria used to make these determinations are provided in Chapter 4.

Landscape connectivity is included in the Biology category because it represents the ability of a target aquatic or riparian species to migrate upstream and downstream along a continuous corridor that meets their habitat requirements. Physical breaks in the corridor, like roads, create a disconnection to their habitat requirements. Landscape connectivity only becomes important after the species of interest are identified. For example, landscape connectivity requirements will be different for turtles than for large mammals like deer and bear. Once the species of interest are identified, landscape connectivity requirements can be determined.

TABLE 10.1 BIOLOGY PARAMETERS, MEASUREMENT METHODS AND AVAILABILITY OF PERFORMANCE STANDARDS

PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD
Microbial Communities	1. Taxonomic Methods 2. Non-Taxonomic Methods 3. Biological Indices	No No Yes
Macrophyte Communities	1. Taxonomic Methods 2. Non-Taxonomic Methods 3. Biological Indices	No No Yes
Benthic Macroinvertebrate Communities	1. Taxonomic Methods 2. Non-Taxonomic Methods 3. Biological Indices	No No Yes
Fish Communities	1. Taxonomic Methods 2. Non-Taxonomic Methods 3. Biological Indices	No No Yes
Landscape Connectivity	1. Spatial Analysis 2. Species Tracking 3. Habitat Models	No No No

10.1 » PARAMETER: MICROBIAL COMMUNITIES

Description

The microbial community in lotic systems is the foundation of the food chain, providing the organic energy to all of the higher trophic levels, including invertebrates and fish. This community is composed of autotrophs and heterotrophs. Autotrophs are the primary producers, making organic compounds through the process of photosynthesis with the uptake of inorganic carbon (CO₂) and release of oxygen. Phytoplankton and algae are the major primary producers within the microbial community. Heterotrophs are the primary consumers of the food chain, including bacteria and fungi. They break down particulate organic carbon (POC) and consume dissolved organic carbon (DOC) for energy, which is transferred to higher trophic levels as they in turn are consumed. This organic processing occurs through microbial respiration and release of CO₂ (Allan and Castillo, 2007). In most lotic systems, heterotrophic production is the predominant source of energy input. Primary production becomes significant, however, in higher order streams and rivers where light is more available (Vannote et al., 1980; Minshall et al., 1985).

The microbial community can be found suspended in the water column, referred to as plankton or seston, and found inhabiting substrates along the bottom of the stream, referred to as periphyton. Plankton is defined as any drifting organism, including autotrophic phytoplankton and algae, and heterotrophic zooplankton and bacteria. Periphyton is a complex community of both autotrophic and heterotrophic microbes, including algae,

fungi, bacteria, protist and other species that provide a link between the substratum and the overlying water column (Wetzel, 1983 and Wetzel, 2001). In lotic systems, periphyton is generally the most important biological community for providing energy to higher trophic levels. Energy contributions from plankton communities become important in larger rivers where light is plentiful and deep water prevents significant periphyton development. Within the periphyton layers, primary production and heterotrophic consumption create a microbial loop that effectively cycles carbon and nutrients (Lowe and LaLiberte, 2006 and Allan and Castillo, 2007). The balance between primary production and decomposition within the microbial community can determine the availability of organic matter and nutrients to higher trophic levels, as well as the amount of oxygen available for aquatic organisms. For a more detailed discussion of primary producer and consumer interactions, refer to Lamberti et al. (2006).

Microbial communities are influenced by hydrology, availability of substratum, light, carbon and nutrients, water quality, and consumer populations (Biggs, 1996; Janauer and Dokilul, 2006). The availability of stable substrates (including rocks, wood, sediments and macrophytes) that are exposed to limited scouring during storm events allows for development of diverse and productive microbial assemblages. Light is required for primary productivity and determines the extent of periphyton development (Figure 10.1). Temperature is one of the most important basic water quality parameters that affect microbial productivity due to thermal regulation of metabolism. Both light and temperature change daily and seasonally to define microbial population dynamics. The availability of carbon as inorganic CO₂ for primary producers, and dissolved and particulate organic carbon (POC) for heterotrophic bacteria and fungi is essential. The hyporheic zone and flow of interstitial water has a significant influence on periphyton productivity because it contributes a source of DOC from the groundwater (Boulton et al., 1998; Wetzel, 2001). Excess nutrients and organic pollution can over-stimulate microbial production, however, which is detrimental to streams as oxygen consumption during decomposition becomes greater than oxygen production (See Physicochemical Chapter: Nutrients and Organic Carbon). Consumer populations of invertebrates and fish can also have a considerable effect on microbial communities, especially periphyton, through their feeding habits (Lamberti, 1996). Although most microbial biomass is consumed as detritus, feeding on living tissues is significant because living tissues are more nutritious (Cummins and Klug, 1979).

Many of the stream restoration techniques used for Levels 1-4 will help develop a stable and productive microbial community. Non-point sources of excess nutrients and organic pollution should be controlled as much as possible within stormwater runoff to ensure there is a balance within the microbial population that contributes more dissolved oxygen than consumed. Large fluctuations in stream velocities during stormflow can be controlled by providing floodplain connectivity and designing a channel to attenuate erosive flows. Floodplain connectivity can also provide organic carbon resources while promoting sediment deposition outside of the channel. Periphyton on most substrates is negatively affected by scour, and may take a long time after large flow events to recolo-

nize and provide food and habitat. Maintaining a stable and healthy hyporheic zone especially benefits periphyton by providing DOC and nutrient resources. Bed form diversity is important to create shallow habitats and substrate protected from increases in stream velocity. Designing a channel for adequate transport of the sediment load and channel stability will prevent sediment inundation of periphyton substrate and reduce turbidity that limits light availability for both plankton and periphyton communities. The presence of large woody debris and in-stream structures can create habitat for microbial communities and help dissipate the energy of higher flows. Overall, stream restoration practices that ensure channel stability and improve water quality will encourage establishment and balanced growth of microbial communities that will provide dissolved oxygen, food and habitat for all trophic levels.

A healthy functioning microbial community occurs when the following conditions are present:

- Removal of excess nutrients and organic pollution, which prevents overstimulation of microbial productivity that will remove dissolved oxygen;
- Floodplain connectivity and bankfull channel, which dissipate energy of large storm events to prevent excessive scouring of substrate, provide access to organic carbon sources available on the floodplain, and prevent sediment inundation of substrate;
- Healthy hyporheic zones, which provide periphyton habitat, and provide an interface with groundwater and DOC inputs;
- Bed form diversity and in-stream structures, which create shallow habitats for light availability, dissipate flow energy, provide opportunities for organic carbon storage and retention, and provide substrates such as large woody debris and rocks; and
- Channel stability that prevents sediment inundation of periphyton habitat and the detrimental effects of turbidity on plankton and periphyton communities.

FIGURE 10.1 GOOD PERIPHYTON HABITAT IN AN INTERMEDIATE SIZE RIVER WITH SHALLOW DEPTH, LIMITED SCOUR, AND PLENTY OF AVAILABLE COBBLE SUBSTRATE



Source: Photo by Will Harman

Measurement Method

Microbial community samples are collected from the field and generally brought back to the laboratory for analysis. Plankton can be collected for measurement from the water column by filtering techniques using a known water sample volume. Periphyton can be collected by scraping known areas of natural substrates and various artificial substrates that have been allowed to colonize over time. The samples can then be analyzed for both taxonomic and non-taxonomic parameters. Algae are the most common microorganism evaluated within samples due to their predominance within the microbial community, as well as because of their well-developed taxonomy and extensive research of their tolerance to environmental stressors (Hines, 1970; Stevenson and Pan, 1999; Stevenson and Smol, 2003). Detailed methods for sampling microbial communities and measurement methods can be found in Weitzel (1979), Wetzel (1983), Hill (1998) and Steinman et al. (2006). A summary of common measurements is presented below, including the direct methods of taxonomic and non-taxonomic measurements and the indirect method of the biological index method.

1. Taxonomic Measurements

Species are identified using visual observations and microscopes. This information is used to determine species composition, their relative abundance (numbers present), species diversity and taxa richness. This information is collected in a project reach, preferably upstream or downstream of the project, and within reference stream(s). Statistical techniques are used to determine if the populations in the project reach are different than the reference conditions established using reference stream data.

2. Non-Taxonomic Measurements

Biomass and productivity are two non-taxonomic measures of microbial communities. For biomass, samples are filtered and the dry weight of the filtered biological material is determined (105°C oven). Ash-free dry mass is then measured (AFDM; 500°C oven) to determine biomass on a carbon basis per volume for plankton and per area for periphyton. Chlorophyll a content can also be assessed to estimate algal biomass proportion, since most all plants contain chlorophyll a in known quantities per species. Microbial productivity can be measured using several methods. A change in biomass over time is a measure of microbial productivity. Artificial substrates, such as dowel rods, clay tiles and Plexiglas plates have been used to evaluate colonization rates over time as a measure of productivity. These methods must take into consideration the effects of disturbance, seasonal changes in microbial communities and consumer interactions, and changes in water quality that may have occurred between sampling dates. For algal species, primary productivity (mass/volume/time or mass/area/time) can also be assessed using gas exchange measurements, generally of oxygen in light and dark containers or over a 24-hour period (Hynes, 1970). These measurements assume that primary production (PP) and community respiration (CR) occur in the light and only CR occurs in the dark. For benthic studies, specialized chambers have been used with stream substrates enclosed to

measure primary production and respiration (Bott et al., 1978; Dodds and Brock, 1998). Net primary productivity (NPP) is the fixed carbon that is stored in biomass and equals gross primary productivity (GPP) measured in the light minus CR measured in the dark. Another method involves measuring the rate of the radiotracer (^{14}C isotope) uptake over time, which is a suitable method for low densities of algae (Peterson and Fry, 1987 and Finlay, 2001).

3. Biological Index

Microbial communities have become good biological indicators of water quality and overall stream condition. Their responses to environmental stressors occur over a shorter time span than other aquatic organisms, and they have higher population turnover rates to measure response. Algae within the periphyton assemblage are the predominant members used as biological indicators for reasons stated above (Hill and Herlihy, 2000; Hill et al., 2000). Algal species have specific response characteristics to habitat loss, and contamination by nutrients, metals, herbicides, hydrocarbons and acidification. Many biological indices have been developed for periphyton algae, based on large surveys of reference data that integrate both taxonomic and non-taxonomic metrics with measurements of stream condition (Karr, 1993). The EPA Rapid Bioassessment Protocol (RBP) for periphyton can be used to guide the development of these biological indices specific to different regions and stream types (Hill and Herlihy, 2000). These indices allow for rapid stream assessments using only a handful of metrics. Measures of microbial communities should not be used alone, however, due to interactions between these populations and their consumers, and due to frequent disturbance of assemblages during storm events (Stevenson, 1996).

The level of effort for all of the measurement methods described above is considered intensive, except for maybe certain biological indices that require only moderate efforts. These methods are also complex because they require trained biologists to adequately collect the organisms, determine characteristics of the community, and effectively compare the community to the reference conditions. Again, certain biological index methods may be moderate in their level of complexity, depending on the variables and methods included (Appendix Ac).

Performance Standards

It is a general assumption that that stream degradation reduces species diversity while creating environments that select for a few tolerant species. In healthy streams, there are generally moderate numbers of many species, including tolerant species that maintain an ecological balance within the biological community. This difference in species assemblages is the underlying premise for development of a biological index that can be used as a tool for rapid stream assessments. Microbial monitoring tools using the periphyton community have been developed for the states of Kentucky, Montana and Oklahoma (Stevenson and Bahls, 1999), Idaho (Fore and Grafe, 2002) and the mid-Atlantic region (Fore, 2003); many more are under development. What some of these biological indices

have found, however, is that the general assumption does not always occur in certain regions and environmental conditions. This research highlights the need for species-specific, regional information from appropriate and adequate reference reaches to develop a reliable biotic index for microbial communities.

An example of a biological index is the Periphyton Index of Biological Integrity (PIBI), based on data collected in the Appalachian region (Hill et al., 2000). The PIBI included algal taxa richness, relative abundances, chlorophyll and biomass (ash-free dry mass) standing crops, and alkaline phosphatase activity. Functioning refers to streams with good stream condition that have PIBI scores in the upper 25th percentile. Not Functioning refers to streams with degraded condition that have PIBI scores in the lower 25th percentile. Functioning-at-Risk streams have PIBI scores between these two percentiles.

TABLE 10.2 MICROBIAL COMMUNITY PERFORMANCE STANDARDS

MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
Periphyton Index of Biological Integrity (PIBI; Hill et al., 2000)	≥ 72	61-71	≤ 60

10.2 » PARAMETER: MACROPHYTES

Description

Macrophytes are the vascular plants, bryophytes and macroscopic algae that grow in and near lotic environments (Hynes, 1970; Westlake, 1974). They are commonly divided into subgroups based on their spatial growth form, including emergents (terrestrial to 1-m depth), floating-leaved (1- to 3-m depth), submerged macrophytes (up to 10-m depth), and free-floating (Sculthorpe, 1967; Eaton et al., 2005). When abundant, macrophytes can be an important autochthonous energy source through primary production. During photosynthesis they transform CO₂ absorbed from the air and water into organic carbon using energy from sunlight. Oxygen is released into the air and water during the process (Wetzel, 2001).

The influence of macrophyte communities on lotic ecosystems is dependent on their abundance and the species present. Vegetative and root structures provide habitat for the microbial community. Benthic macroinvertebrates and fish use macrophyte beds for feeding, reproduction and shelter (Bowden et al., 2006; Janauer and Dokulil, 2006). Macrophyte communities are also highly effective at nutrient cycling and organic matter processing (Clarke, 2002). Most macrophytes are consumed during senescence and as detritus during decomposition with secretion of dissolved organic carbon. Consumption of living tissue is a minor carbon source (Wetzel, 2001). Macrophytes that are rooted to the substrate provide channel stability and have been shown to improve surface-subsurface exchange

of gases, particularly O₂ and CO₂, and nutrients (White and Hendricks, 2000; Clarke, 2002).

Macrophytes are affected by many environmental factors that influence their abundance and diversity. Hydrologic stability is one of the most important variables that control establishment and growth (Westlake, 1974; Haslam, 1987). Rivers with low gradients can have good community development in the littoral areas and backwaters near the bank (Janauer and Dokulil, 2006). As macrophyte density increases, the community can actually modify local flow conditions by decreasing streamflow velocity, protecting habitat and limiting scouring during storm events (Wetzel, 2001; Clarke, 2002). Channel modifications that alter the natural flow regime and sediment dynamics, such as vertical incision, channelization and impoundments, negatively impact macrophytes. Studies have shown that macrophyte communities can experience loss of species, declines in relative abundance and a shift to species that are more tolerant (Baattrup-Pedersen and Riis, 1999; O'Hare et al., 2006). Another important physical requirement of macrophytes is adequate light. In small forest streams, light is generally limited by the riparian canopy, and macrophytes are not abundant. In larger rivers, light is attenuated with increase in depth and turbidity; therefore, macrophytes are found only in shallow waters near the streambanks. Macrophytes are most common in intermediate size rivers where current is low, depths are shallow and there is plenty of sunlight exposure (Westlake, 1974; Baattrup-Pedersen, 2006).

Macrophytes, like all lotic organisms, can be significantly affected by the stream physicochemical conditions. They have preferences for specific temperature and pH ranges, and available carbon and nutrient sources are required for growth and productivity. Carbon and nutrients are typically not limiting, however, due to the ability of most macrophytes to absorb them through both vegetative structures and roots, and due to constant source replenishment by the current (Bowden et al., 2006). When excess nutrients and organic pollution are present, macrophyte communities react based on their species-specific tolerances. Many studies have measured the effects of nutrient and organic pollution on macrophyte assemblages, demonstrating species tolerances, shifts in species composition and changes in abundance (Holmes et al., 1999; Schneider et al., 2000; Haury et al., 2006; Janauer and Dokulil, 2006). Based on the sensitivity of macrophytes to changes in water quality, macrophytes can be good biological indicators of stream condition and are closely linked to Level 4 functions.

Establishment of healthy macrophyte communities in restored channels should only be considered in streams that are appropriate for population establishment, including those with low gradients, shallow depths and adequate sunlight exposure. If the reference stream(s) have significant macrophyte development, then stream restoration techniques should help create that habitat. Hydraulic methods that dampen large fluctuations in discharge, including effective floodplain connectivity and attenuation of stream velocities during large storm events, will allow for establishment and reduce scouring of macrophyte beds. Maintaining a stable and healthy hyporheic zone especially benefits macrophytes with roots that depend on the substrate for nutrients, carbon and gas exchange. Bed form diversity is important to create shallow habitats, and adequate sediment trans-

port prevents inundation of macrophyte beds. The presence of large woody debris and in-stream structures can create habitat for macrophytes, diverting higher flows and creating backwaters (Figure 10.2). Stream restoration practices that ensure channel stability and improve water quality will also encourage establishment and growth of macrophytes that in turn will provide dissolved oxygen, organic carbon and habitat for stream organisms.

Healthy macrophyte communities will be present in lotic environments when the following conditions are met:

- Communities are present in the reference reach, as macrophytes requires certain flow regimes controlled by stream gradient, adequate light and relatively shallow depths that are not present in all stream types;
- Floodplain connectivity, which attenuates stormflows and creates a healthy hyporheic zone benefiting plant roots;
- Relatively constant stream velocities, as less fluctuation in stream velocities allows for macrophyte establishment;
- Bed form diversity, which provides available shallow habitat and helps to transport sediment effectively to avoid inundation of macrophyte beds;
- Large woody debris, which creates backwater areas and provides shelter from high flows for macrophyte establishment and growth; and
- Good water quality, which encourages species diversity and balanced population dynamics that will perpetuate good water quality and provide essential stream habitat.

FIGURE 10.2 PHOTO OF MACROPHYTE DEVELOPMENT IN A RESTORED CHANNEL



Source: Reproduced with permission from Michael Baker Corporation

Measurement Method

Macrophytes should be evaluated within the growing season in order to better identify species and measure growth. Biomass measures should include the entire plant with leaves, shoots and roots differentiated for several reasons. Some species have portions of their communities that senesce quickly before reaching maturity. Other species may have biomass concentrated within the root structure during certain times of their lifecycle (Wetzel, 2001). Since productivity varies seasonally and with light, samples should be taken at the same time of year and same location. Macrophytes respond to physicochemical conditions such as temperature and nutrient concentrations and flow conditions; therefore, it is recommended that these parameters and perhaps others be measured during appropriate macrophyte sampling intervals. Consult state sampling methodologies for detailed instructions.

Macrophytes are commonly evaluated by field observations and by measurements of standing crop collected from the stream and analyzed in the laboratory. Field observations can be made by visual assessment, with glass bottom buckets and other apparatuses in deeper waters. Macrophyte samples are generally collected in a defined area, such as a quadrant or transect, to determine quantitative measurements. Samples can be collected by hand or using specialized equipment, such as a grapnel, in deeper waters. Detailed methods for measuring macrophyte communities can be found in Westlake (1974), Dawson, 2002, Eaton et al. (2005), and Bowden et al. (2006).

Three categories of measurement methods are presented below for macrophyte communities. These categories are the same for the other biological communities discussed in this chapter, including the direct methods for taxonomic and non-taxonomic measurements, and the indirect method of the biological index measurement. The level of effort for all of the measurement methods described below is considered intensive, except for certain biological indices that may require only moderate efforts. These methods are also complex because they require trained biologists to adequately collect the algae and plants, determine characteristics of the community, and effectively compare the community to the reference conditions. Again, certain biological index methods may be moderate in their level of complexity, depending on the variables and methods included (Appendix Ac).

1. Taxonomic Measurements

Examples of taxonomic measurements include species composition, relative abundance and taxa richness. Macrophyte species can typically be identified by visual observation with taxonomic keys. Physical condition and density are additional measurements that can be used to evaluate macrophyte populations.

2. Non-Taxonomic Measurements

Macrophyte biomass and primary productivity are the common methods used to assess communities. Biomass can be determined using measurements of wet weight, dry weight or ash-free dry mass. Chlorophyll a content can be quantified as a measure of biomass, with knowledge of species composition and their typical concentrations. Popu-

lation productivity can be determined by collecting biomass data over time. This method yields net productivity without corresponding measurements of loss to grazing, injury, mortality and respiration. Primary productivity can be measured using similar methods described for algae in the microbial communities section above.

3. Biological Indices

Macrophytes can be used as reliable biological indicators of water quality and stream habitat because they are sessile, have established taxonomy, exhibit species diversity in their ecological tolerances, and there are well-developed sampling techniques available. Certain community characteristics should be kept in mind, however, when sampling to evaluate stream condition. Macrophyte identification may be limited to the growing season, there may be significant natural variation along a reach, and macrophytes may experience a lag-time in recolonization after stream condition has improved, if resources are limited upstream (Trempe and Kohler, 1995; Cronk and Fennessy, 2001).

Biological indices for macrophytes in lotic ecosystems have not yet been developed in the United States. However, the use of macrophytes as biological indicators is historically well established in Europe and is included in regulatory assessments of aquatic systems for impacts and mitigation (Water Framework Directive; European Commission, 2000). Three examples of commonly used biological indices are the Mean Trophic Rank index (MTR; Holmes et al., 1999), the Macrophytical Biological Index for Rivers (IBMR; Haury et al., 2006), and the Trophic Index of Macrophytes (TIM; Schneider et al., 2000). These index methods focus on evaluating the effects of eutrophication in streams due to the common occurrence of this impact. More integrative methods to assess river degradation as a whole are described in Ferreira et al. (2002), Passauer et al. (2004), Schaumburg et al. (2004), and Meilenger (2005). These methods use various ecological metrics for macrophytes that are similar for all organism biological indices, including methods that measure relative abundance, taxa richness, species diversity and distribution, and species tolerances to environmental conditions. The recommended reach length of assessment is typically 100m, and adequate reference reach (unimpacted stream) data should be collected for comparative use with each biological index.

Performance Standards

Performance standards for macrophytes in rivers have not been derived in the United States. The current European standards can be used as guidance for deriving these standards in the United States. These biological indices are based on plant species and their determined tolerance values for ecological condition. These determinations must be made for species present in the United States. The Mean Trophic Rank method (Holmes et al., 1999) is provided in this publication as an example biological index that evaluates the effects of excess nutrients in rivers, a common problem in most streams in our country (Table 10.3). This index uses calculated variables, including Species Trophic Rank (STR) with values representing species tolerance between 1 (eutrophic conditions) and 10 (unenriched waters), and Species Cover Value (SCV) as a percentage ranked between 1 (<

1%) and 9 (> 75%) to determine an overall MTR Score. Streams in the Functioning category would not require nutrient reductions. Functioning-at-Risk would require monitoring of nutrient inputs and nutrient reduction plans. Not Functioning would require reductions in nutrient inputs within a reach. Another biological index presented as an example is one that assesses overall stream condition compared to reference conditions, called the Reference Index (RI; Meilenger, 2005). Streams are divided into categories based on a classification system. The example given in Table 10.3 is for river type TN, which are medium-sized lowland rivers. The results provide an ecological status classification based on the deviation in macrophyte composition and abundance from reference conditions. Streams in the Functioning category would be classified as high or good; Functioning-at-Risk would be classified as moderate, and Not Functioning would be classified as poor or bad.

TABLE 10.3 MACROPHYTE BIOLOGIC INDICES PERFORMANCE STANDARDS

MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
Mean Trophic Rank (MTR); Holmes et al. 1999	> 5	25-65	< 25
Reference Index (RI)	-50 to 100	-70 to -50	< -70

10.3 » PARAMETER: MACROINVERTEBRATE COMMUNITIES

Description

The macroinvertebrate communities of lotic systems are commonly composed of mussels (mollusk), crayfish (crustaceans), worms (annelids) and insects (arthropods). Aquatic insects that live along the substrate are referred to as benthic macroinvertebrates, and this group is the most commonly evaluated in stream systems due to their higher diversity and abundance across stream types. Benthic macroinvertebrates generally have an aquatic immature stage and a terrestrial adult stage. They inhabit many different areas of a stream (Figure 10.3), and location often depends on their primary feeding mechanism. Functional feeding groups are often used to categorize aquatic insects and include predators, collectors, scrapers and shredders (Cummins, 1973; Voshell, 2002). A collector may feed by gathering detritus from the stream bed or by filtering detritus out of the water column, while a scraper scrapes periphyton off of the substrate. Shredders feed by shredding organic material, such as leaves, and can be found in leaf packs that accumulate along banks and woody debris in the channel.

Macroinvertebrate lifecycle demands and processing can have important influences on nutrient and carbon cycles and movement of energy in and around lotic systems. They are an important link in transferring energy up the aquatic food chain as an intermediate

trophic level. Benthic macroinvertebrates feed on periphyton, small bits of organic material, and other organisms and are in turn fed on by fish and terrestrial insectivores (Jackson and Resh, 1989; Wallace and Webster, 1996). Energy flows between terrestrial and aquatic environments, and between allochthonous and autochthonous sources (e.g., the export of autochthonous energy and a return of allochthonous energy contributed by the terrestrial system to the stream channel, and then a flow of energy back to the terrestrial system with the emergence of the adult aquatic insects).

Macroinvertebrates are influenced by water quality, habitat availability and food resources. Benthic macroinvertebrates have a range of sensitivities to changes in organic pollutants, sediments and toxicants, as well as habitat conditions. Macroinvertebrates are good indicators of water quality and stream condition. There are several reasons for this, including: 1) they have relatively short lifecycles that span multiple seasons; 2) species have different tolerances to water quality and stream condition; and 3) they are less mobile than fish and, therefore, cannot easily escape local perturbations (Kuehne, 1962; Bartsch and Ingram, 1966; Wilhm and Dorris, 1968; Warren, 1971; Cairns and Pratt, 1993). The sufficient availability of food resources, including plankton, periphyton and dissolved and particulate organic matter, can promote benthic macroinvertebrate productivity (Richardson, 1993).

Benthic macroinvertebrate communities can benefit from many stream restoration techniques, even in highly degraded systems. Floodplain connectivity and design of an appropriate bankfull channel reduce the impacts of large storm events on habitats and excessive scouring that removes food resources. Organic carbon can be carried from the floodplain to the stream during storm events, and fine sediment can be deposited on the floodplain instead of inundating stream habitats. Benthic macroinvertebrates are associated with the hyporheic zone, using it as physical habitat, as well as feeding on periphyton established at the groundwater-surface water interface where dissolved organic carbon is exchanged. Any stream restoration practice that increases available habitat will enhance communities. Bed form diversity and in-stream structures provide both habitat and enhance stream stability. Structures that are constructed using large woody debris, root wads and other woody material are particularly beneficial to macroinvertebrates because they provide resting and escape cover, increase surface area for feeding, capture additional organic material, and increase retention time of organic material that supports many macrobenthic invertebrate feeding groups. The addition of woody material has been shown to improve density and species diversity of macroinvertebrates (Gerhard and Reich, 2000). Restoration of the riparian plant community is usually a component of stream restoration projects and will significantly benefit aquatic macroinvertebrates by providing thermal regulations, as well as contributions of woody debris and leaf litter to support food chains.

A healthy functioning macroinvertebrate community occurs when the following conditions are present:

- Floodplain connectivity and bankfull channel, which dissipate energy of large storm events to prevent excessive scouring of substrate, provide access to organic carbon sources available on the floodplain and prevent sediment inundation of substrate habitat;
- Healthy hyporheic zones, which provide habitat for macroinvertebrates and facilitate exchange of dissolved constituents for healthy periphyton communities, a valuable food resource;
- Bed form diversity and complexity, create diverse habitats for feeding and reproduction, dissipate stormflow energy, provide opportunities for organic carbon storage and retention, provide substrates such as large woody debris, and provide scour holes and offer shelter;
- Channel stability, which prevents sediment inundation of habitat and the detrimental effects of turbidity on filter feeders; and
- Riparian community, which provides allochthonous carbon inputs for food resources; provides shade for cooler temperatures and provides vegetative roots for available habitat.

FIGURE 10.3 MACROINVERTEBRATES OCCUR IN A VARIETY OF HABITATS WITHIN THE STREAM CHANNEL, INCLUDING THE RIFFLES AND POOLS CREATED BY THE ROCKS AND WOODY DEBRIS IN THIS MOUNTAIN STREAM.



Source: Reproduced with permission from Stream Mechanics

Measurement Methods

Benthic macroinvertebrates sampling is mostly appropriate for perennial channels due to the physical size of the organisms and the higher diversity found in running waters. Assessments on the recovery of benthic macroinvertebrate populations based on reference stream communities are recommended. For the most rapid recolonization after restoration, reference conditions should ideally be present upstream of the restored reach.

The methods used to collect macroinvertebrates are fairly consistent across monitoring protocols. Visual observation along with various types of nets and sieves can be utilized in the different habitats to capture benthic species. Habitats include riffles, pools, leaf packs and woody debris, sediments, and macrophyte beds. Macroinvertebrate samples must be collected in proportion to the relative habitat abundance, and organisms must be collected in proportion to the species abundance in order to get a sample that truly represents the community structure. There are many assessment methods and protocols developed throughout the United States for benthic macroinvertebrates, including the EPA Rapid Bioassessment Protocol (RPB) method (Barbour et al., 1999), the EPA Environmental Monitoring and Assessment Program (EMAP) methods (Klemm et al., 2000), or the North Carolina Department of Natural Resources Division of Water Quality's Benthic Macroinvertebrate Monitoring Protocols (NCDENR, 2006), to name a few. In general, most macroinvertebrate sampling protocols involve a multi-habitat approach since macroinvertebrates occupy diverse habitats within the stream channel.

The three categories of measurement methods associated with biological macroinvertebrate communities are presented below, including the direct methods for taxonomic and non-taxonomic measurements, as well as the indirect method of the biological index measurement. The level of effort is considered intensive, except for certain biological indices that may require only moderate efforts. These methods are also complex because they require trained biologists to adequately collect the macroinvertebrates from different habitats, to determine characteristics of the community, and to effectively compare the community to reference condition assemblages. Again, certain biological index methods may be moderate in their level of complexity, depending on the variables and methods included (Appendix Ac).

1. Taxonomic Measurements

Benthic macroinvertebrate samples can be evaluated for taxonomic measures such as species composition, relative abundance and taxa richness. Mandaville (2002) provides an extensive review of population metrics that are commonly used to assess macroinvertebrate populations. Species identification is performed using the many readily available taxonomic keys, including general keys (e.g., Peckarsky, 1990; Merritt and Cummins, 1996; Smith, 2001; Thorp et al., 2009). State or regional keys should be sought to limit the species to be considered and greatly aid the identification of macroinvertebrate samples. Often, abbreviated samples will just focus on three orders that are the most sensitive to stream condition: Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). Sampling and identification of these three orders is referred to as an EPT assessment.

2. Non-Taxonomic Measurements

Measurements of biomass and secondary production allow for an assessment of how available energy is being utilized for macroinvertebrate growth. Benke (1984, 2010) provides an excellent discussion of the biological parameters that contribute to macrobenthic secondary production. There are many approaches to making secondary production measurements, depending on the application of the data (Benke and Huryn, 2010). Secondary production involves the measure of biomass over some period of time. Often these studies look at the production by a single age group or cohort. One sampling method that is often used for this purpose is the emergence trap. This is a trap placed over the stream that captures adult insects as they leave the water and can provide data for estimating abundance, biomass and production. Consideration should be given to trap placement in order to take a representative sample (Malison et al., 2010). While the emergence trap is relatively easy to use for this purpose, secondary production can also be determined at the aquatic life stage using established collection methods, quantifying biomass and establishing how this changes over a time (Jaynie et al., 2007).

3. Biological Indices

Benthic macroinvertebrates are widely used as a monitoring tool by many water resource agencies (Southerland and Stribling, 1995; USEPA, 2002). The change in populations and species assemblage composition over time can also reveal if the change has been positive or negative. Species have varying tolerances to pollutants, and a biologist experienced at identifying benthic macroinvertebrates should be able to look at a population sample and quickly determine whether or not it is from a stressed aquatic system.

Macroinvertebrate biotic indices generally include assessments of taxonomic and non-taxonomic metrics and include information on tolerances to stream condition and habitat measures. Many state agencies have developed biotic indices that are based on these metrics and data collected in various stream types, including reference reaches in different regions.

Performance Standards

Thresholds for determining if a stream is Functioning based on the macroinvertebrate community must be considered with stream type and the expected community type in mind. In general, it is always best to compare the condition of a project site with observations at stable reference streams. Performance standards for taxonomic and non-taxonomic measurements have generally not been developed. Biotic indices developed for specific stream types and regions that combine these measures with stream physicochemical and habitat conditions can, however, be used as performance standards. Several examples of biotic indices are listed in Table 10.4. Streams that fall into the Not Functioning category would most likely also have very low taxa richness and mostly very tolerant taxa, such as aquatic worms and snails. Engel and Voshell (2002) developed a quantitative multimetric index for volunteers with the Virginia Save Our Streams program to use, and found that it agreed very closely (96%) with the determinations made by professionals. In this study they found 15 candidate macrobenthic-based metrics that exhibited statistical properties

that would make them good measures of water quality. The process used in this study would be beneficial to use for developing a regionally specific biotic index if one does not exist. While these performance standards can be used anywhere, it is recommended that they be evaluated against a sample from a reference stream to ensure they provide the proper measure of performance.

TABLE 10.4 MACROINVERTEBRATE PERFORMANCE STANDARDS

MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
Hilsenhoff Biotic Index (HBI) (Hilsenhoff, 1988)	0.00-4.25 Excellent to Very Good	4.26-5.75 Good to Fair	5.76-10.00 Fairly Poor to Very Poor
WVSCI (Gerritsen et al., 2000; WVDEP)	68-100 Very Good to Good	45-61 Gray Area to Fair	0-45 Poor to Very Poor
Virginia Stream Condition Index (Burton and Gerritsen, 2003)	61-100 Exceptional to Similar to Ref.	40-60 Impaired Tier 1	0-40 Impaired Tier1 & 2
SOS Multimetric Index (Engel and Voshell, 2002)	7-12 Acceptable	N/A	0-6 Unacceptable

10.4 » PARAMETER: FISH COMMUNITIES

Description

Fish are the most ubiquitous vertebrate species found in rivers and streams. Fish are the top aquatic predators in most lotic systems and are utilized for food by many terrestrial species. Stream fishes have many adaptations for living in high velocity environments. They can use low-velocity microhabitats like pools, downstream sides of cover elements, or areas under and between substrate. Stream fishes have bodies that are fusiform and streamlined to reduce drag in high velocity, or they are adapted to living on the bottom with large pectoral fins that are aligned so that flow pushes the fish downward. Fish are often specialized feeders with anatomical adaptations for feeding on the bottom, scraping periphyton, picking macroinvertebrates off of rocks, or capturing other fishes. They have adapted reproductive approaches that protect their eggs and young, such as spawning on the undersides of exposed rocks, building clean pebble bounds in which to scatter their eggs, or burying the eggs in clean, well aerated gravel beds (Balon, 1975).

Fish communities include herbivores, insectivores, detritivores and piscivores. They serve as important links in aquatic food chains because they move the energy captured from lower trophic levels up to higher-level predators, such as terrestrial animals. Just as

with emerging macroinvertebrates, fish also act as the link for moving energy produced or captured in the aquatic environment to the terrestrial environment. One of the most dramatic examples of the importance of fish to aquatic food chains is the influence of anadromous salmon. These fish spend several years at sea feeding and growing and then move into rivers and streams to spawn. After spawning, they die, which provides an influx of nutrients during decomposition. This leads to an increase in food chain productivity, which in turn supports the young salmon as they grow to a size when they return to the ocean for the process to begin again. As top predators in stream systems, fish populations have been shown to affect the structure of prey populations, including the movement of prey from one habitat patch to another (Sih and Wooster, 1994), as well as the structure of the fish community itself through piscivory (Jackson et al., 2001). Given the importance of fish in structuring the populations of their food resources, they play a significant role in the population dynamics, nutrient cycling and energy flow in lotic ecosystems.

The ability of fish populations to fulfill their life history requirements normally depends on streamflow, water quality and habitat availability. Adequate flow in rivers and streams must be maintained to allow fish movement and survival. Impoundment structures can block fish passage and hold streamflow back to levels that will not support fish. Water withdrawals for human activities and consumption may prevent adequate flow during certain seasons where water tables are already low due to normal hydrology (Wootten, 1992). Changes in Physicochemical parameters can have a significant impact on fish. Fish can be highly sensitive to the amount of dissolved oxygen in the water column. When the oxygen levels drop below a certain threshold, this can have dramatic effects on fish populations and “fish kills” result (Hynes, 1960). Stream temperature not only affects fish metabolism between seasons, it also determines their distribution (Hynes, 1970). Warm-water streams and cold-water streams are distinguished as fish habitat based on the presence of certain fish species (Moyle and Cech, 1982). When restoring the functional ecology of a stream, the goal is typically to improve overall fish habitat. Good habitat includes creating riffle, run, pool and glide bed forms, as well as providing diverse cover elements within the channel. Diverse habitat will support different stages of a fish’s life cycle and/or different species of fish over a varying spatial and temporal scale (Rohde et al., 1994). Diverse habitat also produces diverse food sources for fish. This may include patches within a stream that support algae or macrophytes for herbivores; riffles or woody debris that supports various benthic macroinvertebrates; or deep pools where piscivorous predators may ambush smaller fish. Habitat diversity is generally correlated with diversity in fish communities within streams.

Fish are often the primary connection between a water course and the human population that utilizes it. The devotion that these resources inspire is demonstrated by the creation of resource-based groups like BASS and Trout Unlimited. These groups invest significant resources in the preservation of habitats that supports the population in which they are interested. Because their efforts are directed at habitat preservation and restoration, the result often benefits all species using the habitat. This scenario demonstrates the importance that man places on aquatic resources supporting fisheries. It is for this reason

that the benefit of restoration projects on fish populations is important and should be considered as a potential parameter to be evaluated. Fish are good indicators of both short-term and long-term water quality and stream condition because they are relatively long-lived, mobile and many have a lifecycle that requires high water quality. Assessing stream fish populations provides important information for understanding the functioning of the biological community, for evaluating biological integrity and for protecting surface water resource quality (Barbour et al., 1999).

There are many stream restoration practices benefitting fish populations within all four underlying levels of the Stream Functions Pyramid that are similar for other biological communities. Hydrology and flow dynamics are very important for fish populations, particularly considering the essential requirement of adequate flow conditions throughout the seasons. Upstream impoundments and water withdrawals should be addressed prior to design to ensure continuous streamflow. If these upstream flow conditions cannot be addressed, then restoration of fish habitat may be futile. Assessment of reference condition is an important tool for determining if fish are present in the stream type, as well as size that will be restored. Upstream populations will also determine re-establishment of fish communities. If there is no upstream fish population, stocking may be required to introduce the fish into the newly created habitat. Species of special concern, including any threatened or endangered species designated by federal and state agencies, should always be considered first when designing habitat features of a restored stream channel. Hydraulic parameters, including floodplain connectivity and the provision of a bankfull channel, are effective at sustaining fish populations along with other biological communities. A healthy hyporheic zone and substrates that support prey populations will help sustain fish with food resources. Fish habitat created by in-stream structures, large woody debris, macrophyte beds and bed form diversity will allow for feeding, shelter and reproduction, including deep pools and scour holes (Figure 10.4). Established riparian buffers provide shade for temperature regulation and allochthonous inputs to sustain prey populations and the large woody debris. Good water quality is important, especially maintenance of dissolved oxygen levels that result from structures and flow dynamics providing turbulence for oxygen entrainment, and from habitats that provide primary production of algae and macrophytes.

A healthy, functioning fish community occurs when the following conditions are present:

- Continuous upstream streamflow sources, as removal of impoundments and excessive water consumption for human activities will provide adequate streamflow throughout the year;
- Floodplain connectivity and bankfull channel, dissipate energy of large storm events to prevent excessive scouring of substrates used for reproduction (pools), and prevent sediment inundation of substrate habitat;
- Healthy hyporheic zones, which provide habitat for food resources;
- Bed form diversity and in-stream structures, which create diverse habitats for feeding and reproduction, dissipate stormflow energy; provides opportunities for organic

- carbon storage and retention, provide substrates such as large woody debris, and provide scour pools for reproduction, feeding and shelter;
- Channel stability, which prevents sediment inundation of habitat and excessive turbidity that is contributed from channel erosion;
 - Riparian community, which provides allochthonous carbon inputs for food resources, provides shade for cooler temperatures and provides vegetative roots for available habitat; and
 - Adequate dissolved oxygen, which is required for fish survival and health.



FIGURE 10.4 FISH HABITAT IN A SCOUR POOL CREATED BY AN IN-STREAM STRUCTURE, REFERRED TO AS A J-HOOK.

Source: Reproduced with permission from Michael Baker Corporation

Measurement Method

Fisheries resources can be sampled using a variety of approaches, and the sampling methodology selected should be chosen to provide quantifiable measurements for the parameter addressed (Bonar et al., 2009). The USEPA's RBP (Barbour et al., 1999) recommends using electrofishing to collect samples, a common method used by most state fishery departments and fisheries investigators to evaluate fish populations in designated reaches (Carle and Strub, 1978; Zippin, 1956). Snorkeling the study reach and recording observed species is a less intrusive method that some have used. This has

been used as an alternative to electrofishing (Thurow and Schill, 1996; Mullner et al., 1998) for estimating abundance and population size structure. The National Park Service, in conjunction with George Mason University, compiled an Ecological Assessment Methods Database (2010). The database was originally created to provide park managers with a source for identifying and selecting assessment methods for various watershed management practices, including methods for assessing fisheries and their habitat. The database can be accessed at <http://assessmentmethods.nps.gov>.

When evaluating fish communities, there are several factors that must be considered. Fish movement (passage) within the stream, and upstream water quality issues should be considered when interpreting data. Sample design often involves comparisons between restored areas and unrestored areas on the same stream, and should include pre- and post-restoration sampling.

The three categories of measurement methods associated with biological fish communities are presented below including the direct methods for taxonomic and non-taxonomic measurements, as well as the indirect method of the biological index measurement. The level of effort is considered intensive, except for certain biological indices that may require only moderate efforts. These methods are also complex because they require

trained biologists to adequately collect the macroinvertebrates from different habitats, determine characteristics of the community, and effectively compare the community to reference condition assemblages. Again, certain biological index methods may be moderate in their level of complexity, depending on the variables and methods included (Appendix Ac).

1. Taxonomic Measurements

Once a fish population sample is obtained, individuals should be identified to species and enumerated. Fish sample data can be expressed in species composition, relative abundance, species richness (or other taxon), percent similarity between sites, Simpson's Diversity Index (Simpson, 1949), or other similar indexes and metrics.

2. Non-Taxonomic Measurements

Data on population size or biomass will require length and weight data of fish collected within a sample, as well as a good measure of the area sampled. The growth rate, or change in biomass of fish over time, is an estimate of productivity. Growth rate data requires aging fish or estimating age and is a more complicated process than most restoration monitoring programs will undertake; but this process is still a good measure of fish community productivity. Details of both taxonomic and non-taxonomic methods can be found in Hauer and Lamberti (2006), *Methods in Stream Ecology*.

3. Biological Index

As with other taxa, fish population quality can also be expressed in an Index of Biotic Integrity. Karr et al. (1986) recommended 12 measures of fish assemblages that fall into three broad categories: species composition, trophic composition, and fish abundance and condition. This methodology has been applied to evaluations of fish populations, and it has been adjusted by state and regional biologist to reflect regional stream conditions. Angermeier and Karr (1986) used an IBI for stream-fish communities to evaluate water and habitat quality. Roth et al. (1996) used a fish population IBI to demonstrate that habitat and fish assemblage quality was highly correlated.

Performance Standard

For the best results, performance standards should be based on data collected from reference reaches upstream of the restoration reach. A reference condition can be established using the upstream reference reach and/or other reference streams. Multiple samples that account for spatial and temporal variability should be collected before setting these standards. If species to be evaluated include populations that support a fishery, evaluators should consult state fishery agencies to see if they have already established the range of variation that these populations typically exhibit. This information can then help guide empirically establishing performance standards.

Performance standards for taxonomic and non-taxonomic measurements have generally not been developed. However, biotic indices developed for specific stream types, and regions that combine these measures with stream physicochemical and habitat conditions

can be used as performance standards. Several examples of biotic indices are listed in Table 10.5. Streams that fall into the Functioning category have high species diversity and relative abundance, which indicates good stream habitat. The Not Functioning category would most likely have very low taxa richness and mostly very tolerant taxa that indicates poor stream habitat.

TABLE 10.5 FISH COMMUNITY PERFORMANCE STANDARDS

MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING
Mid-Atlantic Highlands IBI (McCormick et al., 2001)	IBI > 72 Good to Excellent	IBI = 56 to 71 Fair	IBI < 56 Poor
Mid-Western Fish Community IBI (Karr et al., 1986)	48-60 Good to Excellent	40-44 Fair	0-34 Poor to No Fish

10.5 » PARAMETER: LANDSCAPE CONNECTIVITY

Description

The importance of using a holistic landscape perspective for understanding stream ecosystem structure and function is well established. Recognition of the connection between the stream and surrounding terrestrial ecosystems was fundamental to the development of stream ecosystem theory (Hynes, 1975; Minshall et al., 1985). The landscape connectivity concept is defined as “the degree to which the landscape (physical structure) facilitates or impedes movement (organism behavior) among resource patches” (Taylor et al., 1993). It includes both structural and functional aspects of the landscape. Structural aspects are the physical relationships among habitat patches and the distance between them. The dimensions of a stream riparian buffer corridor are an example of structural connectivity. Functional aspects are what affect the movement behavior of organisms through the landscape. Most landscape connectivity evaluations include only structural assessment, which may not be at the appropriate spatial scale nor adequate to prevent loss of essential habitat. There is a critical threshold of landscape connectivity that must be maintained in order for the species of interest to persist (With et al., 1997).

In stream restoration projects, landscape connectivity represents the ability of a target aquatic or riparian species to move between habitats. Fish migrate upstream and downstream to feed and reproduce. Benthic macroinvertebrates migrate not only upstream and downstream, but also across the land-water interface between the larval and adult stages. Some benthic macroinvertebrate adults may even require different terrestrial landscape habitats surrounding water to persist. Stream restoration projects can contribute to landscape connectivity using practices at all levels of the Stream Functions Pyramid.

Hydrologic parameters create that link between landscape and lotic system through exchange of water resources, including surface runoff and groundwater inputs. Floodplain connectivity and establishment of riparian buffers are other important land-water connections for organism (plant and animal) movement between habitat patches. Microbial species, plant seeds and spores, and vertebrate eggs can be deposited in terrestrial habitats for migration to the lotic system during high-flow events. Any in-stream structure that promotes habitat diversity and allows passage of animal species or establishment of microbial and plant species is essential for landscape connectivity. Stream stability will protect both aquatic and terrestrial habitats and allow for movement of species. Good water quality and resource availability (carbon and nutrients) are essential for healthy biota that will move between habitats and persist through landscape connectivity.

Landscape connectivity is enhanced when the following conditions are present:

- Long reaches of restoration connected to other high-quality reaches, which provide healthy stream corridors;
- Surface runoff and groundwater inputs, which maintain the connection between land and water habitats and their shared resources;
- Floodplain connectivity and established riparian buffers, which maintain the connection between land and water habitats and their shared resources, and allow movement of species between habitats during life cycle;
- In-stream structures, which can promote organism passage and habitat and substrate for stream organisms;
- Stream stability, which protects aquatic and terrestrial habitats; and
- Good water quality and resource availability, provide the environmental conditions for biological movement and species persistence.

Measurement Method

Measurement methods used to assess landscape connectivity are all direct measures that require intensive level of effort due to the spatial aspects associated with the data required. The methods are all considered complex due to the tools required for assessment, e.g., GIS, GPS and models, as well as the expertise required for data collection and analyses. There are three measurement methods described below.

1. Spatial Analysis

In order to measure overall landscape connectivity effectively, both structural and functional pieces must be included. Structural landscape connectivity can be measured using linear features on the landscape, which are commonly measured with current spatial analysis technologies such as GIS. The length of a riparian corridor or forested wetland patch near a stream would be an example of a linear feature.

2. Species Tracking

Functional landscape connectivity measurements are not as readily available because they are specific to individual species or species groups with similar behaviors. Taylor (1993) details species parameters that can provide information on species movement in response to the landscape structure, including movement rates, dispersal range, mortality during dispersal, and boundary interactions. Species movement is not easy to measure, but knowledge of species behavior can be gathered from the literature and from on-the-ground tracking and satellite GPS technologies. In streams, invertebrates and vertebrates can be tagged for monitoring. Currently there are tracking products available for larger aquatic species (e.g., Pacific salmon; Eiler, 1995), but smaller species and canopy cover issues have not advanced. Consultation with biologists who are familiar with the species of interest, their habitat requirements throughout their life cycle, and their behaviors can help with landscape connectivity measurements.

3. Habitat Models

There are also various habitat models described in the literature that have been developed to provide landscape connectivity assessments specifically (With et al., 1997). There are also GIS-based models that have been developed to help with habitat assessments that can be found at the following websites:

Circuitscape: www.circuitscape.org/Circuitscape/Welcome.html

Conefor Sensinode: www.conefor.org

Funconn: www.nrel.colostate.edu/projects/starmap/funconn_index.htm

Pathmatrix: cmpg.unibe.ch/software/pathmatrix

Performance Standards

There are no performance standards developed for landscape connectivity at this time. The landscape matrix should be included in stream restoration planning, however, in order for the project to provide the greatest biological benefit. Although this matrix most often extends beyond the boundary (and scope) of stream projects, it is important to keep it in mind as a focal point during the planning process in order to establish the landscape connectivity needed for a healthy biological community. Landscape connectivity also relates to proper site selection for a stream restoration project. In order to see the most improvement in the other Biology parameters listed above, it is critical that the restoration reach be “connected” with a high-quality upstream reference reach. The restoration reach, in turn, begins to provide the necessary conditions for future downstream restoration efforts to continue progress towards landscape connectivity for species selected within the stream. Linking restoration projects together is a good way to increase landscape connectivity and work towards watershed scale restoration. This approach provides greater functional lift than restoring discrete stream reaches that are spread out across the watershed.

Chapter 11

Application of the Stream Functions Pyramid

This chapter provides three different examples of how the Stream Functions Pyramid can be applied. These applications include creating function-based goals and objectives, developing stream assessment methods, and establishing stream mitigation debit and credit determination methods.

Goal setting is critical to the success of a project because it communicates why the project is being done and sets expectations on how success will be measured. The goal-setting section provides several examples of goals that will improve stream functions when achieved. The assessment and mitigation sections provide a broad overview of how the Pyramid can be applied. It does not provide a “cookbook” approach to developing a functional assessment methodology or stream mitigation Standard Operating Procedures (SOPs). Rather, the examples and templates provided below are intended to provide a broad-level framework. Scientists and managers may choose to create more specific or quantitative functional assessments and debit/credit determination methods based on the examples provided in this chapter.

11.1 » ADDING PARAMETERS, MEASUREMENTS AND PERFORMANCE STANDARDS

The existing Stream Functions Pyramid Framework includes a wide range of function-based parameters that are applicable for a wide range of environmental settings. However, users may need to add a function-based parameter based on a unique project or assessment goal. This is most likely to occur at the Biology Level because not all forms of aquatic and riparian life are included, e.g., mussels and amphibians. To add a function-based parameter, users should follow the selection criteria outlined in Chapter 4.

11.2 » DEVELOPING GOALS AND OBJECTIVES

Developing goals and objectives is important for projects of all sizes. Well-articulated goals and objectives establish a foundation for project success. Vague, too broad, or poorly articulated goals and objectives often lead to project failure (worst case) and misunderstandings at best. The terms goals and objectives are often used interchangeably; however, there is a difference. Goals are statements about why the project or effort is needed. They are general intentions and often cannot be validated. Objectives are more specific. They help explain how the project will be completed. They are tangible and can be validated, typically by the performance standard.

Even with this differentiation, it can be challenging to develop well-formulated goals and objectives. Part of this difficulty relates to the scale and type of effort that is being undertaken. For example, watershed management plans require goals and objectives at a broad scale, i.e., to cover a large watershed. Stream restoration projects require goals and

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objectives that are typically formulated at a reach scale and after some type of assessment has been completed to determine the problem, i.e., what function(s) needs to be restored. This can be an iterative process as the project team tests the restoration needs against project and watershed constraints.

Regulatory and non-regulatory programs also have goals and objectives, but they may not be tied to a specific watershed or reach. For example, Trout Unlimited, a non-regulatory organization, has broad goals to improve the quality of trout streams, wherever trout streams exist. The Clean Water Act (FWPCA, 1972) has an overall goal for all waterways to be fishable and swimmable.

Section 303 of the CWA includes provisions to have all streams, and rivers support the designated uses identified in their water quality standards (FWPCA, 1972). No net loss of wetland resources is a goal of the Section 404 of the CWA program and the fundamental objective of compensatory mitigation in the regulatory program is to offset environmental losses resulting from unavoidable impacts [33.C.F.R. § 332.3(a)(1)/40 C.F.R. § 230.93(a)(1)].

Many existing stream SOPs associated with the CWA Section 404 program include references to restoring stream dimension, pattern and profile as a way to acquire restoration credits. This has resulted in many stream mitigation plans being created that state the goal of a project is to restore dimension, pattern, and profile, rather than stating goals that provide some type of functional lift to offset permitted losses and better align with the fundamental objective of the CWA Section 404 regulatory program.

The Stream Functions Pyramid can be used to help prepare better goals and objectives for watershed management plans, regulatory and non-regulatory programs, and stream restoration projects. Simply stated, the Pyramid can help link goals and objectives to stream functions. For example, the Pyramid can be used to help articulate goals that relate to the improvement or assessment of stream functions or even function-based parameters. The goal should relate to the primary function(s) of interest, e.g., life history of some type of aquatic life. This information is provided on the Pyramid Overview and the Pyramid Functions and Parameters. Objectives should help explain how the functional improvement will occur. Objectives can also be used to identify the supporting functions needed to meet the goal. The Pyramid Functions and Parameters, Measurement

Methods and Performance Standards are all helpful in formulating objectives. These figures and tables are provided in Appendix A. Other sources for developing stream restoration-related goals and objectives include the NRCS Stream Restoration Design Manual, Part 654, Chapter 2 (USDA NRCS 2007) and the USACE Technical Note, Ecosystem Restoration Objectives and Metrics (McKay et al., 2012).

Developing goals and objectives requires an understanding of how to “enter” the Pyramid, i.e. how to start using the Pyramid Framework. Examples for watershed management plans, regulatory/non-regulatory programs and project designs are provided below.

Watershed Management Plans

Watershed management plans typically include two major components, an inventory of water resource problems, followed by options/recommendations for improvement. These improvement options may include preservation, restoration, stormwater best management practices (BMPs), Low Impact Development (LID), etc. A key to success is to link the appropriate improvement option to the appropriate impairment. This is an area where the Stream Functions Pyramid Framework can help articulate specific goals and objectives by answering the following questions:

1. Look at Pyramid figures in Appendix A. What types of functional losses have occurred in the watershed? Try to relate the losses to function-based parameters, e.g., channelization and loss of floodplain connectivity, and/or population declines to native fish species.
2. Can these functions be restored? This requires an understanding of the stream functions and the cause of the impairment, along with the potential for their improvement.
3. Look at Pyramid figures again. What supporting function-based parameters are needed to assess improvement to the impaired functions listed in number 1?
4. What types of restoration activities are needed to improve those function-based parameters? This could include stream preservation of healthy headwater streams and restoration of degraded stream channels. It could also include stormwater BMPs and LID. An experienced multi-disciplinary team will be required to link the improvement activity to the functional lift.

Answering these questions will allow the team to develop goals and objectives that relate to functional impairments and their potential improvements in the watershed. For example, depending on how the questions were answered, an example goal and associated objectives may include the following.

Goal:

Improve the health of a smallmouth bass fishery. (Note that this relates to Level 5 on the broad-level overview Pyramid.)

Objectives:

1. Reduce stream temperature and improve dissolved oxygen to concentrations required

- by smallmouth bass (Level 4).
2. Improve bed form diversity to meet smallmouth bass habitat requirements (Level 3).
 3. Provide floodplain connectivity to provide the flow dynamics needed for smallmouth bass (Level 2).
 4. Evaluate watershed runoff and flow duration to determine the suitability for supporting smallmouth bass (Level 1).

These objectives are specific function-based parameters that support the higher-level goal of restoring a smallmouth bass fishery. They are quantifiable, tangible and can be measured. In some cases, these parameters have measurement methods that include performance standards. The objectives provided above are just examples and could be changed or expanded for an actual watershed plan. In addition, a wide range of improvement options may be required to meet the watershed scale goals and objectives described above. These activities are discussed in item 4 of the Watershed Management Plans section above.

Regulatory and Non-Regulatory Programs

The same approach provided above for watershed management plans can be used in regulatory and non-regulatory stream improvement programs. For example, non-regulatory programs, such as watershed coalitions and non-profit organizations, set programmatic goals and objectives. As with watershed management plans, these goals are typically established at Level 5 since they relate to some type of aquatic life impairment. An example would be Trout Unlimited with the goal to restore a fishery. The advantage of the Pyramid is that once the aquatic life of interest is identified, the supporting functions can be established through quantifiable objectives. This will help the organization focus its resources by addressing activities that specifically affect the critical functions.

The same holds true for regulatory programs like Sections 303 and 404 of the Clean Water Act (FWPCA, 1972). Under Section 303, states are required to have water quality standards that support designated uses for waterways. Streams that do not meet these requirements are placed on the 303(d) list. For pollutant-impaired waters, Total Maximum Daily Loads (TMDLs) must then be established to address the pollutant(s) causing the impairment. Nationwide, sediment is the second-ranked pollutant causing streams and rivers to be placed on the 303(d) (USEPA, 2012). The causes of impairment are often inferred from results of biological monitoring, i.e., sediment is often identified as a reason that macroinvertebrate populations are negatively impacted.

The Pyramid could be used in impaired waters programs to establish more specific targeted load reduction alternatives based on cause-and-effect relationships shown on the Pyramid. For example, an initial assessment may show that the macroinvertebrate populations have lower abundance and more tolerant taxa than the reference conditions for a given area. Next, the Stream Functions Pyramid can be used to identify all the supporting functions that are required to support a healthy macroinvertebrate community. Third, further assessments can be conducted to determine if those functions (using function-

based parameters and a measurement method appropriate for the study) are Functioning, Functioning-at-Risk or Not-Functioning. Finally, objectives could be established that focus on the improvements needed to change the Not-Functioning and Functioning-at-Risk parameters to Functioning. This would likely include more parameters than just sediment, but would yield a plan with much more detail and potential for success.

The Pyramid can also be used to improve goals and objectives related to Section 404 of the Clean Water Act and compensatory mitigation. As was discussed above, many mitigation providers relate restoration goals to changes in channel dimension, pattern and profile. Mitigation credits are often provided based on these, among other, changes (USACE Wilmington District et al., 2003; USACE Norfolk District and VDEQ, 2007; and USACE Charleston District, 2010). The Pyramid can help practitioners develop goals and objectives that relate directly to stream functions. Over the last few years, attention to stream mitigation requirements associated with stream impacts from coalmining activities in Appalachia has increased. Practitioners and the regulatory community have grappled with how to assess functional lift through compensatory mitigation, especially for projects that include onsite mitigation. The process starts with setting appropriate goals and objectives. An example of how the Pyramid can be used to provide goals and objectives for on-site stream mitigation associated with large scale landscape modifications, such as mining, is provided below.

Example Goals:

1. Achieve replacement of aquatic functions (functions are defined in a function-based assessment) through onsite mitigation.
2. Use natural channel design techniques to re-establish a small headwater stream network after mining activities have ceased.

Example Objectives:

1. Water quality (pH and conductivity) will have similar or more suitable ranges compared to the pre-disturbance condition.
2. Bed form diversity, defined by pool-to-pool spacing and depth variability, will be improved compared to the pre-disturbance condition and will be characterized as Functioning using the Stream Functions Pyramid.
3. A 50-foot-wide riparian buffer composed of native grasses and trees will be established.
4. The restored channel will include large woody debris that meets a Functioning level.
5. The restored channel will have streambank erosion rates that are less than or equal to the existing condition and meet a Functioning level.
6. Floodplain connectivity in the restored channel will meet a Functioning level. Note: floodplain connectivity in v-shaped and colluvial valleys is characterized by a flood-prone area that can be very small.
7. Post-restoration flow duration will match pre-disturbance flow duration.
8. Post-restoration aquatic IBI scores will match or exceed pre-disturbance values.

These goals and objectives are just examples and would be modified based on the function-based assessment and local knowledge of the site. The value of using specific objectives, like the ones above, is that developing performance standards becomes much easier. The performance standards simply quantify the objectives.

Restoration Project Design Goals and Objectives

Restoration projects generally occur at a reach scale and can have significant functional lift of Level 2 and 3 parameters. However, to achieve goals in Levels 4 and 5, a combination of reach scale restoration and adequate upstream watershed health are required. In other words, site selection becomes critically important to achieving Level 4 and 5 goals.

The Stream Functions Pyramid Framework may be the most useful in developing design goals and objectives, which are developed once a restoration site has been selected and some form of functional or existing condition assessment has been completed. Using the Pyramid to assist with functional assessments is discussed in the next section. More information about developing goals and objectives associated with natural channel designs is provided below.

Developing design goals and objectives can be an iterative process. Typically, a broad goal is established early in the process, perhaps prior to the functional assessment. This goal could relate to a broad watershed goal, like restoring a smallmouth bass fishery as described above under Watershed Management Plans. After the assessment, other functional impairments may be identified that prohibit the restoration of a smallmouth bass fishery. These impairments may occur in the upstream watershed and cannot be addressed by the restoration project. In this case, the team would need to pick a different approach or establish new goals based on what can be achieved at the site (reach scale). Often the goal can be revised to improve function-based parameters in Levels 2 and 3, e.g., floodplain connectivity, bed form diversity, lateral stability and riparian vegetation. This will not directly restore a smallmouth bass fishery, but it can indirectly help smallmouth bass recovery by providing the channel form and habitats that they require.

This example illustrates the importance of setting project goals and objectives that are compatible with the health of the watershed. Restoration projects generally occur at a reach scale and can have significant functional lift of Level 2 and 3 parameters. However, to achieve goals in Levels 4 and 5, a combination of reach scale restoration and adequate upstream watershed health are required. In other words, site selection becomes critically important to achieving Level 4 and 5 goals.

Common Mistakes and Ideas for Improvement

A common stream restoration goal is simply to improve aquatic habitat (Fischenich, 2006). This is a poorly stated goal because it does not tell the reader what organism the habitat is for. Habitat requirements for mussels are different than habitat for a trout. If a habitat goal is going to be used, the goal, at a minimum, should state what species the habitat is for, e.g., “The goal of this project is to restore a southeastern native brook trout fishery.” Now the reader knows why the project is proposed. Of course, the term “habitat” is still broad and could include many things. So an even better goal would be “To improve the abundance of native brook trout populations within the project reach.” This is a goal that can be evaluated, and the measure of success is very specific. Objectives associated with this goal would identify the lower-level function-based parameters that must be Functioning in order to increase the abundance of native brook trout. And since this is a Level 5 goal, a thorough assessment of the watershed must be completed to determine if the upstream conditions will support brook trout, even after reach scale restoration. If not, another project reach, perhaps farther upstream, will need to be selected.

Another common and poorly stated goal is to improve water quality. Like habitat, water quality is a very broad concept and means different things to different people. For example, practitioners in West Virginia will typically equate water quality to pH and conductivity because of their work with the coalmining industry. Practitioners working in the eastern US Coastal Plain region will typically think of water quality as a nutrient (e.g., nitrogen and phosphorus) issue. Practitioners in the eastern US Piedmont and Mountain regions may think of water quality as a sediment or turbidity problem. Practitioners in the Pacific Northwest often think of water quality as a temperature problem. There are many other examples across the country, depending on the primary causes of water quality impairment. The key is to be specific. Use the goal to clearly establish why water quality is being addressed: to improve pH, conductivity, nutrients, sediment or other physicochemical properties. And, as with all of the goals, the next step is to develop objectives that identify the supporting, lower-level function-based parameters that must be Functioning in order to meet the goal. This also provides an opportunity to determine if stream restoration is the appropriate solution, or if other techniques are required. For example, stream restoration may have a minimal influence on conductivity and pH.

11.3 » FUNCTION-BASED STREAM ASSESSMENTS

The Pyramid is a framework that can be used as an aid in developing and reviewing function-based stream assessments. Somerville (2010) showed that stream assessments are often completed for a variety of regulatory and non-regulatory reasons, and range from broad assessments of stream condition to specific regulatory requirements. Three uses of function-based stream assessments will be discussed below and include:

- Determining restoration potential and functional lift;
- Determining stream functions lost and gained as part of a compensatory mitigation project; and
- Locating potential stream restoration projects as part of a watershed management plan.

A function-based assessment may include parameters from the Pyramid that are functions themselves; parameters that are not functions but help to describe the function from that category, e.g., bank height ratio from the Geomorphology category to help explain flow dynamics and floodplain connectivity. Parameter selection will be determined by the purpose of the assessment, the funding level and the geographic region. For example, flow duration is more limiting in some regions (and for some restoration types) than it is in others. Simple parameters may be selected for rapid-based assessments, and more complex parameters (that are also functions) may be selected for more intensive studies.

Regardless of the reason for completing function-based stream assessments, the following steps should be completed when using the Pyramid as a guide.

1. Determine the purpose of the assessment.
2. Select parameters from the Pyramid and/or other sources of information about parameters that describe stream functions relevant to the study. Include supporting functions.
3. Determine the appropriate methods for measuring the parameters, e.g., rapid versus intensive, and simple versus complex. This selection will also be dependent on the budget and purpose of the assessment.
4. Determine if the measurement methods need to be adapted based on unique regional characteristics, e.g., karst topography or endangered species.
5. Review the performance standards that are associated with the measurement methods, and determine if they are appropriate based on local environmental conditions and the purpose of the assessment. If possible, update performance standards with information from local reference streams.
6. If deemed necessary by the purpose, develop a scoring method to determine the overall functionality score of the stream reach, i.e., Overall Functioning, Functioning-at-Risk or Not Functioning. Consider having an overall score per functional category as well, e.g., Geomorphology, to help show where functional problems may exist.
7. Establish the length of the assessment (monitoring) period.
8. Implement function-based stream assessment, evaluate its effectiveness in assessing stream functions, and adapt method as necessary.

A description for each of the three general uses for stream assessment methods is provided below, along with examples of parameters from the Pyramid that could be included for that assessment.

Determining Restoration Potential and Functional Lift

The Stream Functions Pyramid Framework can be used to determine the restoration potential at a proposed project site. Restoration potential is the highest level of restoration or functional lift that can be achieved given the site constraints and health of the watershed. Once the restoration potential is known, specific design goals and objectives can be established, or original goals and objectives may need to be refined.

These assessments may include parameters from all five levels of the Pyramid that

quantify and describe the pre-restoration condition of the channel. Common Level 1 parameters include the precipitation/rainfall relationship, channel forming discharge and flood frequency. These parameters are used to quantify and describe the transport of water from the watershed to the channel, and they are needed in order to complete the Hydraulic and Geomorphology portions of the assessment. Common Level 2 parameters include both flow dynamics and floodplain connectivity, since these are critical for determining channel stability. Flow dynamics are typically assessed by measuring stream velocity, shear stress and stream power. Floodplain connectivity is most commonly assessed using the bank height ratio and entrenchment ratio. If the bankfull stage is unknown, stage-versus-discharge estimates using a hydraulic computer model can also be used to assess floodplain connectivity. However, to complete a proper hydraulic assessment to determine channel stability, field surveyed cross sections are required. A longitudinal profile is helpful for measuring bank height ratios along the reach. The profile can also be used for Level 3 assessment.

Level 3 parameters include sediment transport competency and capacity, channel evolution, streambank erosion rates, bed form diversity, large woody debris assessments, and riparian vegetation assessments. These parameters may be measured using rapid or more intensive approaches, based on the complexity of the project and funding level. However, the main purpose of the Level 3 assessment is to determine if the channel is vertically and laterally stable. Channel evolution assessments are used in combination with the above measures to estimate the future trend, i.e., whether the stream is evolving towards stability or instability. Of course, some stream types are naturally unstable; however, these streams should not be candidates for restoration. Common Level 4 parameters include basic water quality measures like pH, conductivity, temperature and dissolved oxygen. Assessments in the eastern US Coastal Plain region may also include nutrient assessments. Level 5 function-based parameters sometimes include macroinvertebrate and fish community assessments. Landscape connectivity is rarely used, but should be considered for providing watershed scale improvements.

The assessment results can then be used to determine the restoration potential. For example, the assessment may indicate that a stream reach is severely incised with extreme bank erosion, low bed form diversity, and no riparian vegetation. If this site is in a rural setting (low lateral constraints) with a healthy watershed, then the restoration potential is high because functional lift can likely be achieved through Level 5. However, if this same site is in an urban area or a setting with lateral constraints — like a road or

Restoration potential is the highest level of restoration or functional lift that can be achieved given the site constraints and health of the watershed. Once the restoration potential is known, specific design goals and objectives can be established, or original goals and objectives may need to be refined.

even cropland — that cannot be removed from production, then the restoration potential is lower because the functional lift may only occur in Levels 2 and 3.

Table 11.1 can be used to illustrate the baseline functions at the project site along with the proposed functional lift; the examples provided above are shown in the table. The values are arbitrary and not associated with a project. The purpose is simply to show how the function-based parameters, measurement methods and performance standards may be used as part of an assessment. The function-based parameters and measurement methods are selected based on the restoration potential, and the performance standards are used to quantify the functional lift.

Determining Stream Functions Lost and Gained as Part of a Compensatory Mitigation Project

The 2008 Mitigation Rule recommends that some type of functional assessment be completed at the permitted impact site and the mitigation site. The purpose of the functional assessment is to determine the functional loss at the permitted impact site and the functional lift at the mitigation site. Functional lift is defined as the difference between the pre-restoration and post-restoration condition. This process is intended to result in replacement of aquatic resources, in this case, the stream ecosystem.

Developing a function-based assessment for this purpose would be very similar to the one used to determine restoration potential and functional lift (described above). One difference is that the assessment would need to be applied at the permitted impact site and the mitigation site. The level of assessment will vary at the impact site, as the level of impact varies from minor (e.g., a culvert replacement or utility crossing) to major (e.g. surface mining or new road construction). For example, if only a few parameters are being affected, then only a few parameters need to be included in the assessment. If all five levels are being affected, the assessment should include parameters from all five levels. For the mitigation sites, the assessment can be more consistent with, and will be similar to, what is described in the restoration potential and functional lift section above. These parameters would then be assessed as part of the monitoring phase, and the data used to determine if performance standards are being achieved.

Locating Potential Stream Restoration Projects Using a Watershed Management Plan

Watershed management plans are becoming common among non-regulatory and regulatory programs. These plans are typically used to (1) identify the sources of stream and water quality impairments; (2) identify stream reaches and sub-watersheds that are relatively un-impacted, and (3) develop management plans to improve stream health and water quality. Federal programs that support watershed management plans include grants provided by Section 319 of the Clean Water Act (FWPCA, 1972), Total Maximum Daily Loads (TMDL), 2008 Mitigation Rule, and others.

Function-based stream assessments fit well with watershed management plans. They are often used as the method for differentiating between impaired and unimpaired

TABLE 11.1 FUNCTIONAL LIFT DETERMINATION

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-RESTORATION CONDITION		POST-RESTORATION CONDITION	
			VALUE	RATING	VALUE	RATING
1 – Hydrology	Channel-Forming Discharge	Regional Curves	200 cfs	N/A	200 cfs	N/A Used as an input parameter for Level 2 and 3
2 – Hydraulics	Floodplain Connectivity	Bank Height Ratio	3.0	Not Functioning	1.0	Functioning
3 – Geomorphology	Bed Form diversity	Entrenchment Ratio	1.1	Not Functioning	3.0	Functioning
			> 7	Not Functioning	4 to 5	Functioning
4 – Physicochemical	Channel Evolution	Simon	Stage 2 to 3	Not Functioning	Stage 6	Functioning
			Width is 12 meters with some human activity	Functioning-At-Risk	Width is > 18 meters and no human activity	Functioning
5 – Biology	Riparian Vegetation	RBP	High/High	Not Functioning	Low/Low	Functioning
5 – Biology	Lateral Stability	BEHI/NBS	Higher than upstream reference reach; does not meet species requirements	Not Functioning	Same as upstream reach and meets species requirements	Functioning
5 – Biology	Water quality	Temperature	7	Not Functioning	4	Functioning
5 – Biology	Macroinvertebrate Communities	Virginia Stream Condition Index				

stream reaches. To complete this task, these assessment methods are often implemented differently at the watershed scale and the reach scale. At the watershed scale, GIS, remote sensing and aerial photography are used to broadly assess parameters that would indicate stable, healthy streams versus unstable streams. These parameters from the Pyramid might include riparian vegetation, lateral stability and landscape pathways, all of which can be assessed with GIS and aerial photography. Some watersheds may be included in FEMA-regulated floodplains and contain Hydrology and Hydraulic characterizations that can be used to estimate floodplain connectivity and flow dynamics.

From this initial screening, on-the-ground, rapid-based assessments can be used to further determine channel stability, channel evolution, restoration potential, basic water chemistry and biological health. Rapid methods are needed so that long reaches of channel can be assessed in a relatively short period of time. The result is a map showing the location of impaired stream reaches, their proximity to other land uses, and a priority ranking for restoration. For example, an impaired stream downstream of a high quality sub-watershed, or an impaired reach between two stable reaches, would be high priorities because the functional lift would transcend the project reach length. Conversely, an impaired reach downstream of multiple point source discharges, or areas of rapid development, may receive a lower priority; therefore, other techniques like stormwater BMPs and Low Impact Development may be recommended instead. Once reaches are selected for a project, a more intensive assessment method to determine channel stability and restoration potential can be implemented.

Additional information about conducting watershed assessments can be found at <http://water.epa.gov/type/watersheds>. There is a wealth of information on this website, but one tool that may be particularly helpful for evaluating potential stream restoration sites is the Recovery Potential Project, a landscape screening tool for assessing the restorability of impaired waters.

11.4 » KEY PARAMETERS

The Stream Functions Pyramid includes over 30 parameters, but it is unlikely that a project would ever need to assess them all. However, there are core or key parameters that can be listed for a variety of common projects, such as restoring channelized streams in alluvial valleys back into meandering streams, restoring small headwater

The Stream Functions Pyramid includes over 30 parameters, but it is unlikely that a project would ever need to assess them all.

streams associated with mining, and improving salmonid fish habitat. Examples of key function-based parameters that should be evaluated before and after restoration are provided below. A variety of rapid and more intensive measurement methods are also provided.

Restoring Channelized Streams in Alluvial Valleys to Meandering Streams

Many projects in the eastern US attempt to restore streams that were enlarged and

deepened through channelization and incision. These projects occur in alluvial valleys, in both urban and rural settings, and with a variety of substrate compositions. The Rosgen Priority Levels are often used as an approach for restoring these streams. Figures 11.1a and 11.1b show before and after photos of a stream restoration project in the Coastal Plain of North Carolina. Figure 11.1a shows a channelized, incised stream that lacks bed form diversity due to low sinuosity and dredging. There is minimal riparian vegetation and nutrient runoff that can easily enter the stream from the adjacent cropland causing eutrophication. Figure 11.1b shows the same project site approximately one growing season after restoration construction was completed. The stream is shallower than the pre-restoration condition, creating enhanced floodplain connectivity and an elevated water table that supports the development of riparian wetlands. The meandering pattern carries both baseflow and bankfull flows effectively, providing longer retention times and opportunities for denitrification. The biggest driver of denitrification is the increased floodplain access by stormflows, water storage on the floodplain, shallow depth to the water table, and establishment of a woody riparian buffer over time.

FIGURE 11.1A PRE-RESTORATION



FIGURE 11.1B POST-RESTORATION



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This project, like most other restoration projects where channelized streams are converted back into meandering systems, highlights four key parameters that must be addressed to achieve project success. The key parameters include: floodplain connectivity, bed form diversity, lateral stability and riparian vegetation. These function-based parameters are shown below in Table 11.2. The second column provides measurement methods that can rapidly be assessed with minimal field measurements. The third column provides measurement methods that provide a more detailed assessment of the stream reach; however, they also require more effort. These more intensive measurement methods require more time in the field to collect data and, in some cases, require repeated monitor-

The key parameters include: floodplain connectivity, bed form diversity, lateral stability and riparian vegetation.

ing over several years, e.g., developing rating curves, establishing erosion rates and measuring vegetation growth.

If these four function-based parameters are addressed properly along with proper site selection, then there is a high probability of achieving success by improving the physical, chemical and biological integrity of the stream. This table should not be used to assume that parameters in other levels of the Pyramid are not important (these all come from Levels 2 and 3). Rather, the intent is to show that these parameters are generally the critical foundation to a healthy stream in most alluvial valleys.

TABLE 11.2 KEY PARAMETERS FOR ASSESSING STREAM FUNCTIONS ASSOCIATED WITH RESTORING MEANDERING STREAMS

PARAMETER	SIMPLE MEASUREMENT METHOD	MORE INTENSIVE MEASUREMENT METHOD
Floodplain Connectivity	Bank Height Ratio, Entrenchment Ratio,	Rating curves (discharge vs. stage)
Bed Form Diversity	Percent Riffle and Pool	Depth Variability
Lateral Stability	Streambank Erosion Rates using BANCS model	Measuring Streambank Erosion Rates with permanent cross sections
Riparian Vegetation	Riparian Buffer Width	Riparian Vegetation Density and Composition-Vegetation Plots

Restoring Small Headwater Streams

The key parameters listed in Table 11.2 would need to be modified slightly for assessing stream functions associated with the restoration of small headwater streams, such as those commonly found in the Appalachian Mountains. The restoration of high-gradient, very small intermittent and ephemeral channels as part of stream mitigation projects is common in coalmining regions. In other areas of the Appalachian Mountains, Trout Unlimited and resource agencies work to restore native brook trout populations in headwater perennial mountain streams that are typically located in colluvial and v-shaped valleys. Unlike the lateral meandering streams discussed above, these streams dissipate energy through vertical meandering of the stream bed, i.e., through a step-pool bed form sequence (Wohl, 2000). These streams do not have floodplains that are built by river meandering processes, but rather have floodprone areas that often extend the width of the bowl- or v-shaped valley. Figures 11.2a and 11.2b show an example of a small headwater mountain stream restoration project. Figure 11.2a shows the stream before restoration. The bed form is devoid of pools due to past cattle trampling and channel widening. Figure 11.2b shows the project after restoration construction. Boulder and wood structures were used to create a step-pool bed form, re-establishing the vertical meandering processes. A bowl-shaped floodprone area provides energy dissipation during flood

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events, and a riparian buffer was established to provide lateral stability.

FIGURE 11.2A PRE-RESTORATION

Cows are periodically allowed to graze.



FIGURE 11.2B POST-RESTORATION



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The same key function-based parameters associated with a natural channel design and listed in Table 11.2 are included here in Table 11.3, with one minor exception. Since these channels do not have floodplains, the function-based parameter is changed to floodprone area connectivity, as it is still important for the channel to only carry the amount of water necessary for sediment transport requirements. Flood flows should be transported in the floodprone area. The simple measurement method for bed form diversity also changes, from percent riffle-pool to pool-to-pool spacing, which is a better measure of vertical meandering and has better performance standards (Leopold, 1994; Gregory et al., 1994; Whittaker, 1987; Chin, 1989, and Grant et al., 1990).

TABLE 11.3 CRITICAL CATEGORIES FOR ASSESSING FUNCTIONS BEFORE AND AFTER STREAM RESTORATION PROJECTS

PARAMETER	SIMPLE MEASUREMENT METHOD	MORE INTENSIVE MEASUREMENT METHOD
Floodplain Connectivity (Floodprone Area Connectivity)	Bank Height Ratio, Entrenchment Ratio,	Rating Curves (discharge vs. stage)
Bed Form Diversity	Pool-to-Pool Spacing	Depth Variability
Lateral Stability	Streambank Erosion Rates using BANCS Model	Measuring Streambank Erosion Rates with Permanent Cross Sections
Riparian Vegetation	Riparian Buffer Width	Riparian Vegetation Density and Composition-Vegetation Plots

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Table 11.3 is primarily for natural channel design, i.e., these parameters are key design parameters that can have a major effect on creating higher-order functional improvements. Additional function-based parameters may be selected when evaluating headwater mountain stream restoration projects for functional lift that is associated with mining activities. Table 11.4 provides an example of the minimum function-based parameters per functional category that are recommended. Measurement method examples are provided that would be appropriate for a mitigation project; some are rapid and others are more intensive.

TABLE 11.4 POSSIBLE FUNCTION-BASED PARAMETERS AND MEASUREMENT METHODS FOR EVALUATING FUNCTIONAL LIFT IN SMALL, HIGH GRADIENT STREAMS

FUNCTIONAL CATEGORY	FUNCTION-BASED PARAMETER	MEASUREMENT METHOD
Hydrology	Rainfall / Runoff	Rationale Method
Hydrology	Flow Duration	Rapid Indicators
Hydraulics	Floodplain (Floodprone area) Connectivity	Bank Height Ratio Entrenchment Ratio
Geomorphology	Large Woody Debris	Large Woody Debris Index
Geomorphology	Bed Form Diversity	Pool-to-Pool Spacing Depth Variability
Geomorphology	Lateral Stability	BEHI/NBS
Geomorphology	Riparian Vegetation	Buffer Width Buffer Composition Buffer Density
Physicochemical	Water Quality	pH Conductivity
Biological	Macroinvertebrate Communities	State Protocol, if available

There are exceptions to the key parameters listed above. It is likely that many small, headwater ephemeral stream channels in the mountain regions are the product of erosion and channel formation due to land clearing practices during post-European settlement. In some of these systems, forest regeneration has occurred over the decades, and the channel that formed is stable. However, from a functional standpoint, it would be better to have valley bottoms rather than channels that provide greater storage capacity for water, wood, and other forms of organic matter. Restoration would typically not be recommended in stable environments; however, small-channel and no-channel approaches for restoring disturbed systems are being investigated by various researchers and practitioners. Examples of natural channel design in small headwater channels can be reviewed at <https://louisville.edu/speed/civil/si>.

Key Parameters for other Types of Restoration

The key parameters listed above are applicable to many full-scale restoration projects. However, some forms of restoration do not require aggressive changes to channel form, and different key parameters may be required for restoration success. Water removal impacts in the arid West are an example where the key parameters listed above would not apply. In these environments, the channel form may include floodplain connectivity, bed form diversity, laterally stability, and have riparian vegetation common for arid regions; however, historically perennial streams can become ephemeral due to excessive water withdrawals. In these cases, flow duration is the key parameter and the restoration activities may include policy/management changes rather than natural channel designs.

Other examples of restorations that may require minimal or no adjustments to channel form include removal of fish passage impediments and eliminating water quality impairments associated with point-source discharges and stormwater runoff. However, these key parameters listed above should still be assessed, or at least considered, before moving forward with other forms of restoration, especially for perennial streams in alluvial valleys. More likely, additional function-based parameters would be added to the list, rather than removing them.

11.5 » REVIEWING EXISTING STREAM ASSESSMENTS

Government agencies often want to evaluate existing stream assessment protocols before making the decision to develop a new one. Somerville and Pruitt (2004) and Somerville (2010) provide a good starting point for evaluating existing stream assessment protocols. New protocols continue to be developed, especially related to stream mitigation. The draft Regional Guidebook for High-gradient Ephemeral and Intermittent Headwater Streams, USACE (2010), is an example of a functional assessment methodology that has been developed in response to mitigation requirements in coalmining regions of West Virginia and Kentucky. Given the volume of existing assessment methodologies, it is important to have criteria for selecting an existing methodology or for making the decision to develop a new methodology. The following checklist may help with this decision.

Checklist for Selecting Existing Stream Assessment Methodologies

1. Determine why a stream assessment is needed. What is the purpose?
2. Is the assessment needed to meet regulatory requirements?
3. Is the existing stream assessment protocol appropriate for your region? In other words, some protocols are developed for very specific environmental settings and conditions, e.g., high gradient or arid.
4. Has the existing stream assessment protocol been peer reviewed, validated, or otherwise assessed for accuracy and precision in relation to direct functional measures?
5. How much is already known about the functional impairments of the watershed? Some understanding of existing impairments is helpful when selecting an existing protocol because the impairments can be related to the function-based parameters from the Pyramid. Then these parameters can be compared to the parameters as-

sessed in the protocol. If there is a good match, then the existing protocol may be selected. Otherwise, other protocols should be reviewed and potentially new protocols may needed to be developed.

6. Are lower-level functional categories included, e.g., Hydrology, Hydraulics, and Geomorphology? Generally, existing protocols are weak in these categories. Review the protocol to ensure that the supporting/"driver" parameters are included.
7. Are the key parameters described in the above sections included? If not, is there a good reason?

11.6 » DEVELOPING DEBITS AND CREDITS

The development of stream debit and credit determination methods continues to evolve as USACE Districts implement the 2008 Mitigation Rule. The Rule does not provide a formula for developing debit or credits. It simply states that a description of the debits or credits will be provided, including the rationale used. In some regions, IRTs have incorporated credit determination methods into SOPs; however, in other areas, the credit determination method is left up to the mitigation provider. The Rule defines debits as a unit of measure that accounts for the functional loss at a permitted impact site. Some mitigation SOPs, like the Unified Stream Methodology (USACE Norfolk District and

The Stream Functions Pyramid can also be used to separate restoration efforts that improve Level 2 and 3 functions, and those that restore through Level 5. As such, IRTs may choose to consider creating two levels of restoration: Restoration 1 and Restoration 2.

VDEQ, 2007) and the Charleston, SC SOP (USACE Charleston District, 2010) provide debit calculations based on a stream condition assessment, similar to a function-based assessment. However, some of the techniques described in the Function-based Assessment section above could be used to better link the functions lost at a permitted impact site to the functions gained at a mitigation site.

Stream mitigation credits are units of measure that represent the accrual or attainment of stream functions at a compensatory mitigation site (33.C.F.R. § 332/40 C.F.R. § 230). The accrual or attainment of stream

function occurs through a variety of approaches, including restoration, enhancement, re-establishment and preservation. The Pyramid Framework can be used to help show the functional lift, especially with stream restoration approaches. Stream restoration is defined in the 2008 Mitigation Rule as the "manipulation of the physical, chemical and biological characteristics of a site with the goal of returning natural/historic functions to a former or degraded aquatic resource." Most stream mitigation SOPs cite this definition; however, functional lift is often tied to the Priority Levels of Restoration (Rosgen, 1997) and/or changes to stream dimension, pattern and profile (Somerville, 2010).

This has led to several problems, including: (1) incentivizing maximum channel manipulation to show changes in dimension, pattern and profile to receive the maximum amount of credits; (2) focusing the objectives and performance standards on dimension, pattern and profile changes instead of stream functions or function-based parameters, making the communication of functional lift difficult; and (3) removing evidence of functional lift from the evaluation of project success. This credit determination method has resulted in many projects being evaluated simply on visual observations of channel stability, in-stream structure integrity, and condition of the riparian buffer. The Stream Functions Pyramid, and the forms shown in the assessment section, can help articulate function-based goals, develop function-based assessments, and then develop credit determination methods based on the potential functional lift. Examples of how to do this are provided in the next section.

The Stream Functions Pyramid can also be used to separate restoration efforts that improve Level 2 and 3 functions, and those that restore through Level 5. As such, IRTs may choose to consider creating two levels of restoration: Restoration 1 and Restoration 2. Restoration 1 would restore functions through Level 5 and represent the highest level of restoration achievable. This would require reach-scale restoration and an upstream watershed that supports aquatic life identified in Level 5. It could also include watershed-scale restoration for small headwater systems. More details are provided below about credits; however, 1 credit per foot is proposed as the maximum number attainable, essentially representing 100% restoration. Restoration 2 is also defined as the restoration of reach-scale functions; however, the upstream watershed may not be suitable for supporting species of interest in Level 5. The restoration project may still be worthwhile (based on the function-based assessment); however, functions are only restored through Level 3.

Therefore, the maximum achievable credits for Restoration 2 would be less than for Restoration 1; perhaps the maximum is 0.8 credits per foot for the example. However, if a mitigation provider continued to work in the watershed and showed appropriate levels of functional improvement in Level 5, the IRT may want to allow the provider to request the additional 0.2 credits per foot to achieve the full 1.0 credit per foot. This would offer incentive for the mitigation providers to perform watershed-scale restoration.

One value in this restoration level approach is that it clearly identifies function-based parameters that a mitigation provider can control (Restoration 2) versus function-based parameters that are more dependent on upstream watershed condition (Restoration 1). For a Restoration 2 example, projects that restore meandering pattern to channelized

One value in this restoration level approach is that it clearly identifies function-based parameters that a mitigation provider can control (Restoration 2) versus function-based parameters that are more dependent on upstream watershed condition (Restoration 1).

streams would show functional improvement in the key parameters shown in Table 11.2 (floodplain connectivity, bed form diversity, lateral stability, riparian vegetation). The mitigation provider has a lot of control over the design and functionality of these parameters. This should improve communication between the provider and the IRT, making the development of performance standards much more specific and quantitative than many current approaches that simply deal with channel form (dimension, pattern and profile). However, further improvements in Levels 4 and 5 are dependent on upstream watershed conditions. To achieve Restoration 1 and receive full restoration credit, the upstream watershed condition combined with reach-scale restoration creates a Functioning ecosystem through Level 5. The mitigation provider does not have control of the upstream watershed condition; however, they do have control over how the project site is selected.

Debit and Credit Templates Overview

The purpose of this section is to show how the Stream Functions Pyramid Framework can be used as an aid in developing stream debit and credit determination methods. Example debit and credit determination templates will be provided, along with examples and case scenarios to illustrate how the Pyramid Framework can be used — at least at a broad level. The main goal of this section is simply to illustrate how the Pyramid might be used to develop debits and credits. It is not intended to be a policy recommendation, but rather “food for thought”. It is a tool, not a rule; however, the approach does try to address requirements in the 2008 Mitigation Rule.

Example templates are provided below to aid IRTs in developing debits and credits. The templates are meant to provide IRTs with ideas on how they can create an SOP that utilizes the Stream Functions Pyramid to help show functional lift. They should be modified to fit local needs and conditions. The SOP template does not address credit release schedules, land protection measures, monitoring designs, service area delineation or other elements of a stream mitigation plan. Rather, the SOP templates focus on how to show appropriate compensation by matching the functions lost at the impact site to the functions gained at the mitigation site by comparing the difference between pre- and post-conditions. These conditions are assessed using the function-based parameters, measurement methods and performance standards from the Pyramid Framework.

Example applications of the template for several impact scenarios (debits) and mitigation scenarios (credits), representing a wide range of conditions from across the country, are provided in Appendix B. The debit scenarios include:

1. Culvert installations,
2. Channelization and bank hardening, and
3. Surface mining of high gradient streams.

The credit scenarios include:

1. Restoration of incised streams;
2. Restoration of stream flow for channels that have excessive water withdrawal;

3. Salmonid fish passage and habitat restoration; and
4. Restoration of high gradient, headwater streams.

Debit and Credit Templates Structure

There are three sample debit and three sample credit templates provided below, along with a description of each. Template 1 for debits and credits shows the functional loss and lift, respectively. Template 2 provides a place where the user can write notes about the rationale used to complete Template 1. There is a Debit Template 2 and a Credit Template 2. Template 3 provides a method for calculating debits (Debit Template 3) and credits (Credit Template 3). A detailed description of each is provided below.

The *Debit Template 1: Functional Loss Determination* (Table 11.5) shows the Pyramid level number and category name. For each category (Hydrology, Hydraulics, etc.) the table shows the parameter selected from the Pyramid, the measurement method, the pre-disturbance condition and the post-disturbance condition. The key parameters are selected based on the type of impact and whether or not the impact is expected to affect the parameter. For example, if a culvert is going to be installed in a stream with a mature bottomland hardwood forest, the riparian vegetation parameter would be selected. This would show that the buffer is Functioning before the permitted impact and is Not Functioning after the impact. All the information needed to complete this table is provided in Chapters 5-9. A summary is provided in Appendix A.

The *Credit Template 1: Functional Lift Determination* (Table 11.6) is identical to the Debit Template 1 (Table 11.5) with two exceptions. The pre-disturbance condition and post-disturbance condition have been changed to pre-restoration condition and post-restoration condition. Parameters and measurement methods are selected to best represent the potential improvement in stream functions.

The main goal of this section is simply to illustrate how the Pyramid might be used to develop debits and credits. It is not intended to be a policy recommendation, but rather “food for thought”. It is a tool, not a rule; however, the approach does try to address requirements in the 2008 Mitigation Rule.

TABLE 11.5 DEBIT TEMPLATE 1: FUNCTIONAL LOSS DETERMINATION

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-DISTURBANCE CONDITION		PREDICTED POST-DISTURBANCE CONDITION	
			VALUE	RATING	VALUE	RATING
1 – Hydrology	Insert key parameter from the Pyramid. Refer to Chapters 5-9.	Choose the appropriate measurement method for the selected parameter.	Enter the actual value determined using the measurement method.	Enter Functioning, at-Risk or Not Functioning based on the performance standard value.	Enter the predicted or measured value determined using the measurement method.	Enter Functioning, Functioning-at-Risk or Not Functioning based on the performance standard value.
2 – Hydraulics	Example Floodplain Connectivity	Example Bank Height Ratio Entrenchment Ratio	Example 1.0 3.0	Example Functioning Functioning	Example 2.5 1.1	Example Not Functioning Not Functioning
3 – Geomorphology						
4 – Physicochemical						
5 – Biology						

TABLE 11.6 CREDIT TEMPLATE 1: FUNCTIONAL LIFT DETERMINATION

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-RESTORATION CONDITION		POST-RESTORATION CONDITION	
			VALUE	RATING	VALUE	RATING
1 – Hydrology	Insert key parameter from the Pyramid. Refer to Chapters 5-9.	Choose the appropriate measurement method for the selected parameter.	Enter the actual value determined using the measurement method.	Enter Functioning, Functioning-at-Risk or Not Functioning based on the performance standard value.	Enter the measured value determined using the measurement method.	Enter Functioning, Functioning-at-Risk or Not Functioning based on the performance standard value.
			Example	Example	Example	Example
2 – Hydraulics	Example Floodplain Connectivity	Bank Height Ratio	3.0	Not Functioning	1.0	Functioning
		Entrenchment Ratio	1.1	Not Functioning	3.0	Functioning
3 – Geomorphology						
4 – Physicochemical						
5 – Biology						

The next tables (Table 11.7 and 11.8) are templates that can be used to provide supporting text about the above pre- and post-condition tables. On the debit side, the table is used to describe the pre-disturbance condition and the rationale for selecting the parameters and measurement methods. The rationale used to predict the post-impact condition should also be provided. The approach is similar on the credit side. For this template, a description of the pre- and post-restoration condition is provided, along with the rationale for selecting key parameters and measurement methods.

TABLE 11.7 DEBIT TEMPLATE 2: PRE- AND POST-DISTURBANCE CONDITIONS AND RATIONALE

Describe Pre-and Post-Disturbance Condition and Rationale for Selecting Parameters

*Enter a short description of the pre- and post-disturbance condition for each functional category. Explain why the selected parameters and their measurement method were used. Also include the rationale for the expected outcome. An abbreviated example is provided below for a **permitted culvert installation**. The remainder of this example is provided in Appendix B.*

Hydrology: The watershed hydrology is stable and is not expected to change. Therefore, Hydrology parameters were not selected.

Hydraulic: The existing channel is not incised and has access to a wide alluvial floodplain, i.e., there is floodplain connectivity. In this example, the culvert will likely cause channel incision downstream of the culvert, and bank height ratios are likely to increase, causing a Not Functioning score. The culvert will provide grade control for the upstream channel and the bank height ratio may decrease because of aggradation.

Geomorphology: see Appendix B, Table B2a

Physicochemical: see Appendix B, Table B2a

Biological: see Appendix B, Table B2a

TABLE 11.8 CREDIT TEMPLATE 2: PRE- AND POST-RESTORATION CONDITIONS AND RATIONALE

Describe Pre-and Post-Restoration Condition and Rationale for Selecting Parameters

*Enter a short description of the pre-and post-restoration condition for each functional category. Explain why the selected parameters and their measurement method were used, along with the rationale for the expected improvement. An abbreviated example is provided below for the **restoration of an incised channel**. The remainder of this example is provided in Appendix B.*

Hydrology: The watershed hydrology is stable and is not expected to change. Therefore, Hydrology parameters were not selected.

Hydraulic: The existing channel is severely incised (Bank Height Ratio of 3) and does not have access to a wide alluvial floodplain. The channel will be reconnected to the floodplain through a Rosgen Priority 1 Restoration. The Bank Height Ratio will be reduced to 1.0, and all flows greater than bankfull will spread onto a floodplain that is 50 times wider than the channel, making the entrenchment ratio well over 2.2.

Geomorphology: see Appendix B, Table B11a

Physicochemical: see Appendix B, Table B11a

Biological: see Appendix B, Table B11a

The third set of templates (Tables 11.9 and 11.10) provides debit and credit ratios based on the results from Template 1. The ratios used to create debits and credits can be modified. The ones used in this template are for demonstration purposes and were chosen to encourage mitigation providers to select projects that have the potential for the greatest functional lift. Credits range from 0 to 1 credit-per-foot of restored channel. Debits range from 1 to 2 debits-per-foot. Therefore, an impact that creates maximum functional loss would be assigned 2 debits-per-foot. Since the maximum credit ratio is 1 credit-per-foot, they will have to perform mitigation on twice the stream length that was impacted. Since a portion of credits is released before a site reaches maturity, a greater amount of mitigation is necessary to address this temporal loss as well as the risk of project failure.

Table 11.9 provides example debit ratios. The first column shows the functionality of the stream reach before an impact occurs. Functionality ranges from Low to High and is based on the pre-disturbance condition from Debit Template 1. The remaining columns show the predicted functional loss from the permitted impact, ranging from no functional loss to high functional loss, based on the predicted functional loss from Debit Template 1. Debit ratios are then assigned to the different levels of functional loss. Therefore, high-quality streams that are more severely impacted would yield more debits than degraded streams that were minimally impacted. A debit adjustment factor is provided for scenarios that may need to be modified based on unique site conditions or because the result fits between two categories.

TABLE 11.9 DEBIT TEMPLATE 3: DEBIT CALCULATIONS

PRE-DISTURBANCE CONDITION	POST-DISTURBANCE CONDITION			
	No Functional Loss	Low to Moderate Functional Loss	Moderate to High Functional Loss	Debit Adjustment (+/-)
Low (Mix of Functioning-at-Risk and Not Functioning)	(Post-disturbance condition matches pre-disturbance condition) No mitigation required	Greater number of Functioning-at-Risk and Not Functioning Scores 1.1 to 1.2	Mostly Not-Functioning Scores 1.2 to 1.3	0.1
Moderate (Mix of Functioning, Functioning-at-Risk, and Not Functioning)		Loss of Functioning scores and/or greater number of Functioning-at-Risk and Not Functioning Scores 1.3 to 1.5	Mix of Functioning-at-Risk and Not Functioning Scores 1.5 to 1.7	0.1
High (Functioning)		Mix of Functioning, Functioning-at-Risk, and Not Functioning Scores 1.7 to 1.9	Mix of Functioning-at-Risk and Not Functioning Scores 2.0	0.2

Tables 11.10 and 11.11, provide examples of credit determination method templates for Restoration 1 and Restoration 2 projects. Specific examples are provided in Appendix B. The table below includes four columns: Credit Category, Pre-Restoration Condition, Post-Restoration Condition and Credit Ratio. The credit ratio is expressed as credit-per-foot with the highest ratio set at 1.0 credit-per-foot for a Restoration 1 project with a Maximum Lift score. Maximum Lift is the first row under the Credit Category. So if a project was 5,000 feet long, the maximum number of credits that could be attained is 5,000. The other categories are Moderate and Low lift. So a project that has several Functioning scores in the baseline condition would have a Low lift and would be given less credit. Note that the post-restoration condition is the same for Maximum, Moderate and Low lift. The difference is in the baseline condition. This reflects a goal of achieving the highest restoration or enhancement possible, but acknowledges that some sites start in a more degraded condition; thus, more lift is created and more credit is given. Again, these ratios are provided only as a guide. Appendix B provides other examples of credit determination methods for other scenarios.

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TABLE 11.10 CREDIT TEMPLATE 3: CREDIT CALCULATIONS FOR RESTORATION 1

RESTORATION 1 CREDIT CATEGORIES	PRE-RESTORATION CONDITION	POST-RESTORATION CONDITION	CREDITS PER FOOT
Maximum Lift	All parameters in Pyramid Levels 2 and 3 have Not Functioning scores. Parameters in Levels 4 and 5 are Not Functioning or Functioning-at-Risk.	Functioning scores for Levels 1-5	0.8 to 1.0
Moderate Lift	Mix of Not-Functioning and Functioning-at-Risk scores for parameter Levels 2 through 5.	Functioning scores for Levels 1-5	0.6 to 0.8
Low Lift	Mix of Not-Functioning, Functioning-at-Risk and Functioning scores for parameter Levels 2 through 5.	Functioning scores for Levels 1-5	0.4 to 0.6

Credits = Credit Ratio (in Credits/Ft) times the restored stream length (ft).

TABLE 11.11 CREDIT TEMPLATE 3: CREDIT CALCULATIONS FOR RESTORATION 2

RESTORATION 2 CREDIT CATEGORIES	PRE-RESTORATION CONDITION	POST-RESTORATION CONDITION	CREDITS PER FOOT
Maximum Lift	All parameters in Pyramid Levels 2 and 3 have Not Functioning scores.	Functioning scores for Levels 1-3	0.6 to 0.8
Moderate Lift	Mix of Not-Functioning and Functioning-at-Risk scores for parameter Levels 2 through 3.	Functioning scores for Levels 1-3	0.4 to 0.6
Low Lift	Mostly Functioning-at-Risk and Functioning scores for parameter Levels 2 through 3. May include some Not-Functioning scores.	Functioning scores for Levels 1-3	0.2 to 0.4

Credits = Credit Ratio (in Credits/Ft) times the restored stream length (ft).

Enhancement Credits

The Pyramid Framework can be used to help develop enhancement credits, although less emphasis is placed on these projects within this document. The 2008 Mitigation Rule defines enhancement as the manipulation of the physical, chemical and biological characteristics of an aquatic resource to heighten, intensify or improve a specific aquatic resource function(s). Enhancement may lead to a gain in certain functions, but could also lead to a decline in other functions. Enhancement does not increase the aquatic resource area, e.g., stream length. An appropriate way to develop stream enhancement credits using the Stream Functions Pyramid Framework as a guide is to complete a function-based assessment before making the determination of whether restoration or enhancement is the better solution. The assessment may be rapid or intensive depending on the project; however, information about which function-based parameters are Functioning and Not Functioning must be determined before the practitioner can know what needs to be enhanced.

Enhancement can lead to projects that achieve the same level of functionality as a Restoration 1 approach above; however, they can also lead to projects that still have several function-based parameters with a Functioning-at-Risk or Not Functioning score. Therefore, the key difference between restoration and enhancement, as described here, is the level of functional lift. Restoration 1 includes changes to many function-based parameters, along with proper site selection, to achieve a fully functioning score. Enhancement may include a change to only one parameter to achieve a fully functioning score, if all other key parameters are functioning, e.g., the riparian buffer. In this example, the product is the same but the amount of functional lift is much less with an enhancement approach. Enhancement can also improve one function-based parameter like lateral stability, but not improve other key parameters like floodplain connectivity or bed form diversity. This would lead to a stream that has some improvement in stream function, but the change is not necessarily significant. And because the stream is not connected to the floodplain, the channel could lose other functions in the future.

A table is not provided for calculating enhancement credits. Rather, some examples of enhancement scenarios are provided below. These examples show how to focus on enhancements to function-based parameters rather than practices like benching or in-stream structures. These practices will likely be used; however, the credits should be based on changes to function-based parameters and not the number of structures. Of course, enhancement credits should also be less than restoration credits on a per, foot basis.

Example Enhancement Scenarios:

1. Projects in non-incised, rural streams within alluvial valleys. The stream is well connected to a floodplain and there are diverse bed forms created from the appropriate plan form geometry and bed form complexity. Streambanks are not eroding at levels above reference conditions, i.e., banks are stable. However, the riparian buffer is thin with only a single row of trees along the streambank.

Enhancement credits could be provided for expanding the buffer. In this case, higher order functions like de-nitrification and even improvements to benthics and fish may occur — if supported by the upstream watershed.

2. Same setting as number 1 and same conditions, except in addition to having a narrow riparian buffer, the bed form diversity is also low, e.g., mostly riffle bed forms due to straightening and vegetation/debris removal.

Enhancement would include improving the bed form diversity, e.g., percent riffle and pool, depth variability, and improving the buffer width and composition. This would be a higher level of enhancement because more than one function-based parameter is being improved.

3. Urban setting, flood control channel. A channelized, trapezoidal channel with streambanks stabilized by rip rap and some vegetation.

High level of enhancement would include providing limited floodplain connectivity by excavating bankfull benches, providing bed form diversity through the installation of in-stream structures, and planting a narrow buffer. Lower-level enhancement would be bank stabilization using vegetation, e.g., bioengineering and perhaps bed form diversity with in-stream structures; however, significant benching and vegetation beyond the top of the streambank would be limited.

Example of Calculating Debits and Credits

The following is an example of how the templates can be used to calculate debits and credits from a hypothetical permitted impact site and a mitigation site.

Impact Site

- 500 feet of culvert with 200 feet of downstream impact and 100 feet of upstream impact. Total impact length is 800 feet.
- The functional condition before disturbance shows a mix of Not-Functioning, Functioning-at-Risk and Functioning scores for Level 2 through 5 parameters. This equals a Functionality Before Impact score of Moderate (Table 11.9).
- A standard installation approach is used instead of an arch culvert or bridge, so post-construction functions will include a greater number of Not-Functioning and Functioning-at-Risk scores for Level 2 through 5 parameters. This equals a Moderate Functional Loss from Table 11.9.
- A Moderate/Moderate score yields a ratio range of 1.3 to 1.5 debits per foot. For this example, a ratio of 1.5 is used.
- The total debits equal $1.5 \times 800 = 1,200$ debits. In other words, 1,200 credits are needed to compensate for the impacts.
- This example could have been broken into three reaches, including upstream of the culvert, through the culvert, and downstream of the culvert, since the impacts will likely vary. An example of calculating debits by reach for a culvert installation is shown in Appendix B.

Off-Site Mitigation

- A 10,000-foot stream restoration site is located that meets the Restoration 1 criteria. A Restoration 1 site includes full restoration of Level 2 and 3 functions and the watershed supports Level 4 and 5 functions.
- The pre-restoration condition shows that all parameters in Pyramid Levels 2 and 3 have Not Functioning scores. Parameters in Levels 4 and 5 are Not Functioning or Functioning-at-Risk.
- The post-restoration condition is predicted to show Functioning scores for Levels 1-5. The stream is well connected to the floodplain with diverse and complex bed forms that are representative of the stream type. Riparian buffer is diverse and has sufficient width to support Level 4 and 5 functions. Since the upstream watershed supports Level 4 and 5 functions, it is predicted that the project reach will achieve Functioning scores for Levels 4 and 5 as well.
- This results in a Maximum Lift score, with a credit ratio range of 0.8 to 1.0 credits per foot.
- For this example, a credit ratio of 1.0 is selected.
- The total credits available at this site are $10,000 \text{ ft} \times 1.0 \text{ credits/ft} = 10,000 \text{ credits}$.

As was mentioned previously, the debits and credits can be modified to meet local conditions and requirements. The debit and credit range selected for these examples was based on two important factors. First, more credits were provided for scenarios that improved more functions, i.e., the more functions that are restored, the more credits. Second, a multiplier is applied to the debits to ensure that debits are never less than the length of impact. The maximum is 2.2:1, meaning that 2.2 times the amount of impacted length may be required for mitigation. The multiplier acknowledges the fact that impacts occur immediately during construction and that mitigation sites take years to reach functional maturity. Since a portion of credits is released before the site reaches maturity, a greater amount of mitigation is warranted for temporal losses to stream functions.

11.7 » STEPS TO DEVELOPING DEBITS AND CREDITS

The following provides general steps for using the Pyramid to develop unique debit and credit determination methods. These steps also provide guidance on how to collect the information necessary to complete the templates described above. Actual steps and tasks will vary based on local needs and conditions, and additional steps will be needed to meet other 2008 Mitigation Rule requirements. For example, the steps below do not address how to develop the Prospectus or the Mitigation Banking Instrument.

Steps to Develop Debits Using the Pyramid

1. List types of impacts for the service area, i.e., culvert crossings, channelization, etc.
2. Select key function-based parameters from the Pyramid that are typically associated with each type of impact. The selected parameters should be based on some form of function-based assessment.

3. Select the appropriate measurement method for each parameter, e.g., simple and rapid-based or more complex and time intensive. This selection should be based on the severity of the impact and difficulty in predicting functional loss.
4. Perform function-based assessment on stream reach proposed to be impacted.
5. Record values for each measurement method and use the performance standards to determine if the function-based parameter is Functioning, Functioning-at-Risk and Not Functioning. Record values on Debit Template 1 (Table 11.5).
6. Provide justification for the selection of function-based parameters and measurement methods in Debit Template 2 (Table 11.6).
7. Develop overall scoring method (optional). Note: This document does not provide a scoring method that combines parameters, their measurement method and performance standard into an overall index of stream function. The document does show a method for calculating debits without this overall score; however, a function index might be a helpful tool for future use.
8. Determine overall baseline condition using scoring method developed in step 6, or refer to the debit calculation method shown in Debit Template 3 (Table 11.9).
9. Calculate overall debits for site. The formula used in this document is the debit ratio multiplied by the impacted stream length.

Steps to Develop Credits Using the Pyramid

1. Develop or use existing watershed management plans for each service area. Locate areas of water quality impairment and stream degradation. Determine the causes of impairment. Also locate areas of high water quality and healthy stream channels. Use the plan to identify stream reaches that can produce high-quality mitigation and, if possible, support the overall improvement of the watershed.
2. Based on the watershed management plan, determine the different types of techniques required to improve watershed health, e.g., stormwater BMPs, stream restoration, stream enhancement, riparian corridor preservation.
3. Perform a function-based assessment of the potential project reach.
4. Determine the restoration potential based on the assessment, watershed condition and constraints.
5. Establish function-based design goals and objectives.
6. Select key parameters from the Pyramid based on the assessment and restoration potential. Select parameters that are expected to change as a result of the restoration or enhancement activity.
7. Select the appropriate measurement method for each parameter, e.g., simple and rapid-based or more complex and time intensive. This selection should be based on the level of effort required to show functional lift.
8. Record the function-based parameter, measurement method and scores using the performance standards on Credit Template 1 (Table 11.6).
9. Provide justification for selecting the parameters and measurement methods on Credit Template 2 (Table 11.8).

10. Develop overall scoring method (optional). Note: This document does not provide a scoring method that combines parameters, their measurement method and performance standard into an overall index of stream function. The document does show a method for calculating credits without this overall score; however, a function index would be a helpful tool for future use.
11. Determine overall baseline condition using scoring method developed in step 10, or refer to the credit calculation method shown in Tables 11.10 and 11.11.
12. Calculate overall credits predicted for the site. The formula used in this document is the credit ratio multiplied by the restored or enhanced stream length.
13. Develop a monitoring plan to verify that the functional lift meets or exceeds the performance standards.

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EPA Stream and Wetland Mitigation Resources

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Stream Channel Reference Sites: An Illustrated Guide to Field Technique

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The Reference Reach — A Blueprint for Natural Channel Design

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Monitoring Wilderness Stream Ecosystems

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EPA Statistical Primer

www.epa.gov/bioindicators/statprimer/statistical_testing.html

Chapter 6

Watershed Assessment of River Stability and Sediment Supply (WARSSS)

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Chapter 7

FishXing Website
www.stream.fs.fed.us/fishxing/index.html

Chapter 8

SAMWin
chl.erdc.usace.army.mil/chl.aspx?p=s&a=SOFTWARE;2

2-D Models with Hydraulic and Sediment Transport Modeling Capabilities
RiverFLO-2D: www.flo-2d.com/products
Mike 21: www.mikebydhi.com

RIVERMorph Software Program
www.rivermorph.com

BAGS Program
www.stream.fs.fed.us/publications/bags.html

Technical Resources for Mitigation
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stream.fs.fed.us/publications/documentsStream.html

Assessing Proper Functioning Condition for Lotic Areas
[ftp.blm.gov/pub/nstc/techrefs/Final%20TR%201737-15.pdf](ftp://blm.gov/pub/nstc/techrefs/Final%20TR%201737-15.pdf)

NRCS Stream Visual Assessment Protocol (SVAP)
www.nrcs.usda.gov/technical/ecs/aquatic/svapfnl.pdf

Watershed Assessment of River Stability and Sediment Supply (WARSSS) Prediction Level Assessment (PLA) Index
water.epa.gov/scitech/datait/tools/warsss/pla_box07.cfm

References

US 301 Environmental Stewardship Study

Link: www.fws.gov/chesapeakebay/streampub.html

Sampling and Analyzing Surface and Subsurface Particles

www.stream.fs.fed.us/publications/documentsStream.html

Spreadsheet Tools and Instructions for Managing Pebble Count Data

www.stream.fs.fed.us/publications/software.html

Chapter 9

EPA Database of State Water Quality Standards

www.epa.gov/waterscience/standards/wqslibrary

EPA Water Quality Monitoring Information

www.epa.gov/storet

Chapter 10

Ecological Assessment Methods Database

assessmentmethods.nbio.gov

Landscape Connectivity

Circuitscape: www.circuitscape.org/Circuitscape/Welcome.html

Conefor Sensinode: www.conefor.org

Funconn: www.nrel.colostate.edu/projects/starmap/funconn_index.htm

Pathmatrix: cmpg.unibe.ch/software/pathmatrix

Chapter 11

Conducting Watershed Assessments

water.epa.gov/type/watersheds

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Appendices

A. STREAM FUNCTIONS PYRAMID

- A. Overview Graphic
- B. Functions & Parameters Graphic
- C. Parameter & Measurement Method Table
- D. Performance Standard Table

B. APPLICATION SCENARIOS

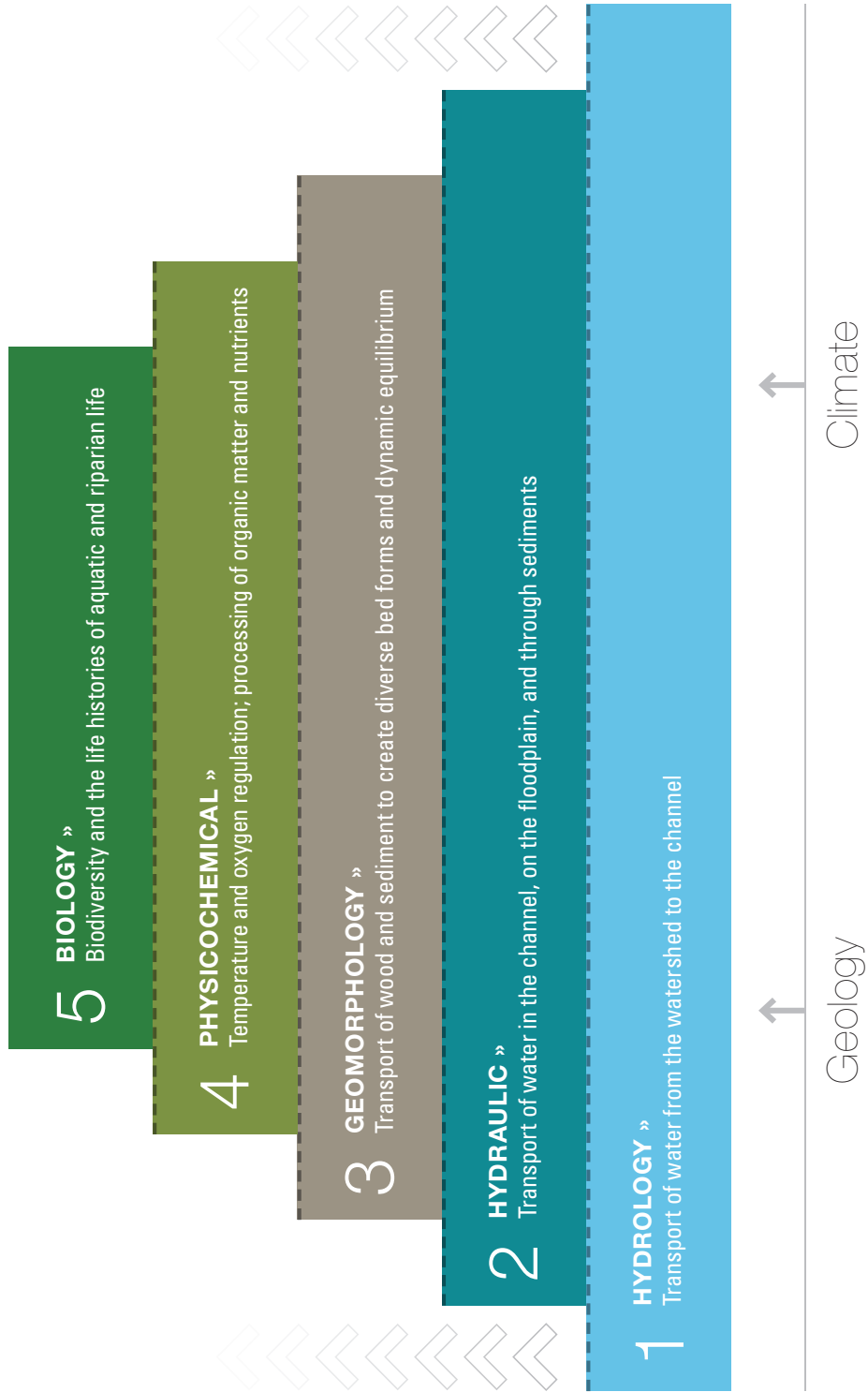
PERMITTED IMPACT SCENARIOS (DEBITS)

- 1. Culvert installations
- 2. Channelization and Bank Hardening
- 3. Surface Mining of High-Gradient Streams

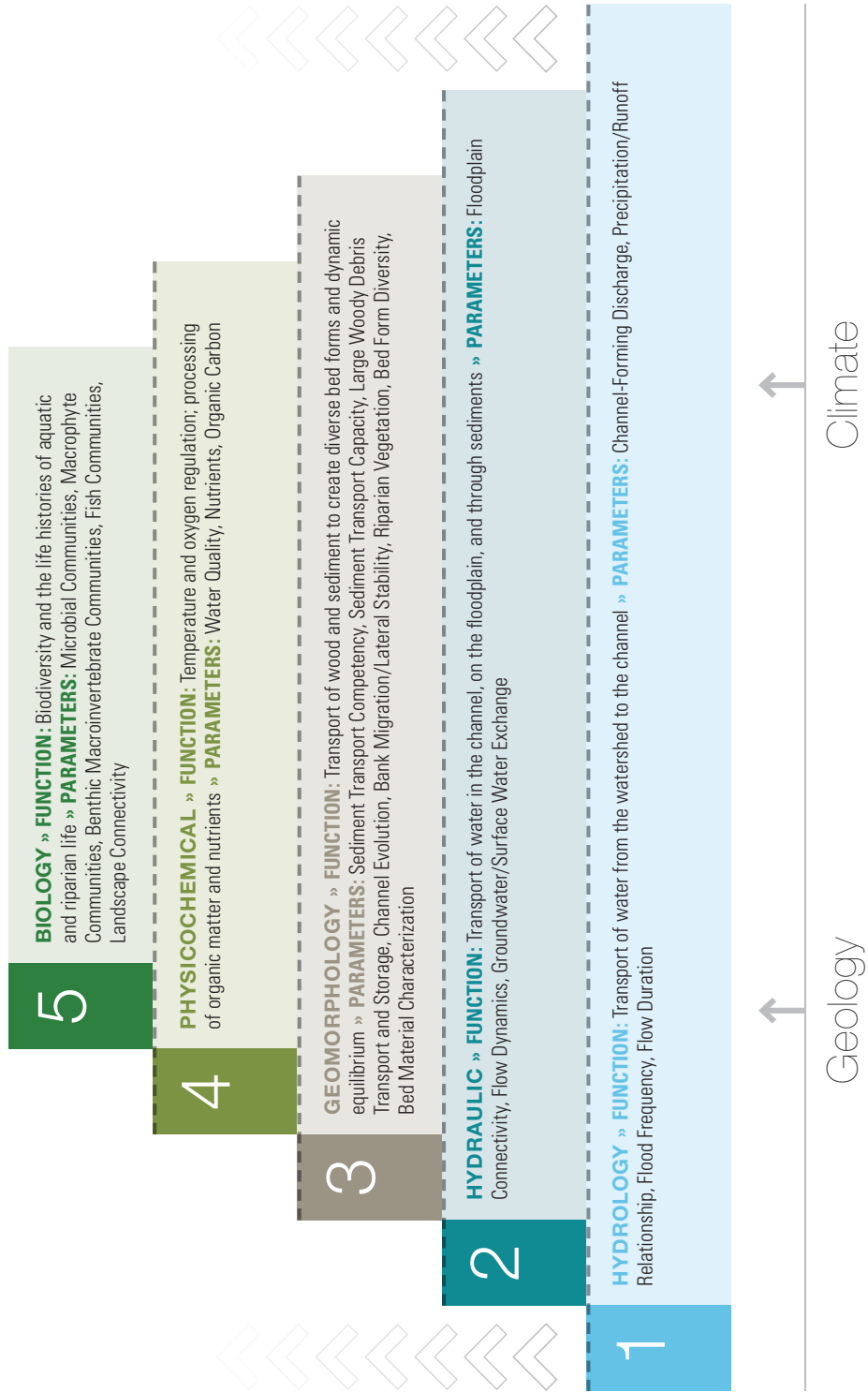
STREAM MITIGATION SCENARIOS (CREDITS)

- 1. Restoration of Incised Channels in Alluvial Valleys
- 2. Restoration of Stream Flow for Channels That Have Excessive Water Withdrawal
- 3. Salmonid Fish Passage and Habitat Restoration
- 4. Restoration of High-Gradient, Headwater Streams

APPENDIX A: STREAM FUNCTIONS PYRAMID
a. OVERVIEW GRAPHIC



APPENDIX A: STREAM FUNCTIONS PYRAMID
b. STREAM FUNCTIONS PYRAMID: FUNCTIONS & PARAMETERS



APPENDIX A: STREAM FUNCTIONS PYRAMID

c. PARAMETER & MEASUREMENT METHOD TABLE

(Details about the categories for the measurement methods, including type, level of effort, level of complexity, and direct/indirect assessment, are provided in Chapter 4. The parameters and measurement methods shown here are examples. Additional parameters and measurement methods can be added based on user needs. Refer to Chapter 4 for instructions on how to add parameters and measurement methods.)

HYDROLOGY					
PARAMETER	MEASUREMENT METHOD	TYPE	LEVEL OF EFFORT	LEVEL OF COMPLEXITY	ASSESSMENT OF PARAMETER
Channel-Forming Discharge	1. Regional Curves	1. Technique	1. Rapid to Intensive, dependent on curve	1. Simple to Complex, dependent on curve	1. Indirect
Precipitation/Runoff Relationship	1. Rational Method 2. HEC-HMS 3. USGS Regional Regression Equations	1. Tool 2. Tool 3. Technique	1. Rapid 2. Moderate 3. Rapid	1. Moderate 2. Complex 3. Moderate	1. Indirect 2. Indirect 3. Indirect
Flood Frequency	1. Bulletin 17b	1. Technique	1. Moderate	3. Complex	1. Direct
Flow Duration	1. Flow Duration Curve 2. Crest Gauge 3. Monitoring Devices 4. Rapid Indicators	1. Technique 2. Tool 3. Tool 4. Assessment approach	1. Moderate to Intensive, dependent on data source 2. Rapid 3. Intensive 4. Rapid	1. Moderate/Complex 2. Simple 3. Moderate 4. Simple	1. Direct/Indirect 2. Indirect 3. Direct 4. Indirect

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
 c. PARAMETER & MEASUREMENT METHOD TABLE

HYDRAULICS					
PARAMETER	MEASUREMENT METHOD	TYPE	LEVEL OF EFFORT	LEVEL OF COMPLEXITY	ASSESSMENT OF PARAMETER
Floodplain Connectivity	1. Bank Height Ratio	1. Technique	1. Rapid/Moderate	1. Simple/Moderate	1. Direct
	2. Entrenchment Ratio	2. Technique	2. Rapid/Moderate	2. Simple/Moderate	2. Direct
	3. Stage Versus Discharge	3. Technique	3. Intensive	3. Complex	3. Indirect
Flow Dynamics	1. Stream Velocity	1. Metric	1. Moderate/Intensive	1. Moderate/Complex	1. Direct
	2. Shear Stress	2. Metric	2. Moderate/Intensive	2. Moderate/Complex	2. Direct
	3. Stream Power	3. Metric	3. Moderate/Intensive	3. Moderate/Complex	3. Direct
Groundwater/Surface Water Exchange	1. Piezometers	1. Tool	1. Intensive	1. Complex	1. Direct
	2. Tracers	2. Tool	2. Intensive	2. Complex	2. Direct
	3. Seepage Meters	3. Tool	3. Intensive	3. Complex	3. Direct

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
c. PARAMETER & MEASUREMENT METHOD TABLE

GEOMORPHOLOGY					
PARAMETER	MEASUREMENT METHOD	TYPE	LEVEL OF EFFORT	LEVEL OF COMPLEXITY	ASSESSMENT OF PARAMETER
Sediment Transport Competency	1. Shear Stress Curve	1. Technique	1. Rapid to Intensive, dependent on curve availability	1. Simple to Complex, dependent on curve availability	1. Indirect
	2. Required Depth and Slope	2. Technique/ Tool	2. Moderate	2. Moderate	2. Indirect
	3. Spreadsheets and Computer Models	3. Tool	3. Moderate/ Intensive	3. Moderate/ Complex	3. Indirect
Sediment Transport Capacity	1. Computer Models	1. Tool	1. Moderate/ Intensive	1. Moderate/ Complex	1. Indirect
	2. FLOWSED and POWERSED	2. Tool	2. Intensive	2. Complex	2. Indirect
	3. BAGS	3. Tool	3. Rapid/Moderate	3. Simple/Moderate	3. Indirect
Large Woody Debris Transport and Storage	1. Wohl LWD Assessment	1. Assessment approach	1. Rapid/Moderate	1. Simple/Moderate	1. Direct for storage and Indirect for transport
	2. Large Woody Debris Index	2. Assessment approach	2. Moderate	2. Moderate	2. Direct for storage and Indirect for transport

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
c. PARAMETER & MEASUREMENT METHOD TABLE

GEOMORPHOLOGY					
PARAMETER	MEASUREMENT METHOD	TYPE	LEVEL OF EFFORT	LEVEL OF COMPLEXITY	ASSESSMENT OF PARAMETER
Channel Evolution	<ol style="list-style-type: none"> 1. Simon Channel Evolution Model 2. Rosgen Stream Type Succession Scenarios 	<ol style="list-style-type: none"> 1. Technique 2. Technique 	<ol style="list-style-type: none"> 1. Rapid/Moderate 2. Moderate 	<ol style="list-style-type: none"> 1. Simple/Moderate 2. Moderate 	<ol style="list-style-type: none"> 1. Indirect 2. Indirect
Bank Migration/ Lateral Stability	<ol style="list-style-type: none"> 1. Meander Width Ratio 2. BEHI / NBS 3. Bank Pins 4. Bank Profiles 5. Cross-Sectional Surveys 6. Bank Stability and Toe Erosion Model 	<ol style="list-style-type: none"> 1. Technique 2. Technique/ Tool 3. Technique 4. Technique 5. Technique 6. Tool 	<ol style="list-style-type: none"> 1. Rapid/Moderate 2. Moderate/ Intensive 3. Intensive 4. Intensive 5. Intensive 6. Intensive 	<ol style="list-style-type: none"> 1. Simple 2. Moderate 3. Moderate 4. Moderate 5. Moderate 6. Complex 	<ol style="list-style-type: none"> 1. Indirect 2. Indirect 3. Direct 4. Direct 5. Direct 6. Indirect

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
 c. PARAMETER & MEASUREMENT METHOD TABLE

GEOMORPHOLOGY					
PARAMETER	MEASUREMENT METHOD	TYPE	LEVEL OF EFFORT	LEVEL OF COMPLEXITY	ASSESSMENT OF PARAMETER
Riparian Vegetation	1. Buffer Width 2. Buffer Density 3. Buffer Composition 4. Buffer Age 5. Buffer Growth 6. Canopy Density 7. Proper Functioning Condition (PFC) 8. NRCS Visual Assessment Protocol 9. Rapid Bioassessment Protocol 10. Watershed Assessment of River Stability and Sediment Supply (WARSSS) 11. USFWS Stream Assessment Ranking Protocol (SAR)	1. Technique 2. Technique 3. Technique 4. Technique 5. Technique 6. Technique 7. Assessment approach 8. Assessment approach 9. Assessment approach 10. Assessment approach 11. Assessment approach	1. Rapid 2. Moderate/Intensive 3. Moderate/Intensive 4. Intensive 5. Intensive 6. Moderate/Intensive 7. Rapid 8. Rapid 9. Rapid 10. Intensive 11. Rapid	1. Simple 2. Moderate 3. Moderate 4. Moderate 5. Moderate 6. Moderate 7. Simple 8. Simple 9. Simple 10. Complex 11. Simple	1. Indirect 2. Direct 3. Direct 4. Direct 5. Direct 6. Direct 7. Indirect 8. Indirect 9. Indirect 10. Indirect 11. Indirect

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
c. PARAMETER & MEASUREMENT METHOD TABLE

GEOMORPHOLOGY					
PARAMETER	MEASUREMENT METHOD	TYPE	LEVEL OF EFFORT	LEVEL OF COMPLEXITY	ASSESSMENT OF PARAMETER
Bed Form Diversity	1. Percent Riffle and Pool	1. Technique	1. Rapid/Moderate	1. Moderate	1. Direct
	2. Facet Slope	2. Technique	2. Moderate	2. Moderate	2. Indirect
	3. Pool-to-Pool Spacing	3. Technique	3. Rapid/Moderate	3. Moderate	3. Indirect
	4. Depth Variability	4. Technique	4. Moderate	4. Moderate	4. Direct
Bed Material Characterization	1. Size Class Pebble Count Analyzer	1. Tool	1. Moderate/Intensive	1. Moderate	1. Direct
	2. Riffle Stability Index (RSI)	2. Technique	2. Moderate/Intensive	2. Moderate	2. Indirect
PHYSICOCHEMICAL					
PARAMETER	MEASUREMENT METHOD	TYPE	LEVEL OF EFFORT	LEVEL OF COMPLEXITY	ASSESSMENT OF PARAMETER
Water Quality	1. Temperature	1. Metric	1. Rapid/Intensive	1. Simple/Moderate	1. Direct
	2. Dissolved Oxygen	2. Metric	2. Rapid/Intensive	2. Simple/Moderate	2. Direct
	3. Conductivity	3. Metric	3. Rapid/Intensive	3. Simple/Moderate	3. Direct
	4. pH	4. Metric	4. Rapid/Intensive	4. Simple/Moderate	4. Direct
	5. Turbidity	5. Metric	5. Rapid/Intensive	5. Simple/Moderate	5. Direct
Nutrients	1. Field test kits using reagents reactions	1. Technique	1. Rapid for screening	1. Simple	1. Direct
	2. Laboratory analysis	2. Technique	2. Intensive	2. Complex	2. Direct

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
c. PARAMETER & MEASUREMENT METHOD TABLE

BIOLOGY					
PARAMETER	MEASUREMENT METHOD	TYPE	LEVEL OF EFFORT	LEVEL OF COMPLEXITY	ASSESSMENT OF PARAMETER
Organic Carbon	1. Laboratory analysis	1. Technique	1. Intensive	1. Complex	1. Direct
Microbial Communities	1. Taxonomic Methods	1. Technique	1. Intensive	1. Complex	1. Direct
	2. Non-Taxonomic Methods	2. Technique	2. Intensive	2. Complex	2. Direct
	3. Biological Indices	3. Assessment approach	3. Moderate/Intensive	3. Moderate/Complex	3. Indirect
Macrophyte Communities	1. Taxonomic Methods	1. Technique	1. Intensive	1. Complex	1. Direct
	2. Non-Taxonomic Methods	2. Technique	2. Intensive	2. Complex	2. Direct
	3. Biological Indices	3. Assessment approach	3. Moderate/Intensive	3. Moderate/Complex	3. Indirect
Benthic Macroinvertebrate Communities	1. Taxonomic Methods	1. Technique	1. Intensive	1. Complex	1. Direct
	2. Non-Taxonomic Methods	2. Technique	2. Intensive	2. Complex	2. Direct
	3. Biological Indices	3. Assessment approach	3. Moderate/Intensive	3. Moderate/Complex	3. Indirect
Fish Communities	1. Taxonomic Methods	1. Technique	1. Intensive	1. Complex	1. Direct
	2. Non-Taxonomic Methods	2. Technique	2. Intensive	2. Complex	2. Direct
	3. Biological Indices	3. Assessment approach	3. Moderate/Intensive	3. Moderate/Complex	3. Indirect
Landscape Connectivity	1. Spatial Analysis	1. Technique	1. Intensive	1. Complex	1. Direct
	2. Species Tracking	2. Technique	2. Intensive	2. Complex	2. Direct
	3. Habitat Models	3. Assessment approach	3. Moderate/Intensive	3. Moderate/Complex	3. Indirect

APPENDIX A: STREAM FUNCTIONS PYRAMID

d. PERFORMANCE STANDARDS TABLE

Notes:

1. Since there are no Hydrology Performance Standards, there is not a Hydrology Summary Table
2. Many of the performance standard values, especially the dimensionless ratios, should be considered as examples that can be modified based on regional differences in reference conditions.
3. Great care should be taken when selecting measurement methods and performance standards. Refer to Chapters 6-10 and the associated references before selecting measurement methods and performance standards.

PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD			SOURCE
		FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING	
Floodplain Connectivity	Bank Height Ratio (BHR)	1.0 to 1.2	1.3 to 1.5	> 1.5	Rosgen, 2001 (proceedings) and 1994 (book)
	Entrenchment Ratio (ER) for C and E Stream Types	> 2.2	2.0 to 2.2	< 2.0	
	Entrenchment Ratio (ER) for B and Bc Stream Types	> 1.4	1.2 to 1.4	< 1.2	
Flow Dynamics	Dimensionless rating curve	Project site $Q/O_{b\text{kf}}$ plots on the curve	Project site $Q/O_{b\text{kf}}$ plots above the curve	Project site $Q/O_{b\text{kf}}$ of 2.0 plots above 1.6 for $d_{db\text{kf}}$	Dunne and Leopold 1978 (book)
	Bankfull Velocity for C and E stream types (ft/s)	3 to 6	6 to 7	> 7	Dunne and Leopold 1978 (book)
	Bankfull Velocity for Cc (ft/s)	< 3	3 to 4	> 5	
	Bankfull Velocity for B stream types (ft/s)	4 to 6	6 to 7	> 7	

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
d. PERFORMANCE STANDARDS TABLE

GEOMORPHOLOGY				PERFORMANCE STANDARD		SOURCE
PARAMETER	MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING		
Large Woody Debris	Large Woody Debris Index (LWDI)	LWDI of project reach equals LWDI of reference reach.	LWDI of project reach does not equal LWDI of reference reach, but is trending in that direction.	LWDI of project reach does not equal LWDI of reference reach and is not trending in that direction.	Davis et al., 2001 (USFS Technical Report)	
Rosgen's Stream Type Succession Scenarios						
Channel Evolution	1. E→C→Gc→F→C→E	E, C	C→Gc and F→C	Gc, F	Rosgen 2010 (conference workshop)	
	2. C→D→C	C	C→D and D→C	D		
	3. C→D→Gc→F→C	C	C→D and F→C	D, Gc, F		
	4. C→G→F→Bc	C, Bc	C→G and F→Bc	G, F		
	5. E→Gc→F→C→E	E, C	E→Gc and F→C	Gc, F		
	6. B→G→Fb→B	B	B→G and Fb→B	G, Fb		
	7. Eb→G→B	Eb, B	Eb→G and G→B	G		
	8. C→G→F→D→C	C	C→G and D→C	G, F, D		
	9. C→G→F→C	C	C→G and F→C	G, F		
	10. E→A→G→F→C→E	E	E→A and F→C	A, G, F		
	11. C→F→C→F→C	First and last C	C→F	F		
	12. C→G→F→C→C→C	First and last C	C→G and C→C	G, F, Fourth C		
Simon Channel Evolution Model Stages						
1. Sinuous, pre-modified	✓				Simon 1989 (journal)	
2. Channelized				✓		
3. Degradation				✓		

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
d. PERFORMANCE STANDARDS TABLE

GEOMORPHOLOGY		PERFORMANCE STANDARD			SOURCE
PARAMETER	MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING	
Channel Evolution	4. Degradation and widening			✓	Simon 1989 (journal)
	5. Aggradation and widening		✓ *	✓	
	6. Quasi-equilibrium	✓			
* Only late Stage 5 of the Simon model, where the stream has begun to construct a new floodplain at a lower elevation, is considered to be Functioning-at-Risk.					
Bank Migration/ Lateral Stability	Meander Width Ratio for C and E stream types	≥ 3.5 (based on reference reach surveys)	3.0 to 3.5 as long as sinuosity is ≥ 1.2	< than 3.0	
	Lateral Erosion rate – Low BEHI Curve	Very low to Moderate NBS	Moderate to Very High NBS	Extreme NBS	
	Lateral Erosion rate – Moderate BEHI Curve	Very low to Low NBS	Low to High NBS	High to Extreme NBS	
	Lateral Erosion rate – High and Very High BEHI Curve	N/A	Low to Moderate NBS	Moderate to Extreme NBS	Rosgen, 2001 (proceedings) and 2006 (book)
	Lateral Erosion rate – Extreme BEHI Curve	N/A	Low NBS	Low to Extreme NBS	
	Lateral Erosion Rate (Bank Pins and Bank Profiles)	Erosion rate is similar to reference reach values, generally < 0.1 ft/yr	0.1 to 0.5 ft/yr	> 0.5 ft/yr	

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
d. PERFORMANCE STANDARDS TABLE

GEOMORPHOLOGY		PERFORMANCE STANDARD			SOURCE
PARAMETER	MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING	
Bank Migration/ Lateral Stability	Lateral Erosion Rate for C4 streams (Cross Sections)	$\frac{w/Dproj}{w/Dref} = 1.0$ to 1.2	$\frac{w/Dproj}{w/Dref} = 1.2$ to 1.4	$\frac{w/Dproj}{w/Dref} = > 1.4$	Simon and Langendoen 2006 (proceedings)
	Bank Stability and Toe Erosion Model	$F_s > 1.3$	$1.0 < F_s < 1.3$	$F_s < 1.0$	
	Average Buffer Width (Ft) C and E Stream Types	> 150	30 to 150	< 30	Meyer et al., 2005 (journal)
	Buffer Width (Ft) from Meander Belt Width for C and E Stream Types	Meander belt width at least 3.5 times the bankfull width plus ≥ 15 feet from outside of meander bend	Meander belt width at least 3.5 times the bankfull width plus 10 to 15 feet from outside of meander bend	Meander belt width ≤ 3.5 times the bankfull width and/or ≤ 10 feet from outside of meander bend	Proposed as an option in this document
Riparian Vegetation	Buffer Density (Stems/ac)	Parameter is similar to reference reach condition, with no additional maintenance required.	Parameter deviates from reference reach condition, limiting function, but the potential exists for full functionality over time or with moderate additional maintenance.	Significantly less functional than reference condition; little or no potential to improve without significant restoration effort.	
	Buffer Age				
	Buffer Composition				
	Buffer Growth				
	Canopy Density				
	Proper Functioning Condition (PFC)	Proper Functioning Condition	Functional At-Risk	Nonfunctional	Prichard et al., 1998 (USFS Technical Report)

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
d. PERFORMANCE STANDARDS TABLE

GEOMORPHOLOGY		PERFORMANCE STANDARD			SOURCE
		MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	
Riparian Vegetation	NRCS Rapid Visual Assessment Protocol	Natural vegetation extends at least one to two active channel widths on each side, or if less than one width, covers entire floodplain. (8-10)	Natural vegetation extends at least one-half to one-third active channel widths on each side, or filtering function moderately compromised. (3-5)	Natural vegetation less than one-third active channel widths on each side, or lack of regeneration, or filtering function severely compromised. (1)	NRCS Technical Report
	The EPA Rapid Bioassessment Protocol (RBP)	Width of riparian zone > 18 meters; humans have not impacted zone. (Optimal, 9-10)	Width of riparian zone 12-18 meters; human activities have minimally impacted zone. (Sub-Optimal, 6-8)	Width of riparian zone < 6 meters; little or no riparian vegetation due to human activity. (Poor, 0-2)	Barbour et al., 1999 (EPA Technical Report)

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
d. PERFORMANCE STANDARDS TABLE

GEOMORPHOLOGY		PERFORMANCE STANDARD			SOURCE
PARAMETER	MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING	
Riparian Vegetation	USFWS Stream Assessment Ranking (SAR)	All three zones of vegetation exist; runoff is primarily sheet flow; hillslopes < 10%; hillslopes > 200 ft from stream; ponding or wetland areas and litter or debris jams are well represented.	Only Zone 2 of vegetation is well represented; runoff is equally sheet and concentrated flow (moderate gully and rill erosion); hillslopes 20-40%; hillslopes 50-100 ft from stream; ponding or wetland areas and litter or debris jams are minimally represented.	No zones of vegetation well represented; runoff is primarily concentrated flow (extensive gully and rill erosion); hillslopes > 40%; hillslopes < 50 ft from stream; ponding or wetland areas and litter or debris jams are not well represented or completely absent.	Allen et al., 1999

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
d. PERFORMANCE STANDARDS TABLE

GEOMORPHOLOGY				PERFORMANCE STANDARD		SOURCE
PARAMETER	MEASUREMENT METHOD	FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING		
Perennial Streams in Alluvial Valleys (C, E)						
Bed Form Diversity	Percent Riffle	60 to 70	70 to 80	> 80	Professional Judgement	
				40 to 60		
				3 to 4 and 5 to 7		
Pool-to-Pool Spacing Ratio (Watersheds < 10 mi ²)	Pool-to-Pool Spacing Ratio (Watersheds > 10 mi ²)	4 to 5	3 to 4 and 5 to 7	< 3.0 and > 7	Leopold 1994, Gregory et al., 1994 journal, Whittake 1987 (book), Chin 1989 (journal), and Grant 1990 (journal)	
Bed Form Diversity	Pool-to-Pool Spacing Ratio (Watersheds > 10 mi ²)	5 to 7	3.5 to 5 and 7 to 8	< 3.5 and > 8	Leopold 1994, Gregory et al., 1994 journal, Whittake 1987 (book), Chin 1989 (journal), and Grant 1990 (journal)	
Bed Form Diversity	Depth Variability – Gravel Bed Streams (Pool Max Depth Ratio)	> 1.5	1.2 to 1.5	< 1.2	Rosgen 2006 (book)	
Bed Form Diversity	Depth Variability – Sand Bed Streams (Pool Max Depth Ratio)	> 1.2	1.1 to 1.2	< 1.1		

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
d. PERFORMANCE STANDARDS TABLE

GEOMORPHOLOGY					
PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD			SOURCE
		FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING	
Bed Material Characterization	Bed material composition	Project Reach is not statistically different than reference reach.	N/A	Project Reach is statistically different (finer) than reference reach.	Bevenger and King, 2005 (USFS Technical Report)
Moderate Gradient Perennial Streams in Colluvial Valleys					
Bed Form Diversity	Pool-to-Pool Spacing Ratio (Slope between 3 and 5%)	2 to 4	4 to 6	>6	Leopold 1994, Gregory et al., 1994 journal), Whittake 1987 (book), Chin 1989 (journal), and Grant 1990 (journal)
	Depth Variability (Pool Max Depth Ratio)	> 1.5	1.2 to 1.5	< 1.2	Leopold 1994, Gregory et al., 1994 journal), Whittake 1987 (book), Chin 1989 (journal), and Grant 1990 (journal)

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
d. PERFORMANCE STANDARDS TABLE

PHYSICOCHEMICAL					SOURCE
PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD			NOT FUNCTIONING
		FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING	
Water Quality	DO Temperature Turbidity	Meets water quality standards for designated use	Meets water quality standards for designated use	Does not meet water quality standards	Performance standards have not been developed for these parameters and are therefore based on reference reach comparisons and state water quality databases.
		Representative of reference reach and meets species requirements	Is not representative of reference reach and does not support species requirements	Is not representative of the reference reach Does not support species requirements	
Water Quality	pH Conductivity Turbidity	Representative of values measured in reference reach	Does not have representative reference reach values or Does not support designated use or species requirements	Statistically different than reference reach and does not support aquatic life	

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
d. PERFORMANCE STANDARDS TABLE

PHYSICOCHEMICAL					SOURCE
PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD			NOT FUNCTIONING
		FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING	
Nutrients	Field test kits using reagents reactions	Meets water quality standards for designated use	Meets water quality standards for designated use, but is not representative of reference reach	Does not meet water quality standards	Performance standards have not been developed for these parameters and are therefore based on reference reach comparisons and state water quality databases.
		Representative of reference reach	Does not cause eutrophication	Is not representative of the reference reach	
	Laboratory analysis	Does not cause eutrophication		Causes eutrophication	
Organic Carbon	Laboratory analysis	Meet reference reach OC concentrations	Do not meet reference reach OC concentrations	Do not meet reference reach OC concentrations and are below a predetermined threshold determined for adequate organic processing	Performance standards have not been developed for these parameters and are therefore based on reference reach comparisons and state water quality databases.

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
d. PERFORMANCE STANDARDS TABLE

BIOLOGY					
PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD		SOURCE	
		FUNCTIONING	FUNCTIONING-AT-RISK / NOT FUNCTIONING		
Microbial Communities	Periphyton Index of Biological Integrity (PIBI)	≥ 72	61-71	Hill et al., 2000 (Journal)	
	Biological Indices				
Macrophytes	Mean Trophic Rank (MTR)	> 65	25-65	Holmes et al., 1999 (Technical Report)	
	Reference Index (RI)	-50 to 100	-70 to -50	Meilenger, 2005 (Journal)	
	Biological Indices				
Macroinvertebrate Communities	Family-Level Biotic Index (FBI) Ranges	0.00-4.25	4.26-5.75	Hilsenhoff, 1988 (Journal)	
	WVSCI Ranges	Excellent to Very Good	Good to Fair	Fairly Poor to Very Poor	
		68-100	45-61	0-45	Gerritsen et al., 2000; WVDEP
		Very Good to Good	Gray Area to Fair	Poor to Very Poor	
		61-100	40-60	0-40	Burton J. and J. Gerritsen, 2003
		Exceptional to Similar to Ref.	Impaired Tier 1	Impaired Tier1 & 2	
	SOS Multimetric Index	7-12	N/A	0-6	Engel and Voshell, 2002
		Acceptable		Unacceptable	

APPENDIX A: STREAM FUNCTIONS PYRAMID (CONT.)
d. PERFORMANCE STANDARDS TABLE

BIOLOGY					
PARAMETER	MEASUREMENT METHOD	PERFORMANCE STANDARD			SOURCE
		FUNCTIONING	FUNCTIONING-AT-RISK	NOT FUNCTIONING	
Fish Communities	Biological Indices				
	Mid-Atlantic Highlands IBI	IBI > 72	IBI = 56 to 71	IBI < 56	McCormick et al., 2001
	Mid-Western Fish Community IBI	Good to Excellent 48-60	Fair 40-44	Poor 0-34	Karr et al., 1986
		Good to Excellent	Fair	Poor to No Fish	

APPENDIX B: APPLICATION SCENARIOS

APPLICATION: STREAM DEBIT AND CREDIT DETERMINATION SCENARIOS

The purpose of Appendix B is to illustrate how the Stream Functions Pyramid and its associated measurement methods and performance standards can be used as an aid in developing debit and credit determination methods for a variety of impact and restoration scenarios. A description of the debit and credit determination method is provided in Chapter 11, and the examples are shown below. These examples are not from actual permit applications or restoration projects. Rather, they are generic, yet realistic scenarios that are used to demonstrate how the debit and credit templates can be applied to a range of scenarios. They are broad based and lack the specificity needed for an actual debit/credit determination method. The purpose of these examples is to generate ideas about how function-based parameters, measurement methods and performance standards can be used in stream mitigation Standard Operating Procedures (SOPs).

The impact or debit scenarios include:

1. Culvert installations;
2. Channelization and bank hardening; and
3. Surface mining of high gradient streams.

The restoration or credit scenarios include:

1. Restoration of incised streams;
2. Restoration of stream flow for channels that have excessive water withdrawal;
3. Salmonid fish passage and habitat restoration; and
4. Restoration of high gradient, headwater streams.

Permitted Impact Scenarios (Debits)

Scenario 1: Culvert Installations

The following is a typical example of a new rural road and culvert installation with a stable, healthy upstream watershed. The post-impact condition is based on typical results of culvert installation and can be modified based on actual results or more quantitative assessments. Table B1A shows the typical impacts associated with culvert installations. Table B2a provides a narrative to support the data shown in table B1A, including the rationale for selecting the parameters. Table B3a shows how debits could be calculated for the permitted impact caused by the culvert installation.

Example Scenario

A permit application has been submitted to install a 60-inch diameter culvert for 500 feet of stream length. This is a standard culvert installation and the impact is predicted to extend 200 feet downstream and 100 feet upstream of the culvert for a total impact length of 800 feet. Upstream and downstream impacts are included based on hydraulic modeling analysis and impacts associated with past installations in the region. If other

culvert installation approaches, e.g., floodplain culverts, are used, the impact length could be reduced to the pipe length.

The upstream watershed has a drainage area of two square miles with a mix of agricultural and suburban land uses. The rainfall/runoff relationship is moderately stable and is not expected to significantly change in the near future. The channel is mildly incised with a Bank Height Ratio of 1.1; however, the channel was straightened in the past, creating a sinuosity of near 1.0. This has resulted in poor bed form diversity and a riffle-pool percentage of 90:10 and pool depth ratios less than 1.5. A vegetative buffer of 50 feet on each side of the channel is providing bank stability and cover, and is an effective filter from adjacent land uses. As a result, the basic water quality is representative of reference reach streams in the region; however, macroinvertebrate and fish communities do not reflect reference conditions due to poor habitat.

Degradation is expected to occur for 200 feet downstream of the culvert. The Bank Height Ratio will increase to 2.5 and the entrenchment ratio will decrease to 1.2. Bed form diversity will remain poor and riffle dominated with a few shallow pools. Some trees along the streambank are predicted to fall due to the high streambanks and large volume of water now carried by the channel. Lateral erosion is predicted to be moderate.

Aggradation is expected to occur for 100 feet upstream of the culvert. The Bank Height Ratio decreases to 1.0 and sand covers the riffles and fills the pools creating a plane bed. The vegetation remains intact.

Referring to Table B1A, the pre-disturbance condition is a mix of Functioning, Functioning-at-Risk, and Not Functioning scores for Levels 2-5. Therefore, the Functionality Before Impact Category (Table BD1c) is **Moderate**. The post-disturbance condition, shown on Table BD1a, indicates that most parameters will be Not Functioning through the culvert and downstream. Impacts are less upstream of the culvert with some parameters remaining as Functioning and a few becoming Not Functioning. Therefore, the culvert and downstream section will be evaluated together as a 700 foot impact with **High Functional loss**. The 100-foot upstream section has mostly Functioning scores with a few Not Functioning scores and is assessed with a **Moderate Functional Loss**.

Scenario 2: Channelization and Bank Hardening

A permit application has been submitted to straighten and “improve” 1,000 linear feet of stream channel. The “improvement” includes dredging (lowering) and widening the channel to carry the 100-year discharge. The bed material will remain with natural gravel, but the streambanks will be graded to a 2:1 slope and protected with rip rap. Backyard lawns will extend outward from the top of the streambank.

The existing channel is moderately incised with a bank height ratio of 1.4. The channel is located in an alluvial valley and has a sinuosity of 1.3 and alternating riffles (70%) and pools (30%). The pools are generally 2 to 2.5 times deeper than the riffles. A 10-foot riparian buffer of mature hardwood trees is present on both sides of the channel, providing bank stability and cover over the channel.

TABLE BD1a DEBIT TEMPLATE 1: FUNCTIONAL LOSS DETERMINATION

Table BD1a is completed by interpreting the information from the paragraph above and selecting parameters, measurement methods and performance standards from Appendix A.

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-DISTURBANCE CONDITION		PREDICTED POST-DISTURBANCE CONDITION	
			VALUE	RATING	VALUE	RATING
1 – Hydrology	Not affected					
	Floodplain Connectivity	Bank Height Ratio	1.1	Functioning	1.0 – Upstream 2.5 – Downstream	Functioning upstream; Not Functioning through culvert and downstream
2 – Hydraulics		Entrenchment Ratio	> 2.2	Functioning	> 2.2 – Upstream 1.2 – Downstream	Functioning upstream; Not Functioning through culvert and downstream
		Rosgen	C or E	Functioning	C or E upstream G downstream	Functioning upstream; Not Functioning through culvert and downstream
3 – Geomorphology	Lateral Stability	BEHI/NBS	Low	Functioning	Low – Upstream Moderate to high downstream	Functioning upstream; Not Functioning Downstream
	Riparian Vegetation	Rapid Bioassessment Protocol	8	Functioning-at-Risk	0 through culvert 8 – Upstream 6 – Downstream	Functioning upstream; Not Functioning through culvert and downstream
	Bed Form Diversity	Percent Riffle & Pool	90:10	Not Functioning	90:10 to 100% riffle	Not Functioning
		Pool Max Depth Ratio	< 1.5	Functioning-at-Risk	< 1.2	Not Functioning
		Bed Material Characterization	Size Class Pebble Count Analyzer	Same as upstream	Finer – upstream of culvert Same – Downstream	Not Functioning upstream and culvert Functioning Downstream

TABLE BD1a DEBIT TEMPLATE 1: FUNCTIONAL LOSS DETERMINATION (CONT.)

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-DISTURBANCE CONDITION		PREDICTED POST-DISTURBANCE CONDITION	
			VALUE	RATING	VALUE	RATING
4 – Physicochemical	Water Quality	Dissolved Oxygen (mg/l)	Same as upstream	Functioning	Lower than upstream	Not Functioning
	Macroinvertebrate Communities	Hilsenhoff Biotic Index (HBI)	6	Not Functioning	8	Not Functioning
5 – Biology	Fish Communities	Index of Biotic Integrity (IBI)	Poor	Not Functioning	Poor	Not Functioning

TABLE BD1b DEBIT TEMPLATE 2: PRE- AND POST-DISTURBANCE CONDITIONS AND RATIONALE

Describe Pre- and Post-Disturbance Condition and Rationale for Selecting Parameters

Hydrology – The watershed hydrology is stable and is not expected to change. Therefore, Hydrology parameters were not selected.

Hydraulics – The existing channel is mildly incised and has access to a wide alluvial floodplain, i.e., there is floodplain connectivity. In this example, the culvert will likely cause channel incision downstream of the culvert, and bank height ratios are likely to increase, causing a Not Functioning score. The culvert will provide grade control for the upstream channel and the bank height ratio may decrease because of aggradation.

Geomorphology – The existing channel is a stable Rosgen C or E stream type that has been straightened, i.e., in this case, a low sinuosity will not change the stream type. The streambanks are stable with minimal bank erosion. There is a riparian buffer of bottomland hardwood trees. The upstream watershed and stream reach is stable. The bed form is riffle dominated due to past channelization. The channel is predicted to remain a C stream type upstream and change to a Gc downstream. Lateral stability will decrease from Functioning to Not Functioning due to channel incision downstream of the culvert. The riparian vegetation is totally removed along the length of the culvert and, therefore, would score Not Functioning. However, the riparian buffer remains intact upstream of the culvert (Functioning). Bed form diversity is altered upstream and downstream of the culvert. Upstream of the culvert, pools fill in with sediment during aggradation. This decreases depth variability and shifts the substrate distribution curve towards sand size material, which in this case is finer than the upstream riffle material. Channel incision downstream, along with a decrease in Width/Depth ratio, causes the riffles to erode and drain the pools. This creates a plane bed form.

Physicochemical – Since the upstream watershed is stable and there is an existing bottomland forest, the basic water quality parameters are Functioning. The only water quality parameter selected to measure is Dissolved Oxygen (DO). The other parameters will likely not be impacted to the point where their functioning score would be significantly different from the upstream reference reach or violate water quality standards. Due to the reduction in depth variability and bed form diversity, DO may shift from Functioning to Not Functioning.

Biology – Due to poor bed form diversity and riparian vegetation prior to culvert installation, macroinvertebrate and fish communities are Not Functioning before and after the disturbance.

Appendix B: Application Scenarios, Culvert Installations

TABLE BD1c DEBIT TEMPLATE 3: DEBIT REQUIREMENTS

PRE-DISTURBANCE CONDITION	POST-DISTURBANCE CONDITION			
	NO FUNCTIONAL LOSS	LOW TO MODERATE FUNCTIONAL LOSS	MODERATE TO HIGH FUNCTIONAL LOSS	DEBIT ADJUSTMENT (+/-)
Low (Mix of Functioning-at-Risk and Not Functioning)	(Post-disturbance condition matches pre-disturbance condition)	Greater number of Functioning-at-Risk and Not Functioning Scores	Mostly Not-Functioning Scores	0.1
		1.1 to 1.2	1.2 to 1.3	
Moderate (Mix of Functioning, Functioning-at-Risk, and Not Functioning)	No mitigation required	Loss of Functioning scores and/or greater number of Functioning-at-Risk and Not Functioning Scores	Mix of Functioning-at-Risk and Not Functioning Scores	0.1
		1.3 to 1.5	1.5 to 1.7	
High (Functioning)		Mix of Functioning, Functioning-at-Risk, and Not Functioning Scores	Mix of Functioning-at-Risk and Not Functioning Scores	0.2
		1.7 to 1.9	2.0	

The overall calculations are shown below. The total debits calculated for this impact is 1260.

REACH	LENGTH (FT)	CATEGORY FROM TABLE B3	DEBIT RATIO (DEBITS/FT)	TOTAL
Upstream	100	Moderate / Moderate	1.4	100 X 1.4 = 140
Culvert and Downstream	700	Moderate / High	1.6	700 X 1.6 = 1120
Total	800			1120 + 140 = 1260

The upstream watershed is rural to suburban and moderately stable without major point sources of pollution. Nonpoint source pollution includes runoff from existing yards, homes, and secondary roads. These land uses have not caused significant increases to the rainfall/runoff relationship. A healthy community of benthic organisms and small native fish lives in the stream. Temperature and DO levels are representative of reference streams.

TABLE BD2a DEBIT TEMPLATE 1: FUNCTIONAL LOSS DETERMINATION

Table BD2a is completed by interpreting the information from the paragraph above and selecting parameters, measurement methods and performance standards from Appendix A.

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-DISTURBANCE CONDITION		PREDICTED POST-DISTURBANCE CONDITION	
			VALUE	RATING	VALUE	RATING
1 – Hydrology	Not affected					
	Floodplain Connectivity	Bank Height Ratio	1.4	Functioning-at-Risk	> 2	Not Functioning
2 – Hydraulics	Riparian Vegetation	Average buffer width	10	Not Functioning	0	Not Functioning
	Bed Form Diversity	Percent Riffle & Pool	70:30	Functioning	90:10 to 100% riffle	Not Functioning
		Pool Max Depth Ratio	2 – 2.5	Functioning	< 1.2	Not Functioning
4 – Physicochemical	Water Quality	Dissolved Oxygen	Same as reference	Functioning	Is not representative of reference reach and does not meet species requirements	Not Functioning
		Temperature	Same as reference	Functioning	Is not representative of reference reach and does not meet species requirements	Not Functioning
5 – Biology	Macroinvertebrate Communities	Family Level Biotic Index (FBI)	4	Functioning	8	Not Functioning
	Fish Communities	Index of Biotic Integrity (IBI)	Good	Functioning	Poor	Not Functioning

TABLE BD2b DEBIT TEMPLATE 2: PRE- AND POST-DISTURBANCE CONDITIONS AND RATIONALE

Describe Pre- and Post-Disturbance Condition and Rationale for Selecting Parameters

Hydrology – The watershed hydrology is stable and is not expected to change. Therefore, Hydrology parameters were not selected.

Hydraulics – The pre-disturbance Bank Height Ratio was provided in the summary report as 1.4, which is Functioning-at-Risk. The predicted post-disturbance ratio was not provided; however, it was stated that the channel would be designed to carry the 100-yr discharge. A Bank Height Ratio much greater than 2.0 is required to carry that amount of water and would be Not Functioning for floodplain connectivity.

Geomorphology – Information about the width of the riparian vegetation and bed form diversity (percent riffle/pool and depth variability) were provided in the summary report. Due to a narrow buffer width, the pre-disturbance condition is Not Functioning for riparian vegetation. Bed form diversity is Functioning. In order to transport water as quickly as possible, it is predicted that the buffer will be maintained as rip rap and maybe grass. Therefore, the riparian vegetation will remain Not Functioning. The channel will also be straightened and designed with a uniform cross section and profile, eliminating pool features. Therefore, a Not Functioning score is given to both bed form diversity measures.

Physicochemical – The summary report stated that the pre-disturbance DO and temperature levels matched the reference reach, which is a Functioning score. The post-disturbance condition is predicted to be Not Functioning due to the lack of buffer and pool features, and an overly wide channel, all of which contribute to higher stream temperatures and therefore lower DO levels.

Biology – The summary report states that a healthy community of benthic organisms and small native fish live in the stream pre-disturbance. Due to the removal of pool habitat and the decline in water quality, the post-disturbance score is Not Functioning.

Referring to Table BD2a, the majority of the pre-disturbance parameters are Functioning. The riparian vegetation is the only Not Functioning parameter and Floodplain Connectivity is Functioning-at-Risk. Using Table BD2c, this provides a Functionality Before Impact score of Moderate, but it would be the high end of Moderate. Table BD2a shows that the predicted post-disturbance condition is mostly Not Functioning with only one measurement method, conductivity, scoring a Functioning-at-Risk. This equals a High Functional Loss on Table BD2c. A Moderate/High yields a debit ratio range of 1.5 to 1.7. Since the pre-disturbance condition was on the higher end of Moderate, the 1.7 ratio is used. Therefore, the total debits for this site is 1,000 linear feet X 1.7 = 1,700 debits.

TABLE BD2c DEBIT TEMPLATE 3: DEBIT REQUIREMENTS

PRE-DISTURBANCE CONDITION	POST-DISTURBANCE CONDITION			
	NO FUNCTIONAL LOSS	LOW TO MODERATE FUNCTIONAL LOSS	MODERATE TO HIGH FUNCTIONAL LOSS	DEBIT ADJUSTMENT (+/-)
Low (Mix of Functioning-at-Risk and Not Functioning)	(Post-disturbance condition matches pre-disturbance condition) No mitigation required	Greater number of Functioning-at-Risk and Not Functioning Scores 1.1 to 1.2	Mostly Not-Functioning Scores 1.2 to 1.3	0.1
Moderate (Mix of Functioning, Functioning-at-Risk, and Not Functioning)		Loss of Functioning scores and/or greater number of Functioning-at-Risk and Not Functioning Scores 1.3 to 1.5	Mix of Functioning-at-Risk and Not Functioning Scores 1.5 to 1.7	0.1
High (Functioning)		Mix of Functioning, Functioning-at-Risk, and Not Functioning Scores 1.7 to 1.9	Mix of Functioning-at-Risk and Not Functioning Scores 2.0	0.2

Scenario 3: Surface Mining of High Gradient Streams

A permit has been submitted to impact 10,000 feet of headwater streams related to a large surface mine. The streams are all located in v-shaped and colluvial valleys and are classified as Rosgen A and B stream types. The streams are vertically and laterally stable with appropriate access to a floodprone area. The bank height ratio is 1.0 and the entrenchment ratio is 1.5. Bed form diversity is characterized by step-pools comprised of cobbles, boulders and large woody debris (LWD). Pool depths are typically greater than 1.5 times the mean riffle depth. Pool to pool spacing is less than 4 times the bankfull width. The riparian buffer spans the entire width of the valley and includes most of the hillslope as well. Buffer composition is characterized by a mature hardwood forest that totally covers the channel with an appropriate understory and minimal invasive species. Water quality is excellent with temperature, DO, pH, and conductivity levels representative of reference conditions. Large woody debris and smaller sticks and leaves can be found in the channel and on the floodprone area in quantities that are representative of reference conditions. Macroinvertebrate and small fish communities are also representative of reference conditions for small headwater channels.

The permitted surface mining operation requires the complete removal of the natural stream channel and associated riparian vegetation during mining. Stormwater BMPs, erosion control devices, and drainage channels will be constructed to comply with federal and state regulations; however, these practices do not prevent the loss of many stream functions. The new drainage channels will carry a 100-year discharge, which is much larger than the bankfull discharge. The channel bed and banks will be stabilized with rip rap. A uniform channel dimension and profile will be designed and constructed. Temporary vegetation will be established to provide erosion control. The post-disturbance water quality is predicted to increase conductivity and temperature and reduce pH and DO levels. The system will be devoid of LWD and smaller organic material. Macroinvertebrate and fish communities will not be representative of reference conditions.

From Table BD3a, the pre-disturbance condition is high with Functioning scores in all five Levels. This equals a **High** for Functionality Before Impact in Table BD3c. Again from Table BD3a, the post-disturbance condition shows mostly Not Functioning scores in all five Levels. This equals a **High** Functional Loss in Table BD3c. A **High/High** yields a debit ratio of 2.0 debits per foot. Therefore, the total debits are 10,000 ft X 2.0 debits/ft = 20,000 debits.

Stream Mitigation Scenarios (Credits)

The credit examples below represent restoration projects that are offsite from the permitted impact. A description of the credit determination method is provided in Chapter 11. For the scenarios below, a variety of credit determination methods are used to: 1) show different approaches to developing stream credits and 2) reflect the sometimes unique characteristics of a site, e.g., water withdrawal and dam removal. It may be helpful to review all of the credit determination methods in order to see the variety of approaches that are used.

The restoration or credit scenarios include:

1. Restoration of incised channels in alluvial valleys;
2. Restoration of stream flow for channels that have excessive water withdrawal;
3. Salmonid fish passage and habitat restoration; and
4. Restoration of high gradient, headwater streams.

Scenario 1: Restoration of Incised Channels in Alluvial Valleys

Channelization and subsequent incision is one of the biggest contributors to stream impairment. Incised channels can be found throughout the US and lead to excessive sedimentation from eroding bed and banks, which smothers aquatic habitats and reduces bed form diversity. These channels are often classified as unstable Rosgen Gc and F stream types. Restoration methods often follow Rosgen's Priority Levels of restoring incised channels (Rosgen, 1997), which is described in Chapter 3. The template below deviates from this approach by specifically focusing on the parameters from the Stream Functions Pyramid that relate to functions. This provides a more direct method for

describing functional lift. However, the same restoration methods that are used to implement Rosgen's Priority Levels can be used here.

Example Scenario

A mitigation provider has secured a restoration project reach of 5,000 feet. The site is located immediately downstream from a state forest and the entire upstream watershed is forested and stable. The existing reach is located on a beef farm and the cattle have full access to the channel. The stream is highly incised with a bank height ratio of 3.0; however, there is a bedrock knickpoint at the upstream end of the project. The stream is not incised upstream of the knickpoint. The channel is very straight and devoid of bed form diversity. Over 90% of the bed is riffle. There is no buffer and bank erosion is prevalent throughout the reach. Because of these impacts, there are few aquatic organisms living in the channel. Stream temperatures are high and DO levels are low, based on a comparison to the upstream reference reach.

Because the upstream watershed is very healthy, the mitigation provider proposes to complete a Restoration 1 approach. As a review, the restoration options are shown below. A description of each is provided in Chapter 11.

Restoration 1 – Reach scale restoration, connected to a healthy watershed

Restoration 2 – Reach scale restoration, variable upstream watershed conditions

For this project, a Rosgen Priority Level 1 restoration approach is proposed. A new meandering channel will be constructed and reconnected to the original floodplain at the bedrock knickpoint. The floodplain is 50 times wider than the channel and a sinuosity of 1.4 is used. The new stream type is a C4. The design includes alternating riffles and pools, with the pools containing root wads with cover logs and other structures to provide stability, LWD and cover. The depth variability includes a percent riffle:pool ratio of 70:30 and maximum pool depth ratios greater than 2.0. A meander width ratio of 7 is used with a buffer that extends for 25 feet beyond the belt width. The old channel (prior to restoration) is filled with material excavated for the new channel with large portions converted into riparian wetlands. Additional wood is used to create wetland complexity and provide habitat for salamanders, frogs and other amphibians. Due to the excellent health of the upstream watershed and the structural improvements to the project reach, DO and temperature levels return to reference condition by the fourth year after restoration construction. The aquatic macroinvertebrate and fish communities return to reference condition by year 5.

Table BC1a shows that the pre-restoration condition for all parameters was Not Functioning and that the predicted post-restoration condition improved all of those parameters to Functioning score. Using Table BC1c, this would yield a **Maximum Lift**, and 0.8 to 1.0 credits per foot could be assigned to the restored channel length. Based on the high quality of this example, a ratio of 1.0 is selected. The restored channel length is 5,000 feet X 1.4 sinuosity = 7,000 feet. Total credits = 7,000 ft X 1.0 = 7,000 credits.

TABLE BD3a DEBIT TEMPLATE 1: FUNCTIONAL LOSS DETERMINATION

Table BD3a is completed by interpreting the information from the paragraph above and selecting parameters, measurement methods and performance standards from Appendix A.

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-DISTURBANCE CONDITION		PREDICTED POST-DISTURBANCE CONDITION	
			VALUE	RATING	VALUE	RATING
1 – Hydrology	Runoff	N/A	N/A	Functioning	N/A	Not Functioning
	Flow Duration	N/A	N/A	Functioning	N/A	Not Functioning
2 – Hydraulics	Floodplain Connectivity	Bank Height Ratio	1.0	Functioning	> 2	Not Functioning
		Entrenchment Ratio	1.4	Functioning	1.2	Functioning-at-Risk
	Groundwater/Surface-Water Interaction	N/A		Functioning	N/A	Not Functioning
3 – Geomorphology	Riparian Vegetation	RBP	9	Functioning	0	Not Functioning
	Bed Form Diversity	Pool to Pool Spacing	< 4	Functioning	> 4	Not Functioning
		Pool Max Depth Ratio	> 1.5	Functioning	< 1.2	Not Functioning
	Large Woody Debris	LWDI	Same as reference condition	Functioning	Does not equal reference condition and is not trending in that direction	Not Functioning
	Bed material characterization	RSI	< 70	Functioning	> 85	Not Functioning

Appendix B: Application Scenarios, Surface Mining of High Gradient Streams

TABLE BD3a DEBIT TEMPLATE 1: FUNCTIONAL LOSS DETERMINATION (CONT.)

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-DISTURBANCE CONDITION		PREDICTED POST-DISTURBANCE CONDITION	
			VALUE	RATING	VALUE	RATING
4 – Physicochemical	Water Quality	Dissolved Oxygen	Same as reference	Functioning	Is not representative of reference reach and does not meet species requirements	Not Functioning
		Temperature	Same as reference	Functioning	Is not representative of reference reach and does not meet species requirements	Not Functioning
		Conductivity	Same as reference	Functioning	Is not representative of reference reach and does not meet species requirements	Not Functioning
		pH	Same as reference	Functioning	Is not representative of reference reach and does not meet species requirements	Not Functioning
5 – Biology	Macroinvertebrate Communities	Family-Level Biotic Index (FBI)	4	Functioning	8	Not Functioning
	Fish Communities	Index of Biotic Integrity (IBI)	Good	Functioning	Poor	Not Functioning

TABLE BD3b DEBIT TEMPLATE 2: PRE- AND POST-DISTURBANCE CONDITIONS AND RATIONALE

Describe Pre- and Post-Disturbance Condition and Rationale for Selecting Parameters

Hydrology – Performance standards have not been provided for Runoff and Flow Duration parameters. However, they are included in this example because surface mining negatively impacts these function-based parameters. Runoff often increases and flow duration decreases to Not Functioning levels, based on a comparison to reference or pre-mining conditions.

Hydraulics – These high-gradient streams do not have floodplains, but they do have floodprone areas that should be accessed at flows greater than bankfull. The post-disturbance bank height ratio is not provided in the report summary; however, the value will be well over 2 to carry the 100-yr discharge. The entrenchment ratio is predicted to decrease slightly as the bankfull channel is replaced with a large trapezoidal channel. Groundwater/surface-water interaction was also selected, even though it doesn't have a performance standard. The pre-disturbance condition would likely include Functioning groundwater/surface-water interaction. If the surface mining operation raises the channel and/or places the channel on fill, these processes will become Not Functioning.

Geomorphology – A mature forest provides a Functioning score for riparian vegetation prior to the disturbance. The riparian vegetation becomes Not Functioning after mining because the vegetation is totally removed. The temporary vegetation does not provide the same stability, cover and water quality as the mature forest. Bed form diversity measures all changes from Functioning to Not Functioning because the drainage channels are not designed with reference condition values of pool-pool-spacing and depth variability. Large woody debris is expected to become Not Functioning because the forest will be cleared (removing the wood source) and the design channels do not incorporate wood. Bed material will move from Functioning to Not Functioning because native mixtures of colluvium will be replaced by rip rap.

Physicochemical – All water quality measurement methods shift from Functioning to Not Functioning because they no longer resemble reference conditions. Dissolved oxygen and pH will likely decrease and conductivity and possibly temperature will increase.

Biology – The macroinvertebrate and fish communities also shift from Functioning to Not Functioning because of all the impacts to the supporting functions. The Hydrology, Hydraulic and Geomorphology functions cannot support the water quality functions that in turn support the Biology functions.

TABLE BD3c DEBIT TEMPLATE 3: DEBIT REQUIREMENTS

PRE-DISTURBANCE CONDITION	POST-DISTURBANCE CONDITION			
	NO FUNCTIONAL LOSS	LOW TO MODERATE FUNCTIONAL LOSS	MODERATE TO HIGH FUNCTIONAL LOSS	DEBIT ADJUSTMENT (+/-)
Low (Mix of Functioning-at-Risk and Not Functioning)	(Post-disturbance condition matches pre-disturbance condition)	Greater number of Functioning-at-Risk and Not Functioning Scores 1.1 to 1.2	Mostly Not Functioning Scores 1.2 to 1.3	0.1
Moderate (Mix of Functioning, Functioning-at-Risk, and Not Functioning)		Loss of Functioning scores and/or greater number of Functioning-at-Risk and Not Functioning Scores 1.3 to 1.5	Mix of Functioning-at-Risk and Not Functioning Scores 1.5 to 1.7	
High (Functioning)	No mitigation required	Mix of Functioning, Functioning-at-Risk, and Not Functioning Scores 1.7 to 1.9	Mix of Functioning-at-Risk and Not Functioning Scores 2.0	0.2

Scenario 2: Restoration of Stream Flow for Channels That Have Excessive Water Withdrawal

The following example is a common stream impairment in the western U.S. where water supply is scarce. In these systems, baseflow often diminishes in a downstream direction due to excessive water withdrawals for drinking water, irrigation, etc. This can have a negative effect on baseflow duration and stream biota. In many cases, water withdrawal can convert a perennial stream to intermittent, with the streambed being totally dry in the summer months.

The *literal* restoration of stream flows, where water is returned to the channel and not used for irrigation or other uses, requires policy decisions that do not apply to the Stream Functions Pyramid. However, there are cases where stream restoration activities may be able to improve base flow conditions. The example below focuses on a scenario that can benefit from alterations to the stream channel (morphology) rather than an example where water is returned to the channel by manipulating the hydrologic cycle.

TABLE BC1a CREDIT TEMPLATE 1: FUNCTIONAL LIFT DETERMINATION

Table BC1a is completed by interpreting the information from the paragraphs above and selecting parameters, measurement methods and performance standards from Appendix A.

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-DISTURBANCE CONDITION		PREDICTED POST-DISTURBANCE CONDITION	
			VALUE	RATING	VALUE	RATING
1 – Hydrology	N/A					
	Floodplain Connectivity	Bank Height Ratio	3.0	Not Functioning	1.0	Functioning
2 – Hydraulics		Entrenchment Ratio	1.1	Not Functioning	> 2.2	Functioning
	Large Woody Debris Storage and Transport	LWDI	LWDI does not equal LWDI of reference reach	Not Functioning	LWDI equals LWDI of reference reach	Functioning
3 – Geomorphology	Channel Evolution	Rosgen Stream Type Succession Scenarios	G or F4	Not Functioning	C 4	Functioning
	Bank Migration/ Lateral Stability	BEHI/NBS	High and Very High BEHI Curve Moderate to Extreme NBS	Not Functioning	Low BEHI Curve Very low to Moderate NBS	Functioning

TABLE BC1a CREDIT TEMPLATE 1: FUNCTIONAL LIFT DETERMINATION (CONT.)

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-DISTURBANCE CONDITION		PREDICTED POST-DISTURBANCE CONDITION	
			VALUE	RATING	VALUE	RATING
3 – Geomorphology	Riparian Vegetation	Buffer Width (ft) from Meander Belt Width	0	Not Functioning	MWR of 7 and additional width of 25 ft	Functioning
		Buffer Density, Composition, Age, Growth and Canopy Density	Significantly less functional than reference reach condition; little or no potential to improve without significant restoration effort.	No Functioning	By year 5, riparian vegetation is on a trajectory to become similar to the upstream reference condition.	Functioning
	Bed Form Diversity	Percent Riffle and Pool Depth Variability (Pool Max Depth Ratio)	90:10 < 1.2	Not Functioning Not Functioning	70:30 > 2	Functioning Functioning
4 – Physicochemical	Basic Water Chemistry	Temperature	Project Reach is statistically different (higher) than reference reach.	Not Functioning	Project Reach is not statistically different than reference reach by year 4.	Functioning
		Dissolved Oxygen	Project Reach is statistically different (lower) than reference reach.	Not Functioning	Project Reach is not statistically different than reference reach by year 4.	Functioning
5 – Biology	Benthic	Family-level Biological Index (FBI)	8	Not Functioning	2	Functioning
	Fish Communities	McCormick Index of Biological Integrity	50	Not Functioning	75	Functioning

TABLE BC1b CREDIT TEMPLATE 2: PRE- AND POST-RESTORATION CONDITIONS AND RATIONALE

Describe Pre- and Post-Restoration Condition and Rationale for Selecting Parameters

Hydrology – The watershed hydrology is stable and is not expected to change. Therefore, Hydrology parameters were not selected.

Hydraulic – The existing channel is severely incised (Bank Height Ratio of 3) and does not have access to a wide alluvial floodplain. The channel will be reconnected to the floodplain through a Rosgen Priority Level 1 Restoration. The Bank Height Ratio will be reduced to 1.0 and all flows greater than bankfull will spread onto a floodplain that is 50 times wider than the channel, making the entrenchment ratio well over 2.2.

Geomorphology – The existing channel is an incised Gc or F4 channel. The stream is straight and incised with poor bed form diversity and severe bank erosion. The valley is wide without constraints, but the riparian buffer is very thin. The new channel will include a sinuosity of 1.4, which will reduce stream velocity and help support bed form diversity. The additional wood structures will also help create deeper pools and better depth variability. A wide riparian buffer will be planted to help maintain bank stability, provide cover, and regulate water and air temperatures. Large woody debris will be incorporated into the channel to provide further bed form complexity and habitat. The predicted result is that all of the Geomorphology parameters and associated measurement methods shown in Table B4a will shift from Not Functioning to Functioning.

Physicochemical – Since the upstream watershed is nearly pristine, water quality entering the project reach is very good. Temperature does increase through the project reach due to lack of vegetative cover and the high channel width associated with G/F channels, creating Not Functioning scores pre-restoration. The lack of bed form diversity and high temperatures cause low DO levels. These two parameters are selected because they are impaired but can likely be improved with restoration efforts. The restoration activities under the Geomorphology category, along with healthy watershed, will provide the channel form necessary to reduce water temperature and increase DO levels. This is primarily through the increase in bed form diversity (improved riffles) and the establishment of a wide riparian buffer. Since these parameters and measurement methods require an established buffer in addition to proper channel form, they are predicted to take 4 years to reach a Functioning score.

Biology – Similar to the Physicochemical parameters, the Biology conditions entering the project reach are Functioning, but become degraded due to the reach conditions. Macroinvertebrate and Fish Community parameters are selected because the reach scale activities in combination with the high quality watershed indicate a high potential for restoring these parameters to a Functioning level. The improvement to Pyramid Levels 2-4, along with the health of the upstream watershed, will provide the channel form and processes necessary to support Functioning macroinvertebrate and fish communities. However, since the water quality parameter will not reach a Functioning level until year 4, it is predicted to take 5 years to reach a Functioning score for macroinvertebrate and fish communities.

TABLE BC1c CREDIT TEMPLATE 3: CREDIT CALCULATIONS

RESTORATION 1 CREDIT CATEGORIES	PRE-RESTORATION CONDITION	POST-RESTORATION CONDITION	CREDITS PER FOOT
Maximum Lift	All parameters in Pyramid Levels 2 and 3 have Not Functioning scores. Parameters in Levels 4 and 5 are Not Functioning or Functioning-at-Risk.	Functioning scores for Levels 1-5	0.8 to 1.0
Moderate Lift	Mix of Not-Functioning and Functioning-at-Risk scores for parameter Levels 2 through 5	Functioning scores for Levels 1-5	0.6 to 0.8
Low Lift	Mix of Not-Functioning, Functioning-at-Risk and Functioning scores for parameter Levels 2 through 5	Functioning scores for Levels 1-5	0.4 to 0.6

Example Scenario

A 5,000 foot restoration project has been secured to improve base flow conditions that have been impacted by excessive water withdrawals. The project reach is in an agricultural setting and the withdrawals are used for irrigation. The stream is in a wide alluvial valley and is approximately 75 feet wide. The sinuosity is 1.3, which is appropriate given the stream and valley condition. The channel is moderately incised with a Bank Height Ratio of 1.2. There is a 10-foot buffer with a mixture of cottonwoods and some herbaceous vegetation; however, beyond that is cropland. The moderate incision and lack of buffer has created localized bank erosion in the outside of several meander bends. The streambed and banks are comprised of well-graded (poorly sorted) gravel, sand, and cobble with the median particle size in the gravel range. Bed form diversity is moderate with pools existing in the outside of the meander bends; however, the overall depth variability and complexity is low. This is primarily caused by the lack of baseflow and LWD. When baseflow is present, basic water quality parameters of DO, temperature and pH are representative of reference conditions. However, due to the adjacent cropland, lack of buffer and incision, nitrate-nitrogen levels are higher than reference conditions, but not high enough to cause eutrophication. Macroinvertebrate and fish communities reflect reference reach conditions in the winter, but not the summer when baseflow is low or absent.

The goal of the restoration project is to improve baseflow duration in the summer months, reduce streambank erosion, and to reduce nitrate-nitrogen levels. A restoration approach is proposed to work with the existing channel alignment since the overall planform geometry is stable and to save the existing cottonwoods that help provide bank

stability, cover and denitrification. The dimension of the channel will be modified to create a smaller baseflow channel within the existing bankfull channel. In addition, in-stream structures will be used to raise the stream bed and thereby reduce the Bank Height Ratio to 1.0. The objective with this approach is to improve groundwater/surface-water interaction by raising the water table and increasing bank storage in the winter months. Gravel material will be excavated from the pools and used to construct the riffles. Cross vanes will be used to raise the bed, provide grade control and increase the number of pools. Large woody debris will also be introduced into the channel to further aid in raising the bed and creating pools. The increased number of pools in conjunction with the improved groundwater/surface-water interaction is predicted to improve baseflow. Bioengineering and LWD will be used to stabilize the eroding streambanks. In addition, the buffer will be expanded to 100 feet on both sides of the stream. This will provide a buffer to treat nutrient (nitrogen) runoff and create favorable conditions for denitrification. These changes are predicted to return water quality, nutrient, macroinvertebrate and fish communities to reference conditions.

Table BC2c shows the credit ratios in credits per foot for restoration projects associated with excessive water withdrawals. The rows represent the function scores from the pre-restoration condition provided in Table BC2a. The columns are from the post-restoration scores in Table BC2a. Credits are only provided for functional lift, so if the post-restoration condition is equal to or less than the pre-restoration condition, credits are not provided. In addition, categories are assigned to the different levels of functional lift. Projects with low pre-restoration functionality scores are eligible for restoration credits, moderate pre-restoration scores for enhancement, and high pre-restoration scores for preservation. This is shown in Table BC2a.

For this example, the Before Functionality score is **Low** — Flow duration is Not Functioning, there is a mix of Functioning-at-Risk and Not Functioning scores for Levels 2-4 and the Level 5 scores are Not Functioning. All post-restoration scores are Functioning, so this equals a **High** After Functionality score. A **Low/High** result yields a credit ratio of 1.0. Therefore, the total amount of credits for this site is 5,000 ft X 1.0 credits/ft = 5,000 credits.

Scenario 3: Salmonid Fish Passage and Habitat Restoration

The restoration of salmonid fish passage and habitat is a major focus in the Pacific Northwest and to a lesser degree in the Atlantic Northeast. In the Northwest, the construction and maintenance of dams have had a negative impact on the migration of salmonids from the ocean to headwater spawning areas. In addition, fish habitat has been reduced from logging and other impacts that have created channel incision and changes to bed material size and composition.

TABLE BC2a CREDIT TEMPLATE 1: FUNCTIONAL LIFT DETERMINATION

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-RESTORATION CONDITION		POST-RESTORATION CONDITION	
			VALUE	RATING	VALUE	RATING
1 – Hydrology	Flow Duration	N/A		Not Functioning	N/A	Functioning
	Floodplain Connectivity	Bank Height Ratio	1.2	Functioning	1.0	Functioning
	Groundwater/Surface-Water Interaction	N/A		Functioning-at-Risk	N/A	Functioning
	Large Woody Debris Storage and Transport	LWDI	LWDI does not equal LWDI of reference reach.	Not Functioning	LWDI equals LWDI of reference reach.	Functioning
	Bank Migration/Lateral Stability	BEHI/NBS in meander bends	High and Very High BEHI Curve Moderate to Extreme NBS	Functioning-at-Risk	Low BEHI Curve Very low to Moderate NBS	Functioning
2 – Hydraulics	Riparian Vegetation	Average Buffer Width (ft)	10	Not Functioning	100 ft	Functioning
		Buffer Density, Composition, Age, Growth and Canopy Density	Significantly less functional than reference reach condition; little or no potential to improve without significant restoration effort.	Not Functioning	By year 5, riparian vegetation is on a trajectory to become similar to the upstream reference condition.	Functioning

TABLE BC2a CREDIT TEMPLATE 1: FUNCTIONAL LIFT DETERMINATION (CONT.)

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-RESTORATION CONDITION		POST-RESTORATION CONDITION	
			VALUE	RATING	VALUE	RATING
2 – Hydraulics	Bed Form Diversity	Percent Riffle and Pool	80:20	Functioning-at-Risk	65:35	Functioning
		Depth Variability (Pool Max Depth Ratio)	1.2	Functioning-at-Risk	> 2	Functioning
4 – Physicochemical	Water Quality	Temperature	Project Reach is not statistically different than reference.	Functioning	Project Reach is not statistically different than reference reach.	Functioning
		Dissolved Oxygen	Project Reach is not statistically different than reference.	Functioning	Project Reach is not statistically different than reference reach.	Functioning
	Nutrients	Nitrate-Nitrogen	Not representative of reference reach, but does not cause eutrophication.	Functioning-At-Risk	Project reach is representative of reference reach.	Functioning
		Benthic	Family-Level Biological Index (FBI)	5 / 8	Not Functioning in summer/ Functioning in winter	8
5 – Biology	Fish Communities	McCormick Index of Biological Integrity	50 / 75	Not Functioning in summer/ Functioning in winter	75	Functioning

TABLE BC2b CREDIT TEMPLATE 2: PRE- AND POST-RESTORATION CONDITIONS AND RATIONALE

Describe Pre- and Post-Restoration Condition and Rationale for Selecting Parameters

Hydrology – Performance standards are not provided from flow duration; however, the summary report states that flow duration does not support species requirements in the summer months. For these scenarios, the upstream reach or paired watershed can be used to set a performance standard based on the reference condition.

Hydraulic – Floodplain connectivity is Functioning with a Bank Height Ratio of 1.2; however, this is on the border between Functioning and Functioning-at-Risk. The post-restoration condition is predicted to improve floodplain connectivity by decreasing the ratio to 1.0. This may help improve groundwater/surface-water interactions and support denitrification. Groundwater/surface-water interaction was selected even though there is not a performance standard to acknowledge that these processes are key to improving flow duration. Groundwater/surface-water interaction can be assessed directly with shallow wells or tracers or indirectly assessed by measuring the results like the Physicochemical and Biology parameters and measurement methods.

Geomorphology – Large woody debris has been removed from the channel and is Not Functioning. Large woody debris will be added to the channel to create pools and encourage bed aggradation. The prediction is that post-restoration condition will be Functioning. There is a 10-foot buffer with cottonwood trees that will remain. The buffer will be expanded to 100 feet to provide bank stability, cover, and treatment of agricultural runoff. The existing bank erosion is on the outside of the meander bends, and since the overall pattern is stable, bioengineering and wood structures will be used to improve lateral stability to a Functioning level. Existing bed form diversity is Functioning-at-Risk because pools are shallow and only located in the apex of bends. Large woody debris and in-stream structures will be used to create a more complex bed form.

Physicochemical – Temperature and DO levels are used to measure water quality and are both Functioning when water is present. These levels are supported by the existing cottonwood trees, moderate bed form diversity, and health of the upstream watershed. No change in the function score is predicted post-restoration, however these parameters will be measurable for longer periods of time due to longer flow duration. Elevated levels of nitrate-nitrogen enter the stream before restoration from adjacent cropland. Post-restoration buffer and higher water table will support denitrification processes.

Biology – Macroinvertebrate and fish communities are Not Functioning in the summer months when flow duration is below the level needed to support aquatic life. Post-restoration, macroinvertebrate and fish communities will be Functioning year round.

TABLE BC2c CREDIT TEMPLATE 3: CREDIT CALCULATIONS

BEFORE FUNCTIONALITY		AFTER FUNCTIONALITY			Category
		Low (Flow duration is Functioning-at-Risk. Other key parameters in Level 2-4 are Functioning-at-Risk or Not Functioning). Key parameters in Level 5 are Not Functioning)	Moderate (Flow duration is Functioning. Other key parameters in Level 2-4 are Functioning-at-Risk or Not Functioning). Key parameters in Level 5 are Not Functioning)	High (Flow duration is Functioning. Other key parameters in Level 2-5 are Functioning)	
Low (Flow duration is Not Functioning. Other key parameters in Level 2-4 are Functioning-at-Risk or Not Functioning). Key parameters in Level 5 are Not Functioning)	_____	_____	0.8	1.0	Restoration
Moderate (Flow duration is Not Functioning. Other key parameters in Level 2-4 are a mix of Functioning, Functioning-at-Risk and Not Functioning). Key parameters in Level 5 are Functioning-at-Risk and Not Functioning)	_____	_____	_____	0.6	Enhancement
High (Flow duration is Not Functioning. Other key parameters in Level 2-4 are a mix of Functioning, Functioning-at-Risk and Not Functioning). Key parameters in Level 5 are Functioning-at-Risk and Not Functioning)	_____	_____	_____	0.2	Preservation

Appendix B: Application Scenarios, Fish Passage

Restoration efforts have focused on dam removal and restoring salmonid habitat, typically by adding large woody debris to the channels. These engineered log jams are often used to raise the stream bed, stabilize streambanks, and to create sediment storage areas upstream of the log jam while coarsening the bed downstream. The example below includes the removal of a dam to create fish passage and the installation of LWD and other natural structures to stabilize the bed and create salmonid habitat.

Example Scenario

A restoration site has been secured that includes a 10-foot high dam removal and 10,000 feet of degraded channel, 2,000 feet downstream of the dam and 8,000 feet upstream. The stream is approximately 50 feet wide with a gravel/cobble bed. The watershed is forested, but is managed for silviculture. The existing Bank Height Ratio is 1.5 downstream of the dam with moderate bank erosion and a coarse bed. The bed has aggraded upstream of the dam, reducing the Bank Height Ratio to 1.2 and creating a finer grain size distribution for the bed material. Streambank erosion is low. A forested buffer extends the width of the valley throughout the full length of the project reach. Basic water quality (pH, DO, conductivity and turbidity) meets the species requirements for salmonids, which are plentiful downstream of the dam. These fish, however, are unable to migrate past the dam due to its height. In addition, the bed material upstream is unsuitable for salmonid habitat due to the aggradation of fine sediments.

The restoration approach includes the removal of the 10-foot high dam and the installation of engineered log jams and other structures to stabilize the stream bed. The structures will be installed throughout the project length to reduce Bank Height Ratios downstream of the dam and to spread out the elevation drop throughout the reach. The structures will create a step-pool bed form, creating more resting areas for salmonids. Fine grain sediments will still accumulate upstream of the structures leaving coarser material downstream. However, the individual facet length of finer grained sediment will be much less than above the dam. In addition, the wood will provide refuge for the fish and habitat for aquatic insects.

The pre-restoration condition is a mix of Functioning, Functioning-at-Risk and Not Functioning scores, with the downstream condition scoring lower for Hydraulic, Geomorphology and Biology functions. This equals a Before Functionality score of **Moderate**. The post-restoration condition is predicted to be Functioning for all key parameters, yielding an **After** Restoration score of High. A **Moderate/High** score provides a credit ratio of 0.7. The total number of credits is 10,000 feet X 0.7 credit/ft = 7,000 credits.

TABLE BC3a CREDIT TEMPLATE 1: FUNCTIONAL LIFT DETERMINATION

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-RESTORATION CONDITION		POST-RESTORATION CONDITION	
			VALUE	RATING	VALUE	RATING
1 – Hydrology	N/A	N/A		N/A		N/A
2 – Hydraulics	Floodplain Connectivity	Bank Height Ratio	1.5 (Downstream of dam) 1.2 (Upstream of dam)	Functioning-at-Risk Functioning	1.2	Functioning
	Flow Dynamics	Velocity	Does not meet species requirements	Not Functioning	Meets species requirements	Functioning
3 – Geomorphology	Large Woody Debris Storage and Transport	LWDI	LWDI does not equal LWDI of reference reach	Not Functioning	LWDI equals LWDI of reference reach	Functioning
	Bank Migration/Lateral Stability	BEHI/NBS	Moderate downstream of dam Low upstream of dam	Functioning-at-Risk Functioning	Low	Functioning
	Riparian Vegetation	Average Buffer Width (ft)	> 150	Functioning	> 150	Functioning
Bed Form Diversity	Depth Variability (Pool Max Depth Ratio)	Buffer Density, Composition, Age, Growth and Canopy Density	Similar to reference reach condition	Functioning	Similar to reference reach condition	Functioning
			1.2 (Downstream of dam) < 1.2 (Upstream of dam)	Functioning-at-Risk Not Functioning	> 2	Functioning

TABLE BC3a CREDIT TEMPLATE 1: FUNCTIONAL LIFT DETERMINATION (CONT.)

LEVEL AND CATEGORY	PARAMETER	MEASUREMENT METHOD	PRE-RESTORATION CONDITION		POST-RESTORATION CONDITION	
			VALUE	RATING	VALUE	RATING
4 – Physicochemical	Basic Water Quality	Temperature	Project Reach is not statistically different than reference.	Functioning	Project Reach is not statistically different than reference reach.	Functioning
			Project Reach is not statistically different than reference.	Functioning	Project Reach is not statistically different than reference reach.	Functioning
			Project Reach is not statistically different than reference.	Functioning	Project Reach is not statistically different than reference reach.	Functioning
5 – Biology	Benthic Macroinvertebrate Communities	Family-Level Biological Index (FBI)	5 (Downstream)	Functioning-at-Risk Not Functioning	2	Functioning
			8 (Upstream)	Functioning-at-Risk Not Functioning	75	Functioning
	Fish Communities	McCormick Index of Biological Integrity	70 (Downstream) 55 (Upstream)	Functioning-at-Risk Not Functioning		

TABLE BC3b CREDIT TEMPLATE 2: PRE- AND POST-RESTORATION CONDITIONS AND RATIONALE

Describe Pre- and Post-Restoration Condition and Rationale for Selecting Parameters

Hydrology – While silviculture can change the rainfall/runoff relationship, the watershed hydrology in this example is stable. Hydrology parameters are used for the design, but not as performance standards.

Hydraulic – A Bank Height Ratio of 1.5 indicates that the channel is moderately incised downstream of the dam. This may be due to reduced sediment supply caused by the dam, past changes to hydrology, past channelization, or a combination of impacts. The lower Bank Height Ratio of 1.2 upstream of the dam is caused by sedimentation. Flow dynamics was not described in the example scenario; however, the dam and channel incision will increase channel velocities downstream of the dam. For this reason, velocity was added as a measurement method. For this example, a performance standard was added based on species requirements.

Geomorphology – Large woody debris has been removed from the channel and is therefore Not Functioning before restoration. Engineered log jams will be the primary structure used in the restoration and will create a Functioning score post-restoration. There is moderate bank erosion downstream of the dam, which is primarily a result of channel incision. This has created a Functioning-at-Risk pre-restoration score. The structures will be used to reduce the bank heights and improve bank stability, improving the score to Functioning. A mature forest exists throughout the project reach and is Functioning pre- and post-restoration. Bed form diversity is measured by depth variability and shows a Functioning-at-Risk pre-restoration score downstream of the dam. This is caused by a reduction in sediment supply and channel incision. There are fewer riffles and pools upstream of the dam due to sedimentation, resulting in a Not Functioning score.

Physicochemical – All water quality measurement methods are Functioning pre- and post-restoration for this example due to the health of the upstream watershed and low water retention from the dam.

Biology – The two methods of measurement shown are examples from Chapter 10 and were developed for different regions. As methods are developed for the Northwest, they should be added as a measurement method. If indexes are not available, a reference reach approach could be used to compare the pre- and post-restoration condition to a reference condition specifically for salmonids.

TABLE BC3c CREDIT TEMPLATE 3: CREDIT CALCULATIONS

BEFORE FUNCTIONALITY	AFTER FUNCTIONALITY			Category
	Low (Dam is removed. Key parameters in Level 2-4 are Functioning-at-Risk or Not Functioning). Key parameters in Level 5 are Not Functioning)	Moderate (Dam is removed. Key parameters in Level 2-4 are Functioning or Functioning-at-Risk. Key parameters in Level 5 are Functioning-at-Risk)	High (Dam is removed. Key parameters in Level 2-5 are Functioning)	
Low (Dam is in place. Key parameters in Level 2-4 are Functioning-at-Risk or Not Functioning). Key parameters in Level 5 are Not Functioning)	_____	0.8	1.0	Restoration
Moderate (Dam is in place. Key parameters in Level 2-4 are a mix of Functioning, Functioning-at-Risk and Not Functioning). Key parameters in Level 5 are Functioning-at-Risk and Not Functioning)	_____	0.6	0.7	Enhancement

Scenario 4: Restoration of High Gradient, Headwater Streams

The restoration of high gradient, headwater streams is common in mountain regions of the US, especially the Appalachian Mountains where restoration is often associated with coal mining impacts. In addition, mountain headwater streams are often restored in the East and the West to improve trout fishing. These streams are often found in v-shaped or colluvial valleys and are often A or B stream types, and sometimes Cb stream types. Energy is dissipated through vertical meandering rather than lateral meandering, which is measured by sinuosity. In these higher-gradient streams, step-pool bed forms create vertical meandering, which dissipates energy and creates the habitat needed for many fish species, including trout. Therefore, restoration efforts focus more on bed form diversity and more specifically measurement methods like pool-to-pool spacing and pool depths than measures like sinuosity.

Example Scenario

A stream restoration project has been secured to restore 12,000 feet of mountain headwater streams. The representative valley slope is 5% and the stream types are a B4. The streams are located on an abandoned mine site. A uniform channel was sized to carry the 25-year discharge and material from the mine site was used to line the channels. There are no trees along the riparian corridor other than a few small shrubs. Over the years, the channels have further incised and bank erosion is prevalent throughout the reaches. The streams are ephemeral to perennial; however, due to poor bed form diversity and high flow energy, the stream does not support aquatic life in the perennial reaches. The pH of the stream is a little lower than reference conditions.

The restoration approach is a watershed scale effort. The ephemeral, intermittent and perennial streams are reconstructed based on natural channel design principles. The focus of the restoration is to create a channel that only carries the bankfull discharge. All other flows are transported onto a floodprone area, including the 25-year discharge. This is also called a nested-channel approach. The pool-to-pool spacing and pool depths are designed based on the slope of the channel, with steeper reaches having shorter pool spacing than flatter reaches. A combination of boulders and wood are used to create the step-pool structures. The channels are connected through a dendritic drainage pattern. Topsoil and mulch are used to amend the soils in the riparian area and a 200-foot buffer of hardwood trees and native shrubs is established.

This scenario fits the same credit determination method as the restoration of incised channels. For this example, the pre-restoration condition included all Not Functioning scores. Since this is a watershed scale approach, all of the post-restoration scores are Functioning through Level 5. This results in a **Maximum Lift** with a credit range of 0.8 to 1.0. For this example, 0.9 credits are used. The total credits are 12,000 feet X 0.9 credits/ft = 10,800 credits.

TABLE BC4a CREDIT TEMPLATE 1: FUNCTIONAL LIFT DETERMINATION

LEVEL AND CATEGORY	PARAMETER	PRE-RESTORATION CONDITION		POST-RESTORATION CONDITION	
		VALUE	RATING	VALUE	RATING
1 – Hydrology	N/A	N/A	N/A	N/A	N/A
2 – Hydraulics	Floodplain Connectivity	Bank Height Ratio	> 2.0	Not Functioning	Functioning
3 – Geomorphology	Large Woody Debris Storage and Transport	LWDI	LWDI does not equal LWDI of reference reach	Not Functioning	Functioning
		Bank Migration/Lateral Stability	BEHI/NBS	High	Not Functioning
	Riparian Vegetation	Average Buffer Width (ft)	0	Not Functioning	Functioning
		Buffer Density, Composition, Age, Growth and Canopy Density	None	Similar to reference reach condition	Functioning
	Bed Form Diversity	Depth Variability (Pool Max Depth Ratio)	< 1.2	Not Functioning	Functioning

TABLE BC4a CREDIT TEMPLATE 1: FUNCTIONAL LIFT DETERMINATION (CONT.)

LEVEL AND CATEGORY	PARAMETER	PRE-RESTORATION CONDITION		POST-RESTORATION CONDITION	
		VALUE	RATING	VALUE	RATING
4 – Physicochemical	Water Quality	pH			
			Slightly lower than reference condition	Project Reach is not statistically different than reference reach and support species requirements by year 10.	Functioning
5 – Biology	Benthic Macroinvertebrate Communities	WVSCI	40	70 by year 10	Functioning
	Fish Communities	Mid-Atlantic Highlands IBI	35	75 by year 10	Functioning

TABLE BC4b CREDIT TEMPLATE 2: PRE- AND POST-RESTORATION CONDITIONS AND RATIONALE

Describe Pre- and Post-Restoration Condition and Rationale for Selecting Parameters

Hydrology – For this example, the Hydrology is stable enough to proceed with the project, especially since the restoration is a watershed-scale effort. Restoration efforts will likely reduce runoff and may increase flow duration. Therefore, there parameters could be added as performance standards and evaluated against a reference condition.

Hydraulic – The Bank Height Ratio was not provided for the pre-restoration scenario; however, the channel was designed to carry a 25-year discharge and would therefore be severely incised. The new channel will be sized within the larger channel to carry the bankfull discharge and the larger channel will be used as a floodprone area. This will convert the Hydraulic functions from Not Functioning to Functioning. Groundwater/surface-water exchange was not selected for this example, because the restoration approach is a watershed-scale approach and there isn't a concern about the stream classification, e.g., ephemeral or intermittent. If this was a concern, additional restoration approaches could be used to change the groundwater/surface-water interaction. And in reality, the addition of step-pools will likely improve flow through the hyporheic zone.

Geomorphology – The existing channel is devoid of LWD. Wood will be incorporated into the step-pool channels so that the restored stream has an amount of wood that is representative of reference streams. Pre-restoration bank erosion is high due to the oversized channel and absence of vegetation. The change in channel dimension and the establishment of a riparian buffer will reduce bank erosion to Functioning levels. The crux of the restoration approach is the establishment of step-pool bed forms. These features will provide vertical control and dissipate energy. They will also provide key habitat, along with LWD, for native fish species.

Physicochemical – pH is Functioning-at-Risk due to past mining activities, the over-sized channel, and lack of riparian vegetation. The combination of changes to channel dimension (nested-channel), bed form diversity (LWD and step-pools), re-establishment of the drainage network, and establishment of a riparian buffer will slowly improve water quality. It is predicted to take 10 years before fully Functioning scores will be obtained.

Biology – Macroinvertebrate and fish communities are Not Functioning pre-restoration due to all of the impacts to Level 2-4 functions. The restoration of these functions will support the recruitment of aquatic insects and native fish. It is predicted that Functioning levels will be achieved by year 10.

Appendix B: Application Scenarios, Restoration of High Gradient Streams

TABLE BC4c CREDIT TEMPLATE 3: CREDIT CALCULATIONS

CREDIT CATEGORIES	PRE-RESTORATION CONDITION	POST-RESTORATION CONDITION	CREDITS PER FOOT
Maximum Lift	All parameters in Pyramid Levels 2 and 3 have Not Functioning scores. Parameters in Levels 4 and 5 are Not Functioning or Functioning-at-Risk.	Functioning scores for Levels 1-5.	0.8 to 1.0
Moderate Lift	Mix of Not-Functioning and Functioning-at-Risk scores for parameter Levels 2 through 5.	Functioning scores for Levels 1-5.	0.6 to 0.8
Low Lift	Mix of Not-Functioning, Functioning-at-Risk and Functioning scores for parameter Levels 2 through 5.	Functioning scores for Levels 1-5.	0.4 to 0.6



APPENDIX A MAINTENANCE REQUIREMENTS FLOW CONTROL, CONVEYANCE, AND WQ FACILITIES

NO. 1 – DETENTION PONDS			
Maintenance Component	Defect or Problem	Conditions When Maintenance Is Needed	Results Expected When Maintenance Is Performed
Site	Trash and debris	Any trash and debris which exceed 1 cubic foot per 1,000 square feet (this is about equal to the amount of trash it would take to fill up one standard size office garbage can). In general, there should be no visual evidence of dumping.	Trash and debris cleared from site.
	Noxious weeds	Any noxious or nuisance vegetation which may constitute a hazard to County personnel or the public.	Noxious and nuisance vegetation removed according to applicable regulations. No danger of noxious vegetation where County personnel or the public might normally be.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
	Grass/groundcover	Grass or groundcover exceeds 18 inches in height.	Grass or groundcover mowed to a height no greater than 6 inches.
Top or Side Slopes of Dam, Berm or Embankment	Rodent holes	Any evidence of rodent holes if facility is acting as a dam or berm, or any evidence of water piping through dam or berm via rodent holes.	Rodents removed or destroyed and dam or berm repaired.
	Tree growth	Tree growth threatens integrity of slopes, does not allow maintenance access, or interferes with maintenance activity. If trees are not a threat or not interfering with access or maintenance, they do not need to be removed.	Trees do not hinder facility performance or maintenance activities.
	Erosion	Eroded damage over 2 inches deep where cause of damage is still present or where there is potential for continued erosion. Any erosion observed on a compacted slope.	Slopes stabilized using appropriate erosion control measures. If erosion is occurring on compacted slope, a licensed civil engineer should be consulted to resolve source of erosion.
	Settlement	Any part of a dam, berm or embankment that has settled 4 inches lower than the design elevation.	Top or side slope restored to design dimensions. If settlement is significant, a licensed civil engineer should be consulted to determine the cause of the settlement.
Storage Area	Sediment accumulation	Accumulated sediment that exceeds 10% of the designed pond depth.	Sediment cleaned out to designed pond shape and depth; pond reseeded if necessary to control erosion.
	Liner damaged (If Applicable)	Liner is visible or pond does not hold water as designed.	Liner repaired or replaced.
Inlet/Outlet Pipe.	Sediment accumulation	Sediment filling 20% or more of the pipe.	Inlet/outlet pipes clear of sediment.
	Trash and debris	Trash and debris accumulated in inlet/outlet pipes (includes floatables and non-floatables).	No trash or debris in pipes.
	Damaged	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering at the joints of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of the inlet/outlet pipe.
Emergency Overflow/Spillway	Tree growth	Tree growth impedes flow or threatens stability of spillway.	Trees removed.
	Rock missing	Only one layer of rock exists above native soil in area five square feet or larger or any exposure of native soil on the spillway.	Spillway restored to design standards.

NO. 2 – INFILTRATION FACILITIES			
Maintenance Component	Defect or Problem	Conditions When Maintenance Is Needed	Results Expected When Maintenance Is Performed
Site	Trash and debris	Any trash and debris which exceed 1 cubic foot per 1,000 square feet (this is about equal to the amount of trash it would take to fill up one standard size office garbage can). In general, there should be no visual evidence of dumping.	Trash and debris cleared from site.
	Noxious weeds	Any noxious or nuisance vegetation which may constitute a hazard to County personnel or the public.	Noxious and nuisance vegetation removed according to applicable regulations. No danger of noxious vegetation where County personnel or the public might normally be.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
	Grass/groundcover	Grass or groundcover exceeds 18 inches in height.	Grass or groundcover mowed to a height no greater than 6 inches.
Infiltration Pond, Top or Side Slopes of Dam, Berm or Embankment	Rodent holes	Any evidence of rodent holes if facility is acting as a dam or berm, or any evidence of water piping through dam or berm via rodent holes.	Rodents removed or destroyed and dam or berm repaired.
	Tree growth	Tree growth threatens integrity of dams, berms or slopes, does not allow maintenance access, or interferes with maintenance activity. If trees are not a threat to dam, berm, or embankment integrity or not interfering with access or maintenance, they do not need to be removed.	Trees do not hinder facility performance or maintenance activities.
	Erosion	Eroded damage over 2 inches deep where cause of damage is still present or where there is potential for continued erosion. Any erosion observed on a compacted slope.	Slopes stabilized using appropriate erosion control measures. If erosion is occurring on compacted slope, a licensed civil engineer should be consulted to resolve source of erosion.
	Settlement	Any part of a dam, berm or embankment that has settled 4 inches lower than the design elevation.	Top or side slope restored to design dimensions. If settlement is significant, a licensed civil engineer should be consulted to determine the cause of the settlement.
Infiltration Pond, Tank, Vault, Trench, or Small Basin Storage Area	Sediment accumulation	If two inches or more sediment is present or a percolation test indicates facility is working at or less than 90% of design.	Facility infiltrates as designed.
	Liner damaged (If Applicable)	Liner is visible or pond does not hold water as designed.	Liner repaired or replaced.
Infiltration Tank Structure	Plugged air vent	Any blockage of the vent.	Tank or vault freely vents.
	Tank bent out of shape	Any part of tank/pipe is bent out of shape more than 10% of its design shape.	Tank repaired or replaced to design.
	Gaps between sections, damaged joints or cracks or tears in wall	A gap wider than ½-inch at the joint of any tank sections or any evidence of soil particles entering the tank at a joint or through a wall.	No water or soil entering tank through joints or walls.
Infiltration Vault Structure	Damage to wall, frame, bottom, and/or top slab	Cracks wider than ½-inch, any evidence of soil entering the structure through cracks or qualified inspection personnel determines that the vault is not structurally sound.	Vault is sealed and structurally sound.

NO. 2 – INFILTRATION FACILITIES			
Maintenance Component	Defect or Problem	Conditions When Maintenance Is Needed	Results Expected When Maintenance Is Performed
Inlet/Outlet Pipes	Sediment accumulation	Sediment filling 20% or more of the pipe.	Inlet/outlet pipes clear of sediment.
	Trash and debris	Trash and debris accumulated in inlet/outlet pipes (includes floatables and non-floatables).	No trash or debris in pipes.
	Damaged	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering at the joints of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of the inlet/outlet pipe.
Access Manhole	Cover/lid not in place	Cover/lid is missing or only partially in place. Any open manhole requires immediate maintenance.	Manhole access covered.
	Locking mechanism not working	Mechanism cannot be opened by one maintenance person with proper tools. Bolts cannot be seated. Self-locking cover/lid does not work.	Mechanism opens with proper tools.
	Cover/lid difficult to remove	One maintenance person cannot remove cover/lid after applying 80 lbs of lift.	Cover/lid can be removed and reinstalled by one maintenance person.
	Ladder rungs unsafe	Missing rungs, misalignment, rust, or cracks.	Ladder meets design standards. Allows maintenance person safe access.
Large access doors/plate	Damaged or difficult to open	Large access doors or plates cannot be opened/removed using normal equipment.	Replace or repair access door so it can be opened as designed.
	Gaps, doesn't cover completely	Large access doors not flat and/or access opening not completely covered.	Doors close flat; covers access opening completely.
	Lifting Rings missing, rusted	Lifting rings not capable of lifting weight of door or plate.	Lifting rings sufficient to lift or remove door or plate.
Infiltration Pond, Tank, Vault, Trench, or Small Basin Filter Bags	Plugged	Filter bag more than ½ full.	Replace filter bag or redesign system.
Infiltration Pond, Tank, Vault, Trench, or Small Basin Pre-settling Ponds and Vaults	Sediment accumulation	6" or more of sediment has accumulated.	Pre-settling occurs as designed
Infiltration Pond, Rock Filter	Plugged	High water level on upstream side of filter remains for extended period of time or little or no water flows through filter during heavy rain storms.	Rock filter replaced evaluate need for filter and remove if not necessary.
Infiltration Pond Emergency Overflow Spillway	Rock missing	Only one layer of rock exists above native soil in area five square feet or larger, or any exposure of native soil at the top of out flow path of spillway. Rip-rap on inside slopes need not be replaced.	Spillway restored to design standards.
	Tree growth	Tree growth impedes flow or threatens stability of spillway.	Trees removed.

NO. 3 – DETENTION TANKS AND VAULTS			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Site	Trash and debris	Any trash and debris which exceed 1 cubic foot per 1,000 square feet (this is about equal to the amount of trash it would take to fill up one standard size office garbage can). In general, there should be no visual evidence of dumping.	Trash and debris cleared from site.
	Noxious weeds	Any noxious or nuisance vegetation which may constitute a hazard to County personnel or the public.	Noxious and nuisance vegetation removed according to applicable regulations. No danger of noxious vegetation where County personnel or the public might normally be.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
	Grass/groundcover	Grass or groundcover exceeds 18 inches in height.	Grass or groundcover mowed to a height no greater than 6 inches.
Tank or Vault Storage Area	Trash and debris	Any trash and debris accumulated in vault or tank (includes floatables and non-floatables).	No trash or debris in vault.
	Sediment accumulation	Accumulated sediment depth exceeds 10% of the diameter of the storage area for ½ length of storage vault or any point depth exceeds 15% of diameter. Example: 72-inch storage tank would require cleaning when sediment reaches depth of 7 inches for more than ½ length of tank.	All sediment removed from storage area.
Tank Structure	Plugged air vent	Any blockage of the vent.	Tank or vault freely vents.
	Tank bent out of shape	Any part of tank/pipe is bent out of shape more than 10% of its design shape.	Tank repaired or replaced to design.
	Gaps between sections, damaged joints or cracks or tears in wall	A gap wider than ½-inch at the joint of any tank sections or any evidence of soil particles entering the tank at a joint or through a wall.	No water or soil entering tank through joints or walls.
Vault Structure	Damage to wall, frame, bottom, and/or top slab	Cracks wider than ½-inch, any evidence of soil entering the structure through cracks or qualified inspection personnel determines that the vault is not structurally sound.	Vault is sealed and structurally sound.
Inlet/Outlet Pipes	Sediment accumulation	Sediment filling 20% or more of the pipe.	Inlet/outlet pipes clear of sediment.
	Trash and debris	Trash and debris accumulated in inlet/outlet pipes (includes floatables and non-floatables).	No trash or debris in pipes.
	Damaged	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering at the joints of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of the inlet/outlet pipe.

NO. 3 – DETENTION TANKS AND VAULTS			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Access Manhole	Cover/lid not in place	Cover/lid is missing or only partially in place. Any open manhole requires immediate maintenance.	Manhole access covered.
	Locking mechanism not working	Mechanism cannot be opened by one maintenance person with proper tools. Bolts cannot be seated. Self-locking cover/lid does not work.	Mechanism opens with proper tools.
	Cover/lid difficult to remove	One maintenance person cannot remove cover/lid after applying 80 lbs of lift.	Cover/lid can be removed and reinstalled by one maintenance person.
	Ladder rungs unsafe	Missing rungs, misalignment, rust, or cracks.	Ladder meets design standards. Allows maintenance person safe access.
Large access doors/plate	Damaged or difficult to open	Large access doors or plates cannot be opened/removed using normal equipment.	Replace or repair access door so it can be opened as designed.
	Gaps, doesn't cover completely	Large access doors not flat and/or access opening not completely covered.	Doors close flat; covers access opening completely.
	Lifting Rings missing, rusted	Lifting rings not capable of lifting weight of door or plate.	Lifting rings sufficient to lift or remove door or plate.

NO. 4 – CONTROL STRUCTURE/FLOW RESTRICTOR			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
Structure	Trash and debris	Trash or debris of more than ½ cubic foot which is located immediately in front of the structure opening or is blocking capacity of the structure by more than 10%.	No Trash or debris blocking or potentially blocking entrance to structure.
		Trash or debris in the structure that exceeds 1/3 the depth from the bottom of basin to invert the lowest pipe into or out of the basin.	No trash or debris in the structure.
		Deposits of garbage exceeding 1 cubic foot in volume.	No condition present which would attract or support the breeding of insects or rodents.
	Sediment	Sediment exceeds 60% of the depth from the bottom of the structure to the invert of the lowest pipe into or out of the structure or the bottom of the FROP-T section or is within 6 inches of the invert of the lowest pipe into or out of the structure or the bottom of the FROP-T section.	Sump of structure contains no sediment.
	Damage to frame and/or top slab	Corner of frame extends more than ¾ inch past curb face into the street (If applicable).	Frame is even with curb.
		Top slab has holes larger than 2 square inches or cracks wider than ¼ inch.	Top slab is free of holes and cracks.
		Frame not sitting flush on top slab, i.e., separation of more than ¾ inch of the frame from the top slab.	Frame is sitting flush on top slab.
	Cracks in walls or bottom	Cracks wider than ½ inch and longer than 3 feet, any evidence of soil particles entering structure through cracks, or maintenance person judges that structure is unsound.	Structure is sealed and structurally sound.
		Cracks wider than ½ inch and longer than 1 foot at the joint of any inlet/outlet pipe or any evidence of soil particles entering structure through cracks.	No cracks more than ¼ inch wide at the joint of inlet/outlet pipe.
	Settlement/ misalignment	Structure has settled more than 1 inch or has rotated more than 2 inches out of alignment.	Basin replaced or repaired to design standards.
	Damaged pipe joints	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering the structure at the joint of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of inlet/outlet pipes.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
	Ladder rungs missing or unsafe	Ladder is unsafe due to missing rungs, misalignment, rust, cracks, or sharp edges.	Ladder meets design standards and allows maintenance person safe access.
FROP-T Section	Damage	T section is not securely attached to structure wall and outlet pipe structure should support at least 1,000 lbs of up or down pressure.	T section securely attached to wall and outlet pipe.
		Structure is not in upright position (allow up to 10% from plumb).	Structure in correct position.
		Connections to outlet pipe are not watertight or show signs of deteriorated grout.	Connections to outlet pipe are water tight; structure repaired or replaced and works as designed.
		Any holes—other than designed holes—in the structure.	Structure has no holes other than designed holes.

NO. 4 – CONTROL STRUCTURE/FLOW RESTRICTOR			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
Cleanout Gate	Damaged or missing	Cleanout gate is missing.	Replace cleanout gate.
		Cleanout gate is not watertight.	Gate is watertight and works as designed.
		Gate cannot be moved up and down by one maintenance person.	Gate moves up and down easily and is watertight.
		Chain/rod leading to gate is missing or damaged.	Chain is in place and works as designed.
Orifice Plate	Damaged or missing	Control device is not working properly due to missing, out of place, or bent orifice plate.	Plate is in place and works as designed.
	Obstructions	Any trash, debris, sediment, or vegetation blocking the plate.	Plate is free of all obstructions and works as designed.
Overflow Pipe	Obstructions	Any trash or debris blocking (or having the potential of blocking) the overflow pipe.	Pipe is free of all obstructions and works as designed.
	Deformed or damaged lip	Lip of overflow pipe is bent or deformed.	Overflow pipe does not allow overflow at an elevation lower than design
Inlet/Outlet Pipe	Sediment accumulation	Sediment filling 20% or more of the pipe.	Inlet/outlet pipes clear of sediment.
	Trash and debris	Trash and debris accumulated in inlet/outlet pipes (includes floatables and non-floatables).	No trash or debris in pipes.
	Damaged	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering at the joints of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of the inlet/outlet pipe.
Metal Grates (If Applicable)	Unsafe grate opening	Grate with opening wider than 7/8 inch.	Grate opening meets design standards.
	Trash and debris	Trash and debris that is blocking more than 20% of grate surface.	Grate free of trash and debris. footnote to guidelines for disposal
	Damaged or missing	Grate missing or broken member(s) of the grate.	Grate is in place and meets design standards.
Manhole Cover/Lid	Cover/lid not in place	Cover/lid is missing or only partially in place. Any open structure requires urgent maintenance.	Cover/lid protects opening to structure.
	Locking mechanism Not Working	Mechanism cannot be opened by one maintenance person with proper tools. Bolts cannot be seated. Self-locking cover/lid does not work.	Mechanism opens with proper tools.
	Cover/lid difficult to Remove	One maintenance person cannot remove cover/lid after applying 80 lbs. of lift.	Cover/lid can be removed and reinstalled by one maintenance person.

NO. 5 – CATCH BASINS AND MANHOLES			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
Structure	Sediment	Sediment exceeds 60% of the depth from the bottom of the catch basin to the invert of the lowest pipe into or out of the catch basin or is within 6 inches of the invert of the lowest pipe into or out of the catch basin.	Sump of catch basin contains no sediment.
	Trash and debris	Trash or debris of more than ½ cubic foot which is located immediately in front of the catch basin opening or is blocking capacity of the catch basin by more than 10%.	No Trash or debris blocking or potentially blocking entrance to catch basin.
		Trash or debris in the catch basin that exceeds 1/3 the depth from the bottom of basin to invert the lowest pipe into or out of the basin.	No trash or debris in the catch basin.
		Dead animals or vegetation that could generate odors that could cause complaints or dangerous gases (e.g., methane).	No dead animals or vegetation present within catch basin.
		Deposits of garbage exceeding 1 cubic foot in volume.	No condition present which would attract or support the breeding of insects or rodents.
	Damage to frame and/or top slab	Corner of frame extends more than ¾ inch past curb face into the street (If applicable).	Frame is even with curb.
		Top slab has holes larger than 2 square inches or cracks wider than ¼ inch.	Top slab is free of holes and cracks.
		Frame not sitting flush on top slab, i.e., separation of more than ¾ inch of the frame from the top slab.	Frame is sitting flush on top slab.
	Cracks in walls or bottom	Cracks wider than ½ inch and longer than 3 feet, any evidence of soil particles entering catch basin through cracks, or maintenance person judges that catch basin is unsound.	Catch basin is sealed and is structurally sound.
		Cracks wider than ½ inch and longer than 1 foot at the joint of any inlet/outlet pipe or any evidence of soil particles entering catch basin through cracks.	No cracks more than 1/4 inch wide at the joint of inlet/outlet pipe.
	Settlement/ misalignment	Catch basin has settled more than 1 inch or has rotated more than 2 inches out of alignment.	Basin replaced or repaired to design standards.
	Damaged pipe joints	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering the catch basin at the joint of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of inlet/outlet pipes.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
	Inlet/Outlet Pipe	Sediment accumulation	Sediment filling 20% or more of the pipe.
Trash and debris		Trash and debris accumulated in inlet/outlet pipes (includes floatables and non-floatables).	No trash or debris in pipes.
Damaged		Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering at the joints of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of the inlet/outlet pipe.

NO. 5 – CATCH BASINS AND MANHOLES			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
Metal Grates (Catch Basins)	Unsafe grate opening	Grate with opening wider than $\frac{7}{8}$ inch.	Grate opening meets design standards.
	Trash and debris	Trash and debris that is blocking more than 20% of grate surface.	Grate free of trash and debris. footnote to guidelines for disposal
	Damaged or missing	Grate missing or broken member(s) of the grate. Any open structure requires urgent maintenance.	Grate is in place and meets design standards.
Manhole Cover/Lid	Cover/lid not in place	Cover/lid is missing or only partially in place. Any open structure requires urgent maintenance.	Cover/lid protects opening to structure.
	Locking mechanism Not Working	Mechanism cannot be opened by one maintenance person with proper tools. Bolts cannot be seated. Self-locking cover/lid does not work.	Mechanism opens with proper tools.
	Cover/lid difficult to Remove	One maintenance person cannot remove cover/lid after applying 80 lbs. of lift.	Cover/lid can be removed and reinstalled by one maintenance person.

NO. 6 – CONVEYANCE PIPES AND DITCHES			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Pipes	Sediment & debris accumulation	Accumulated sediment or debris that exceeds 20% of the diameter of the pipe.	Water flows freely through pipes.
	Vegetation/roots	Vegetation/roots that reduce free movement of water through pipes.	Water flows freely through pipes.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
	Damage to protective coating or corrosion	Protective coating is damaged; rust or corrosion is weakening the structural integrity of any part of pipe.	Pipe repaired or replaced.
	Damaged	Any dent that decreases the cross section area of pipe by more than 20% or is determined to have weakened structural integrity of the pipe.	Pipe repaired or replaced.
Ditches	Trash and debris	Trash and debris exceeds 1 cubic foot per 1,000 square feet of ditch and slopes.	Trash and debris cleared from ditches.
	Sediment accumulation	Accumulated sediment that exceeds 20% of the design depth.	Ditch cleaned/flushed of all sediment and debris so that it matches design.
	Noxious weeds	Any noxious or nuisance vegetation which may constitute a hazard to County personnel or the public.	Noxious and nuisance vegetation removed according to applicable regulations. No danger of noxious vegetation where County personnel or the public might normally be.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
	Vegetation	Vegetation that reduces free movement of water through ditches.	Water flows freely through ditches.
	Erosion damage to slopes	Any erosion observed on a ditch slope.	Slopes are not eroding.
	Rock lining out of place or missing (If Applicable)	One layer or less of rock exists above native soil area 5 square feet or more, any exposed native soil.	Replace rocks to design standards.

NO. 7 – DEBRIS BARRIERS (E.G., TRASH RACKS)			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed.
Site	Trash and debris	Trash or debris plugging more than 20% of the area of the barrier.	Barrier clear to receive capacity flow.
	Sediment accumulation	Sediment accumulation of greater than 20% of the area of the barrier	Barrier clear to receive capacity flow.
Structure	Cracked broken or loose	Structure which bars attached to is damaged - pipe is loose or cracked or concrete structure is cracked, broken or loose.	Structure barrier attached to is sound.
Bars	Bar spacing	Bar spacing exceeds 6 inches.	Bars have at most 6 inches spacing.
	Damaged or missing bars	Bars are bent out of shape more than 3 inches.	Bars in place with no bends more than ¾ inch.
		Bars are missing or entire barrier missing.	Bars in place according to design.
		Bars are loose and rust is causing 50% deterioration to any part of barrier.	Repair or replace barrier to design standards.

NO. 8 – ENERGY DISSIPATERS			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed.
Site	Trash and debris	Trash and/or debris accumulation.	Dissipater clear of trash and/or debris.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
Rock Pad	Missing or moved Rock	Only one layer of rock exists above native soil in area five square feet or larger or any exposure of native soil.	Rock pad prevents erosion.
Dispersion Trench	Pipe plugged with sediment	Accumulated sediment that exceeds 20% of the design depth.	Pipe cleaned/flushed so that it matches design.
	Not discharging water properly	Visual evidence of water discharging at concentrated points along trench (normal condition is a "sheet flow" of water along trench).	Water discharges from feature by sheet flow.
	Perforations plugged.	Over 1/4 of perforations in pipe are plugged with debris or sediment.	Perforations freely discharge flow.
	Water flows out top of "distributor" catch basin.	Water flows out of distributor catch basin during any storm less than the design storm.	No flow discharges from distributor catch basin.
	Receiving area over-saturated	Water in receiving area is causing or has potential of causing landslide problems.	No danger of landslides.
Gabions	Damaged mesh	Mesh of gabion broken, twisted or deformed so structure is weakened or rock may fall out.	Mesh is intact, no rock missing.
	Corrosion	Gabion mesh shows corrosion through more than ¼ of its gage.	All gabion mesh capable of containing rock and retaining designed form.
	Collapsed or deformed baskets	Gabion basket shape deformed due to any cause.	All gabion baskets intact, structure stands as designed.
	Missing rock	Any rock missing that could cause gabion to loose structural integrity.	No rock missing.
Manhole/Chamber	Worn or damaged post, baffles or side of chamber	Structure dissipating flow deteriorates to ½ or original size or any concentrated worn spot exceeding one square foot which would make structure unsound.	Structure is in no danger of failing.
	Damage to wall, frame, bottom, and/or top slab	Cracks wider than ½-inch or any evidence of soil entering the structure through cracks, or maintenance inspection personnel determines that the structure is not structurally sound.	Manhole/chamber is sealed and structurally sound.
	Damaged pipe joints	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering the structure at the joint of the inlet/outlet pipes.	No soil or water enters and no water discharges at the joint of inlet/outlet pipes.

NO. 9 – FENCING			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Site	Erosion or holes under fence	Erosion or holes more than 4 inches high and 12-18 inches wide permitting access through an opening under a fence.	No access under the fence.
Wood Posts, Boards and Cross Members	Missing or damaged parts	Missing or broken boards, post out of plumb by more than 6 inches or cross members broken	No gaps on fence due to missing or broken boards, post plumb to within 1½ inches, cross members sound.
	Weakened by rotting or insects	Any part showing structural deterioration due to rotting or insect damage	All parts of fence are structurally sound.
	Damaged or failed post foundation	Concrete or metal attachments deteriorated or unable to support posts.	Post foundation capable of supporting posts even in strong wind.
Metal Posts, Rails and Fabric	Damaged parts	Post out of plumb more than 6 inches.	Post plumb to within 1½ inches.
		Top rails bent more than 6 inches.	Top rail free of bends greater than 1 inch.
		Any part of fence (including post, top rails, and fabric) more than 1 foot out of design alignment.	Fence is aligned and meets design standards.
		Missing or loose tension wire.	Tension wire in place and holding fabric.
	Deteriorated paint or protective coating	Part or parts that have a rusting or scaling condition that has affected structural adequacy.	Structurally adequate posts or parts with a uniform protective coating.
	Openings in fabric	Openings in fabric are such that an 8-inch diameter ball could fit through.	Fabric mesh openings within 50% of grid size.

NO. 10 – GATES/BOLLARDS/ACCESS BARRIERS			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Chain Link Fencing Gate	Damaged or missing members	Missing gate.	Gates in place.
		Broken or missing hinges such that gate cannot be easily opened and closed by a maintenance person.	Hinges intact and lubed. Gate is working freely.
		Gate is out of plumb more than 6 inches and more than 1 foot out of design alignment.	Gate is aligned and vertical.
		Missing stretcher bar, stretcher bands, and ties.	Stretcher bar, bands, and ties in place.
	Locking mechanism does not lock gate	Locking device missing, no-functioning or does not link to all parts.	Locking mechanism prevents opening of gate.
	Openings in fabric	Openings in fabric are such that an 8-inch diameter ball could fit through.	Fabric mesh openings within 50% of grid size.
Bar Gate	Damaged or missing cross bar	Cross bar does not swing open or closed, is missing or is bent to where it does not prevent vehicle access.	Cross bar swings fully open and closed and prevents vehicle access.
	Locking mechanism does not lock gate	Locking device missing, no-functioning or does not link to all parts.	Locking mechanism prevents opening of gate.
	Support post damaged	Support post does not hold cross bar up.	Cross bar held up preventing vehicle access into facility.
Bollards	Damaged or missing	Bollard broken, missing, does not fit into support hole or hinge broken or missing.	No access for motorized vehicles to get into facility.
	Does not lock	Locking assembly or lock missing or cannot be attached to lock bollard in place.	No access for motorized vehicles to get into facility.
Boulders	Dislodged	Boulders not located to prevent motorized vehicle access.	No access for motorized vehicles to get into facility.
	Circumvented	Motorized vehicles going around or between boulders.	No access for motorized vehicles to get into facility.

NO. 11 – GROUNDS (LANDSCAPING)			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Site	Trash or litter	Any trash and debris which exceed 1 cubic foot per 1,000 square feet (this is about equal to the amount of trash it would take to fill up one standard size office garbage can). In general, there should be no visual evidence of dumping.	Trash and debris cleared from site.
	Noxious weeds	Any noxious or nuisance vegetation which may constitute a hazard to County personnel or the public.	Noxious and nuisance vegetation removed according to applicable regulations. No danger of noxious vegetation where County personnel or the public might normally be.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
	Grass/groundcover	Grass or groundcover exceeds 18 inches in height.	Grass or groundcover mowed to a height no greater than 6 inches.
Trees and Shrubs	Hazard	Any tree or limb of a tree identified as having a potential to fall and cause property damage or threaten human life. A hazard tree identified by a qualified arborist must be removed as soon as possible.	No hazard trees in facility.
	Damaged	Limbs or parts of trees or shrubs that are split or broken which affect more than 25% of the total foliage of the tree or shrub.	Trees and shrubs with less than 5% of total foliage with split or broken limbs.
		Trees or shrubs that have been blown down or knocked over.	No blown down vegetation or knocked over vegetation. Trees or shrubs free of injury.
		Trees or shrubs which are not adequately supported or are leaning over, causing exposure of the roots.	Tree or shrub in place and adequately supported; dead or diseased trees removed.

NO. 12 – ACCESS ROADS			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
Site	Trash and debris	Trash and debris exceeds 1 cubic foot per 1,000 square feet (i.e., trash and debris would fill up one standards size garbage can).	Roadway drivable by maintenance vehicles.
		Debris which could damage vehicle tires or prohibit use of road.	Roadway drivable by maintenance vehicles.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
	Blocked roadway	Any obstruction which reduces clearance above road surface to less than 14 feet.	Roadway overhead clear to 14 feet high.
Any obstruction restricting the access to a 10- to 12 foot width for a distance of more than 12 feet or any point restricting access to less than a 10 foot width.		At least 12-foot of width on access road.	
Road Surface	Erosion, settlement, potholes, soft spots, ruts	Any surface defect which hinders or prevents maintenance access.	Road drivable by maintenance vehicles.
	Vegetation on road surface	Trees or other vegetation prevent access to facility by maintenance vehicles.	Maintenance vehicles can access facility.
Shoulders and Ditches	Erosion	Erosion within 1 foot of the roadway more than 8 inches wide and 6 inches deep.	Shoulder free of erosion and matching the surrounding road.
	Weeds and brush	Weeds and brush exceed 18 inches in height or hinder maintenance access.	Weeds and brush cut to 2 inches in height or cleared in such a way as to allow maintenance access.
Modular Grid Pavement	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
	Damaged or missing	Access surface compacted because of broken or missing modular block.	Access road surface restored so road infiltrates.

NO. 13 – BASIC BIOSWALE (GRASS)			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
Site	Trash and debris	Any trash and/or debris accumulated on the bioswale site.	No trash or debris on the bioswale site.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
Swale Section	Sediment accumulation	Sediment depth exceeds 2 inches in 10% of the swale treatment area.	No sediment deposits in grass treatment area of the bioswale.
		Sediment inhibits grass growth over 10% of swale length.	Grass growth not inhibited by sediment.
		Sediment inhibits even spreading of flow.	Flow spreads evenly through swale
	Erosion/scouring	Eroded or scoured swale bottom due to channelization or high flows.	No eroded or scoured areas in bioswale. Cause of erosion or scour addressed.
	Poor vegetation coverage	Grass is sparse or bare or eroded patches occur in more than 10% of the swale bottom.	Swale has no bare spots and grass is thick and healthy.
	Grass too tall	Grass excessively tall (greater than 10 inches), grass is thin or nuisance weeds and other vegetation have taken over.	Grass is between 3 and 4 inches tall, thick and healthy. No clippings left in swale. No nuisance vegetation present.
	Excessive shade	Grass growth is poor because sunlight does not reach swale.	Health grass growth or swale converted to a wet bioswale.
	Constant baseflow	Continuous flow through the swale, even when it has been dry for weeks or an eroded, muddy channel has formed in the swale bottom.	Baseflow removed from swale by a low-flow pea-gravel drain or bypassed around the swale.
	Standing water	Water pools in the swale between storms or does not drain freely.	Swale freely drains and there is no standing water in swale between storms.
Channelization	Flow concentrates and erodes channel through swale.	No flow channels in swale.	
Flow Spreader	Concentrated flow	Flow from spreader not uniformly distributed across entire swale width.	Flows are spread evenly over entire swale width.
Inlet/Outlet Pipe	Sediment accumulation	Sediment filling 20% or more of the pipe.	Inlet/outlet pipes clear of sediment.
	Trash and debris	Trash and debris accumulated in inlet/outlet pipes (includes floatables and non-floatables).	No trash or debris in pipes.
	Damaged	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering at the joints of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of the inlet/outlet pipe.

NO. 14 – WET BIOSWALE			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance Is Performed
Site	Trash and debris	Any trash and/or debris accumulated at the site.	No trash or debris at the site.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
Swale Section	Sediment accumulation	Sediment depth exceeds 2 inches in 10% of the swale treatment area.	No sediment deposits in treatment area.
	Erosion/scouring	Eroded or scoured swale bottom due to channelization or high flows.	No eroded or scoured areas in bioswale. Cause of erosion or scour addressed.
	Water depth	Water not retained to a depth of about 4 inches during the wet season.	Water depth of 4 inches through out swale for most of wet season.
	Vegetation ineffective	Vegetation sparse, does not provide adequate filtration or crowded out by very dense clumps of cattail or nuisance vegetation.	Wetland vegetation fully covers bottom of swale and no cattails or nuisance vegetation present.
	Insufficient water	Wetland vegetation dies due to lack of water.	Wetland vegetation remains healthy (may require converting to grass lined bioswale)
Flow Spreader	Concentrated flow	Flow from spreader not uniformly distributed across entire swale width.	Flows are spread evenly over entire swale width.
Inlet/Outlet Pipe	Sediment accumulation	Sediment filling 20% or more of the pipe.	Inlet/outlet pipes clear of sediment.
	Trash and debris	Trash and debris accumulated in inlet/outlet pipes (includes floatables and non-floatables).	No trash or debris in pipes.
	Damaged	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering at the joints of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of the inlet/outlet pipe.

NO. 15 – FILTER STRIP			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance Is Performed
Site	Trash and debris	Any trash and debris accumulated on the filter strip site.	Filter strip site free of any trash or debris
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
Grass Strip	Sediment accumulation	Sediment accumulation on grass exceeds 2 inches depth.	No sediment deposits in treatment area.
	Erosion/scouring	Eroded or scoured swale bottom due to channelization or high flows.	No eroded or scoured areas in bioswale. Cause of erosion or scour addressed.
	Grass too tall	Grass excessively tall (greater than 10 inches), grass is thin or nuisance weeds and other vegetation have taken over.	Grass is between 3 and 4 inches tall, thick and healthy. No clippings left in swale. No nuisance vegetation present.
	Vegetation ineffective	Grass has died out, become excessively tall (greater than 10 inches) or nuisance vegetation is taking over.	Grass is healthy, less than 9 inches high and no nuisance vegetation present.
Flow Spreader	Concentrated flow	Flow from spreader not uniformly distributed across entire swale width.	Flows are spread evenly over entire swale width.
Inlet/Outlet Pipe	Sediment accumulation	Sediment filling 20% or more of the pipe.	Inlet/outlet pipes clear of sediment.
	Trash and debris	Trash and debris accumulated in inlet/outlet pipes (includes floatables and non-floatables).	No trash or debris in pipes.
	Damaged	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering at the joints of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of the inlet/outlet pipe.

NO. 16 – WETPOND			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance Is Performed
Site	Trash and debris	Any trash and debris accumulated on the wetpond site.	Wetpond site free of any trash or debris.
	Noxious weeds	Any noxious or nuisance vegetation which may constitute a hazard to County personnel or the public.	Noxious and nuisance vegetation removed according to applicable regulations. No danger of noxious vegetation where County personnel or the public might normally be.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
	Grass/groundcover	Grass or groundcover exceeds 18 inches in height.	Grass or groundcover mowed to a height no greater than 6 inches.
Side Slopes of Dam, Berm, internal berm or Embankment	Rodent holes	Any evidence of rodent holes if facility is acting as a dam or berm, or any evidence of water piping through dam or berm via rodent holes.	Rodents removed or destroyed and dam or berm repaired.
	Tree growth	Tree growth threatens integrity of dams, berms or slopes, does not allow maintenance access, or interferes with maintenance activity. If trees are not a threat to dam, berm or embankment integrity, are not interfering with access or maintenance or leaves do not cause a plugging problem they do not need to be removed.	Trees do not hinder facility performance or maintenance activities.
	Erosion	Eroded damage over 2 inches deep where cause of damage is still present or where there is potential for continued erosion. Any erosion observed on a compacted slope.	Slopes stabilized using appropriate erosion control measures. If erosion is occurring on compacted slope, a licensed civil engineer should be consulted to resolve source of erosion.
Top or Side Slopes of Dam, Berm, internal berm or Embankment	Settlement	Any part of a dam, berm or embankment that has settled 4 inches lower than the design elevation.	Top or side slope restored to design dimensions. If settlement is significant, a licensed civil engineer should be consulted to determine the cause of the settlement.
	Irregular surface on internal berm	Top of berm not uniform and level.	Top of berm graded to design elevation.
Pond Areas	Sediment accumulation (except first wetpool cell)	Accumulated sediment that exceeds 10% of the designed pond depth.	Sediment cleaned out to designed pond shape and depth.
	Sediment accumulation (first wetpool cell)	Sediment accumulations in pond bottom that exceeds the depth of sediment storage (1 foot) plus 6 inches.	Sediment storage contains no sediment.
	Liner damaged (If Applicable)	Liner is visible or pond does not hold water as designed.	Liner repaired or replaced.
	Water level (all wetpool cells)	Cell level(s) drops more than 12 inches in any 7-day period.	Cell level(s) drops less than 12 inches in any 7-day period.
	Algae mats (first wetpool cell)	Algae mats develop over more than 10% of the water surface should be removed.	Algae mats removed (usually in the late summer before Fall rains, especially in Sensitive Lake Protection Areas.)

NO. 16 – WETPOND			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance Is Performed
	Design planting and vegetation survival and maintenance	Sparse or dying design planting, or when design plantings are not thriving across 80% or more of the design vegetated areas within the pond; invasive vegetation e.g., cattails	Design plantings and vegetation are thriving and appropriately spaced across 80% or more of the design vegetated areas within the pond; invasives removed including root clumps
Gravity Drain	Inoperable valve	Valve will not open and close.	Valve opens and closes normally.
	Valve won't seal	Valve does not seal completely.	Valve completely seals closed.
Emergency Overflow Spillway	Tree growth	Tree growth impedes flow or threatens stability of spillway.	Trees removed.
	Rock missing	Only one layer of rock exists above native soil in area five square feet or larger, or any exposure of native soil at the top of out flow path of spillway. Rip-rap on inside slopes need not be replaced.	Spillway restored to design standards.
Inlet/Outlet Pipe	Sediment accumulation	Sediment filling 20% or more of the pipe.	Inlet/outlet pipes clear of sediment.
	Trash and debris	Trash and debris accumulated in inlet/outlet pipes (includes floatables and non-floatables).	No trash or debris in pipes.
	Damaged	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering at the joints of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of the inlet/outlet pipe.

NO. 17 – WETVAULT			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
Site	Trash and debris	Trash and debris accumulated on facility site.	Trash and debris removed from facility site.
Treatment Area	Trash and debris	Any trash and debris accumulated in vault (includes floatables and non-floatables).	No trash or debris in vault.
	Sediment accumulation	Sediment accumulation in vault bottom exceeds the depth of the sediment zone plus 6 inches.	No sediment in vault.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
Vault Structure	Damage to wall, frame, bottom, and/or top slab	Cracks wider than ½-inch, any evidence of soil entering the structure through cracks, vault does not retain water or qualified inspection personnel determines that the vault is not structurally sound.	Vault is sealed and structurally sound.
	Baffles damaged	Baffles corroding, cracking, warping and/or showing signs of failure or baffle cannot be removed.	Repair or replace baffles or walls to specifications.
	Ventilation	Ventilation area blocked or plugged.	No reduction of ventilation area exists.
Inlet/Outlet Pipe	Sediment accumulation	Sediment filling 20% or more of the pipe.	Inlet/outlet pipes clear of sediment.
	Trash and debris	Trash and debris accumulated in inlet/outlet pipes (includes floatables and non-floatables).	No trash or debris in pipes.
	Damaged	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering at the joints of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of the inlet/outlet pipe.
Gravity Drain	Inoperable valve	Valve will not open and close.	Valve opens and closes normally.
	Valve won't seal	Valve does not seal completely.	Valve completely seals closed.
Access Manhole	Access cover/lid damaged or difficult to open	Access cover/lid cannot be easily opened by one person. Corrosion/deformation of cover/lid.	Access cover/lid can be opened by one person.
	Locking mechanism not working	Mechanism cannot be opened by one maintenance person with proper tools. Bolts cannot be seated. Self-locking cover/lid does not work.	Mechanism opens with proper tools.
	Cover/lid difficult to remove	One maintenance person cannot remove cover/lid after applying 80 lbs of lift.	Cover/lid can be removed and reinstalled by one maintenance person.
	Access doors/plate has gaps, doesn't cover completely	Large access doors not flat and/or access opening not completely covered.	Doors close flat; covers access opening completely.
	Lifting Rings missing, rusted	Lifting rings not capable of lifting weight of door or plate.	Lifting rings sufficient to lift or remove door or plate.
	Ladder rungs unsafe	Missing rungs, misalignment, rust, or cracks.	Ladder meets design standards. Allows maintenance person safe access.

NO. 18 – STORMWATER WETLAND			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance Is Performed
Site	Trash and debris	Trash and debris accumulated on facility site.	Trash and debris removed from facility site.
	Noxious weeds	Any noxious or nuisance vegetation which may constitute a hazard to County personnel or the public.	Noxious and nuisance vegetation removed according to applicable regulations. No danger of noxious vegetation where County personnel or the public might normally be.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
	Grass/groundcover	Grass or groundcover exceeds 18 inches in height.	Grass or groundcover mowed to a height no greater than 6 inches.
Side Slopes of Dam, Berm, internal berm or Embankment	Rodent holes	Any evidence of rodent holes if facility is acting as a dam or berm, or any evidence of water piping through dam or berm via rodent holes.	Rodents removed or destroyed and dam or berm repaired.
	Tree growth	Tree growth threatens integrity of dams, berms or slopes, does not allow maintenance access, or interferes with maintenance activity. If trees are not a threat to dam, berm, or embankment integrity or not interfering with access or maintenance, they do not need to be removed.	Trees do not hinder facility performance or maintenance activities.
	Erosion	Eroded damage over 2 inches deep where cause of damage is still present or where there is potential for continued erosion. Any erosion observed on a compacted slope.	Slopes stabilized using appropriate erosion control measures. If erosion is occurring on compacted slope, a licensed civil engineer should be consulted to resolve source of erosion.
Top or Side Slopes of Dam, Berm, internal berm or Embankment	Settlement	Any part of a dam, berm or embankment that has settled 4 inches lower than the design elevation.	Top or side slope restored to design dimensions. If settlement is significant, a licensed civil engineer should be consulted to determine the cause of the settlement.
	Irregular surface on internal berm	Top of berm not uniform and level.	Top of berm graded flat to design elevation.
Pond Areas	Sediment accumulation (first cell/forebay)	Sediment accumulations in pond bottom that exceeds the depth of sediment storage (1 foot) plus 6 inches.	Sediment storage contains no sediment.
	Sediment accumulation (wetland cell)	Accumulated sediment that exceeds 10% of the designed pond depth.	Sediment cleaned out to designed pond shape and depth.
	Liner damaged (If Applicable)	Liner is visible or pond does not hold water as designed.	Liner repaired or replaced.
	Water level (first cell/forebay)	Cell level drops more than 12 inches in any 7-day period.	Cell level drops no more than 12 inches in any 7-day period.
	Water level (wetland cell)	Cell does not retain water for at least 10 months of the year or wetland plants are not surviving.	Water retained at least 10 months of the year or wetland plants are surviving.
	Algae mats (first cell/forebay)	Algae mats develop over more than 10% of the water surface should be removed.	Algae mats removed (usually in the late summer before Fall rains, especially in Sensitive Lake Protection Areas.)

NO. 18 – STORMWATER WETLAND			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance Is Performed
	Vegetation	Vegetation dead, dying, or overgrown (cattails) or not meeting original planting specifications across more than 20% of the entire design vegetated area within the pond.	Plants in wetland cell surviving across 80% or more of the entire design vegetated area within the pond and not interfering with wetland function.
Gravity Drain	Inoperable valve	Valve will not open and close.	Valve opens and closes normally.
	Valve won't seal	Valve does not seal completely.	Valve completely seals closed.
Emergency Overflow Spillway	Tree growth	Tree growth impedes flow or threatens stability of spillway.	Trees removed.
	Rock missing	Only one layer of rock exists above native soil in area five square feet or larger, or any exposure of native soil at the top of out flow path of spillway. Rip-rap on inside slopes need not be replaced.	Spillway restored to design standards.
Inlet/Outlet Pipe	Sediment accumulation	Sediment filling 20% or more of the pipe.	Inlet/outlet pipes clear of sediment.
	Trash and debris	Trash and debris accumulated in inlet/outlet pipes (includes floatables and non-floatables).	No trash or debris in pipes.
	Damaged	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering at the joints of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of the inlet/outlet pipe.

NO. 19 – SAND FILTER POND			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance Is Performed
Site	Trash and debris	Trash and debris accumulated on facility site.	Trash and debris removed from facility site.
	Noxious weeds	Any noxious or nuisance vegetation which may constitute a hazard to County personnel or the public.	Noxious and nuisance vegetation removed according to applicable regulations. No danger of noxious vegetation where County personnel or the public might normally be.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
	Grass/groundcover (not in the treatment area)	Grass or groundcover exceeds 18 inches in height.	Grass or groundcover mowed to a height no greater than 6 inches.
Pre-Treatment (if applicable)	Sediment accumulation	Sediment accumulations in pond bottom that exceeds the depth of sediment storage (1 foot) plus 6 inches.	Sediment storage contains no sediment.
	Liner damaged (If Applicable)	Liner is visible or pond does not hold water as designed.	Liner repaired or replaced.
	Water level	Cell empty, doesn't hold water.	Water retained in first cell for most of the year.
	Algae mats	Algae mats develop over more than 10% of the water surface should be removed.	Algae mats removed (usually in the late summer before Fall rains, especially in Sensitive Lake Protection Areas.)
Pond Area	Sediment accumulation	Sediment or crust depth exceeds ½-inch over 10 % of surface area of sand filter.	No sediment or crust deposit on sand filter that would impede permeability of the filter section.
	Grass (if applicable)	Grass becomes excessively tall (greater than 6 inches) or when nuisance weeds and other vegetation start to take over or thatch build up occurs.	Mow vegetation and/or remove nuisance vegetation.
Side Slopes of Pond	Rodent holes	Any evidence of rodent holes if facility is acting as a dam or berm, or any evidence of water piping through dam or berm via rodent holes.	Rodents removed or destroyed and dam or berm repaired.
	Tree growth	Tree growth threatens integrity of dams, berms or slopes, does not allow maintenance access, or interferes with maintenance activity. If trees are not a threat to dam, berm, or embankment integrity or not interfering with access or maintenance, they do not need to be removed.	Trees do not hinder facility performance or maintenance activities.
	Erosion	Eroded damage over 2 inches deep where cause of damage is still present or where there is potential for continued erosion. Any erosion observed on a compacted slope.	Slopes stabilized using appropriate erosion control measures. If erosion is occurring on compacted slope, a licensed civil engineer should be consulted to resolve source of erosion.

NO. 19 – SAND FILTER POND			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance Is Performed
Sand Filter Media	Plugging	Drawdown of water through the sand filter media, takes longer than 24 hours, and/or flow through the overflow pipes occurs frequently. A sieve analysis of >4% -100 or >2% -200 requires replacing sand filter media.	Sand filter media surface is aerated or the surface is scraped and replaced, and drawdown rate is normal.
	Prolonged flows	Sand is saturated for prolonged periods of time (several weeks) and does not dry out between storms due to continuous base flow or prolonged flows from detention facilities.	Excess flows bypassed or confined to small portion of filter media surface.
	Short circuiting	Flows become concentrated over one section of the sand filter rather than dispersed or drawdown rate of pool exceeds 12 inches per hour.	Flow and percolation of water through the sand filter is uniform and dispersed across the entire filter area and drawdown rate is normal.
	Media thickness	Sand thickness is less than 18 inches.	Rebuild sand thickness to a minimum of 18 inches.
Underdrains and Clean-Outs	Sediment/debris	Underdrains or clean-outs partially plugged or filled with sediment and/or debris. Junction box/cleanout wyes not watertight.	Underdrains and clean-outs free of sediment and debris and are watertight.
Inlet/Outlet Pipe	Sediment accumulation	Sediment filling 20% or more of the pipe.	Inlet/outlet pipes clear of sediment.
	Trash and debris	Trash and debris accumulated in inlet/outlet pipes (includes floatables and non-floatables).	No trash or debris in pipes.
	Damaged	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering at the joints of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of the inlet/outlet pipe.
Rock Pad	Missing or out of place	Only one layer of rock exists above native soil in area five square feet or larger, or any exposure of native soil.	Rock pad restored to design standards.
Flow spreader	Concentrated flow	Flow from spreader not uniformly distributed across sand filter.	Flows spread evenly over sand filter.

NO. 20 – SAND FILTER VAULT			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
Site	Trash and debris	Trash and debris accumulated on facility site.	Trash and debris removed from facility site.
	Noxious weeds	Any noxious or nuisance vegetation which may constitute a hazard to County personnel or the public.	Noxious and nuisance vegetation removed according to applicable regulations. No danger of noxious vegetation where County personnel or the public might normally be.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oil, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
	Grass/groundcover	Grass or groundcover exceeds 18 inches in height.	Grass or groundcover mowed to a height no greater than 6 inches.
Pre-Treatment Chamber	Sediment accumulation	Sediment accumulation exceeds the depth of the sediment zone plus 6 inches.	Sediment storage contains no sediment.
Sand Filter Media	Sediment accumulation	Sediment depth exceeds ½-inch on sand filter media.	Sand filter freely drains at normal rate.
	Trash and debris	Trash and debris accumulated in vault (floatables and non-floatables).	No trash or debris in vault.
	Plugging	Drawdown of water through the sand filter media, takes longer than 24 hours, and/or flow through the overflow pipes occurs frequently. A sieve analysis of >4% -100 or >2% -200 requires replacing sand filter media.	Sand filter media drawdown rate is normal.
	Short circuiting	Seepage or flow occurs along the vault walls and corners. Sand eroding near inflow area. Cleanout wyes are not watertight.	Sand filter media section re-laid and compacted along perimeter of vault to form a semi-seal. Erosion protection added to dissipate force of incoming flow and curtail erosion.
Vault Structure	Damaged to walls, frame, bottom and/or top slab.	Cracks wider than ½-inch, any evidence of soil entering the structure through cracks or qualified inspection personnel determines that the vault is not structurally sound.	Vault replaced or repaired to provide complete sealing of the structure.
	Ventilation	Ventilation area blocked or plugged.	No reduction of ventilation area exists.
Underdrains and Cleanouts	Sediment/debris	Underdrains or clean-outs partially plugged, filled with sediment and/or debris or not watertight.	Underdrains and clean-outs free of sediment and debris and sealed.
Inlet/Outlet Pipe	Sediment accumulation	Sediment filling 20% or more of the pipe.	Inlet/outlet pipes clear of sediment.
	Trash and debris	Trash and debris accumulated in inlet/outlet pipes (includes floatables and non-floatables).	No trash or debris in pipes.
	Damaged	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering at the joints of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of the inlet/outlet pipe.

NO. 20 – SAND FILTER VAULT			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
Access Manhole	Cover/lid not in place	Cover/lid is missing or only partially in place. Any open manhole requires immediate maintenance.	Manhole access covered.
	Locking mechanism not working	Mechanism cannot be opened by one maintenance person with proper tools. Bolts cannot be seated. Self-locking cover/lid does not work.	Mechanism opens with proper tools.
	Cover/lid difficult to remove	One maintenance person cannot remove cover/lid after applying 80 lbs of lift.	Cover/lid can be removed and reinstalled by one maintenance person.
	Ladder rungs unsafe	Missing rungs, misalignment, rust, or cracks.	Ladder meets design standards. Allows maintenance person safe access.
Large access doors/plate	Damaged or difficult to open	Large access doors or plates cannot be opened/removed using normal equipment.	Replace or repair access door so it can be opened as designed.
	Gaps, doesn't cover completely	Large access doors not flat and/or access opening not completely covered.	Doors close flat; covers access opening completely.
	Lifting Rings missing, rusted	Lifting rings not capable of lifting weight of door or plate.	Lifting rings sufficient to lift or remove door or plate.

NO. 21 – STORMFILTER (CARTRIDGE TYPE)			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
Facility	Documentation	Update facility inspection record after each inspection.	Maintenance records are up to date.
		Provide certification of replaced filter media.	Filter media is certified to meet Stormfilter [®] specifications.
Site	Trash and debris	Any trash or debris which impairs the function of the facility.	Trash and debris removed from facility.
	Contaminants and pollution	Any evidence of contaminants or pollution such as oils, gasoline, concrete slurries or paint.	Materials removed and disposed of according to applicable regulations. Source control BMPs implemented if appropriate. No contaminants present other than a surface oil film.
	Life cycle	System has not been inspected for three years.	Facility is re-inspected and any needed maintenance performed.
Vault Treatment Area	Sediment on vault floor	Greater than 2 inches of sediment.	Vault is free of sediment.
	Sediment on top of cartridges	Greater than ½ inch of sediment.	Vault is free of sediment.
	Multiple scum lines above top of cartridges	Thick or multiple scum lines above top of cartridges. Probably due to plugged canisters or underdrain manifold.	Cause of plugging corrected, canisters replaced if necessary.
Vault Structure	Damage to wall, Frame, Bottom, and/or Top Slab	Cracks wider than ½-inch and any evidence of soil particles entering the structure through the cracks, or qualified inspection personnel determines the vault is not structurally sound.	Vault replaced or repaired to design specifications.
	Baffles damaged	Baffles corroding, cracking warping, and/or showing signs of failure as determined by maintenance/inspection person.	Repair or replace baffles to specification.
Filter Media	Standing water in vault	9 inches or greater of static water in the vault for more than 24 hours following a rain event and/or overflow occurs frequently. Probably due to plugged filter media, underdrain or outlet pipe.	No standing water in vault 24 hours after a rain event.
	Short circuiting	Flows do not properly enter filter cartridges.	Flows go through filter media.
Underdrains and Clean-Outs	Sediment/debris	Underdrains or clean-outs partially plugged or filled with sediment and/or debris.	Underdrains and clean-outs free of sediment and debris.
Inlet/Outlet Pipe	Sediment accumulation	Sediment filling 20% or more of the pipe.	Inlet/outlet pipes clear of sediment.
	Trash and debris	Trash and debris accumulated in inlet/outlet pipes (includes floatables and non-floatables).	No trash or debris in pipes.
	Damaged	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering at the joints of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of the inlet/outlet pipe.
Access Manhole	Cover/lid not in place	Cover/lid is missing or only partially in place. Any open manhole requires immediate maintenance.	Manhole access covered.
	Locking mechanism not working	Mechanism cannot be opened by one maintenance person with proper tools. Bolts cannot be seated. Self-locking cover/lid does not work.	Mechanism opens with proper tools.
	Cover/lid difficult to remove	One maintenance person cannot remove cover/lid after applying 80 lbs of lift.	Cover/lid can be removed and reinstalled by one maintenance person.

NO. 21 – STORMFILTER (CARTRIDGE TYPE)			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
	Ladder rungs unsafe	Missing rungs, misalignment, rust, or cracks.	Ladder meets design standards. Allows maintenance person safe access.
Large access doors/plate	Damaged or difficult to open	Large access doors or plates cannot be opened/removed using normal equipment.	Replace or repair access door so it can be opened as designed.
	Gaps, doesn't cover completely	Large access doors not flat and/or access opening not completely covered.	Doors close flat and cover access opening completely.
	Lifting Rings missing, rusted	Lifting rings not capable of lifting weight of door or plate.	Lifting rings sufficient to lift or remove door or plate.
Inspection	Frequency	<p>Maintenance conditions are site-specific, depending on pollutant loading.</p> <p>FIRST YEAR POST CONSTRUCTION: Monthly during wet season, every other month during dry season</p> <p>FOLLOWING FIRST YEAR: Continue monthly until site-specific frequency is established, then follow that schedule</p> <p>AT A MINIMUM, FOLLOWING FIRST YEAR: Annually (or quarterly if used as primary treatment) and following significant storms.</p>	Inspect Stormfilter facility for any maintenance deficiencies; maintain or replace as required per established site-specific schedule and manufacturer's requirements.

NO. 22 – BAFFLE OIL/WATER SEPARATOR			
Maintenance Component	Defect	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
Site	Trash and debris	Any trash or debris which impairs the function of the facility.	Trash and debris removed from facility.
	Contaminants and pollution	Floating oil in excess of 1 inch in first chamber, any oil in other chambers or other contaminants of any type in any chamber.	No contaminants present other than a surface oil film.
Vault Treatment Area	Sediment accumulation	Sediment accumulates exceeds 6 inches in the vault.	No sediment in the vault.
	Discharge water not clear	Inspection of discharge water shows obvious signs of poor water quality- effluent discharge from vault shows thick visible sheen.	Effluent discharge is clear.
	Trash or debris accumulation	Any trash and debris accumulation in vault (floatables and non-floatables).	Vault is clear of trash and debris.
	Oil accumulation	Oil accumulations that exceed 1 inch, at the surface of the water in the oil/water separator chamber.	No visible oil depth on water.
Vault Structure	Damage to Wall, Frame, Bottom, and/or Top Slab	Cracks wider than ½-inch or evidence of soil particles entering the structure through the cracks, or maintenance/inspection personnel determines that the vault is not structurally sound.	Vault replaced or repaired to design specifications.
	Baffles damaged	Baffles corroding, cracking, warping and/or showing signs of failure as determined by maintenance inspection personnel.	Repair or replace baffles to specifications.
Gravity Drain	Inoperable valve	Valve will not open and close.	Valve opens and closes normally.
	Valve won't seal	Valve does not seal completely.	Valve completely seals closed.
Inlet/Outlet Pipe	Sediment accumulation	Sediment filling 20% or more of the pipe.	Inlet/outlet pipes clear of sediment.
	Trash and debris	Trash and debris accumulated in inlet/outlet pipes (includes floatables and non-floatables).	No trash or debris in pipes.
	Damaged	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering at the joints of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of the inlet/outlet pipe.
Access Manhole	Cover/lid not in place	Cover/lid is missing or only partially in place. Any open manhole requires immediate maintenance.	Manhole access covered.
	Locking mechanism not working	Mechanism cannot be opened by one maintenance person with proper tools. Bolts cannot be seated. Self-locking cover/lid does not work.	Mechanism opens with proper tools.
	Cover/lid difficult to remove	One maintenance person cannot remove cover/lid after applying 80 lbs of lift.	Cover/lid can be removed and reinstalled by one maintenance person.
	Ladder rungs unsafe	Missing rungs, misalignment, rust, or cracks.	Ladder meets design standards. Allows maintenance person safe access.
Large access doors/plate	Damaged or difficult to open	Large access doors or plates cannot be opened/removed using normal equipment.	Replace or repair access door so it can be opened as designed.
	Gaps, doesn't cover completely	Large access doors not flat and/or access opening not completely covered.	Doors close flat and cover access opening completely.
	Lifting Rings missing, rusted	Lifting rings not capable of lifting weight of door or cover/lid.	Lifting rings sufficient to lift or remove cover/lid.

NO. 23 – COALESCING PLATE OIL/WATER SEPARATOR			
Maintenance Component	Defect	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
Site	Trash and debris	Any trash or debris which impairs the function of the facility.	Trash and debris removed from facility.
	Contaminants and pollution	Floating oil in excess of 1 inch in first chamber, any oil in other chambers or other contaminants of any type in any chamber.	No contaminants present other than a surface oil film.
Vault Treatment Area	Sediment accumulation in the forebay	Sediment accumulation of 6 inches or greater in the forebay.	No sediment in the forebay.
	Discharge water not clear	Inspection of discharge water shows obvious signs of poor water quality - effluent discharge from vault shows thick visible sheen.	Repair function of plates so effluent is clear.
	Trash or debris accumulation	Trash and debris accumulation in vault (floatables and non-floatables).	Trash and debris removed from vault.
	Oil accumulation	Oil accumulation that exceeds 1 inch at the water surface in the in the coalescing plate chamber.	No visible oil depth on water and coalescing plates clear of oil.
Coalescing Plates	Damaged	Plate media broken, deformed, cracked and/or showing signs of failure.	Replace that portion of media pack or entire plate pack depending on severity of failure.
	Sediment accumulation	Any sediment accumulation which interferes with the operation of the coalescing plates.	No sediment accumulation interfering with the coalescing plates.
Vault Structure	Damage to Wall, Frame, Bottom, and/or Top Slab	Cracks wider than ½-inch and any evidence of soil particles entering the structure through the cracks, or maintenance inspection personnel determines that the vault is not structurally sound.	Vault replaced or repaired to design specifications.
	Baffles damaged	Baffles corroding, cracking, warping and/or showing signs of failure as determined by maintenance/inspection person.	Repair or replace baffles to specifications.
Ventilation Pipes	Plugged	Any obstruction to the ventilation pipes.	Ventilation pipes are clear.
Shutoff Valve	Damaged or inoperable	Shutoff valve cannot be opened or closed.	Shutoff valve operates normally.
Inlet/Outlet Pipe	Sediment accumulation	Sediment filling 20% or more of the pipe.	Inlet/outlet pipes clear of sediment.
	Trash and debris	Trash and debris accumulated in inlet/outlet pipes (includes floatables and non-floatables).	No trash or debris in pipes.
	Damaged	Cracks wider than ½-inch at the joint of the inlet/outlet pipes or any evidence of soil entering at the joints of the inlet/outlet pipes.	No cracks more than ¼-inch wide at the joint of the inlet/outlet pipe.
Access Manhole	Cover/lid not in place	Cover/lid is missing or only partially in place. Any open manhole requires immediate maintenance.	Manhole access covered.
	Locking mechanism not working	Mechanism cannot be opened by one maintenance person with proper tools. Bolts cannot be seated. Self-locking cover/lid does not work.	Mechanism opens with proper tools.
	Cover/lid difficult to remove	One maintenance person cannot remove cover/lid after applying 80 lbs of lift.	Cover/lid can be removed and reinstalled by one maintenance person.
	Ladder rungs unsafe	Missing rungs, misalignment, rust, or cracks.	Ladder meets design standards. Allows maintenance person safe access.

NO. 23 – COALESCING PLATE OIL/WATER SEPARATOR			
Maintenance Component	Defect	Condition When Maintenance is Needed	Results Expected When Maintenance is Performed
Large access doors/plate	Damaged or difficult to open	Large access doors or plates cannot be opened/removed using normal equipment.	Replace or repair access door so it can be opened as designed.
	Gaps, doesn't cover completely	Large access doors not flat and/or access opening not completely covered.	Doors close flat and cover access opening completely.
	Lifting Rings missing, rusted	Lifting rings not capable of lifting weight of door or plate.	Lifting rings sufficient to lift or remove door or plate.

NO. 24 – CATCH BASIN INSERT			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Media Insert	Visible Oil	Visible oil sheen passing through media	Media inset replaced.
	Insert does not fit catch basin properly	Flow gets into catch basin without going through media.	All flow goes through media.
	Filter media plugged	Filter media plugged.	Flow through filter media is normal.
	Oil absorbent media saturated	Media oil saturated.	Oil absorbent media replaced.
	Water saturated	Catch basin insert is saturated with water, which no longer has the capacity to absorb.	Insert replaced.
	Service life exceeded	Regular interval replacement due to typical average life of media insert product, typically one month.	Media replaced at manufacturer's recommended interval.
	Seasonal maintenance	When storms occur and during the wet season.	Remove, clean and replace or install new insert after major storms, monthly during the wet season or at manufacturer's recommended interval.

NO. 25 – DRYWELL BMP			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Preventative	Plugging, obstructions	Any cause limiting flow into drywell.	Drywell able to receive full flow prior to and during wet season.
Site	Trash and debris	Trash or debris that could end up in the drywell is evident.	No trash or debris that could get into the drywell can be found.
Pipes	Inlet is plugged	The entrance to the pipe is restricted due to sediment, trash, or debris.	The entrance to the pipe is not restricted.
	Vegetation/roots	Vegetation/roots that reduce free movement of water through pipes.	Water flows freely through pipes.
	Plugged	Sediment or other material prevents free flow of water through the pipe.	Water flows freely through pipes.
	Broken or joint leaks.	Damage to the pipe or pipe joints allowing water to seep out.	Pipe does not allow water to exit other than at the outlet.
Structure	Basin leaks	Holes or breaks in the basin allow water to leave the basin at locations other than per design.	Basin is sealed and allows water to exit only where designed.
Filter Media	Filter media plugged	Filter media plugged.	Flow through filter media is normal.
Inspection	Frequency	Annually and prior to and following significant storms.	Inspect drywell system for any defects of deficiencies.

NO. 26 – GRAVEL FILLED INFILTRATION TRENCH BMP			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Preventative	Blocking, obstructions	Debris or trash limiting flow to infiltration trench.	Infiltration trench able to receive full flow prior to and during wet season.
Site	Trash and debris	Trash or debris that could end up in the infiltration trench is evident.	No trash or debris that could get into the infiltration trench can be found.
Pipes	Inlet is plugged	The entrance to the pipe is restricted due to sediment, trash, or debris.	The entrance to the pipe is not restricted.
	Vegetation/roots	Vegetation/roots that reduce free movement of water through pipes.	Water flows freely through pipes.
	Plugged	Sediment or other material prevents free flow of water through the pipe.	Water flows freely through pipes.
	Broken or joint leaks.	Damage to the pipe or pipe joints allowing water to seep out.	Pipe does not allow water to exit other than at the outlet to the trench.
Structure	Flow not reaching trench	Flows are not getting into the trench as designed.	Water enters and exits trench as designed.
	Cleanout/inspection access does not allow cleaning or inspection of trench	The cleanout/inspection access is not available.	Cleanout/inspection access is available.
Filter Media	Filter media plugged	Filter media plugged.	Flow through filter media is normal.
Inspection	Frequency	Annually and prior to and following significant storms.	Inspect infiltration trench system for any defects of deficiencies.

NO. 27 – GRAVEL FILLED DISPERSION TRENCH BMP			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Preventative	Blocking, obstructions	Debris or trash limiting flow to dispersion trench or preventing spreader function.	Dispersion trench able to receive full flow prior to and during wet season.
Site	Trash and debris	Trash or debris that could end up in the dispersion trench is evident.	No trash or debris that could get into the dispersion trench can be found.
Pipes	Inlet is plugged	The entrance to the pipe is restricted due to sediment, trash, or debris.	The entrance to the pipe is not restricted.
	Vegetation/roots	Vegetation/roots that reduce free movement of water through pipes.	Water flows freely through pipes.
	Plugged	Sediment or other material prevents free flow of water through the pipe.	Water flows freely through pipes.
	Broken joint or joint leaks.	Damage to the pipe or pipe joints allowing water to seep out.	Pipe does not allow water to exit other than at the outlet to the trench.
	Cleanout caps	Cleanout caps are broken, missing, or buried.	Cleanout caps are accessible and intact.
Structure	Flow not reaching trench	Flows are not getting into the trench as designed.	Water enters and exits trench as designed.
	Perforated pipe plugged	Flow not able to enter or properly exit from perforated pipe.	Water freely enters and exits perforated pipe.
	Flow not spreading evenly at outlet of trench	Outlet flows channelizing or not spreading evenly from trench.	Sheet flow occurs at the outlet of the trench.
	Cleanout/inspection access does not allow cleaning or inspection of perforated pipe	The cleanout/inspection access is not available.	Cleanout/inspection access is available.
Filter Media	Filter media plugged	Filter media plugged.	Flow through filter media is normal.
Inspection	Frequency	Annually and prior to and following significant storms.	Inspect dispersion trench system for any defects or deficiencies.

NO. 28 – NATIVE VEGETATED SURFACE / NATIVE VEGETATED LANDSCAPE BMP			
Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Results Expected When Maintenance Is Performed
Site	Trash and debris	Trash and debris accumulated on the native vegetated surface/native vegetated landscape site.	Native vegetated surface site free of any trash or debris.
Vegetation	Native vegetation type	Less than two species each of native trees, shrubs, and groundcover occur in the design area.	A minimum of two species each of native trees, shrubs, and groundcover is established and healthy.
	Native vegetated area	Less than 90% if the required vegetated area has healthy growth.	A minimum of 90% of the required vegetated area has healthy growth.
	Undesirable vegetation	Weeds, blackberry, and other undesirable plants are invading more than 10% of vegetated area.	Less than 10% undesirable vegetation occurs in the required native vegetated surface area.
Vegetated Area	Soil compaction	Soil in the native vegetation area compacted.	Less than 8% of native vegetation area is compacted.
	Insufficient area	Less than 3.5 square feet of native vegetation area for every 1 square foot of impervious surface.	A minimum of 3.5 square feet of native vegetation area for every 1 square foot of impervious surface.
	Excess slope	Slope of native vegetation area greater than 15%.	Slope of native growth area does not exceed 15%.
Inspection	Frequency	Annually	Inspect native vegetation area for any defects or deficiencies

NO. 29 – PERFORATED PIPE CONNECTIONS BMP			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Preventative	Blocking, obstructions	Debris or trash limiting flow into perforated pipe system or outfall of BMP is plugged or otherwise nonfunctioning.	Outfall of BMP is receiving designed flows from perforated pipe connection.
Inflow	Inflow impeded	Inflow into the perforated pipe is partially or fully blocked or altered to prevent flow from getting into the pipe.	Inflow to the perforated pipe is unimpeded.
Pipe Trench Area	Surface compacted	Ground surface over the perforated pipe trench is compacted or covered with impermeable material.	Ground surface over the perforated pipe is not compacted and free of any impervious cover.
Outflow	Outflow impeded	Outflow from the perforated pipe into the public drainage system is blocked.	Outflow to the public drainage system is unimpeded.
Outfall Area	Erosion or landslides	Existence of the perforated pipe is causing or exasperating erosion or landslides.	Perforated pipe system is sealed off and an alternative BMP is implemented.
Inspection	Frequency	Annually and prior to and following significant storms.	Perforated pipe system is operating as designed.

NO. 30 – PERMEABLE PAVEMENT BMP			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Preventative	Surface cleaning/ vegetation control	Media surface vacuumed or pressure washed annually, vegetation controlled to design maximum. Weed growth suggesting sediment accumulation.	No dirt, sediment, or debris clogging porous media, or vegetation limiting infiltration.
Porous Concrete, Porous Asphaltic Concrete, and Permeable Pavers	Trash and debris	Trash and debris on the pavement interfering with infiltration; leaf drop in fall season.	No trash or debris interfering with infiltration.
	Sediment accumulation	Sediment accumulation on the pavement interfering with infiltration; runoff from adjacent areas depositing sediment/debris on pavement.	Pavement infiltrates as designed; adjacent areas stabilized.
	Infiltration rate	Pavement does not infiltrate at a rate of 10 inches per hour.	Pavement infiltrates at a rate greater than 10 inches per hour.
	Ponding	Standing water for a long period of time on the surface of the pavement.	Standing water infiltrates at the desired rate.
	Broken or cracked pavement	Pavement is broken or cracked.	No broken pavement or cracks on the surface of the pavement.
	Settlement	Uneven pavement surface indicating settlement of the subsurface layer.	Pavement surface is uniformly level.
	Moss growth	Moss growing on pavement interfering with infiltration.	No moss interferes with infiltration.
	Inflow	Inflow to the pavement is diverted, restricted, or depositing sediment and debris on the pavement.	Inflow to pavement is unobstructed and not bringing sediment or debris to the pavement.
	Underdrain	Underdrain is not flowing when pavement has been infiltrating water.	Underdrain flows freely when water is present.
	Overflow	Overflow not controlling excess water to desired location; native soil is exposed or other signs of erosion damage are present.	Overflow permits excess water to leave the site at the desired location; Overflow is stabilized and appropriately armored.
Permeable Pavers	Broken or missing pavers	Broken or missing paving blocks on surface of pavement.	No missing or broken paving blocks interfering with infiltration.
	Level surface	Uneven surface due to settlement or scour of fill in the interstices of the paving blocks.	Pavement surface is uniformly level.
	Compaction	Poor infiltration due to soil compaction between paving blocks.	No soil compaction in the interstices of the paver blocks limiting infiltration.
	Dead grass	Grass in the interstices of the paving blocks is dead.	Healthy grass is growing in the interstices of the paver blocks.
Inspection	Frequency	Annually and after large storms, and as needed seasonally to control leaf drop, evergreen needles etc.	Permeable pavement is functioning normally.

NO. 31 – BIORETENTION BMP			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Preventative	Vegetation	Vegetation to be watered and pruned as needed and mulch applied to a minimum of 2 inches to maintain healthy growth.	Healthy vegetation growth with full coverage as designed.
Bioretention Area	Trash and debris	Trash and debris in the bioretention area; leaf drop in the fall season.	No trash or debris In the bioretention area.
	Sediment accumulation	Sediment accumulation in the bioretention area interfering with infiltration.	Water in the bioretention infiltrates as designed.
	Ponding	Standing water in the bioretention area for more than two days.	Standing water infiltrates at the desired rate.
	Inflow	Inflow not getting into bioretention; debris/sediment blockage at inlet features; native soil is exposed or other signs of erosion damage is present.	Unobstructed and properly routed inflow into bioretention area; inlet is stabilized and appropriately armored.
	Overflow outlet	Overflow water not controlled by outlet features; native soil is exposed or other signs of erosion damage is present.	Outlet features control overflow; overflow is stabilized and appropriately armored.
	Underdrain	Underdrain is not flowing when bioretention area has been infiltrating water.	Underdrain flows freely when water is present.
Vegetation	Plant health	Plants not thriving across at least 80% of the entire design vegetated area within the BMP; overly dense vegetation requiring pruning.	Healthy water tolerant plants in bioretention area, plants thriving across at least 80% of the entire design vegetated area within the facility.
	Plant species	Plants not water tolerant species.	Plants are water tolerant.
	Weeds	Weeds growing in bioretention area.	No weeds in bioretention area.
	Watering	Planting schedule requires frequent watering (approx. weekly Year 1, bimonthly Years 2 and 3) for new facilities, and as needed for established plantings or dry periods	Plants are established and thriving
	Pest Control	Signs of pests, such as wilting or chewed leaves or bark, spotting or other indicators; extended ponding period encouraging mosquitoes	Plant community is pest-free when following an approved Integrated Pest Management plan; bioretention functioning normally and ponding controlled as needed for pest control
Containment Berm and Earthen Slopes	Erosion;	Erosion occurring at earthen slopes or containment berm side slope.	Erosion on the containment berm and side slopes has been repaired and the cause of the erosion corrected.
	Voids created by nuisance animals (e.g., rodents) or tree roots	Voids affecting berm integrity or creating leaky pond condition	Voids have been repaired; facility is free of nuisance animals following an approved Integrated Pest Management plan.
	Settlement	Any part of the containment berm top has less than 6 inches of freeboard from the maximum pond level to the top of the berm.	A minimum of 6 inches freeboard from the maximum pond level to the top of the berm.
Amended Soil	Soil nutrients	Soil not providing plant nutrients.	Soil providing plant nutrients.
	Bare spots	Bare spots on soil in bioretention area.	No bare spots, bioretention area covered with vegetation or mulch mixed into the underlying soil.
	Compaction	Poor infiltration due to soil compaction in the bioretention area.	No soil compaction in the bioretention area.
Inspection	Frequency	Annually and after large storms, and as needed seasonally for pruning, plant maintenance, pest control and to control leaf drop, evergreen needles etc.	Bioretention facility is functioning normally; plant community is thriving and pest-free.

NO. 32 – RAINWATER HARVESTING BMP			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Preventative	Storage volume	No rain water in storage unit at the beginning of the rain season.	Maximum storage available at the beginning of the rain season (Oct. 1 st).
Collection Area	Trash and debris	Trash of debris on collection area may plug filter system	Collection area clear of trash and debris.
Filter	Restricted or plugged	Filter is partially or fully plugged preventing water from getting in to the storage unit.	Filter is allowing collection water into storage unit.
Inspection	Frequency	Annually and after large storms	Rain harvesting equipment is functioning normally.
	Maintenance log	A Maintenance log must be kept and available for review by KC staff.	Maintenance log is kept and is available to KC staff.

NO. 33 – ROCK PAD BMP			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Site	Trash and debris	Trash and debris accumulated on rock pad site.	Rock pad site free of any trash or debris.
Rock Pad Area	Rock pad size	Rock pad is not 2 feet by 3 feet by 6 inches thick or as designed.	Rock pad is 2 feet by 3 feet by 6 inches thick or as designed.
	Vegetation	Vegetation is seen growing in or through rock pad.	No vegetation within rock pad area.
Rock	Exposed soil	Soil can be seen through the rock pad.	Full thickness of the rock pad is in place, no soil visible through rock pad.
Inspection	Frequency	Annually and after large storms	Rock pad is functioning normally.

NO. 34 – SHEET FLOW BMP			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Site	Trash and debris	Trash and debris accumulated on the sheet flow site.	Sheet flow site free of any trash or debris.
Sheet flow area	Erosion	Soil erosion occurring in sheet flow zone.	Soil erosion is not occurring and rills and channels have been repaired.
	Concentrated flow	Sheet flow is not occurring in the sheet flow zone.	Sheet flow area is regraded to provide sheet flow.
Inspection	Frequency	Annually and after large storms	Rain harvesting equipment is functioning normally.

NO. 35 – SPLASH BLOCK BMP			
Maintenance Component	Defect or Problem	Conditions When Maintenance is Needed	Results Expected When Maintenance is Performed
Site	Trash and debris	Trash and debris accumulated on the splash block.	Splash block site free of any trash or debris.
Splash Block	Dislodged	Splash block moved from outlet of downspout.	Splash block correctly positioned to catch discharge from downspout.
	Channeling	Water coming off the splash block causing erosion.	No erosion occurs from the splash block.
	Downspout water misdirected	Water coming from the downspout is not discharging to the dispersal area.	Water is discharging normally to the dispersal area.
Inspection	Frequency	Annually and after large storms.	Rain harvesting equipment is functioning normally.

Bond Quantities Worksheet

Site Improvement Bond Quantity Worksheet

S15 Web date: 04/03/2015



Department of Permitting & Environmental Review

35030 SE Douglas Street, Suite 210
Snoqualmie, Washington 98065-9266
206-296-6600 TTY Relay 711

For alternate formats, call 206-296-6600.

Project Name: Queen City Farms Phase III Refill
Location: 17825 Cedar Grove Road SE; Maple Valley, WA 98038

Date: 8/30/2019
Project No.: PREA17-0003
Activity No.: _____

Clearing greater than or equal to 5,000 board feet of timber?

yes

X no

If yes,

Forest Practice Permit Number: _____

(RCW 76.09)

Note: All prices include labor, equipment, materials, overhead and profit. Prices are from RS Means data adjusted for the Seattle area or from local sources if not included in the RS Means database.

Site Improvement Bond Quantity Worksheet

S15 Web date: 04/03/2015

		Reference #	Unit Price	Unit	Quantity	# of Applications	Cost
EROSION/SEDIMENT CONTROL							
	Number						
Backfill & compaction-embankment	ESC-1		\$ 6.00	CY		0	
Check dams, 4" minus rock	ESC-2	SWDM 5.4.6.3	\$ 80.00	Each	15	1	1200
Crushed surfacing 1 1/4" minus	ESC-3	WSDOT 9-03.9(3)	\$ 95.00	CY		0	
Ditching	ESC-4		\$ 9.00	CY	500	1	4500
Excavation-bulk	ESC-5		\$ 2.00	CY	2000	1	4000
Fence, silt	ESC-6	SWDM 5.4.3.1	\$ 1.50	LF			
Fence, Temporary (NGPE)	ESC-7		\$ 1.50	LF		0	
Hydroseeding	ESC-8	SWDM 5.4.2.4	\$ 0.80	SY	25000	1	20000
Jute Mesh	ESC-9	SWDM 5.4.2.2	\$ 3.50	SY		0	
Mulch, by hand, straw, 3" deep	ESC-10	SWDM 5.4.2.1	\$ 2.50	SY		0	
Mulch, by machine, straw, 2" deep	ESC-11	SWDM 5.4.2.1	\$ 2.00	SY		0	
Piping, temporary, CPP, 6"	ESC-12		\$ 12.00	LF		0	
Piping, temporary, CPP, 8"	ESC-13		\$ 14.00	LF		0	
Piping, temporary, CPP, 12"	ESC-14		\$ 18.00	LF		0	
Plastic covering, 6mm thick, sandbagged	ESC-15	SWDM 5.4.2.3	\$ 4.00	SY		0	
Rip Rap, machine placed; slopes	ESC-16	WSDOT 9-13.1(2)	\$ 45.00	CY	200	1	9000
Rock Construction Entrance, 50'x15'x1'	ESC-17	SWDM 5.4.4.1	\$ 1,800.00	Each		0	
Rock Construction Entrance, 100'x15'x1'	ESC-18	SWDM 5.4.4.1	\$ 3,200.00	Each		0	
Sediment pond riser assembly	ESC-19	SWDM 5.4.5.2	\$ 2,200.00	Each		0	
Sediment trap, 5' high berm	ESC-20	SWDM 5.4.5.1	\$ 19.00	LF		0	
Sed. trap, 5' high, riprapped spillway berm section	ESC-21	SWDM 5.4.5.1	\$ 70.00	LF		0	
Seeding, by hand	ESC-22	SWDM 5.4.2.4	\$ 1.00	SY		0	
Sodding, 1" deep, level ground	ESC-23	SWDM 5.4.2.5	\$ 8.00	SY		0	
Sodding, 1" deep, sloped ground	ESC-24	SWDM 5.4.2.5	\$ 10.00	SY		0	
TESC Supervisor	ESC-25		\$ 110.00	HR	80	1	8800
Water truck, dust control	ESC-26	SWDM 5.4.7	\$ 140.00	HR			
WRITE-IN-ITEMS **** (see page 9)							
Dozer Grading (unit price X each hour)			\$ 150.00	Each	40	1	6000

ESC SUBTOTAL:	\$ 53,500.00
30% CONTINGENCY & MOBILIZATION:	\$ 16,050.00
ESC TOTAL:	<u>\$ 69,550.00</u>
COLUMN:	A

Site Improvement Bond Quantity Worksheet

Web date: 04/03/2015

				Existing Right-of-Way		Future Public Right of Way & Drainage Facilities		Private Improvements		
		Unit Price	Unit	Quant.	Cost	Quant.	Cost	Quant.	Cost	
GENERAL ITEMS		No.								
Backfill & Compaction- embankment	GI - 1	\$ 6.00	CY							
Backfill & Compaction- trench	GI - 2	\$ 9.00	CY					2563	23,067.00	
Clear/Remove Brush, by hand	GI - 3	\$ 1.00	SY					2738	2,738.00	
Clearing/Grubbing/Tree Removal	GI - 4	\$ 10,000.00	Acre							
Excavation - bulk	GI - 5	\$ 2.00	CY					13126	26,252.00	
Excavation - Trench	GI - 6	\$ 5.00	CY					2563	12,815.00	
Fencing, cedar, 6' high	GI - 7	\$ 20.00	LF							
Fencing, chain link, vinyl coated, 6' high	GI - 8	\$ 20.00	LF							
Fencing, chain link, gate, vinyl coated, 20'	GI - 9	\$ 1,400.00	Each							
Fencing, split rail, 3' high	GI - 10	\$ 15.00	LF							
Fill & compact - common barrow	GI - 11	\$ 25.00	CY							
Fill & compact - gravel base	GI - 12	\$ 27.00	CY							
Fill & compact - screened topsoil	GI - 13	\$ 39.00	CY							
Gabion, 12" deep, stone filled mesh	GI - 14	\$ 65.00	SY							
Gabion, 18" deep, stone filled mesh	GI - 15	\$ 90.00	SY							
Gabion, 36" deep, stone filled mesh	GI - 16	\$ 150.00	SY							
Grading, fine, by hand	GI - 17	\$ 2.50	SY							
Grading, fine, with grader	GI - 18	\$ 2.00	SY							
Monuments, 3' long	GI - 19	\$ 250.00	Each							
Sensitive Areas Sign	GI - 20	\$ 7.00	Each							
Sodding, 1" deep, sloped ground	GI - 21	\$ 8.00	SY							
Surveying, line & grade	GI - 22	\$ 850.00	Day							
Surveying, lot location/lines	GI - 23	\$ 1,800.00	Acre					1	1,800.00	
Traffic control crew (2 flaggers)	GI - 24	\$ 120.00	HR							
Trail, 4" chipped wood	GI - 25	\$ 8.00	SY							
Trail, 4" crushed cinder	GI - 26	\$ 9.00	SY							
Trail, 4" top course	GI - 27	\$ 12.00	SY							
Wall, retaining, concrete	GI - 28	\$ 55.00	SF							
Wall, rockery	GI - 29	\$ 15.00	SF							

SUBTOTAL

66,672.00

Site Improvement Bond Quantity Worksheet

Web date: 04/03/2015

				Existing Right-of-way		Future Public Right of Way & Drainage Facilities		Private Improvements			
		Unit Price	Unit	Quant.	Cost	Quant.	Cost	Quant.	Cost		
ROAD IMPROVEMENT											
	No.										
AC Grinding, 4' wide machine < 1000sy	RI - 1	\$ 30.00	SY								
AC Grinding, 4' wide machine 1000-2000sy	RI - 2	\$ 16.00	SY								
AC Grinding, 4' wide machine > 2000sy	RI - 3	\$ 10.00	SY								
AC Removal/Disposal	RI - 4	\$ 35.00	SY								
Barricade, type III (Permanent)	RI - 6	\$ 56.00	LF								
Curb & Gutter, rolled	RI - 7	\$ 17.00	LF								
Curb & Gutter, vertical	RI - 8	\$ 12.50	LF								
Curb and Gutter, demolition and disposal	RI - 9	\$ 18.00	LF								
Curb, extruded asphalt	RI - 10	\$ 5.50	LF								
Curb, extruded concrete	RI - 11	\$ 7.00	LF								
Sawcut, asphalt, 3" depth	RI - 12	\$ 1.85	LF								
Sawcut, concrete, per 1" depth	RI - 13	\$ 3.00	LF								
Sealant, asphalt	RI - 14	\$ 2.00	LF								
Shoulder, AC, (see AC road unit price)	RI - 15	\$ -	SY								
Shoulder, gravel, 4" thick	RI - 16	\$ 15.00	SY								
Sidewalk, 4" thick	RI - 17	\$ 38.00	SY								
Sidewalk, 4" thick, demolition and disposal	RI - 18	\$ 32.00	SY								
Sidewalk, 5" thick	RI - 19	\$ 41.00	SY								
Sidewalk, 5" thick, demolition and disposal	RI - 20	\$ 40.00	SY								
Sign, handicap	RI - 21	\$ 85.00	Each								
Striping, per stall	RI - 22	\$ 7.00	Each								
Striping, thermoplastic, (for crosswalk)	RI - 23	\$ 3.00	SF								
Striping, 4" reflectorized line	RI - 24	\$ 0.50	LF								

SUBTOTAL

Site Improvement Bond Quantity Worksheet

Web date: 04/03/2015

				Existing Right-of-way		Future Public Right of Way & Drainage Facilities		Private Improvements			
		Unit Price	Unit	Quant.	Cost	Quant.	Cost	Quant.	Cost		
ROAD SURFACING		No.		(4" Rock = 2.5 base & 1.5" top course)				9 1/2" Rock= 8" base & 1.5" top course)			
Additional 2.5" Crushed Surfacing	RS - 1	\$ 3.60	SY								
HMA 1/2" Overlay, 1.5"	RS - 2	\$ 14.00	SY								
HMA 1/2" Overlay 2"	RS - 3	\$ 18.00	SY								
HMA Road, 2", 4" rock, First 2500 SY	RS - 4	\$ 28.00	SY								
HMA Road, 2", 4" rock, Qty. over 2500 SY	RS - 5	\$ 21.00	SY								
HMA Road, 3", 9 1/2" Rock, First 2500 SY	RS - 6	\$ 42.00	SY								
HMA Road, 3", 9 1/2" Rock, Qty Over 2500 SY	RS - 7	\$ 35.00	SY								
Not Used	RS - 8										
Not Used	RS - 9										
HMA Road, 6" Depth, First 2500 SY	RS - 10	\$ 33.10	SY								
HMA Road, 6" Depth, Qty. Over 2500 SY	RS - 11	\$ 30.00	SY								
HMA 3/4" or 1", 4" Depth	RS - 12	\$ 20.00	SY								
Gravel Road, 4" rock, First 2500 SY	RS - 13	\$ 15.00	SY					2500	37,500.00		
Gravel Road, 4" rock, Qty. over 2500 SY	RS - 14	\$ 10.00	SY					3687	36,870.00		
PCC Road (Add Under Write-Ins w/Design)	RS - 15										
Thickened Edge	RS - 17	\$ 8.60	LF								

SUBTOTAL

Site Improvement Bond Quantity Worksheet

Web date: 04/03/2015

				Existing Right-of-way		Future Public Right of Way & Drainage Facilities		Private Improvements	
		Unit Price	Unit	Quant.	Cost	Quant.	Cost	Quant.	Cost
<u>DRAINAGE</u> (CPP = Corrugated Plastic Pipe, N12 or Equivalent) For Culvert prices, Average of 4' cover was assumed. Assume perforated PVC is same price as solid pipe.									
Access Road, R/D	D - 1	\$ 21.00	SY						
Bollards - fixed	D - 2	\$ 240.74	Each						
Bollards - removable	D - 3	\$ 452.34	Each						
* (CBs include frame and lid)									
CB Type I	D - 4	\$ 1,500.00	Each						
CB Type II	D - 5	\$ 1,750.00	Each						
CB Type II, 48" diameter	D - 6	\$ 2,300.00	Each						
for additional depth over 4'	D - 7	\$ 480.00	FT						
CB Type II, 54" diameter	D - 8	\$ 2,500.00	Each					6	15,000.00
for additional depth over 4'	D - 9	\$ 495.00	FT						
CB Type II, 60" diameter	D - 10	\$ 2,800.00	Each						
for additional depth over 4'	D - 11	\$ 600.00	FT						
CB Type II, 72" diameter	D - 12	\$ 3,600.00	Each						
for additional depth over 4'	D - 13	\$ 850.00	FT						
Through-curb Inlet Framework (Add)	D - 14	\$ 400.00	Each						
Cleanout, PVC, 4"	D - 15	\$ 150.00	Each						
Cleanout, PVC, 6"	D - 16	\$ 170.00	Each						
Cleanout, PVC, 8"	D - 17	\$ 200.00	Each						
Culvert, PVC, 4"	D - 18	\$ 10.00	LF						
Culvert, PVC, 6"	D - 19	\$ 13.00	LF						
Culvert, PVC, 8"	D - 20	\$ 15.00	LF						
Culvert, PVC, 12"	D - 21	\$ 23.00	LF						
Culvert, CMP, 8"	D - 22	\$ 19.00	LF						
Culvert, CMP, 12"	D - 23	\$ 29.00	LF						
Culvert, CMP, 15"	D - 24	\$ 35.00	LF						
Culvert, CMP, 18"	D - 25	\$ 41.00	LF						
Culvert, CMP, 24"	D - 26	\$ 56.00	LF					173	9,688.00
Culvert, CMP, 30"	D - 27	\$ 78.00	LF						
Culvert, CMP, 36"	D - 28	\$ 130.00	LF						
Culvert, CMP, 48"	D - 29	\$ 190.00	LF						
Culvert, CMP, 60"	D - 30	\$ 270.00	LF						
Culvert, CMP, 72"	D - 31	\$ 350.00	LF						

SUBTOTAL

24,688.00

Site Improvement Bond Quantity Worksheet

Web date: 04/03/2015

DRAINAGE CONTINUED	No.	Unit Price	Unit	Existing Right-of-way		Future Public Right of Way & Drainage Facilities		Private Improvements	
				Quant.	Cost	Quant.	Cost	Quant.	Cost
Culvert, Concrete, 8"	D - 32	\$ 25.00	LF						
Culvert, Concrete, 12"	D - 33	\$ 36.00	LF						
Culvert, Concrete, 15"	D - 34	\$ 42.00	LF						
Culvert, Concrete, 18"	D - 35	\$ 48.00	LF						
Culvert, Concrete, 24"	D - 36	\$ 78.00	LF						
Culvert, Concrete, 30"	D - 37	\$ 125.00	LF						
Culvert, Concrete, 36"	D - 38	\$ 150.00	LF						
Culvert, Concrete, 42"	D - 39	\$ 175.00	LF						
Culvert, Concrete, 48"	D - 40	\$ 205.00	LF						
Culvert, CPP, 6"	D - 41	\$ 14.00	LF						
Culvert, CPP, 8"	D - 42	\$ 16.00	LF						
Culvert, CPP, 12"	D - 43	\$ 24.00	LF						
Culvert, CPP, 15"	D - 44	\$ 35.00	LF						
Culvert, CPP, 18"	D - 45	\$ 41.00	LF						
Culvert, CPP, 24"	D - 46	\$ 56.00	LF						
Culvert, CPP, 30"	D - 47	\$ 78.00	LF						
Culvert, CPP, 36"	D - 48	\$ 130.00	LF						
Ditching	D - 49	\$ 9.50	CY						
Flow Dispersal Trench (1,436 base+)	D - 50	\$ 28.00	LF						
French Drain (3' depth)	D - 51	\$ 26.00	LF						
Geotextile, laid in trench, polypropylene	D - 52	\$ 3.00	SY						
Mid-tank Access Riser, 48" dia, 6' deep	D - 54	\$ 2,000.00	Each						
Pond Overflow Spillway	D - 55	\$ 16.00	SY				120		1920
Restrictor/Oil Separator, 12"	D - 56	\$ 1,150.00	Each						
Restrictor/Oil Separator, 15"	D - 57	\$ 1,350.00	Each						
Restrictor/Oil Separator, 18"	D - 58	\$ 1,700.00	Each						
Riprap, placed	D - 59	\$ 42.00	CY				187		7854
Tank End Reducer (36" diameter)	D - 60	\$ 1,200.00	Each						
Trash Rack, 12"	D - 61	\$ 350.00	Each						
Trash Rack, 15"	D - 62	\$ 410.00	Each						
Trash Rack, 18"	D - 63	\$ 480.00	Each						
Trash Rack, 21"	D - 64	\$ 550.00	Each						

SUBTOTAL

9774

Site Improvement Bond Quantity Worksheet

Web date: 04/03/2015

		Existing Right-of-way			Future Public Right of Way & Drainage Facilities			Private Improvements	
		Unit Price	Unit	Quant.	Price	Quant.	Cost	Quant.	Cost
PARKING LOT SURFACING Not To Be Used For Roads Or Shoulders									
	No.								
2" AC, 2" top course rock & 4" borrow	PL - 1	\$ 21.00	SY	NA		NA			
2" AC, 1.5" top course & 2.5" base course	PL - 2	\$ 28.00	SY	NA		NA			
4" select borrow	PL - 3	\$ 5.00	SY	NA		NA			
1.5" top course rock & 2.5" base course	PL - 4	\$ 14.00	SY	NA		NA			
UTILITY POLES & STREET LIGHTING Utility pole relocation costs must be accompanied by Franchise Utility's Cost Estimate									
Utility Pole(s) Relocation	UP-1	Lump Sum							
Street Light Poles w/Luminaires	UP-2	\$ 7,500.00	Each						
WRITE-IN-ITEMS									
(Such as detention/water quality vaults.)	No.								
Streambed cobbles	WI - 1	\$ 30.91	CY					41	1,267.31
One-man boulders	WI - 2	\$ 38.21	Each					100	3,821.00
Large woody debris	WI - 3	\$ 600.00	Each					20	12,000.00
Gravel backfill for drain	WI - 4	\$ 40.78	CY					856	34,907.68
Native trees- see plant list- 1 gal	WI - 5	\$ 4.90	SF					421	2,062.90
Multiple native shrubs- 1 gal	WI - 6	\$ 4.90	SF					4125	20,212.50
Multiple native shrubs- bare root/stakes	WI - 7	\$ 1.90	SF					3438	6,531.25
Sedges and Rushes- plugs x4	WI - 8	\$ 1.50	SF					22000	33,000.00
Perennials and ferns- 4" containers	WI - 9	\$ 1.90	SF					3724	7,075.13
	WI - 10								

SUBTOTAL			
SUBTOTAL (SUM ALL PAGES):			296,381.77
30% CONTINGENCY & MOBILIZATION:			88,914.53
GRANDTOTAL:			385,296.29
COLUMN:	B	C	D

Site Improvement Bond Quantity Worksheet

Web date: 04/03/2015

Original bond computations prepared by:

Name: Katie Saltanovitz, PE
 PE Registration Number: 47594
 Firm Name: Landau Associates, Inc.
 Address: 130 2nd Ave S, Edmonds, WA 98020

Date: 8/30/2019
 Tel. #: (425) 778-0907
 Project No: PREA17-0003

FINANCIAL GUARANTEE REQUIREMENTS

	PERFORMANCE BOND* AMOUNT	MINIMUM BOND* AMOUNT REQUIRED FOR RECORDING OR TEMPORARY OCCUPANCY AT SUBSTANTIAL COMPLETION ***	PUBLIC ROAD & DRAINAGE MAINTENANCE/DEFECT BOND*
Stabilization/Erosion Sediment Control (ESC)	(A) \$ 69,550.0		
Existing Right-of-Way Improvements	(B) \$ -		
Future Public Right of Way & Drainage Facilities	(C) \$ -		
Private Improvements	(D) \$ 385,296.3		
Calculated Quantity Completed			
Total Right-of Way and/or Site Restoration Bond**/** (First \$7,500 of bond* shall be cash.)	(A+B) \$ 69,550.0		
Performance Bond* Amount (A+B+C+D) = TOTAL	(T) \$ 454,846.3 Minimum is \$2000.	T x 0.30 \$ 136,453.9 Minimum is \$2000.	
Maintenance/Defect Bond* Total			(B+C) x 0.25 = \$ - Minimum is \$2000.

NAME OF PERSON PREPARING BOND* REDUCTION: _____

Date: _____

* **NOTE:** The word "bond" as used in this document means a financial guarantee acceptable to King County.

** **NOTE:** KCC 27A authorizes right of way and site restoration bonds to be combined when both are required.

The restoration requirement shall include the total cost for all TESC as a minimum, not a maximum. In addition, corrective work, both on- and off-site needs to be included. Quantities shall reflect worse case scenarios not just minimum requirements. For example, if a salmonid stream may be damaged, some estimated costs for restoration needs to be reflected in this amount. The 30% contingency and mobilization costs are computed in this quantity.

*** **NOTE:** Per KCC 27A, total bond amounts remaining after reduction shall not be less than 30% of the original amount (T) or as revised by major design changes.

REQUIRED BOND* AMOUNTS ARE SUBJECT TO REVIEW AND MODIFICATION BY KING COUNTY

Phase III Clearing and Grading Permit Application Forms



King County
Department of Permitting
and Environmental Review
 35030 SE Douglas St., Suite 210
 Snoqualmie, WA 98065-9266
206-296-6600 TTY Relay: 711
 www.kingcounty.gov

**Affidavit for Application
 Form**

For alternate formats, call 206-296-6600.

Parcel # (s) Tax Lot No. 582306-9009 (Portion)	Permit #
Legal Description: The South half of Section 28, Township 23 North, Range 6 East, Willamette Meridian, Situate in the County of King	Project Valuation \$4,500,000
Address of proposed work: 17825 Cedar Grove Road SE, Maple Valley, WA 98038	Address not yet assigned <input type="checkbox"/>
Related permits or Pre-App #:	GRDE18-0048

Contractor's License #: TBD	Expiration Date:
---------------------------------------	-------------------------

OR

Owner Affidavit In Lieu of Contractor Registration: required for a property owner doing all of the work under this permit themselves.

I certify under penalty of perjury that I am the property owner and I am exempt from the requirements of the Contractor Registration laws, RCW 18.27, (Definitions, RCW 18.27.010 and Exemptions, RCW 18.27.090) and I will do all my own work.

Signature: _____

DESCRIPTIVE SUMMARY OF PROPOSED WORK			
The proposal is for reclamation and refill of the Phase III portion of the main gravel pit at the Queen City Farms site. Phase III is located between Phase I and II refill areas, south of Queen City Lake and north of Cedar Grove Road SE. Phase III refill operations will commence when Phase II refill operations near completion. Fill will be placed in 20-ft staged lifts. Each lift will be hydroseeded and reclaimed. The Phase III Refill project includes restoration of the Tributary 316A channel to discharge into Queen City Lake, and construction of stormwater conveyance and infiltration ponds.			
PROPERTY OWNER			
NAME	PHONE	EMAIL	
Stephan Banchemo; Queen City Farms, Inc.	(206)832-3001	steveb@cgcompost.com	
MAILING ADDRESS	CITY	STATE	ZIP
7343 East Marginal Way South	Seattle	WA	98108
APPLICANT <input checked="" type="checkbox"/> same as owner			
NAME	PHONE	EMAIL	
MAILING ADDRESS	CITY	STATE	ZIP

Critical Area Compliance:

The undersigned applicant declares: 1.) That the applicant is competent to be a witness herein; 2.) That the applicant is the applicant for the above project; 3.) That to the best of the applicant's knowledge, the critical areas on the development proposal site have not been illegally altered; and 4.) That the applicant has not previously been found in violation of critical areas regulations for any property in King County, or alternatively, that if there have been any violations, such violations have been cured to the satisfaction of King County.

I am submitting for a permit authorized by the international building, residential, fire, or mechanical codes and in anticipation of having it approved or approved with conditions, I have read the following statement and understand that failure to comply with all conditions once construction is begun may necessitate an immediate work stoppage until such time as compliance with the stipulated conditions is attained. I certify that I have made a diligent inquiry regarding the need for concurrent state or federal permits to engage in the work requested under this building permit, and no such permits are required or I will have obtained the required permits prior to issuance of this permit. I understand that the granting of this permit shall not be construed as satisfying the requirements of other applicable federal, state or local laws or regulations. In addition, I understand and agree that this permit does not authorize the violation of regulations. In addition, I understand and agree that this building permit does not authorize the violation of the Endangered Species Act as set forth at 16 U.S.C. § 1531-1543, including the prohibition on the "take" of threatened or endangered species. "Take" is defined at 16 U.S.C. § 1532(19). I fully understand that it is my sole responsibility to determine whether such "take" restrictions would be violated by work done pursuant to this permit, and I understand that I am precluded by Federal Law from undertaking work authorized by this permit if that work would violate the "take" restrictions set forth at 16 U.S.C. §1538, 50 C.F.R. §17.21, 50 C.F.R. §17.31, 50 C.F.R. §223, and 50 C.F.R. §224.

I certify under penalty of perjury and under the laws of the State of Washington the foregoing is true and correct. I further certify that all easements, deed restrictions, or other encumbrances restricting the use of the property are shown on the site plans submitted with this application. I further certify that I am familiar with King County's Community Trails Preservation Program, and I am/ am not interested in granting a voluntary easement for a rural equestrian trail. We (I) have been given authorization from the property owner to obtain this permit.

I accept financial responsibility for all fees associated with this permit or approval and will receive any applicable billings and/or refunds. As applicant I will receive and be responsible for all correspondence related to this permit record.

Applicant: Queen City Farms, Inc. J. STEPHAN BANCHEMO JR.

 Signature: Joseph Banchemo J Date: 8/29/19



King County
Department of Permitting
and Environmental Review
35030 SE Douglas Street, Suite 210
Snoqualmie, Washington 98065-9266
206-296-6600 TTY Relay: 711
www.kingcounty.gov

**Certification & Transfer
of Applicant Status**

For alternate formats, call 206-296-6600.

Permit Number: GRDE18-0048

FOR CURRENT OWNER:

I, Stephan Banchemo, (print name) hereby certify that I am an/the owner of the property which is the subject of this application for permit or approval. If I am not the sole owner of the property, I certify that I am authorized by any and all other owners of the property to make this certification and transfer any and all rights I/we have to apply for this permit or approval to the person listed below.

I, therefore, certify that Queen City Farms, Inc. (print name) is the "applicant" for this permit or approval and shall remain the "applicant" for the duration of this permit or approval unless "applicant" status is transferred in writing on a form provided by this department. By being the "applicant," that individual assumes **financial responsibility for all fees** and will receive any refunds paid.

I certify under penalty of perjury under the laws of the State of Washington that the foregoing is true and correct.

Stephan Banchemo
Signature of Owner

8/29/19
Date Signed

FOR INDIVIDUALS:

I, _____, (print name) hereby certify that I am the "applicant" for this permit or approval. I shall remain the "applicant" for the duration of this permit or approval unless "applicant" status is transferred in writing on a form provided by this department. **I accept financial responsibility for all fees** associated with this permit or approval and will receive any refunds. My mailing address is:

I certify under penalty of perjury under the laws of the State of Washington that the foregoing is true and correct.

Signature of Applicant

Date Signed

OR

FOR CORPORATIONS/BUSINESS ASSOCIATIONS:

I, Stephan Banchemo, (print name) hereby certify that I am an authorized agent of Queen City Farms, Inc., a corporation or other business association authorized in the State of Washington and that this business association is the "applicant" for this permit or approval and **is financially responsible for all fees** and will receive any refunds paid. This association shall remain the "applicant" for the duration of this permit or approval unless "applicant" status is transferred in writing on the form provided by this department. The mailing address of this business association is:

7343 East Marginal Way South
Seattle, WA 98108

I certify under penalty of perjury under the laws of the State of Washington that the foregoing is true and correct.

Stephan Banchemo
Signature of Applicant

8/29/19
Date Signed



King County
Department of Permitting
and Environmental Review
 35030 SE Douglas St., Ste. 210
 Snoqualmie, WA 98065-9266
206-296-6600 TTY Relay: 711
 www.kingcounty.gov

Clearing and Grading Permit Application Worksheet

PART I: Project Information – To be filled out by applicant:

Project Name: Queen City Farms Phase III Refill
Street Address: 17825 Cedar Grove Road SE; Maple Valley, WA 98038
Pre-Application File No.: PREA17-0003
Clearing/Grading Permit Application No.: GRDE18-0048
Other Related Application/Permit Nos.: GRDE14-0053, GRDE15-0214, L12GI017, PREA19-1093

Property Information:

Parcel No(s) : 2823069009, 3323069027
Zoning: RA-5, M
Community Plan: Tahoma-Raven Heights **Lot size:** 13,717,915 s.f.
Thomas Guide Page: 658, 657, 687, 688 **Other:** Township 23 N, Range 6 E, Section 28

Project Description:

The proposal is for reclamation and refill of the Phase III portion of the main gravel pit at the Queen City Farms site. Phase III is located between Phase I and II refill areas, south of Queen City Lake and north of Cedar Grove Road SE. Phase III refill operations will commence when Phase II refill operations near completion. Fill will be placed in 20-ft staged lifts. Each lift will be hydroseeded and reclaimed. The Phase III Refill project includes restoration of the Tributary 316A channel to discharge into Queen City Lake, and construction of stormwater conveyance and infiltration ponds.

Project Area & Volumes:

Total Area Cleared/Graded:	<u>100</u>	ac.	Volume of Excavation:	<u>13,100</u>	c.y.
Total New Impervious Surface:	<u>61,600</u>	s.f.	Volume of Fill (Exported):	<u>0</u>	c.y.
Total New Pervious Surface:	<u>0</u>	s.f.	Volume of Fill (Imported):	<u>2.5 million</u>	c.y.

Applicant: Stephan Banchemo; Queen City Farms, Inc.
Address : 7343 East Marginal Way South
Seattle, WA 98108
Phone No.: (206) 832 - 3001
E-Mail: steveb@cgcompost.com

Owner: Stephan Banchemo; Queen City Farms, Inc.
Address: 7343 East Marginal Way South, Suite 200
 Seattle, WA 98108
Phone No: (206) 832 - 3001
E-Mail: steveb@cgcompost.com

Agent: Landau Associates, Inc., Katie Saltanovitz, PE
Address: 130 2nd Ave S., Edmonds, WA 98020

Phone No: 425-778-0907
E-Mail: ksaltanovitz@landauinc.com

PART II: Submittal Requirements – To be filled out by DPER staff:

Permit Type: _____ DPER Staff Assigned: _____

Submittal Requirements:

- _____ Affidavit for Application Form
- _____ Clearing / Grading Plan (Scaled & Dimensioned)
- _____ Temporary Erosion Sedimentation Control Plan (TESC)
- _____ Drainage Plan and Calculations
- _____ Grading Earthwork Calculations
- _____ Environmental Checklist including Green House Gas Emission Worksheet
- _____ Environmental Determination
- _____ Critical Area Plan & Studies
- _____ Soil Amendment Plan
- _____ Fee Application Worksheet
- _____ Other: _____
- _____ Other: _____

Part III: Property Information – To be filled out by DPER staff:

Have critical area reports been prepared for this or adjoining properties? yes no
 Has a critical area notice on title been recorded on this or adjoining property? yes no

Critical Area	Contains		Abuts		Comments
	Yes	No	Yes	No	
Wetlands					
Aquatic Areas					
Steep Slope					
Landslide Hazard					
Erosion Hazard					
Seismic Hazard					
Coalmine Hazard					
Floodplain					
Critical Aquifer Recharge					
Channel Migration					
Wildlife Habitat					
Wildlife Corridor					

Part IV: Additional Permits Required for Proposal – To be filled out by DPER staff

Types	Required Y/N	Received Y/N	Comments
Building Permit			
Demolition Permit			
Forest Practice Permit			
ROW Use Permit			
Critical Area Exception			
Shorelines SSDP or Exemption			
Franchise ROW Use Permit			
USACE Permit			
WSDOT Access Permit			
HPA from WDFW			
NPDES			
JARPA			
Other?			
Other?			

Part V: Documents Routed for Review:

	Required Y/N	To:	Comments
Clearing / Grading			
Drainage			
Traffic			
Wetlands / Streams			
Geotechnical			
Flood Hazard			
Planning			
Building / Structural			
Other?			
Other?			

Joint Aquatic Resources Program Application



WASHINGTON STATE

Joint Aquatic Resources Permit Application (JARPA) Form^{1,2} [\[help\]](#)

USE BLACK OR BLUE INK TO ENTER ANSWERS IN THE WHITE SPACES BELOW.



US Army Corps of Engineers®
Seattle District

AGENCY USE ONLY

Date received:

Agency reference #:

Tax Parcel #(s):

Part 1—Project Identification

1. Project Name (A name for your project that you create. Examples: Smith's Dock or Seabrook Lane Development) [\[help\]](#)

Queen City Farms Phase III Reclamation Project

Part 2—Applicant

The person and/or organization responsible for the project. [\[help\]](#)

2a. Name (Last, First, Middle)

Banchero, Steve

2b. Organization (If applicable)

Queen City Farms, Inc.

2c. Mailing Address (Street or PO Box)

7343 East Marginal Way South

2d. City, State, Zip

Seattle, WA 98108

2e. Phone (1)

206-832-3001

2f. Phone (2)

2g. Fax

206-832-3030

2h. E-mail

steveb@cgcompost.com

¹Additional forms may be required for the following permits:

- If your project may qualify for Department of the Army authorization through a Regional General Permit (RGP), contact the U.S. Army Corps of Engineers for application information (206) 764-3495.
- If your project might affect species listed under the Endangered Species Act, you will need to fill out a Specific Project Information Form (SPIF) or prepare a Biological Evaluation. Forms can be found at <http://www.nws.usace.army.mil/Missions/CivilWorks/Regulatory/PermitGuidebook/EndangeredSpecies.aspx>.
- Not all cities and counties accept the JARPA for their local Shoreline permits. If you need a Shoreline permit, contact the appropriate city or county government to make sure they accept the JARPA.

²To access an online JARPA form with [\[help\]](#) screens, go to

http://www.epermitting.wa.gov/site/alias_resourcecenter/jarpa_jarpa_form/9984/jarpa_form.aspx.

For other help, contact the Governor's Office for Regulatory Innovation and Assistance at (800) 917-0043 or help@oria.wa.gov.

Part 3—Authorized Agent or Contact

Person authorized to represent the applicant about the project. (Note: Authorized agent(s) must sign 11b of this application.) [\[help\]](#)

3a. Name (Last, First, Middle)			
Weber, Eric			
3b. Organization (If applicable)			
Landau Associates, Inc.			
3c. Mailing Address (Street or PO Box)			
2107 South C Street			
3d. City, State, Zip			
Tacoma, WA 98402			
3e. Phone (1)	3f. Phone (2)	3g. Fax	3h. E-mail
(253) 926-2493			eweber@landauinc.com

Part 4—Property Owner(s)

Contact information for people or organizations owning the property(ies) where the project will occur. Consider both **upland and aquatic** ownership because the upland owners may not own the adjacent aquatic land. [\[help\]](#)

- Same as applicant. (Skip to Part 5.)
- Repair or maintenance activities on existing rights-of-way or easements. (Skip to Part 5.)
- There are multiple upland property owners. Complete the section below and fill out [JARPA Attachment A](#) for each additional property owner.
- Your project is on Department of Natural Resources (DNR)-managed aquatic lands. If you don't know, contact the DNR at (360) 902-1100 to determine aquatic land ownership. If yes, complete [JARPA Attachment E](#) to apply for the Aquatic Use Authorization.

4a. Name (Last, First, Middle)			
4b. Organization (If applicable)			
4c. Mailing Address (Street or PO Box)			
4d. City, State, Zip			
4e. Phone (1)	4f. Phone (2)	4g. Fax	4h. E-mail

Part 5–Project Location(s)

Identifying information about the property or properties where the project will occur. [\[help\]](#)

- There are multiple project locations (e.g. linear projects). Complete the section below and use [JARPA Attachment B](#) for each additional project location.

5a. Indicate the type of ownership of the property. (Check all that apply.) [help]			
<input checked="" type="checkbox"/> Private <input type="checkbox"/> Federal <input type="checkbox"/> Publicly owned (state, county, city, special districts like schools, ports, etc.) <input type="checkbox"/> Tribal <input type="checkbox"/> Department of Natural Resources (DNR) – managed aquatic lands (Complete JARPA Attachment E)			
5b. Street Address (Cannot be a PO Box. If there is no address, provide other location information in 5p.) [help]			
17825 Cedar Grove Road SE			
5c. City, State, Zip (If the project is not in a city or town, provide the name of the nearest city or town.) [help]			
Maple Valley, WA 98038			
5d. County [help]			
King			
5e. Provide the section, township, and range for the project location. [help]			
¼ Section	Sections	Township	Range
Multiple	28, 29, 32, 33	23N	6E
5f. Provide the latitude and longitude of the project location. [help]			
<ul style="list-style-type: none"> Example: 47.03922 N lat. / -122.89142 W long. (Use decimal degrees - NAD 83) 			
47.446697 N LAT / -122.051349 W LONG			
5g. List the tax parcel number(s) for the project location. [help]			
<ul style="list-style-type: none"> The local county assessor's office can provide this information. 			
282306-9009, 332306-9030, 332306-9042			
5h. Contact information for all adjoining property owners. (If you need more space, use JARPA Attachment C.) [help]			
Name	Mailing Address	Tax Parcel # (if known)	
Cedar Hills Landfill & Treatment Center – King County	500 4TH AVE, STE 830	212306-9016	
	SEATTLE, WA 98104		
Cedar Shores Land, LLC	9125 10TH AVE S	292306-9084, -9803, 322306-9001	
	SEATTLE, WA 98108		
Cedar Grove Composting, LLC	7343 EAST MARGINAL WAY S	292306-9080	
	SEATTLE WA 98108		
First South Properties, LLC	7343 EAST MARGINAL WAY S	292306-9082	
	SEATTLE WA 98108		

5i. List all wetlands on or adjacent to the project location. [\[help\]](#)

Several wetlands (A [Queen City Lake], B, C, D/F, G, H, I, J, and K) are located on site within the Project Area. Wetlands A, B, C, D/F are located upstream of the Phase III Reclamation Area in the vicinity of the Upper Reach of Tributary 316A. Wetlands A through F were initially delineated in 2009 as part of the design and permitting of the compost pad facility project (LAI 2009; see Additional Documents submitted with this JARPA) and verified/updated as part of a follow-up assessment of wetlands and waterways in March 2019. Wetlands G through K are new wetlands. Data sheets and rating forms for verified and new wetlands are included with this JARPA. Wetlands G and H were identified and delineated in the vicinity of the Upper Reach of Tributary 316A during the March 2019 assessment. Wetlands I, J, and K were delineated within the Phase III Reclamation Area along the Engineered Reach. Additionally, two wetlands (31 and 56) previously delineated are located off site and outside the Project Area to the south of Cedar Grove Road SE. Wetland 31 is approximately 16.2 acres, and Wetland 56 is approximately 16.8 acres. Both Wetland 31 and Wetland 56 are important local recharge areas to groundwater (LAI 2007; see Additional Documents submitted with this JARPA). The location of wetlands in relation to the Phase III Reclamation Area and the reaches of Tributary 316A are shown on JARPA figures starting on Sheet 4.

5j. List all waterbodies (other than wetlands) on or adjacent to the project location. [\[help\]](#)

Waterbodies that are adjacent to the Phase III Reclamation Area include Queen City Lake, the Upper Reach of Tributary 316A, the Main Gravel Pit Lake, the Main Infiltration Area, Watercourse B, and Watercourse E. Queen City Farms, Inc. also plans to construct three stormwater ponds in the area: the West, East and South Ponds. These waterbodies will not be impacted by the Phase III Reclamation Project except for a small segment (84 linear feet [lf]) of the Upper Reach where the channel will be rerouted. The Engineered Reach of Tributary 316A, Watercourse D, and Watercourse F are all within the Phase III Reclamation Area and will be directly impacted by the project. Watercourse C will also be impacted within the Reclamation Area but is outside the Engineered Reach. These features are shown on the JARPA figures starting on Sheet 4. None of the waterbodies listed above are fish-bearing and all water associated with these features infiltrates on site except for the Queen City Spring. The Cedar River, the nearest fish-bearing waterbody, is more than 2,500 feet from the project. For more information, an overview of the original location of discharge of Tributary 316A and how it has been modified over time is presented in the Tributary 316A Historical Discharge Review technical memorandum (LAI 2018d; see Additional Documents submitted with this JARPA).

5k. Is any part of the project area within a 100-year floodplain? [\[help\]](#)

Yes No Don't know

5l. Briefly describe the vegetation and habitat conditions on the property. [\[help\]](#)

The Phase III Project Area (the Project Area) consists of the Phase III Reclamation Area including the Tributary 316A Engineered Reach, Upper Reach, and Restored Reach, Queen City Lake, and the Queen City Lake Overflow Pipeline. The site is located on property owned by Queen City Farms, Inc. (QCF) and Cedar Shores Land, LLC and is located at 17825 Cedar Grove Road SE. The property is identified by the King County Treasurer and Assessor's Office as Parcel Nos. 282306-9009, 332306-9030, and 332306-9042. The Project Area encompasses about 200 acres and consists mostly of disturbed vegetation or bare ground. Reclamation area phases and property ownership are presented on Sheet 3 of the JARPA figures. The Phase III Reclamation Area consists primarily of disturbed vegetation including weeds, grasses, and non-native vegetation. Portions of the Phase III Reclamation Area overlap with the Phase I and Phase II Reclamation Areas. The Phase I and II Reclamation Areas are being actively mined as discussed below. The Engineered Reach of Tributary 316A is located entirely within the Phase III Reclamation Area. The Engineered Reach flows through an approximately 100-foot-wide corridor (164,835 square feet [sf]) of vegetation dominated by early seral broad-leaf trees with clearings of scrub-shrub and emergent plants. Non-native species are prevalent along this reach and include reed canarygrass (*Phalaris arundinacea*), Himalayan blackberry (*Rubus armeniacus*), Scotch broom (*Cytisus scoparius*), poison hemlock (*Conium maculatum*), and thistle (*Cirsium* sp.). Native northwest species of plants that were noted along the vegetated corridor include Red alder (*Alnus rubra*), black cottonwood (*Populus balsamifera*), Douglas fir (*Pseudotsuga menziesii*), Pacific willow (*Salix lasiandra*), and sword fern (*Polystichum munitum*). In general, habitat conditions within the Engineered Reach have been frequently disturbed. There are several wetlands located along the Upper and the Engineered Reaches of Tributary 316A as listed in Part 5i and

a few small watercourses associated with these features as listed in Part 5j. Photographs of existing conditions within the Project Area are presented on the JARPA figures starting on Sheet 17.

5m. Describe how the property is currently used. [\[help\]](#)

Gravel mining was conducted at the QCF property and the Cedar Shores property from the 1970s through the 1990s. The portion of the active gravel mine on the QCF property is roughly 120 acres. The northwest corner of the QCF property is currently used to operate the Cedar Grove composting facility. Reclamation of the gravel mine area is ongoing and being conducted in three phases. The western portion of the property and the adjacent Cedar Shores, LLC property is currently being restored under Phase I in accordance with grading permit GRDE15-0053 issued by the King County Department of Permitting and Environmental Review. The eastern portion of the QCF property is being restored under Phase II in accordance with grading permit GRDE15-0214 issued by King County; the Phase III permit application is currently being reviewed by King County. Reclamation of the gravel mine is being conducted in part to fulfill the requirements of the Washington State Department of Natural Resources (DNR) reclamation permit number 70-010880. The Engineered Reach currently conveys stormwater from Tributary 316A and overflow stormwater from the compost pad facility infiltration area to the Main Infiltration Area.

5n. Describe how the adjacent properties are currently used. [\[help\]](#)

The Phase III Reclamation Project Area is located just north of Cedar Grove Road SE and is surrounded by industrial activity that has been modified by ongoing gravel mining. Land use on the surrounding properties consist of industrial, rural-residential, and gravel mining. The Phase III Project Area and properties to the west are zoned Mineral. The property to the north is currently used by King County for operation of the Cedar Hills Regional Landfill, and properties directly to the east and south are zoned Rural Residential. A list of owners of adjoining properties is provided in Section 5h and Attachment C. Adjoining parcels and their ownership are also presented on Sheet 3 of the JARPA figures.

5o. Describe the structures (above and below ground) on the property, including their purpose(s) and current condition. [\[help\]](#)

There is an existing composting facility operating on the QCF property with several buildings and other structures that are part of the ongoing compost operations. There are no structures located within the Project Area.

5p. Provide driving directions from the closest highway to the project location, and attach a map. [\[help\]](#)

From I-405:



Take the WA-169 S exit, EXIT 4, toward MAPLE VALLEY/ENUMCLAW.

0.3 mi



Turn RIGHT onto SE MAPLE VALLEY HWY/WA-169. Continue to follow WA-169.

7.5 mi



Turn LEFT onto CEDAR GROVE RD SE.

0.8 mi



End at 17825 Cedar Grove Rd SE Maple Valley, WA 98038-6211

Also see Vicinity Map on Sheet 1.

Part 6–Project Description

6a. Briefly summarize the overall project. You can provide more detail in 6b. [\[help\]](#)

The Phase III Reclamation Project includes the following elements: 1) installing a French drain in the engineered drainage channel to continue to infiltrate stormwater flows and to discharge any stormwater overflows from the Compost Pad to the Main Infiltration Area; 2) replacing the current surface water overflow channel (Watercourse C) from Queen City Lake with a 24-inch-diameter subsurface pipeline to divert high flows away from Queen City Lake; 3) reclaiming the area of the engineered drainage channel that is located within the Phase III Reclamation Area footprint; 4) grading and filling the Phase I and Phase II Reclamation Areas that overlap with the Phase III Reclamation Area as needed; 5) rerouting Tributary 316A from its current location back to its historical discharge location into and near Queen City Lake; and 6) restoring the rerouted segment of Tributary 316A with native vegetation and riparian habitat to replace the functions and values currently provided by Tributary 316A and the engineered drainage channel. The rerouted segment of Tributary 316A will create approximately 975 lf of stream channel, 9,750 sf of ordinary high water, and 48,750 sf of stream buffer. Approximately 1,164 lf of the Engineered Reach, 86 lf of the Upper Reach, and 1,087 sf of Wetland H will be impacted as part of the reroute. Watercourses D and F, as discussed below in Part 8, will also be impacted. The Project Area consists of the Phase III Reclamation Area (including the engineered drainage channel), the proposed 24-inch overflow pipe from Queen City Lake that will be directed to the East Pond, the upper reaches of Tributary 316A downstream of the rerouted segment, and the rerouted segment of Tributary 316A. The Project Area and parcels are shown on Sheet 1 of the JARPA figures. The Phase III Reclamation Project Area and site features, including the location of the proposed restored reach and the existing Upper and Engineered Reaches of Tributary 316A, are shown on the JARPA figures starting on Sheet 4.

6b. Describe the purpose of the project and why you want or need to perform it. [\[help\]](#)

The purpose of the Phase III Project is to reclaim a portion of the main gravel pit located primarily between reclamation areas for Phase I and II and to regrade these areas where they overlap with the Phase III Reclamation Area. The project is being implemented in a manner that will ultimately protect surface and subsurface hydrology and reclaim the former mine in accordance with King County's grading permits for reclamation Phases I and II (GRDE15-0053 and GRDE15-0214). The Phase III Reclamation Area as shown on the figures is about 97 acres (approximately 2.5 million cubic yards [cy] of material). The area within the Engineered Reach of Tributary 316A that will be filled is about 4 acres (approximately 264,120 cy of material). The project will fill wetlands and areas below the ordinary high water mark (OHWM) associated primarily with the Engineered Reach, as shown on Sheet 8 of the JARPA figures. Reclamation of all three phases is being conducted in part to fulfill the requirements of DNR reclamation permit number 70-010880. Phase III reclamation operations will be in accordance with the updated State Environmental Policy Act Checklist, and King County's Clearing and Grading Permit Conditions of Approval and other permit conditions as required.

6c. Indicate the project category. (Check all that apply) [\[help\]](#)

- | | | | | |
|--|---|--|---|---------------------------------------|
| <input checked="" type="checkbox"/> Commercial | <input type="checkbox"/> Residential | <input type="checkbox"/> Institutional | <input type="checkbox"/> Transportation | <input type="checkbox"/> Recreational |
| <input type="checkbox"/> Maintenance | <input checked="" type="checkbox"/> Environmental Enhancement | | | |

6d. Indicate the major elements of your project. (Check all that apply) [\[help\]](#)

<input type="checkbox"/> Aquaculture	<input type="checkbox"/> Culvert	<input type="checkbox"/> Float	<input type="checkbox"/> Retaining Wall (upland)
<input type="checkbox"/> Bank Stabilization	<input type="checkbox"/> Dam / Weir	<input type="checkbox"/> Floating Home	<input type="checkbox"/> Road
<input type="checkbox"/> Boat House	<input type="checkbox"/> Dike / Levee / Jetty	<input type="checkbox"/> Geotechnical Survey	<input type="checkbox"/> Scientific Measurement Device
<input type="checkbox"/> Boat Launch	<input type="checkbox"/> Ditch	<input type="checkbox"/> Land Clearing	<input type="checkbox"/> Stairs
<input type="checkbox"/> Boat Lift	<input type="checkbox"/> Dock / Pier	<input type="checkbox"/> Marina / Moorage	<input type="checkbox"/> Stormwater facility
<input type="checkbox"/> Bridge	<input type="checkbox"/> Dredging	<input type="checkbox"/> Mining	<input type="checkbox"/> Swimming Pool
<input type="checkbox"/> Bulkhead	<input type="checkbox"/> Fence	<input type="checkbox"/> Outfall Structure	<input type="checkbox"/> Utility Line
<input type="checkbox"/> Buoy	<input type="checkbox"/> Ferry Terminal	<input type="checkbox"/> Piling/Dolphin	
<input type="checkbox"/> Channel Modification	<input type="checkbox"/> Fishway	<input type="checkbox"/> Raft	

Other: Mining Reclamation, Aquatic Habitat Restoration

6e. Describe how you plan to construct each project element checked in 6d. Include specific construction methods and equipment to be used. [\[help\]](#)

- Identify where each element will occur in relation to the nearest waterbody.
- Indicate which activities are within the 100-year floodplain.

The estimated volume of material that will be required to fill the Phase III Reclamation Area is 2.5 million cubic yards (cy). The estimated volume of material that will be required to fill the Engineered Reach within the reclamation area is 264,120 cy. The Phase III Reclamation Project will commence when Phase II Reclamation Project operations near completion. Phase III Reclamation operations will be conducted similarly to operations for Phase II. Fill will be placed in 20-foot staged lifts within the Phase III Reclamation Area. Each lift will be hydroseeded and reclaimed. The maximum daily (1,640) and PM peak-hour (100) number of truck trips set for the Phase II permit will apply to Phase III. The night haul route and related noise restrictions for Phase II would similarly apply to Phase III site operations. Construction equipment that will be used during Phase III Reclamation activities will be consistent with Phases I and II and is anticipated to include excavators, graders, and dump trucks.

Construction of the 24-inch overflow pipeline from Queen City Lake to the East Pond will involve excavating an approximately 3-foot-wide trench along the proposed length of pipeline from the existing culvert outlet at Queen City Lake to the East Pond, installing a 24-inch PVC pipeline in the trench, and backfilling the pipeline. The East Pond will be modified at the outlet to include a flow control structure and overflow spillway and riprap basin according to the specifications provided on Sheets 8 and 9 of the JARPA figures.

The Restored Reach of Tributary 316A will be constructed by excavating material from the current grade along the proposed channel, constructing a series of step pools separated by 2-man rock weirs, anchoring large woody debris within the step pools, and establishing each step pool with approximately 10 feet of ordinary high water and a 25-foot stream buffer measured from either side of the OHWM. The area within the OHWM and the buffer area will be installed with appropriate native species of plants as presented on Sheets 14 through 16 of the JARPA figures. Stream flows from the Upper Reach of Tributary 316A will be diverted into the restored reach after construction is complete. Access to the restored channel during construction will be from the compost pad facility and existing roads adjacent to the area. The existing upper reach and associated wetlands will not be disturbed as part of this project.

Best Management Practices will be used to control construction-related stormwater during construction of the restored channel in accordance with the requirements of DNR reclamation permit number 70-010880, the updated State Environmental Policy Act Checklist, King County's Clearing and Grading Permit Conditions of Approval, and other permit conditions, as required.

<p>6f. What are the anticipated start and end dates for project construction? (Month/Year) [help]</p> <ul style="list-style-type: none"> If the project will be constructed in phases or stages, use JARPA Attachment D to list the start and end dates of each phase or stage.
<p>Start Date: <u>2022</u> End Date: <u>2030</u> <input type="checkbox"/> See JARPA Attachment D</p>
<p>6g. Fair market value of the project, including materials, labor, machine rentals, etc. [help]</p>
<p>\$5,000,000</p>
<p>6h. Will any portion of the project receive federal funding? [help]</p> <ul style="list-style-type: none"> If yes, list each agency providing funds.
<p><input type="checkbox"/> Yes <input checked="" type="checkbox"/> No <input type="checkbox"/> Don't know</p>

Part 7–Wetlands: Impacts and Mitigation

- Check here if there are wetlands or wetland buffers on or adjacent to the project area.
(If there are none, skip to Part 8.) [\[help\]](#)

<p>7a. Describe how the project has been designed to avoid and minimize adverse impacts to wetlands. [help]</p>
<p><input type="checkbox"/> Not applicable</p>
<p>The Phase III Reclamation Project has been designed to restore Tributary 316A surface water hydrology and groundwater infiltration patterns to pre-mining conditions and to restore stream channel and wetland habitat in the rerouted reach of Tributary 316A. Wetlands A through F and the Upper Reach of Tributary 316A downstream of the rerouted channel will not be disturbed. Additional analysis of the expected influence of relocating the stream segment on wetland hydrology and function for downstream Wetlands A through F, is presented in the Restoration of Tributary 316A and Impacts on Existing Wetlands technical memorandum (LAI 2018b; see Additional Documents submitted with this JARPA). Historically, prior to mining, the tributary flowed onto the QCF property from the northwest and terminated at Queen City Lake and the permeable soil directly west of the lake near the proposed channel. As a result, all the surface flow in this drainage was stored in Queen City Lake (which had no surface water outlet) and infiltrated into the underlying aquifer system. When mining occurred in this area in the early 1990s, Tributary 316A was channeled across the gravel pit floor in a designed and engineered conveyance structure similar to what exists today (the Engineered Reach of Tributary 316A). The Phase III Reclamation Project will restore the original hydrology to Tributary 316A and Queen City Lake. The resultant surface water flow will infiltrate into the groundwater system and take years to discharge. This detention function will provide steady recharge to the regional aquifer and the Cedar River. Consequently, the rerouting and restoration of Tributary 316A will have a net positive ecological benefit for this portion of the Cedar River watershed.</p>
<p>7b. Will the project impact wetlands? [help]</p>
<p><input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Don't know</p>
<p>7c. Will the project impact wetland buffers? [help]</p>
<p><input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Don't know</p>
<p>7d. Has a wetland delineation report been prepared? [help]</p> <ul style="list-style-type: none"> If Yes, submit the report, including data sheets, with the JARPA package.
<p><input type="checkbox"/> Yes <input checked="" type="checkbox"/> No (Data sheets and ratings have been included as attachments to the JARPA; delineated wetland boundaries and buffers are presented on the JARPA figures starting on Sheet 4.)</p>

7e. Have the wetlands been rated using the Western Washington or Eastern Washington Wetland Rating System? [\[help\]](#)

- If Yes, submit the wetland rating forms and figures with the JARPA package.

Yes No Don't know

7f. Have you prepared a mitigation plan to compensate for any adverse impacts to wetlands? [\[help\]](#)

- If Yes, submit the plan with the JARPA package and answer 7g.
- If No, or Not applicable, explain below why a mitigation plan should not be required.

Yes No Don't know

A wetland mitigation plan is not required for this project as the Phase III reclamation activities will result in a net ecological gain to wetlands and streams in the watershed through restoration of Tributary 316A and rerouting the flows from this system into Queen City Lake. The functions and values from the engineered drainage channel that will be filled during the Phase III Reclamation Project will be replaced in the restored stream channel as discussed in more detail below. Restoring the hydrology of the system will also benefit wetland and stream resources downgradient of the site as well as the Cedar River.

7g. Summarize what the mitigation plan is meant to accomplish, and describe how a watershed approach was used to design the plan. [\[help\]](#)

N/A

7h. Use the table below to list the type and rating of each wetland impacted, the extent and duration of the impact, and the type and amount of mitigation proposed. Or if you are submitting a mitigation plan with a similar table, you can state (below) where we can find this information in the plan. [\[help\]](#)

Activity (fill, drain, excavate, flood, etc.)	Wetland Name/ Location ¹	Wetland type and rating category ²	Impact area (sq. ft. or Acres)	Duration of impact ³	Proposed mitigation type ⁴	Wetland mitigation area (sq. ft. or acres)
Excavate	Wetland H (Upper Reach)	Depressional Category III	1,088 sf	Permanent	N/A	N/A
Fill	Wetland I (Engineered Reach)	Depressional Category III	51,578 sf	Permanent	N/A	N/A
Fill	Wetland J (Engineered Reach)	Riverine Category III	2,363 sf	Permanent	N/A	N/A
Fill	Wetland K (Engineered Reach)	Slope Category IV	8,217 sf	Permanent	N/A	N/A

¹ If no official name for the wetland exists, create a unique name (such as "Wetland 1"). The name should be consistent with other project documents, such as a wetland delineation report.

² Ecology wetland category based on current Western Washington or Eastern Washington Wetland Rating System. Provide the wetland rating forms with the JARPA package.

³ Indicate the days, months or years the wetland will be measurably impacted by the activity. Enter "permanent" if applicable.

⁴ Creation (C), Re-establishment/Rehabilitation (R), Enhancement (E), Preservation (P), Mitigation Bank/In-lieu fee (B)

Page number(s) for similar information in the mitigation plan, if available: _____

7i. For all filling activities identified in 7h, describe the source and nature of the fill material, the amount in cubic yards that will be used, and how and where it will be placed into the wetland. [\[help\]](#)

Fill material will be composed of clean, local material sourced from construction excavations in the surrounding region. The estimated volume of fill for the entire Phase III Reclamation Area is 2.5 million cy. The estimated volume of fill for the Engineered Reach portion of the Phase III Reclamation Area is 264,120 cy.

7j. For all excavating activities identified in 7h, describe the excavation method, type and amount of material in cubic yards you will remove, and where the material will be disposed. [\[help\]](#)

Excavating activities will occur in Wetland H and upland areas during the construction of the restored Tributary 316A stream channel. Approximately 3,931 cy will be excavated as part of restoration activities and the material will be primarily used as fill in the Phase III Reclamation Area.

Part 8—Waterbodies (other than wetlands): Impacts and Mitigation

In Part 8, “waterbodies” refers to non-wetland waterbodies. (See Part 7 for information related to wetlands.) [\[help\]](#)

Check here if there are waterbodies on or adjacent to the project area. (If there are none, skip to Part 9.)

8a. Describe how the project is designed to avoid and minimize adverse impacts to the aquatic environment. [\[help\]](#)

Not applicable

The Phase III Reclamation Project has been designed to maintain hydrology and groundwater infiltration patterns that were in existence prior to mining activities in the 1960s and 1970s. Future infiltration that occurs in the Phase III Project Area will be distributed as infiltration primarily as discharge from Queen City Lake to the underlying aquifer system. Discharge to Queen City Lake and the underlying aquifer system occurs primarily during the winter with the exception of minor discharge through the French drain to the Main Infiltration Area. This minor discharge also infiltrates to the underlying aquifer system. Discharge into the aquifer system via Queen City Lake will take multiple years to reach surface water discharge (assuming a groundwater velocity of 250 feet/year). By the time it discharges, the infiltrated water should be about 11 degrees centigrade, the approximate ambient temperature of groundwater in Aquifer 2 as measured over many years as part of Superfund site investigations. A flow chart that documents the movement of infiltrated water through the aquifer system is provided on Figure 25 of the Geology, Surface Water Hydrology, and Groundwater Hydrology technical memorandum (LAI 2007; see Additional Documents submitted with this JARPA).

Discharge from Tributary 316A into Queen City Lake would mix with discharge coming directly from the Cedar Hills Landfill and is expected to have similar or better water quality. Infiltration from Queen City Lake would then pass through Aquifer 1, a thick vadose zone, Aquifer 2, and potentially Aquifer 3 (see Figure 21 of Geology, Surface Water Hydrology, and Groundwater Hydrology technical memorandum) (LAI 2007; see Additional Documents submitted with this JARPA) before recharging surface water. Potential impacts to water quality would be expected to be mitigated through natural attenuation processes in the aquifers. These aquifers are monitored at both the QCF and Cedar Hills Landfill properties for geochemical parameters and hazardous constituents. Typical water quality values for Aquifer 2 are: pH = 6.3; Conductivity = 250 μ S/cm; Nitrate < 1.0 mg/L; Ferrous (dissolved) iron < 1.0 mg/L; Dissolved oxygen < 8 mg/L.

The rerouting of Tributary 316A back into Queen City Lake will have an overall net benefit to downstream waterbodies because it will result in steady recharge via long groundwater flow paths to downstream wetland and stream resources. In addition to the benefits to the regional aquifer, the Restored Reach of Tributary 316A will improve hydrologic function through reducing the potential for downstream erosion by retaining surface water flows from Tributary 316A for a longer period of time and ultimately infiltrating all of the surface water on site and improving water quality through increasing seasonal ponding and inundation and reducing the volume of surface flows within each step pool along the restored reach. The project will also result in an overall increase in habitat function through the creation of emergent wetlands and the placement of large woody debris in the channel. The restored reach will also have a more continuous and intact riparian buffer than what currently exists in the engineered reach.

8b. Will your project impact a waterbody or the area around a waterbody? [\[help\]](#)

Yes No

8c. Have you prepared a mitigation plan to compensate for the project’s adverse impacts to non-wetland waterbodies? [\[help\]](#)

- **If Yes**, submit the plan with the JARPA package and answer 8d.
- **If No, or Not applicable**, explain below why a mitigation plan should not be required.

Yes No Don't know

A wetland mitigation plan is not required for this project as the Phase III reclamation activities will result in a net ecological gain to wetlands and streams in the watershed. The functions and values from the Engineered Reach of Tributary 316A that will be filled during the Phase III Reclamation will be restored when Tributary 316A is rerouted. The restored stream channel has been designed with several important elements to improve water quality, hydrology, and habitat functions from the Engineered Reach of Tributary 316A as summarized below.

Specific functions that have been incorporated into the design of the restored stream channel include:
 1) groundwater recharge enhancement; 2) increased seasonal ponding; 3) reducing surface water flows; 4) increased potential for removing sediment and pollutants; and 5) increasing habitat complexity and connectivity both within the channel and within the restored riparian buffer. The restored stream channel will incorporate approximately 20 benches along its length, to provide a series of step pools and placement of in-stream habitat features. Each step pool will be planted with native emergent vegetation and each in-stream structure will be installed with riprap check dams and large woody debris. The side slopes of the channel will be stabilized with biodegradable erosion control material and native vegetation (instead of riprap armoring) to mimic natural conditions. The lowest point of the constructed channel will be filled with streambed cobbles, to decrease sedimentation and allow infiltration along the length of the channel (rather than creating an impervious lining). A riparian buffer on either side of the channel will also be planted with native vegetation for aquatic habitat and to buffer the stream channel.

Pre project hydrographs of Tributary 316A have not been collected. Stream flow has been modeled in the completed channel and is presented in the Stormwater Calculations (LAI 2018c; see Additional Documents submitted with this JARPA). There is extensive hydrologic data on Queen City Lake and Aquifer 1. These two features are receiving waters for Tributary 316A discharge. Historical hydrographs for Tributary 316A are presented in Attachments 2 and 3 of the Geology, Surface Water Hydrology, and Groundwater Hydrology technical memorandum (LAI 2007; see Additional Documents submitted with this JARPA). In addition, a Queen City Lake hydroperiod analysis was conducted based on streamflow modeling and historical Queen City Lake hydrographs. No significant effect was found on hydroperiod from historical conditions (LAI 2018a; see Additional Documents submitted with this JARPA).

8d. Summarize what the mitigation plan is meant to accomplish. Describe how a watershed approach was used to design the plan.

- If you already completed 7g you do not need to restate your answer here. [\[help\]](#)

N/A

8e. Summarize impact(s) to each waterbody in the table below. [\[help\]](#)

Activity (clear, dredge, fill, pile drive, etc.)	Waterbody Name/Location ¹	Impact location ²	Duration of impact ³	Amount of material (cubic yards) to be placed in or removed from waterbody	Area (sq. ft. or linear ft.) of waterbody directly affected
Cut/Fill	Tributary 316A Upper Reach	Within OHWM	Permanent	0.6 CY Cut 151 CY Fill	86 lf 1,008 sf
Cut/Fill	Tributary 316A Upper Reach	Within 25-ft buffer	Temporary (1 growing season)	162 CY Cut 154 CY Fill	2,690 sf

Activity (clear, dredge, fill, pile drive, etc.)	Waterbody Name/Location ¹	Impact location ²	Duration of impact ³	Amount of material (cubic yards) to be placed in or removed from waterbody	Area (sq. ft. or linear ft.) of waterbody directly affected
Fill	Tributary 316A Engineered Reach	Within OHWM	Permanent	The estimated volume of fill for the entire Phase III Reclamation Area is 2.5 million cy over 97 acres. The estimated volume of fill for the Engineered Reach is 264,120 cy over 4 acres.	Engineered Reach Impacts: 1,154 lf 23,495 sf OHWM
Fill	Watercourse C	Within OHWM	Permanent	The estimated volume of fill for the entire Phase III Reclamation Area is 2.5 million cy over 97 acres. The estimated volume of fill for the Engineered Reach is 264,120 cy over 4 acres.	675 lf 1,572 sf
Fill	Watercourse D (Engineered Reach)	Within OHWM	Permanent	The estimated volume of fill for the entire Phase III Reclamation Area is 2.5 million cy over 97 acres. The estimated volume of fill for the Engineered Reach is 264,120 cy over 4 acres.	66 lf 297 sf OHWM
Fill	Watercourse F (Engineered Reach)	Within OHWM	Permanent	The estimated volume of fill for the entire Phase III Reclamation Area is 2.5 million cy over 97 acres. The estimated volume of fill for the Engineered Reach is 264,120 cy over 4 acres.	90 lf 304 sf OHWM

¹ If no official name for the waterbody exists, create a unique name (such as "Stream 1") The name should be consistent with other documents provided.

² Indicate whether the impact will occur in or adjacent to the waterbody. If adjacent, provide the distance between the impact and the waterbody and indicate whether the impact will occur within the 100-year flood plain.

³ Indicate the days, months or years the waterbody will be measurably impacted by the work. Enter "permanent" if applicable.

8f. For all activities identified in 8e, describe the source and nature of the fill material, amount (in cubic yards) you will use, and how and where it will be placed into the waterbody. [\[help\]](#)

Fill material will be composed of clean, local material sourced from construction excavations in the surrounding region. The estimated volume for the Phase III Reclamation Area is 2.5 million cy over 92 acres. The estimated volume of fill specifically for the Engineered Reach portion within the Phase III Reclamation Area is 264,230 cy over 4 acres. Approximately 305 cy of fill will be used to reroute the Upper Reach of Tributary 316A into the restored reach. Clean stream cobbles and soil amendments will be used during the channel restoration project from ongoing mining and compost operations.

8g. For all excavating or dredging activities identified in 8e, describe the method for excavating or dredging, type and amount of material you will remove, and where the material will be disposed. [\[help\]](#)

Excavating activities will occur within a portion of the Upper Reach of Tributary 316A and the upland stream buffer to reroute the existing stream channel into the restored channel. Approximately 162 cy of material, including gravel substrate and upland soils, will be excavated from the existing stream channel and stream buffer and the material will be used on site as fill for the stream restoration.

Part 9—Additional Information

Any additional information you can provide helps the reviewer(s) understand your project. Complete as much of this section as you can. It is ok if you cannot answer a question.

9a. If you have already worked with any government agencies on this project, list them below. [\[help\]](#)

Agency Name	Contact Name	Phone	Most Recent Date of Contact
King County Department of Permitting and Environmental Review (DPER) ^(a)	Randy Sandin Amanda Reeck	206-477-0378 206-263-5783	May 2, 2017 August 23, 2017
US Environmental Protection Agency (EPA) ^(b)	Jeremy Jennings	206-553-2724	July 26, 2018
US Army Corps of Engineers (USACE) Seattle District	Kaitlyn White, Project Manager, Regulatory Branch	206-316-3156	March 6, 2017

(a) King County has required EPA approval for a prior site grading permit and it is anticipated that this same condition will be applied to the Phase III grading permit. Landau Associates (Jennifer Wynkoop and Eric Weber), Queen City Farms, Inc. (Steve Banchoero), and the EPA project manager (Jeremy Jennings) met on July 26, 2018 to discuss the Phase III refill/reclamation project and its rationale.

(b) The Phase III Reclamation Project is being conducted almost entirely within the Queen City Farms Superfund Site (QCF Superfund Site). The QCF Superfund Site was placed on the National Priorities List in September 1984 and is undergoing hazardous waste cleanup activities under the regulatory oversight of the EPA. The QCF Superfund Site includes the entire 320-acre property encompassed by Parcels Nos. 282306-9009 and 332306-9042, which are shown on Sheet 3 of the JARPA figures.

9b. Are any of the wetlands or waterbodies identified in Part 7 or Part 8 of this JARPA on the Washington Department of Ecology's 303(d) List? [\[help\]](#)

- If Yes, list the parameter(s) below.

<ul style="list-style-type: none"> If you don't know, use Washington Department of Ecology's Water Quality Assessment tools at: http://www.ecy.wa.gov/programs/wq/303d/.
<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No
N/A
9c. What U.S. Geological Survey Hydrological Unit Code (HUC) is the project in? [help] <ul style="list-style-type: none"> Go to http://cfpub.epa.gov/surf/locate/index.cfm to help identify the HUC.
17110012
9d. What Water Resource Inventory Area Number (WRIA #) is the project in? [help] <ul style="list-style-type: none"> Go to http://www.ecy.wa.gov/water/wria/index.html to find the WRIA #.
Cedar-Sammamish Watershed (WRIA 8), within the lower Cedar River subbasin.
9e. Will the in-water construction work comply with the State of Washington water quality standards for turbidity? [help] <ul style="list-style-type: none"> Go to http://www.ecy.wa.gov/programs/wq/swqs/criteria.html for the standards.
<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> Not applicable
9f. If the project is within the jurisdiction of the Shoreline Management Act, what is the local shoreline environment designation? [help] <ul style="list-style-type: none"> If you don't know, contact the local planning department. For more information, go to: http://www.ecy.wa.gov/programs/sea/sma/laws_rules/173-26/211_designations.html.
<input type="checkbox"/> Urban <input type="checkbox"/> Natural <input type="checkbox"/> Aquatic <input type="checkbox"/> Conservancy <input type="checkbox"/> Other: _____
9g. What is the Washington Department of Natural Resources Water Type? [help] <ul style="list-style-type: none"> Go to http://www.dnr.wa.gov/forest-practices-water-typing for the Forest Practices Water Typing System.
<input type="checkbox"/> Shoreline <input type="checkbox"/> Fish <input type="checkbox"/> Non-Fish Perennial <input checked="" type="checkbox"/> Non-Fish Seasonal
9h. Will this project be designed to meet the Washington Department of Ecology's most current stormwater manual? [help] <ul style="list-style-type: none"> If No, provide the name of the manual your project is designed to meet.
<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
Name of manual: <u>also, King County Surface Water Design Manual</u>
9i. Does the project site have known contaminated sediment? [help] <ul style="list-style-type: none"> If Yes, please describe below.
<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No
N/A

9j. If you know what the property was used for in the past, describe below. [\[help\]](#)

In the early 1970s, the QCF property was (and still is) zoned Q-M (Quarry Mining). Sand and gravel was mined from the property through the 1990s. Since the late 1990s, the property has been used to operate a composting facility. A portion of the property is also a federal Superfund site as shown on Sheet 4 of the JARPA figures. Reclamation of the gravel mine area is ongoing and being conducted in three phases. Phase I is being completed under grading permit GRDE15-0053 issued by the King County Department of Permitting and Environmental Review; Phase II will be completed under grading permit GRDE15-0214 issued by King County; the Phase III permit application is in preparation. Reclamation of Phase III is being conducted in part to fulfill the requirements of the DNR reclamation permit number 70-010880.

9k. Has a cultural resource (archaeological) survey been performed on the project area? [\[help\]](#)

- **If Yes**, attach it to your JARPA package.

Yes No

The Washington Information System for Architectural & Archaeological Records Data (WISAARD) was reviewed and no landmarks, features, or other evidence of Indian or historic use or occupation were listed in the project area. The areas in question as part of this project have been active as a gravel mining operation since the early 1990s. In addition, no buildings on or near the project area were identified as eligible for inclusion in national, state, or local preservation registers.

9l. Name each species listed under the federal Endangered Species Act that occurs in the vicinity of the project area or might be affected by the proposed work. [\[help\]](#)

There are no federally listed species that occur in the vicinity of the project area that might be affected by the proposed work. A no effect Biological Evaluation that documents no effects to listed species or designated critical habitat has been prepared and submitted along with this JARPA.

9m. Name each species or habitat on the Washington Department of Fish and Wildlife's (WDFW) Priority Habitats and Species (PHS) List that might be affected by the proposed work. [\[help\]](#)

The WDFW PHS interactive mapper was reviewed. No priority habitats or species were identified in the action area of the project.

Part 10–SEPA Compliance and Permits

Use the resources and checklist below to identify the permits you are applying for.

- Online Project Questionnaire at <http://apps.oria.wa.gov/opas/>.
- Governor’s Office for Regulatory Innovation and Assistance at (800) 917-0043 or help@oria.wa.gov.
- For a list of addresses to send your JARPA to, click on [agency addresses for completed JARPA](#).

10a. Compliance with the State Environmental Policy Act (SEPA). (Check all that apply.) [\[help\]](#)

- For more information about SEPA, go to www.ecy.wa.gov/programs/sea/sepa/e-review.html.

- A copy of the SEPA determination or letter of exemption is included with this application.
- A SEPA determination is pending with King County (lead agency). The expected decision date is TBD
- I am applying for a Fish Habitat Enhancement Exemption. (Check the box below in 10b.) [\[help\]](#)
- This project is exempt (choose type of exemption below).
- Categorical Exemption. Under what section of the SEPA administrative code (WAC) is it exempt?

- Other: _____
- SEPA is pre-empted by federal law.

10b. Indicate the permits you are applying for. (Check all that apply.) [\[help\]](#)

LOCAL GOVERNMENT

Local Government Shoreline permits:

- Substantial Development Conditional Use Variance
- Shoreline Exemption Type (explain): _____

Other City/County permits:

- Floodplain Development Permit Critical Areas Ordinance

STATE GOVERNMENT

Washington Department of Fish and Wildlife:

- Hydraulic Project Approval (HPA) Fish Habitat Enhancement Exemption – [Attach Exemption Form](#)

Washington Department of Natural Resources:

- Aquatic Use Authorization
Complete [JARPA Attachment E](#) and submit a check for \$25 payable to the Washington Department of Natural Resources.
Do not send cash.

Washington Department of Ecology:

- Section 401 Water Quality Certification

FEDERAL GOVERNMENT

United States Department of the Army permits (U.S. Army Corps of Engineers): NWP 27 (Aquatic Habitat Restoration, Enhancement, and Establishment Activities)

- Section 404 (discharges into waters of the U.S.) Section 10 (work in navigable waters)

United States Coast Guard permits:

- General Bridge Act Permit Private Aids to Navigation (for non-bridge projects)

Part 11—Authorizing Signatures

Signatures are required before submitting the JARPA package. The JARPA package includes the JARPA form, project plans, photos, etc. [\[help\]](#)

11a. Applicant Signature (required) [\[help\]](#)

I certify that to the best of my knowledge and belief, the information provided in this application is true, complete, and accurate. I also certify that I have the authority to carry out the proposed activities, and I agree to start work only after I have received all necessary permits.

I hereby authorize the agent named in Part 3 of this application to act on my behalf in matters related to this application. SB (initial)

By initialing here, I state that I have the authority to grant access to the property. I also give my consent to the permitting agencies entering the property where the project is located to inspect the project site or any work related to the project. SB (initial)

Steve Banchemo, President
Applicant Printed Name

Steve Banchemo
Applicant Signature

4/10/19
Date

11b. Authorized Agent Signature [\[help\]](#)

I certify that to the best of my knowledge and belief, the information provided in this application is true, complete, and accurate. I also certify that I have the authority to carry out the proposed activities and I agree to start work only after all necessary permits have been issued.

Eric Weber, Landau Associates
Authorized Agent Printed Name

Eric Weber
Authorized Agent Signature

April 10, 2019
Date

11c. Property Owner Signature (if not applicant) [\[help\]](#)

Not required if project is on existing rights-of-way or easements (provide copy of easement with JARPA).

I consent to the permitting agencies entering the property where the project is located to inspect the project site or any work. These inspections shall occur at reasonable times and, if practical, with prior notice to the landowner.

Steve Banchemo
Property Owner Printed Name

Steve Banchemo
Property Owner Signature

4/10/19
Date

Queen City Farms Inc.

18 U.S.C §1001 provides that: Whoever, in any manner within the jurisdiction of any department or agency of the United States knowingly falsifies, conceals, or covers up by any trick, scheme, or device a material fact or makes any false, fictitious, or fraudulent statements or representations or makes or uses any false writing or document knowing same to contain any false, fictitious, or fraudulent statement or entry, shall be fined not more than \$10,000 or imprisoned not more than 5 years or both.

If you require this document in another format, contact the Governor's Office for Regulatory Innovation and Assistance (ORIA) at (800) 917-0043. People with hearing loss can call 711 for Washington Relay Service. People with a speech disability can call (877) 833-6341. ORIA publication number: ORIA-16-011 rev. 07/2017

References

- LAI. 2007. Technical Memorandum: Geology, Surface Water Hydrology and Groundwater Hydrology, Queen City Farms Refill Project, Maple Valley, Washington. Landau Associates, Inc. January 29.
- LAI. 2009. Final: Critical Area Mitigation Report, Cedar Grove Composting Proposed Finished Product Storage Pad, Cedar Grove Road SE. Landau Associates, Inc. June 16.
- LAI. 2018a. Technical Memorandum: Queen City Lake Wetland Hydroperiod Analysis, Queen City Farms Phase III Refill, Maple Valley, Washington. Landau Associates, Inc. April 4.
- LAI. 2018b. Addendum Special Report 6.12 Technical Memorandum: Restoration of Tributary 316A and Impacts on Existing Wetlands, Cedar Grove Compost Facility, Maple Valley, Washington. Landau Associates, Inc. November 5.
- LAI. 2018c. Stormwater Calculations. Landau Associates, Inc. February 28, March 23, and April 6.
- LAI. 2018d. Technical Memorandum: Tributary 316A Historical Discharge Review, Queen City Farms, Maple Valley, Washington. Landau Associates, Inc. April 4.

Contact Information for Adjoining Property Owners



WASHINGTON STATE
Joint Aquatic Resources Permit
Application (JARPA) [\[help\]](#)



US Army Corps
of Engineers®
Seattle District

AGENCY USE ONLY

Date received: _____

Agency reference #: _____

Tax Parcel #(s): _____

TO BE COMPLETED BY APPLICANT [\[help\]](#)

Project Name: _____

Location Name (if applicable): _____

Attachment C:
Contact information for adjoining
property owners. [\[help\]](#)

Use this attachment only if you have more than four adjoining property owners.

Use black or blue ink to enter answers in white spaces below.

1. Contact information for all adjoining property owners. [help]		
Name	Mailing Address	Tax Parcel # (if known)
Neal and Kathleen Frodsham	PO BOX 1279 MAPLE VALLEY WA	272306-9009
Brenda and Alan Haines	16809 230TH AVE SE MAPLE VALLEY WA	272306-9105
5-22 Investments	19100 SW 51ST AVE TUALATIN OR	272306-9125
Sandra Forman	2808 SAINT DIZIER DR HENDERSON NV	292306-9079
QCF LLC	7343 EAST MARGINAL WAY S SEATTLE WA	332306-9069
Cedar Shores Land LLC	9125 10TH AVE S SEATTLE WA	292306-9083
JT and Erica Batterson	16717 230TH AVE SE MAPLE VALLEY WA	272306-9126
QCF LLC	3415 115TH AVE NE BELLEVUE WA	332306-9027

If you require this document in another format, contact the Governor's Office for Regulatory Innovation and Assistance (ORIA) at (800) 917-0043. People with hearing loss can call 711 for Washington Relay Service. People with a speech disability can call (877) 833-6341. ORIA publication number: ORIA-16-014 rev. 10/2016



WASHINGTON STATE
Joint Aquatic Resources Permit
Application (JARPA) [\[help\]](#)



US Army Corps
of Engineers®
Seattle District

AGENCY USE ONLY

Date received: _____

Agency reference #: _____

Tax Parcel #(s): _____

TO BE COMPLETED BY APPLICANT [\[help\]](#)

Project Name: _____

Location Name (if applicable): _____

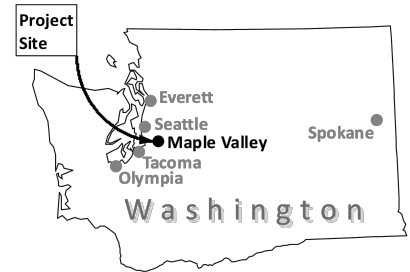
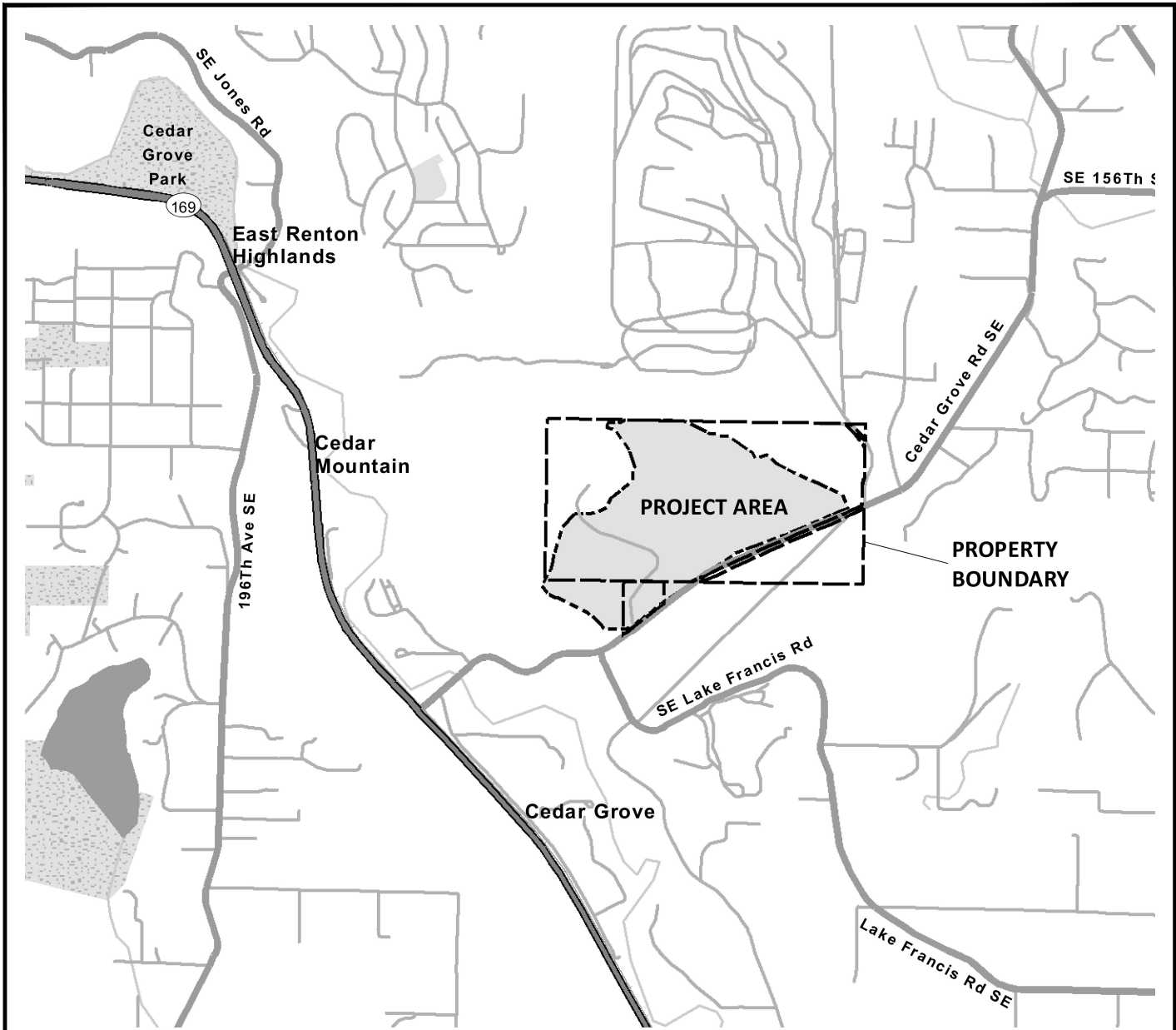
Attachment C:
Contact information for adjoining
property owners. [\[help\]](#)

Use this attachment only if you have more than four adjoining property owners.

Use black or blue ink to enter answers in white spaces below.

1. Contact information for all adjoining property owners. [help]		
Name	Mailing Address	Tax Parcel # (if known)
2015-3 IH2 Borrower LP	21001 N TATUM BLVD #1630-630 PHOENIX AZ	272306-9104
J & L Property Mgmt 3 LLC	805 80TH ST SW EVERETT WA	332306-9080
Jason and Laurie Moe	337 ELK HEIGHTS RD CLE ELUM WA	332306-9081

If you require this document in another format, contact the Governor's Office for Regulatory Innovation and Assistance (ORIA) at (800) 917-0043. People with hearing loss can call 711 for Washington Relay Service. People with a speech disability can call (877) 833-6341. ORIA publication number: ORIA-16-014 rev. 10/2016



Data Source: Esri 2012.

REFERENCE: NWP-2018-481

PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA

LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038
TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.
LAT/LONG: 47.446697"N, -122.051349"W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
 PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

VICINITY MAP

PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A

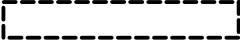

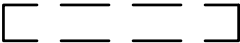


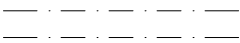
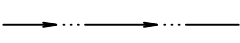
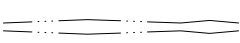

APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108

DATE: APRIL 12, 2019

SHEET: 1 OF 24

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LEGEND

	PROJECT AREA
	PHASE III RECLAMATION AREA
	PARCEL BOUNDARY
	WETLAND AREA
	WETLAND BUFFER
	STREAM BUFFER
	WATERCOURSE FLOW PATH
	SURVEYED ORDINARY HIGH WATER MARK (OHWM)
	APPROXIMATE EDGE OF GRAVEL OR PAVED GROUND SURFACE

NOTE: Larger, color versions of these plans may be found in the "Technical Information Report" (*Technical Information Report, Queen City Farms Refill Project, Cedar Grove Road SE* prepared for Queen City Farms, Inc. by Landau Associates, March 30, 2018). Pertinent information has been reproduced to fit this page format.

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REFERENCE: NWP-2018-481

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LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038

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LAT/LONG: 47.446697"N, -122.051349"W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

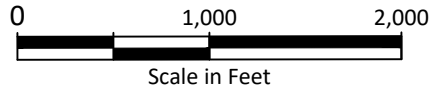
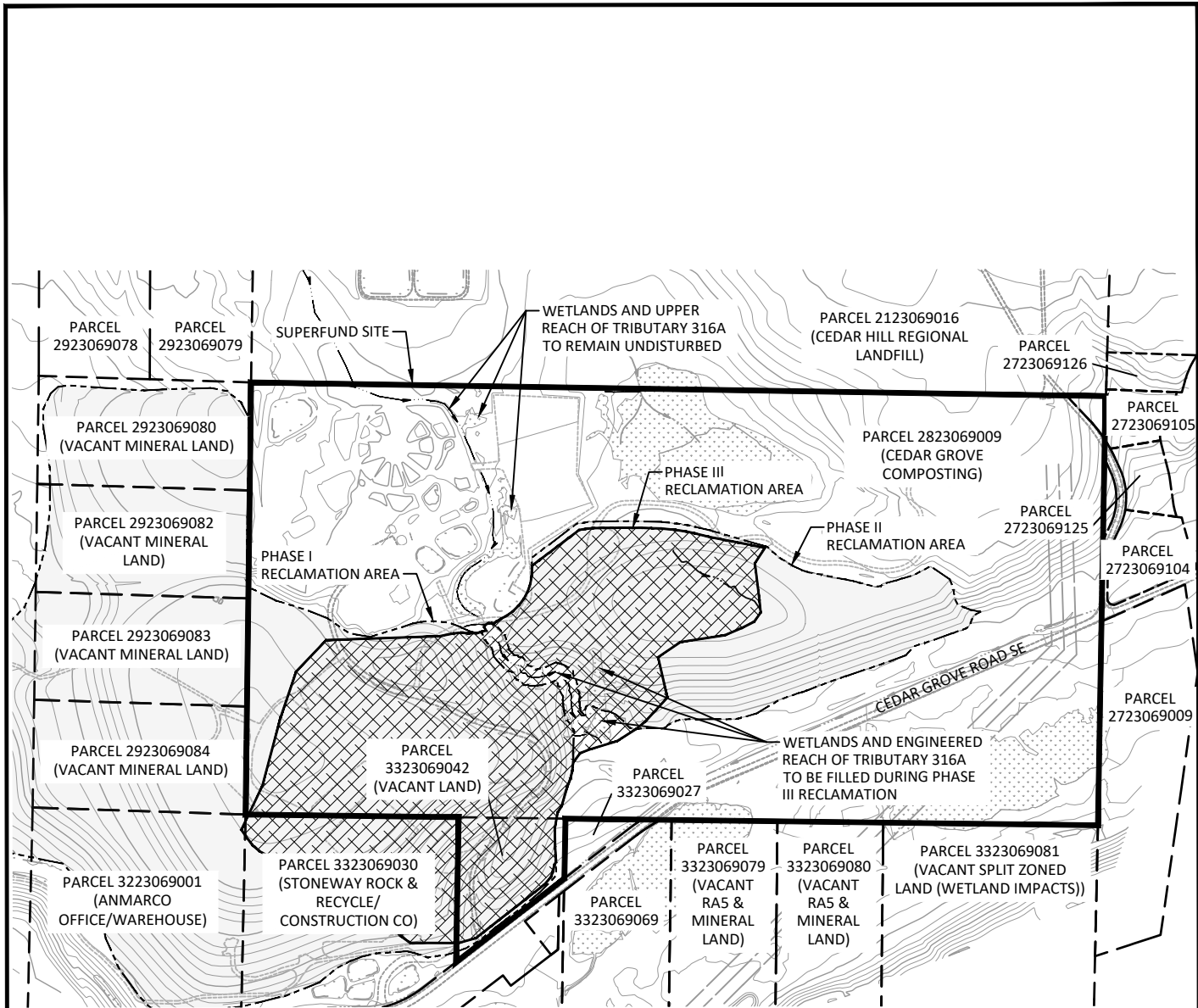
LEGEND & MISC

PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A

APPLICATION BY: QUEEN CITY FARMS, INC.
7343 EAST MARGINAL WAY SOUTH
SEATTLE, WASHINGTON, 98108

DATE: APRIL 12, 2019

SHEET: 2 OF 24



\\EDMGIS03\GRAPHICS\PROJECTS\992\002\050\05-1\JARPA\JARPA_SHEET 3.DWG

REFERENCE: NWP-2018-481

PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA

LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038

TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.

LAT/LONG: 47.446697"N, -122.051349"W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

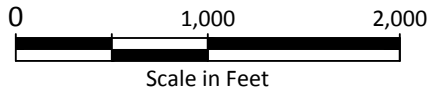
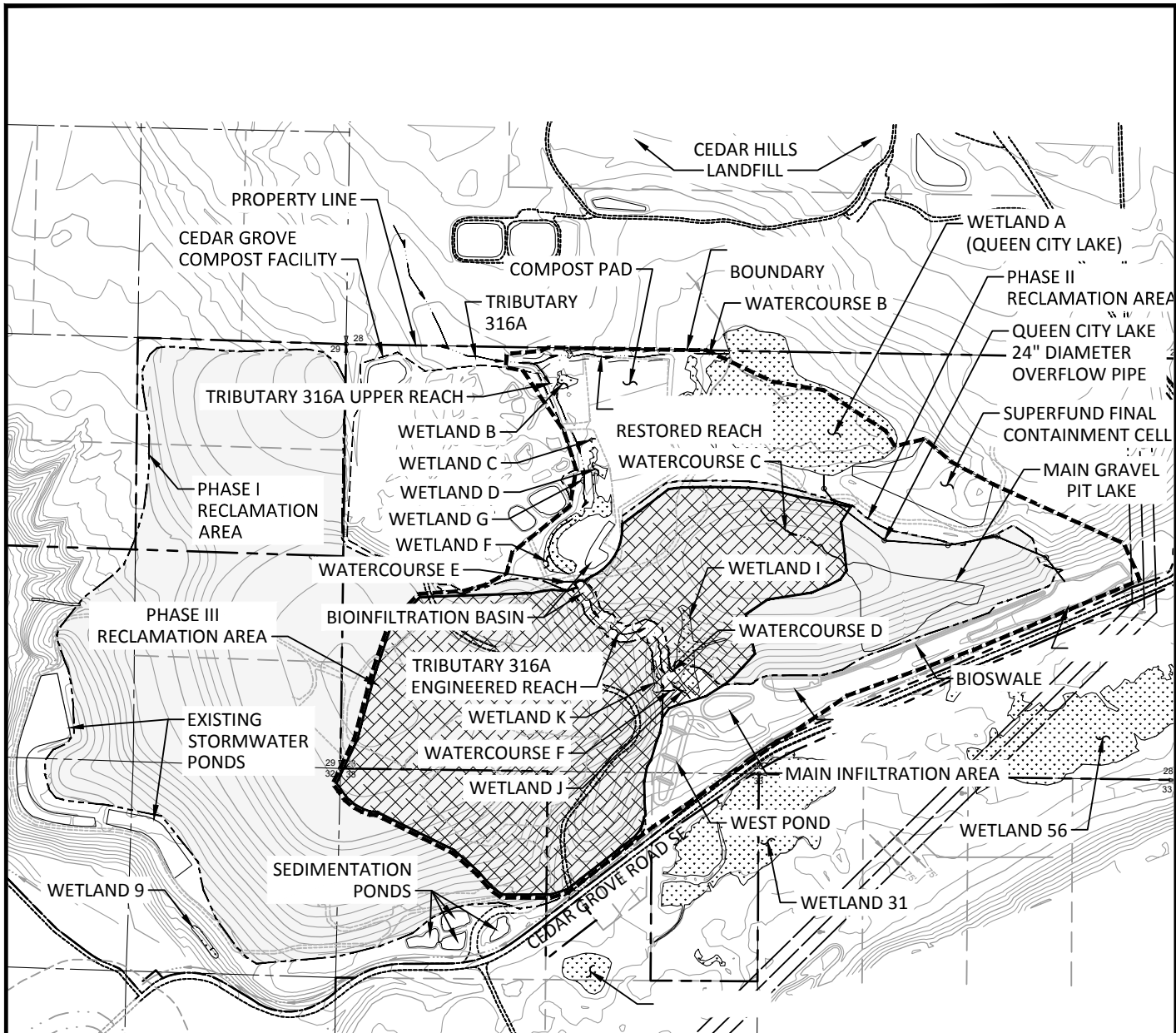
**REFILL PHASE AND
PROPERTY OWNERSHIP MAP**

PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A

APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108

DATE: APRIL 12, 2019

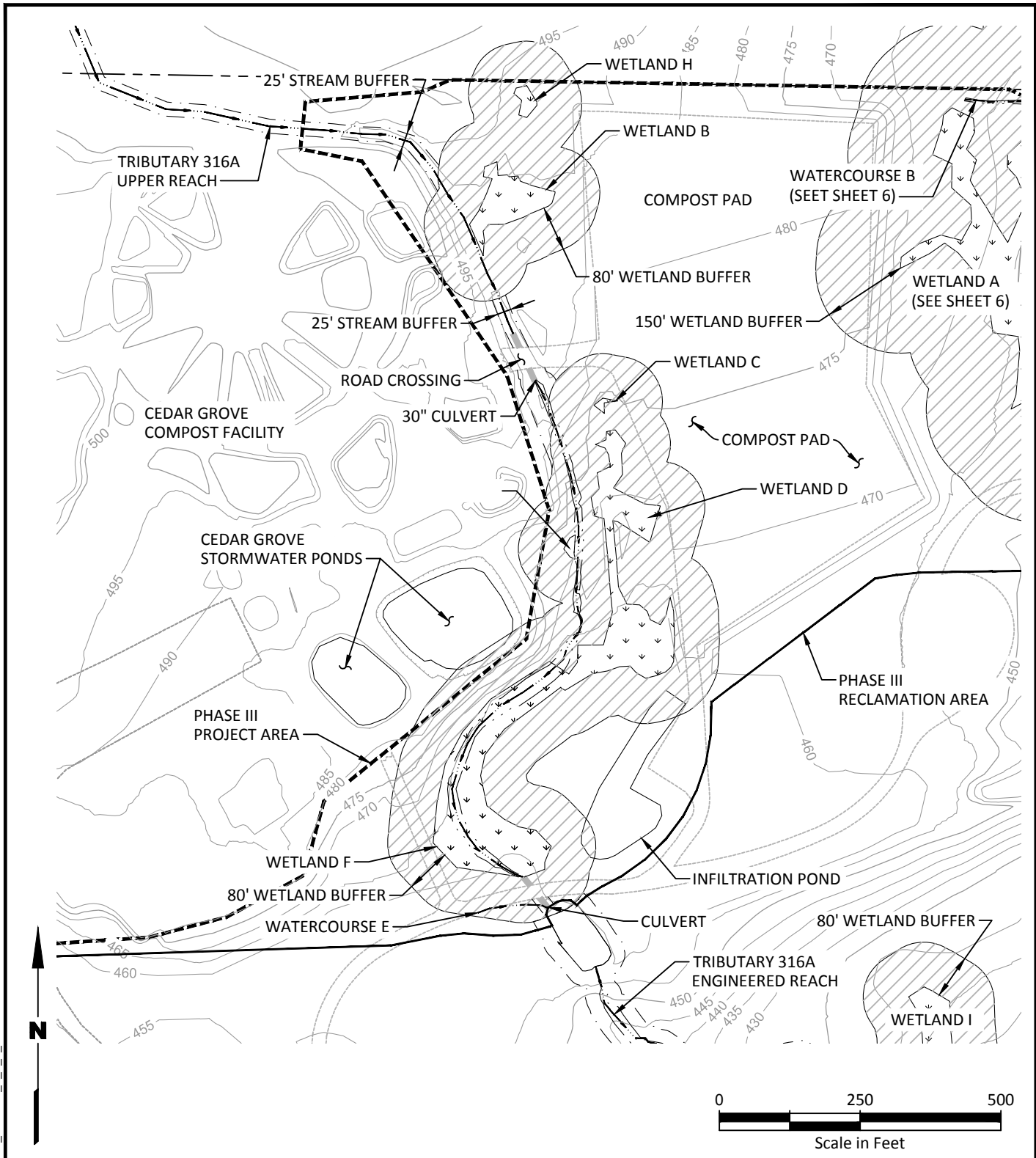
SHEET: 3 OF 24



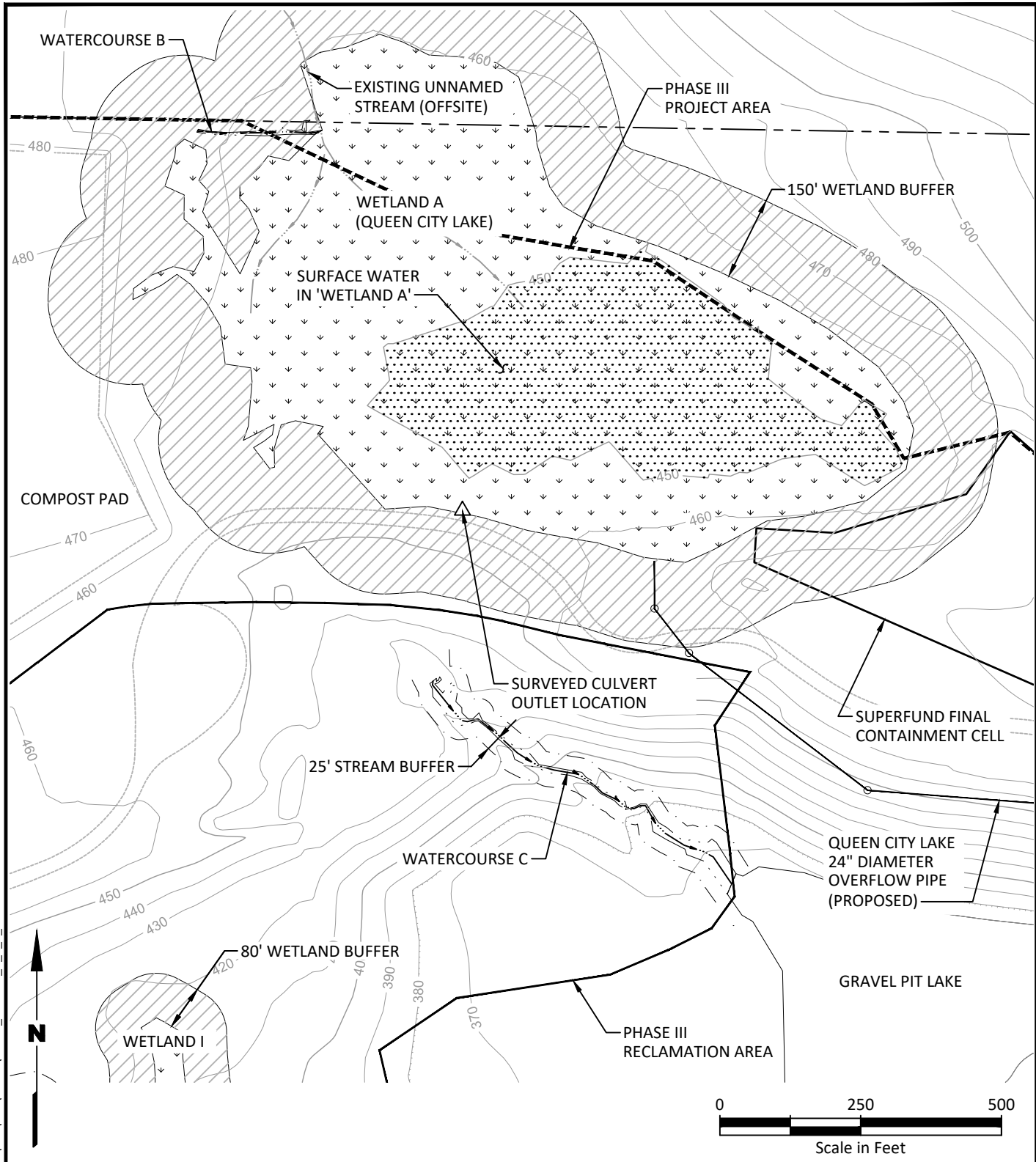
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<p>REFERENCE: NWP-2018-481</p> <p>PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA</p> <p>LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038</p> <p>TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.</p> <p>LAT/LONG: 47.446697"N, -122.051349"W</p> <p>ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C</p>	<p align="center">QUEEN CITY FARMS PHASE III RECLAMATION PROJECT</p> <p align="center">KING COUNTY, WASHINGTON</p> <p align="center">PHASE III REFILL PROJECT AREA AND KEY SITE FEATURES</p>	<p>PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A</p> <p>APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108</p> <p>DATE: AUGUST 30, 2019</p> <p>SHEET: 4 OF 24</p>
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<p>REFERENCE: NWP-2018-481</p> <p>PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA</p> <p>LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038</p> <p>TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.</p> <p>LAT/LONG: 47.446697"N, -122.051349"W</p> <p>ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C</p>	<p>QUEEN CITY FARMS PHASE III RECLAMATION PROJECT</p> <p>KING COUNTY, WASHINGTON</p> <p>UPPER REACH TRIBUTARY 316A BASELINE CONDITIONS</p>	<p>PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A</p> <p>APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108</p> <p>DATE: AUGUST 30, 2019</p> <p>SHEET: 5 OF 24</p>
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REFERENCE: NWP-2018-481

PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA

LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST
 MAPLE VALLEY, WASHINGTON, 98038
TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.
LAT/LONG: 47.446697"N, -122.051349"W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
 PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

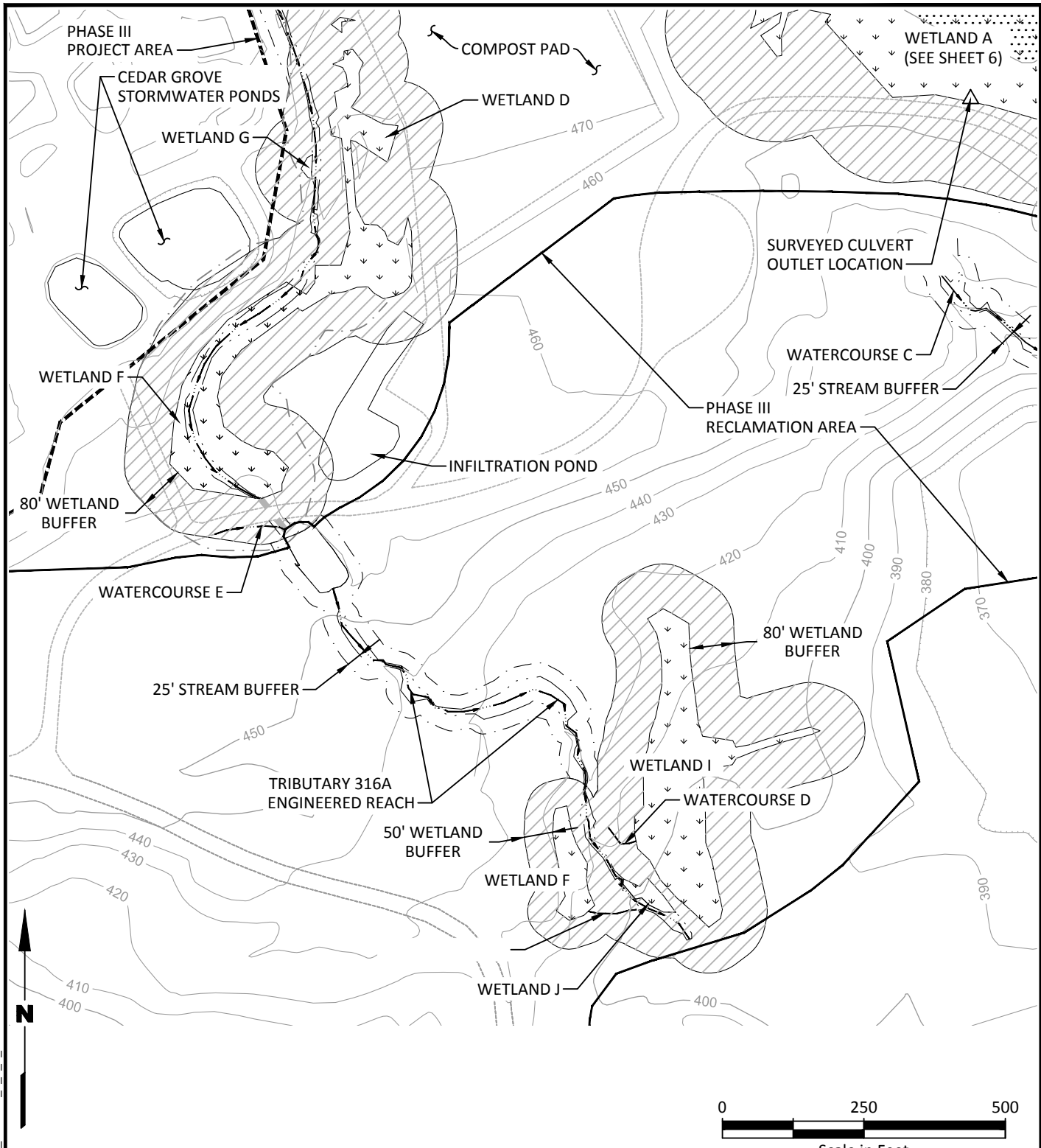
**WETLAND A (QUEEN CITY LAKE)
 BASELINE CONDITIONS**

PROPOSED PROJECT: RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A

APPLICATION BY: QUEEN CITY FARMS, INC.
 7343 EAST MARGINAL WAY SOUTH
 SEATTLE, WASHINGTON, 98108

DATE: APRIL 12, 2019

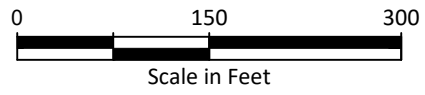
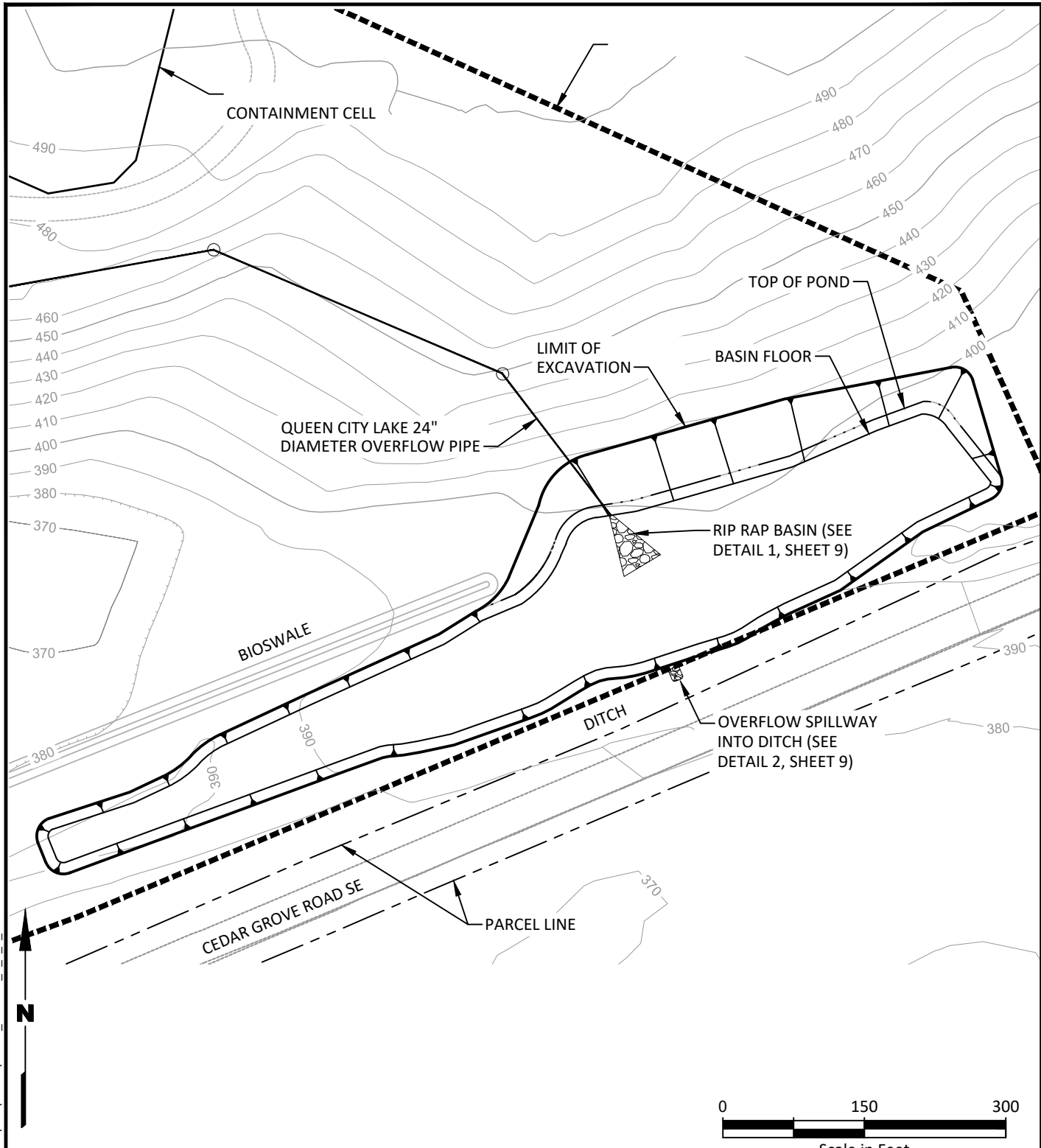
SHEET: 6 OF 24



SOURCE: 1993 Queen City Farms Drainage Channel Realignment Plans (Parametrix)

<p>REFERENCE: NWP-2018-481</p> <p>PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA</p> <p>LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038</p> <p>TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.</p> <p>LAT/LONG: 47.446697"N, -122.051349"W</p> <p>ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C</p>	<p>QUEEN CITY FARMS PHASE III RECLAMATION PROJECT</p> <p>KING COUNTY, WASHINGTON</p> <p>SITE PLAN ENGINEERED REACH EXISTING CONDITIONS</p>	<p>PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A</p> <p>APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108</p> <p>DATE: AUGUST 30, 2019</p> <p>SHEET: 7 OF 24</p>
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SOURCE: 1993 Queen City Farms Drainage Channel Realignment Plans (Parametrix)

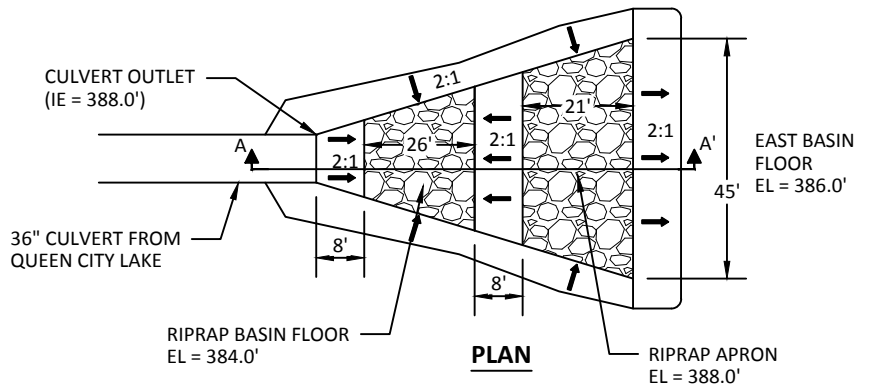
<p>REFERENCE: NWP-2018-481</p> <p>PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA</p> <p>LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038</p> <p>TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.</p> <p>LAT/LONG: 47.446697"N, -122.051349"W</p> <p>ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C</p>	<p>QUEEN CITY FARMS PHASE III RECLAMATION PROJECT</p> <p>KING COUNTY, WASHINGTON</p> <p>PROPOSED PIPELINE & EAST RETENTION POND PLAN</p>	<p>PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A</p> <p>APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108</p> <p>DATE: APRIL 12, 2019</p> <p>SHEET: 8 OF 24</p>
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STORMWATER STANDARDS

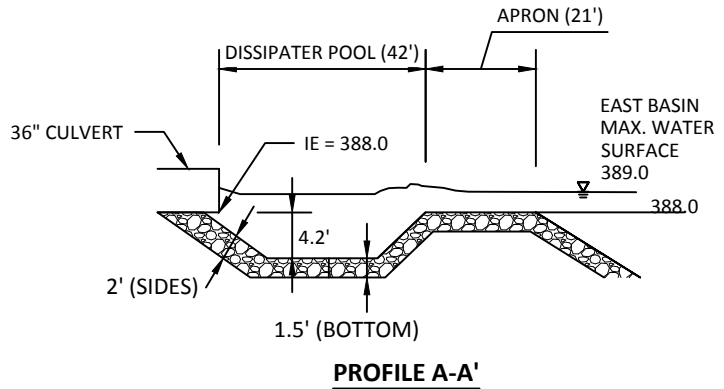
INFILTRATION POND

INFILTRATION RATE: 20 IN/HR
 TOP OF POND = 390.00
 MAX WATER SURFACE = 389.00
 BOTTOM OF POND = 386.00
 POND BOTTOM AREA = 100,400 SF
 POND BOTTOM AREA REQUIRED = 78,500 SF
 VOLUME PROVIDED = 457,100 CF

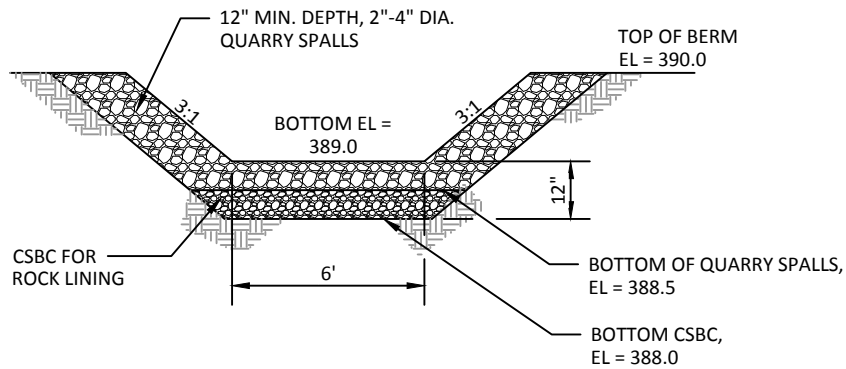


INFILTRATION FACILITY NOTE:

THE REQUIREMENTS FOR DRAINAGE FACILITY CONSTRUCTION AND OPERATION ARE SPECIFIED BY KING COUNTY CODE 9.04.09C AND THE PUBLIC RULE FOR RETENTION/DETENTION FACILITIES: IN OPERATION REQUIREMENTS. INFILTRATION FACILITIES MUST BE FIELD TESTED TO VERIFY THE DESIGN RATE OF SOIL INFILTRATIONS. THIS TESTING MUST BE COMPLETE AND APPROVED BY KING COUNTY PRIOR TO THE CONSTRUCTION OF ANY IMPROVEMENTS AND/OR BUILDING ON THE SITE. CONTACT THE LAND USE SITE DEVELOPMENT SERVICES SECTION TO DETERMINE THE APPROPRIATE TEST METHOD FOR THE DRAINAGE FACILITY.



1 RIP RAP BASIN
NOT TO SCALE



2 OVERFLOW SPILLWAY DETAIL
NOT TO SCALE

\\EDWIGIS03\GRAPHICS\PROJECTS\92\002\050\051\JARPA\JARPA_SHEET 5_6_7_8_9.DWG

REFERENCE: NWP-2018-481

PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA

LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038
TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.
LAT/LONG: 47.446697°N, -122.051349°W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
 PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

**PROPOSED EAST RETENTION
 POND RIP RAP BASIN AND
 OVERFLOW SPILLWAY DETAILS**

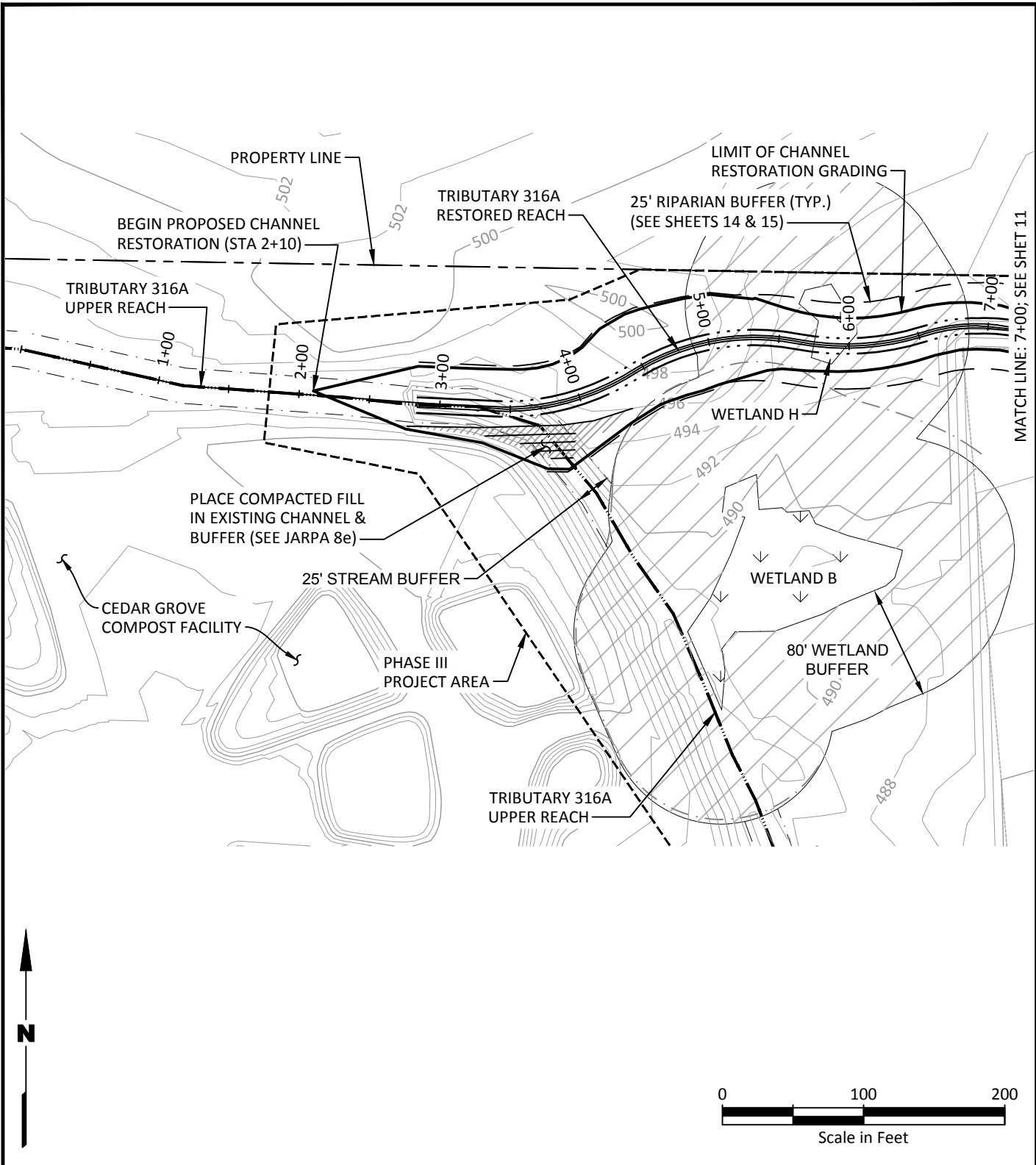
PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A

APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108

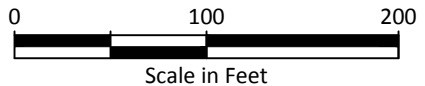
DATE: APRIL 12, 2019

SHEET: 9 OF 24

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MATCH LINE: 7+00; SEE SHET 11



REFERENCE: NWP-2018-481

PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA

LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST
MAPLE VALLEY, WASHINGTON, 98038
TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.
LAT/LONG: 47.446697"N, -122.051349"W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

**TRIBUTARY 316A RESTORED
REACH STREAM CHANNEL PLAN**

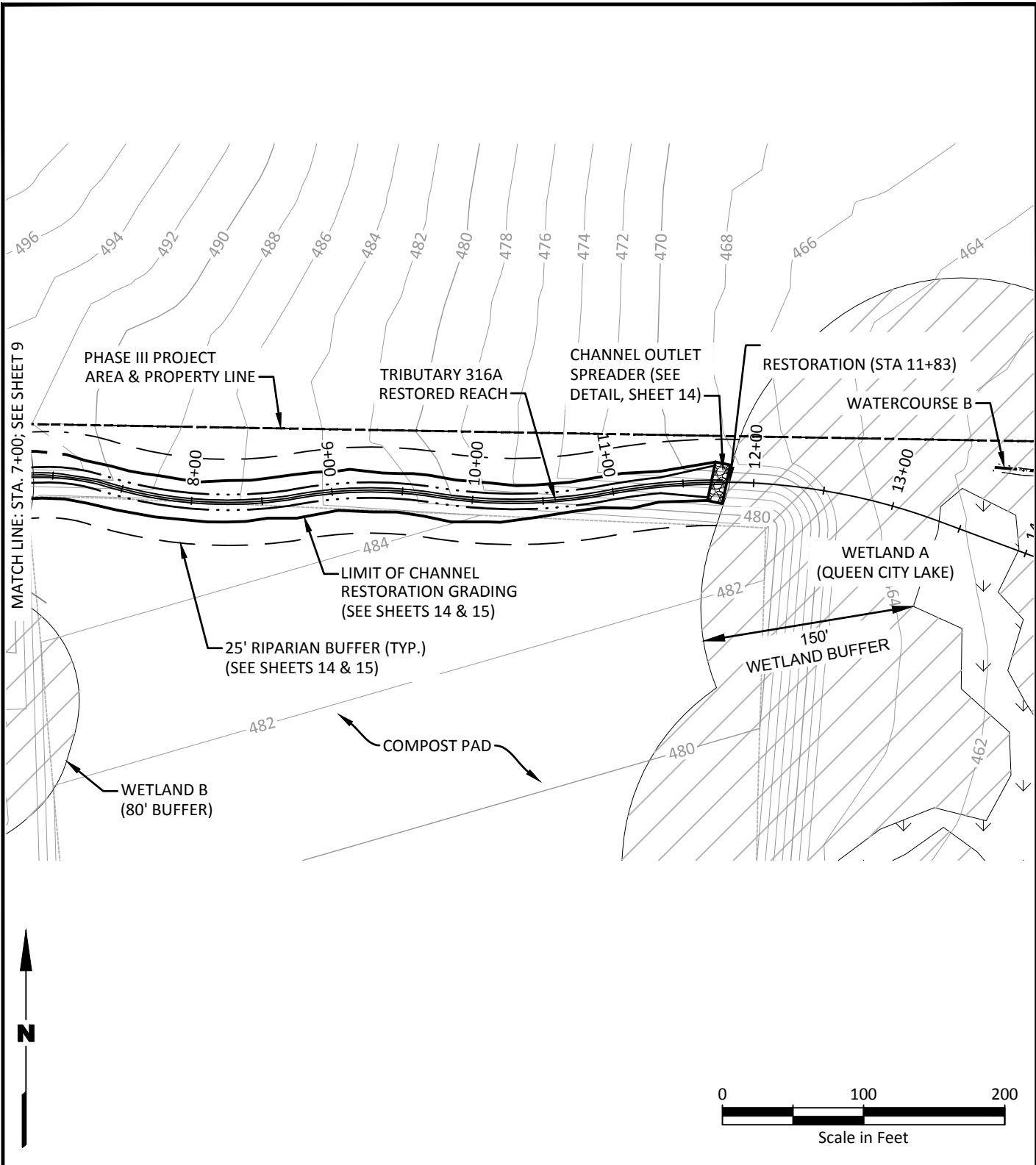
PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A

APPLICATION BY: QUEEN CITY FARMS, INC.
7343 EAST MARGINAL WAY SOUTH
SEATTLE, WASHINGTON, 98108

DATE: APRIL 12, 2019

SHEET: 10 OF 24

\\EDMIGIS03\GRAPHICS\PROJECTS\92\002\050\051\JARPA\JARPA_SHEET 10_11_12_13.DWG



REFERENCE: NWP-2018-481

PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA

LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038

TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.

LAT/LONG: 47.446697"N, -122.051349"W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

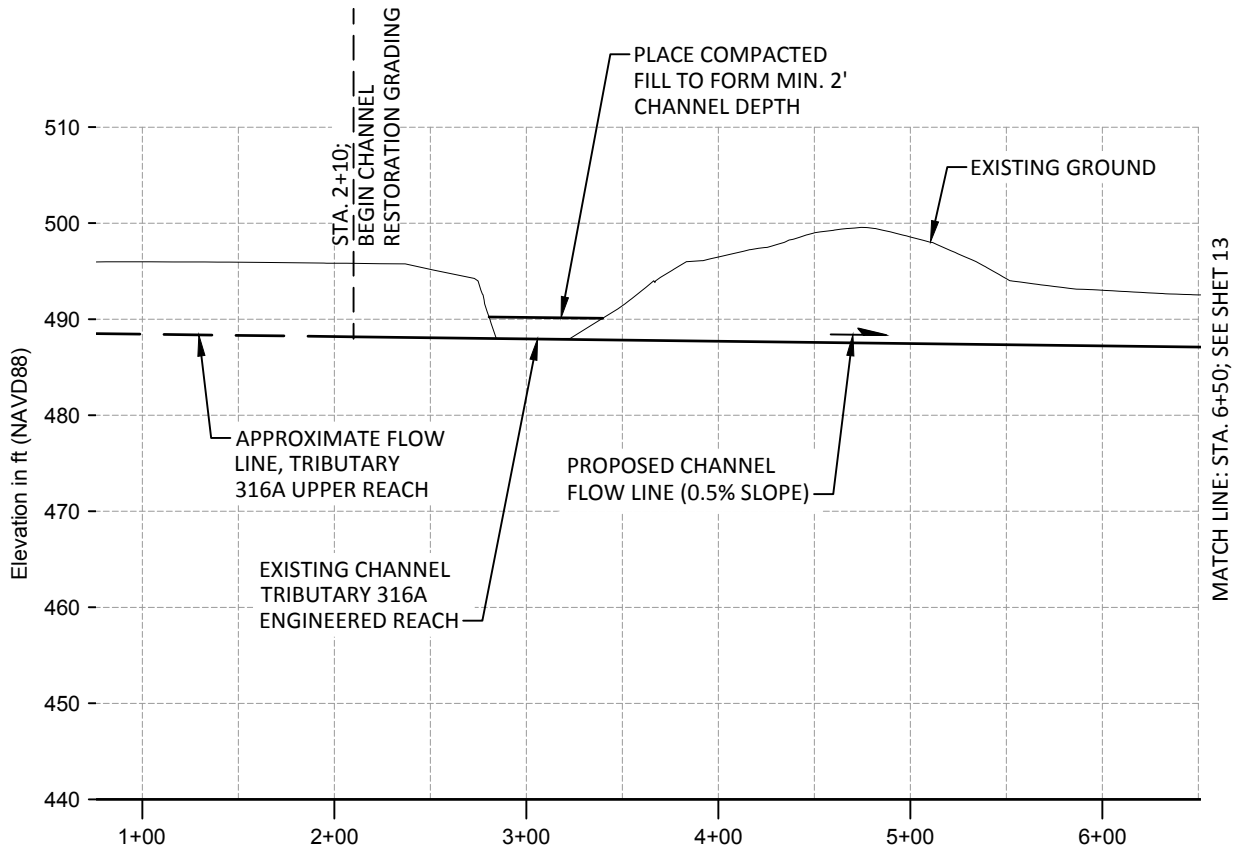
**TRIBUTARY 316A RESTORED
REACH STREAM CHANNEL PLAN**

PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A

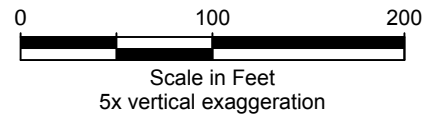
APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108

DATE: APRIL 12, 2019

SHEET: 11 OF 24



TRIBUTARY 316A RESTORED REACH STREAM CHANNEL PROFILE
 HORIZONTAL SCALE IN FEET: 1" = 100'
 VERTICAL SCALE IN FEET: 1" = 20'



\\EDMIGIS03\GRAPHICS\PROJECTS\92\002\050\051\JARPA\JARPA_SHEET 10_11_12_13.DWG

REFERENCE: NWP-2018-481

PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA

LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038

TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.

LAT/LONG: 47.446697"N, -122.051349"W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
 PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

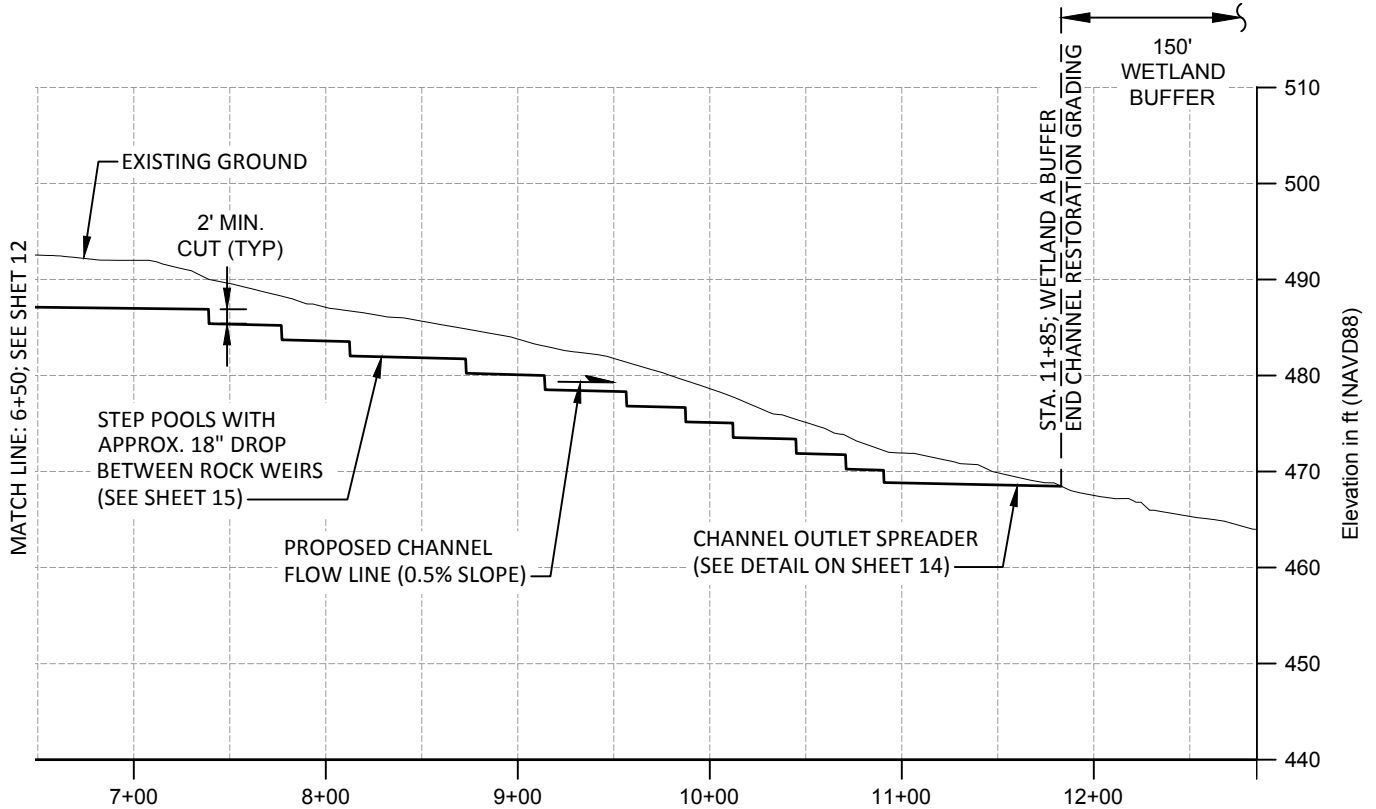
**TRIBUTARY 316A
 RESTORED REACH
 STREAM CHANNEL PROFILE**

PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A

APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108

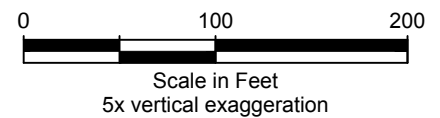
DATE: APRIL 12, 2019

SHEET: 12 OF 24



TRIBUTARY 316A RESTORED REACH STREAM CHANNEL PROFILE

HORIZONTAL SCALE IN FEET: 1" = 100'
 VERTICAL SCALE IN FEET: 1" = 20'



\\EDMIGIS03\GRAPHICS\PROJECTS\92\002\050\051\JARPA\JARPA_SHEET 10_11_12_13.DWG

REFERENCE: NWP-2018-481

PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA

LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038

TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.

LAT/LONG: 47.446697"N, -122.051349"W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
 PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

**TRIBUTARY 316A
 RESTORED REACH
 STREAM CHANNEL PROFILE**

PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A

APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108

DATE: APRIL 12, 2019

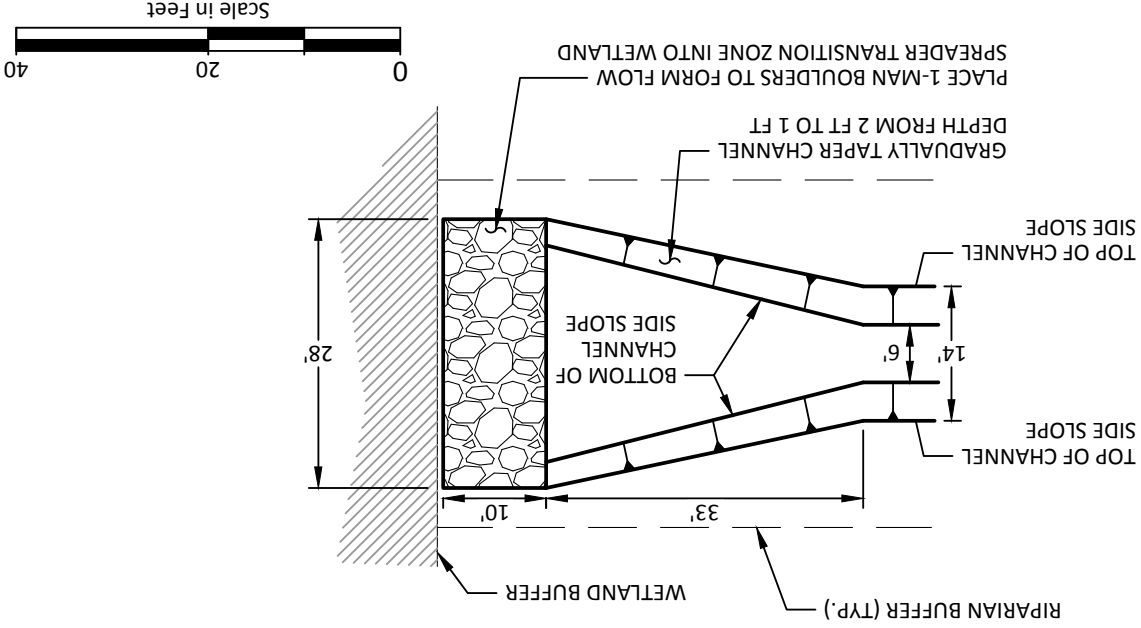
SHEET: 13 OF 24

PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A
APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108
DATE: AUGUST 30, 2019
SHEET: 14 OF 24

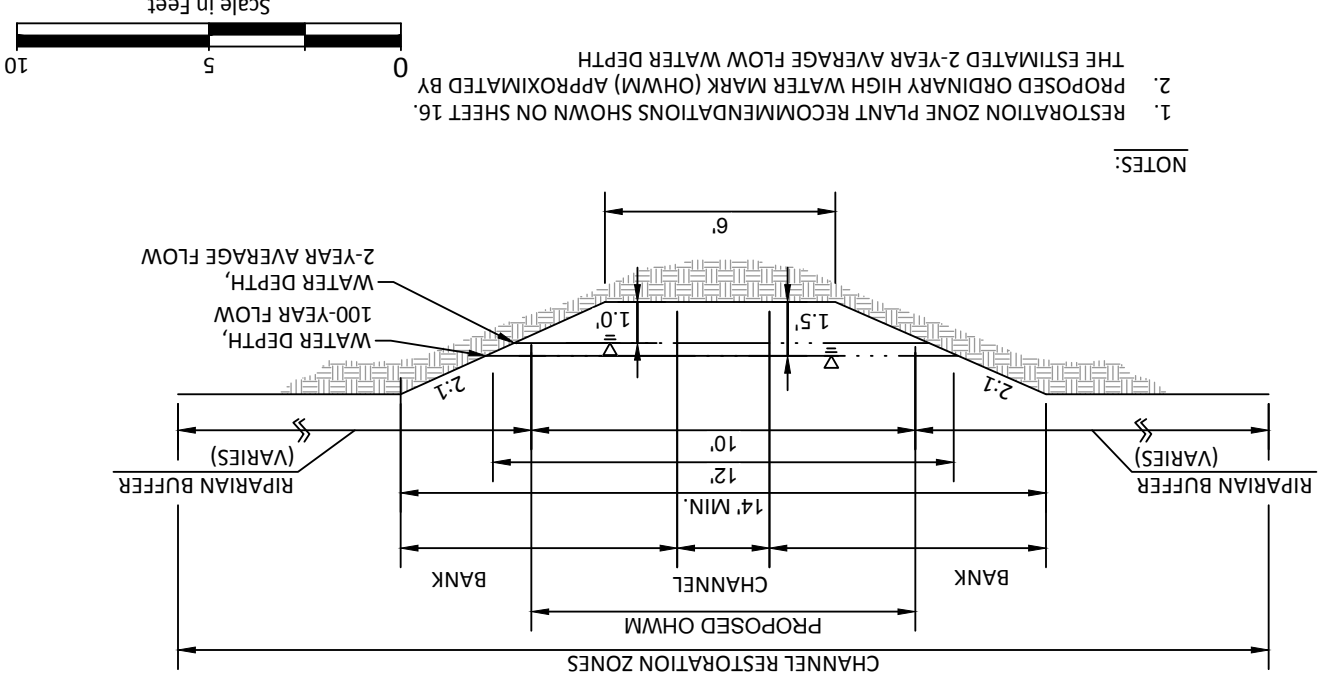
QUEEN CITY FARMS PHASE III RECLAMATION PROJECT
KING COUNTY, WASHINGTON
TRIBUTARY 316A RESTORED REACH TYPICAL STREAM CHANNEL SECTION & OUTLET SPREADER DETAIL

REFERENCE: NWP-2018-481
PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA
LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038
TOWNSHIP/RANGE: S 28, T 23 N, R 8 E Q5 NE, SW W.M.
LAT/LONG: 47.446697°N, -122.051349°W
ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

CHANNEL OUTLET SPREADER DETAIL
 SCALE: 1"=20'

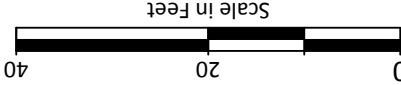
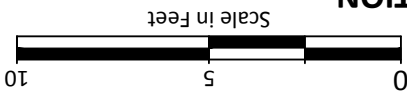


TYPICAL RESTORED STREAM CHANNEL SECTION
 SCALE: 1"=5'

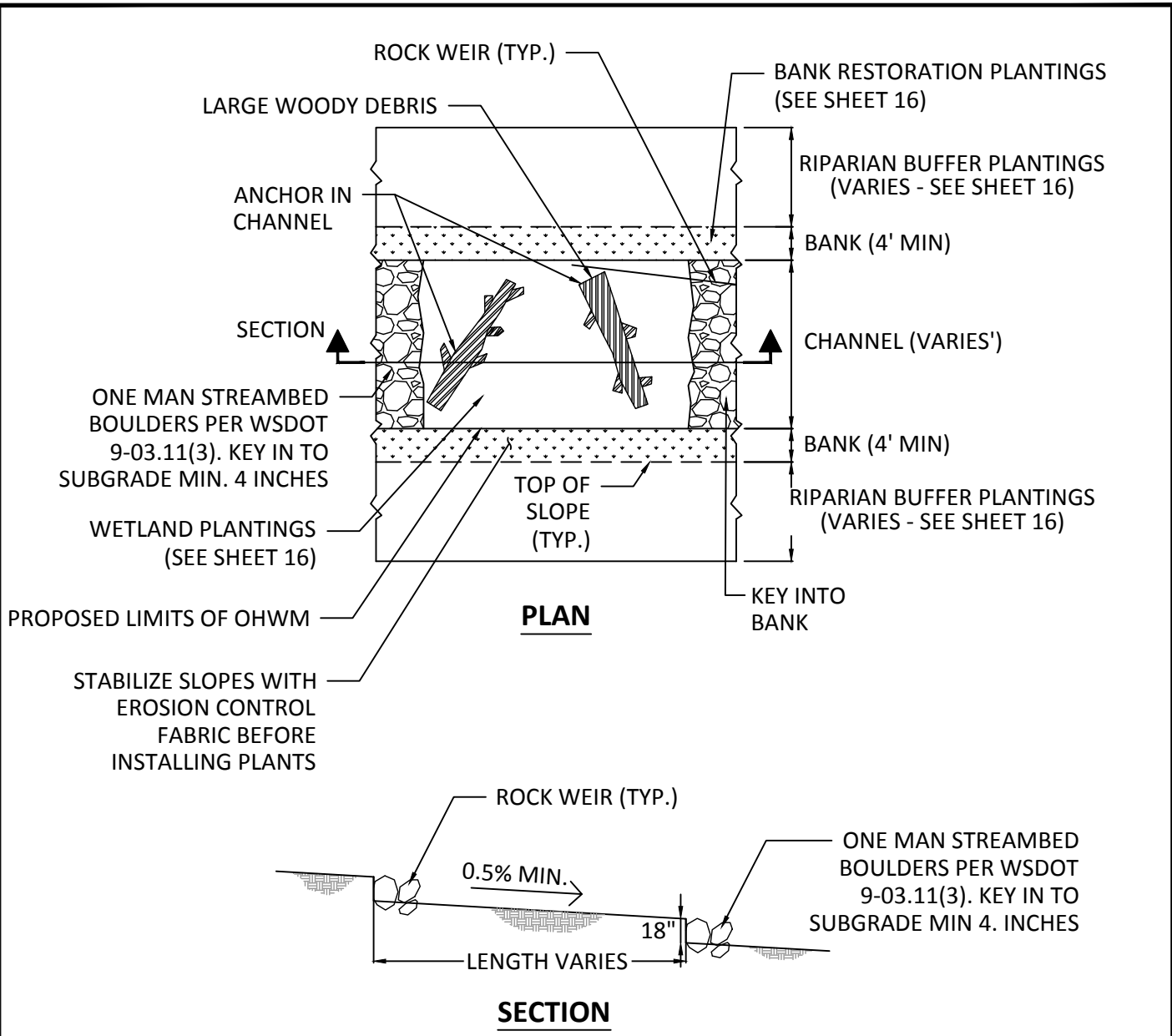


NOTES:

- RESTORATION ZONE PLANT RECOMMENDATIONS SHOWN ON SHEET 16.
- PROPOSED ORDINARY HIGH WATER MARK (OHWM) APPROXIMATED BY THE ESTIMATED 2-YEAR AVERAGE FLOW WATER DEPTH.



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NOTES:

1. INSTALL HIGH VISIBILITY FENCE AND SIGNAGE ALONG OUTER EDGE OF BUFFER TO PROTECT NEWLY PLANTED AREA.

DETAIL - STEP POOLS

NOT TO SCALE

<p>REFERENCE: NWP-2018-481</p> <p>PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA</p> <p>LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038</p> <p>TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.</p> <p>LAT/LONG: 47.446697"N, -122.051349"W</p> <p>ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C</p>	<p>QUEEN CITY FARMS PHASE III RECLAMATION PROJECT</p> <p>KING COUNTY, WASHINGTON</p> <p>TRIBUTARY 316A RESTORED REACH STEP POOL PLAN AND SECTION</p>	<p>PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A</p> <p>APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108</p> <p>DATE: APRIL 12, 2019</p> <p>SHEET: 15 OF 24</p>
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RESTORATION ZONES	COMMON NAME	SCIENTIFIC NAME	MINIMUM SPACING (O.C. FT)	FORM	MAX HEIGHT (FT)	LIGHT NEEDS ¹	SITE PLACEMENT ²	COMMENTS
CHANNEL								
	PACIFIC WILLOW ³	<i>Salix lucida</i>	1	5' STAKES	36	HA	SS	INSTALL WILLOWS AT EDGE OF STREAMBANK BUT OUTSIDE OF GRADED CHANNEL. INSTALL SLOUGH SEDGE IN CLUMPS OF 4 PLANTS WITH 1-FT ON-CENTER SPACING WITHIN GRADED CHANNEL. DO NOT PLANT WILLOWS WITHIN THALWEG.
	SITKA WILLOW ³	<i>Salix sitchensis</i>	1	5' STAKES	25	HA	WE,SS,WB	
	SLOUGH SEDGE ⁴	<i>Carex obnupta</i>	1	PLUGS	4.5	ST	SS	
BANK								
	BLACK COTTONWOOD	<i>Populus trichocarpa</i>	10	1-GAL	200	HA	WE,WB,SS	INSTALL THESE RECOMMENDED PLANTS ACCORDING TO THEIR SITE PLACEMENT NEEDS.
	CASCARA	<i>Rhamus purshiana</i>	10	1-GAL	25	HA	WE,WB	WETTER EDGE INDICATES
	BLACK TWINBERRY	<i>Lonicera involucrata</i>	4	1-GAL	10	SI-ST	WE,WB	INSTALLING PLANT CLOSER TO THE EDGE OF STREAM CHANNEL
	SALMONBERRY	<i>Rubus spectabilis</i>	4	BARE ROOT	15	HA	WE,WB	BELOW THE OHWM. DRIER
	RED-OSIER DOGWOOD ⁵	<i>Cormus sericea</i>	4	BARE ROOT	20	SI-ST	WE,WB	BUFFER INDICATES INSTALLING PLANT HIGHER ON
	NOOTKA ROSE	<i>Rosa nutkana</i>	4	BARE ROOT	10	SI-ST	WE,WB	STREAMBANK ABOVE THE OHWM.
	RED ALDER	<i>Alnus rubra</i>	4	BARE ROOT	80	SI-ST	WE,WB,SS	
	PACIFIC NINEBARK	<i>Physocarpus capitatus</i>	4	1-GAL	13	ST	DB	
RIPARIAN BUFFER								
	BIGLEAF MAPLE	<i>Acer macrophyllum</i>	10	1-GAL	100	ST	DB	INSTALL THESE RECOMMENDED
	PAPER BIRCH	<i>betula papyrifera</i>	10	1-GAL	230	ST	WE,WB	PLANTS ACCORDING TO THEIR
	OCEAN SPRAY	<i>Holodiscus discolor</i>	4	1-GAL	10	SI-ST	DB	SITE PLACEMENT NEEDS. ALL
	SERVICEBERRY	<i>Amelanchier ainifolia</i>	4	1-GAL	35	SI-ST	WE,WB	PLANTS SHOULD BE ADAPTABLE
	COMMON SNOWBERRY	<i>Symphoricarpos albus</i>	4	1-GAL	6	SI-ST	DB	TO DRIER BUFFER CONDITIONS.
	RED-FLOWERING CURRENT	<i>Rives sanguineum</i>	4	1-GAL	13	SI-ST	DB	PLANTS MAY NEED
	WOOD ROSE	<i>Rosa gymnocarpa</i>	4	1-GAL	7	ST	DB	SUPPLEMENTAL WATERING
	RED ELDERBERRY	<i>Sambucus racemosa</i>	4	1-GAL	20	HA	WB,DB	DURING FIRST YEAR
	INDIAN PLUM	<i>Oemlaria cerasiformis</i>	4	BARE ROOT	15	HA	WE,WB,DB	FOLLOWING INSTALLATION.

NATIVE HYDROSEED MIX:

SCIENTIFIC NAME	COMMON NAME	PROPORTIONS BY WEIGHT
<i>Alopecurus geniculatus</i>	WATER FOXTAIL	15%
<i>Agrostis stolonifera</i>	SPREADING BENTGRASS	15%
<i>Glyceria grandis</i>	REED MANAGRASS	15%
<i>Deschampsia cespitosa</i>	TUFTED HAIRGRASS	15%
<i>Eleocharis palustris</i>	CREEPING SPIKE RUSH	10%
<i>Juncus tenuis</i>	SLENDER RUSH	10%
<i>Scirpus microcarpus</i>	SMALL-FRUITED BULL RUSH	10%
<i>Carex obnupta</i>	SLOUGH SEDGE	10%

¹LIGHT NEEDS:

SI = SHADE INTOLERANT
ST = SHADE TOLERANT
SD = SHADE DEPENDENT
HA = HIGHLY ADAPTABLE

²SITE PLACEMENT:

DB = DRIER BUFFER
WB = WETTER BUFFER
WE = WETTER EDGE
SS = SATURATED SOILS

NOTES:

1. PLANT FORMS ARE APPROXIMATE AND WILL BE BASED ON AVAILABILITY FROM SUPPLIER AT TIME OF INSTALLATION.
2. PLANT SPECIES SUBSTITUTIONS FROM RESTORATION ZONES WILL BE APPROVED BY WETLAND BIOLOGIST PRIOR TO ORDERING PLANT STOCK.
3. PLANT WILLOWS AT EDGE OF STREAMBANK OUTSIDE OF GRADED CHANNEL.
4. PLANT SLOUGH SEDGE THROUGHOUT GRADED CHANNEL AT 1-FT O.C.
5. DOGWOOD PLANTS WILL NEED TO BE PROTECTED FROM BROWSING BY WILDLIFE.

<p>REFERENCE: NWP-2018-481</p> <p>PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA</p> <p>LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038</p> <p>TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.</p> <p>LAT/LONG: 47.446697"N, -122.051349"W</p> <p>ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C</p>	<p>QUEEN CITY FARMS PHASE III RECLAMATION PROJECT</p> <p>KING COUNTY, WASHINGTON</p> <p>TRIBUTARY 316A RESTORED REACH RECOMMENDED STREAM CHANNEL AND BUFFER PLANTINGS</p>	<p>PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A</p> <p>APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108</p> <p>DATE: AUGUST 30, 2019</p> <p>SHEET: 16 OF 24</p>
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PHOTO 1: CONCRETE CHECK DAMS CONSTRUCTED AS PART OF THE ENGINEERED CHANNEL. LOOKING NORTH, NORTH OF THE SOUTHERN ACCESS ROAD, CONCRETE CHECK DAMS DIRECT-FLOW INTO THE CULVERT LEADING TO THE MAIN INFILTRATION AREA.



PHOTO 2: UPPER REACH OF THE TRIBUTARY 316A CHANNEL AT THE NORTH END OF THE PROPERTY, FACING SOUTH.

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REFERENCE: NWP-2018-481

PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA

LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038

TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.

LAT/LONG: 47.446697"N, -122.051349"W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

**TRIBUTARY 316A AND
ASSOCIATED WETLANDS
AND WATERWAYS PHOTOS**

PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A

APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108

DATE: APRIL 12, 2019

SHEET: 17 OF 24



PHOTO 3: WETLAND A, FACING EAST AT WEST SIDE OF WETLAND.



PHOTO 4: WATERCOURSE B, FACING WEST.

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REFERENCE: NWP-2018-481

PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA

LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038

TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.

LAT/LONG: 47.446697"N, -122.051349"W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

**TRIBUTARY 316A AND
ASSOCIATED WETLANDS
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APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108

DATE: APRIL 12, 2019

SHEET: 18 OF 24



PHOTO 5: WETLAND B, FACING NORTHWEST.



PHOTO 6: WETLAND C, FACING SOUTH FROM NORTH END OF WETLAND.

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REFERENCE: NWP-2018-481

PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA

LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038

TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.

LAT/LONG: 47.446697"N, -122.051349"W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

**TRIBUTARY 316A AND
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PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A

APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108

DATE: APRIL 12, 2019

SHEET: 19 OF 24



PHOTO 7: WETLAND D/F, FACING NORTHEAST.



PHOTO 8: WETLAND G, FACING SOUTHEAST FROM WEST SIDE OF WETLAND.

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REFERENCE: NWP-2018-481

PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA

LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038

TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.

LAT/LONG: 47.446697"N, -122.051349"W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

**TRIBUTARY 316A AND
ASSOCIATED WETLANDS
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PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A

APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108

DATE: APRIL 12, 2019

SHEET: 20 OF 24



PHOTO 9: WETLAND H, FACING NORTH TOWARD NORTHERN PROPERTY BOUNDARY FROM NORTHWEST SIDE OF WETLAND.



PHOTO 10: WATERCOURSE D, FACING SOUTHEAST TOWARD WETLAND I.

\\EDM\GIS03\PROJECTS\992\050\051\JARPA\JARPA_SHEET_14-24.DWG

REFERENCE: NWP-2018-481

PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA

LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038

TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.

LAT/LONG: 47.446697"N, -122.051349"W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

**TRIBUTARY 316A AND
ASSOCIATED WETLANDS
AND WATERWAYS PHOTOS**

PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A

APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108

DATE: APRIL 12, 2019

SHEET: 21 OF 24



PHOTO 11: WETLAND I, FACING NORTHWEST FROM SOUTH END OF WETLAND.



PHOTO 12: WETLAND J, FACING WEST TOWARD TRIBUTARY 316A FROM EAST SIDE OF WETLAND.

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REFERENCE: NWP-2018-481

PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA

LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038

TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.

LAT/LONG: 47.446697"N, -122.051349"W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

**TRIBUTARY 316A AND
ASSOCIATED WETLANDS
AND WATERWAYS PHOTOS**

PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A

APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108

DATE: APRIL 12, 2019

SHEET: 22 OF 24



PHOTO 13: WETLAND K, FACING NORTH FROM SOUTH END OF WETLAND.



PHOTO 14: WATERCOURSE F, FACING WEST. WATERCOURSE F FLOWS EAST FROM WETLAND K TO THE ENGINEERED REACH OF TRIBUTARY 316A.

\\EDM\GIS03\GRAPHICS\PROJECTS\92\002\050\051\JARPA\JARPA_SHEET 14-24.DWG

REFERENCE: NWP-2018-481

PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA

LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038

TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.

LAT/LONG: 47.446697"N, -122.051349"W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

**TRIBUTARY 316A AND
ASSOCIATED WETLANDS
AND WATERWAYS PHOTOS**

PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A

APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108

DATE: APRIL 12, 2019

SHEET: 23 OF 24



PHOTO 15: WATERCOURSE E, FACING EAST. WATERCOURSE E FLOWS EAST INTO THE ENGINEERED BIOINFILTRATION POND.



PHOTO 16: LOOKING NORTH ACROSS THE ENGINEERED INFILTRATION POND FROM ITS SOUTHERN BOUNDARY. THE NORTHERN ACCESS ROAD TO THE COMPOST PAD IS LOCATED TO THE NORTH OF THE POND.

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REFERENCE: NWP-2018-481

PURPOSE: GRADING PERMIT FOR PHASE III RECLAMATION AREA

LOCATION: 17825 CEDAR GROVE ROAD SOUTHWEST MAPLE VALLEY, WASHINGTON, 98038

TOWNSHIP/RANGE: S 28, T 23 N, R 8 E QS NE, SW W.M.

LAT/LONG: 47.446697"N, -122.051349"W

ADJACENT PROPERTY OWNERS: SEE JARPA ATTACHMENT C

**QUEEN CITY FARMS
PHASE III RECLAMATION PROJECT**

KING COUNTY, WASHINGTON

**TRIBUTARY 316A AND
ASSOCIATED WETLANDS
AND WATERWAYS PHOTOS**

PROPOSED PROJECT: REFILL AND RECLAIM PHASE III RECLAMATION AREA, RELOCATE AND RESTORE TRIBUTARY 316A

APPLICATION BY: QUEEN CITY FARMS, INC. 7343 EAST MARGINAL WAY SOUTH SEATTLE, WASHINGTON, 98108

DATE: AUGUST 30, 2019

SHEET: 24 OF 24

Stormwater Facility Summary Sheets

STORMWATER FACILITY SUMMARY SHEET

(provide one Stormwater Facility Summary Sheet per *Natural Discharge Location*)

OVERVIEW: _____ (Queen City Lake/Tributary 316A)

Project Name
Queen City Farms Phase III

Project Location
17825 Cedar Grove Rd SE, Maple Valley, WA

Downstream Drainage Basins:
Major Basin Name Maple Hills Sub-Basin, Cedar Hills Sub-basin, Main Gravel Pit Sub-basin
Immediate Basin Name _____

GENERAL FACILITY INFORMATION:

Detention		Infiltration		Water Quality		Flow Control	
Type	# of	Type	# of	Type	# of facilities	Performance Std	
Ponds	3	Ponds	2	Ponds	3	<input checked="" type="checkbox"/>	Basic
Vaults	_____	Tanks	_____	Vaults	_____	<input type="checkbox"/>	Conservation
Tanks	_____	Frenches	_____	Tanks	_____	<input type="checkbox"/>	Flood Problem

If no flow control facility, check one:

- Project qualifies for KCSWDM Exemption (KCSWDM 1.2.3):
 - Basic Exemption
 - Impervious Surface Exemption for Transportation Redevelopment projects
 - Cost Exemption for Parcel Redevelopment projects
 - Direct Discharge Exemption
 - Other _____
- Project qualifies for 0.1 cfs Exception per KCSWDM 1.2.3
- No flow control required per approved KCSWDM Adjustment No. _____
- Flow control provided in regional/shared facility per approved approved KCSWDM Adjustment No. _____
Shared Facility Name/Location: _____
- No flow control required (other, provide justification): _____

DPER Permit No. GRDE18-0048
Date 8/30/2019
NPDES Permit No. _____

Parcel No. 2823069009, 3323069027
Retired Parcel No. _____

Project includes Landscape Management Plan? yes
(include copy with TIR as Appendix) no

Declarations of Covenant	Recording No.
<i>Leachable Metals</i>	_____
<i>Impervious Surface Limit</i>	_____
<i>Flow Control BMPs</i>	_____
<i>Clearing Limit</i>	_____
<i>Drainage Facility</i>	_____
<i>Landscape Management Plan</i>	_____

TREATMENT SUMMARY FOR TOTAL IMPERVIOUS SURFACES

(Applies to Commercial parcels only)	Area	% of Total
Total Acreage (ac)	97	-----
Total Impervious Acreage (ac)	1.5	1.6
Total impervious surface served by flow control facility(ies) (sq ft)	66,960	1.6
Impervious surface served by flow control facility(ies) designed 1990 or later (sq ft)	66,960	1.6
Impervious surface served by pervious surface absorption (sq ft)	0	0
Impervious surface served by approved water quality facility(ies) (sq ft)	66,960	1.6

PROVIDE FACILITY DETAILS AND FACILITY SKETCH FOR EACH FACILITY ON REVERSE. USE ADDITIONAL SHEETS AS NEEDED FOR ADDITIONAL FACILITIES

STORMWATER FACILITY SUMMARY SHEET

DPER Permit No. GRDE18-0048

(provide one Stormwater Facility Summary Sheet per *Natural Discharge Location*)

Project Name	Queen City Farms Phase III
Project Location	17825 Cedar Grove Rd SE, Maple Valley, WA

Downstream Drainage Basins:

Major Basin Name Maple Hills Sub-Basin, Cedar Hills Sub-basin, Main Gravel Pit Sub-basin
 Immediate Basin Name _____

FLOW CONTROL FACILITY:		Basin: Main Gravel Pit Sub-basin	
Facility Name/Number <u>West Pond</u>		<input type="checkbox"/> New Facility	
Facility Location <u>Refer to site improvement plans</u>		<input checked="" type="checkbox"/> Existing Facility	
UIC? <input type="checkbox"/> yes <input checked="" type="checkbox"/> no UIC Site ID: <u>N/A</u>			
Live Storage Volume <u>64,998</u>	<input checked="" type="checkbox"/> cu.ft. <input type="checkbox"/> ac.ft.	Live Storage Depth (ft) <u>4</u>	Volume Factor of Safety <u>1.24</u>
Control Structure location: <u>N/A</u>			
Type of Control Structure:	No. of Orifices/Restrictions _____		
<input type="checkbox"/> Riser in vault	Size of Orifice/Restriction (in.) No.1 _____		
<input type="checkbox"/> Riser in Type II CB	(numbered starting with lowest No.2 _____		
<input type="checkbox"/> Weir in Type II CB	orifice): No.3 _____		
	(inches in decimal format) No.4 _____		
		Dam Safety Regulations (WA State Dept of Ecology):	
		Reservoir Volume above natural grade	<input type="checkbox"/> cu.ft. <input type="checkbox"/> ac.ft.
		Depth of Reservoir above natural grade	(ft)

Project Impervious Acres Served	<u>0.77</u>
% of Total Project Impervious Acres Served	<u>50%</u>
No. of Lots Served	<u>N/A</u>

WATER QUALITY FACILITIES	Design Information
Indicate no. of water quality facilities/BMPs for each type:	Water Quality design flow (cfs) <u>N/A</u>
_____ Flow dispersion	Water Quality treated volume (sandfilter) (cu.ft.) <u>N/A</u>
_____ Filter strip	Water Quality storage volume (wetpool) (cu.ft.) <u>38,963</u>
_____ Biofiltration swale <input type="checkbox"/> regular, <input type="checkbox"/> wet or <input type="checkbox"/> continuous inflow	<input type="checkbox"/> Landscape management plan <input type="checkbox"/> Farm management plan
_____ Wetvault <input type="checkbox"/> combined w/detention	_____ High flow bypass structure (e.g., flow-splitter catch basin)
¹ _____ Wetpond <input type="checkbox"/> basic <input type="checkbox"/> large <input checked="" type="checkbox"/> combined w/detention	_____ Oil/water separator <input type="checkbox"/> baffle <input type="checkbox"/> coalescing plate
_____ Pre-settling pond	_____ Storm filter
_____ Stormwater wetland	_____ Pre-settling structure (Manufacturer: _____)
_____ Sand filter <input type="checkbox"/> basic <input type="checkbox"/> large <input type="checkbox"/> regular <input type="checkbox"/> linear <input type="checkbox"/> vault	_____ Catch basin inserts (Manufacturer: _____)
Sand bed depth (inches) _____	_____ Source controls
• Is facility lined? <input type="checkbox"/> yes <input checked="" type="checkbox"/> no If so, what marker is used above liner? _____	

Facility Summary Sheet Sketch: All detention, infiltration and water quality facilities must include a detailed sketch (11"x17" reduced size plan sheets preferred).

NOTE: Refer to site improvement plans for facility details.

STORMWATER FACILITY SUMMARY SHEET

DPER Permit No. GRDE18-0048

(provide one Stormwater Facility Summary Sheet per *Natural Discharge Location*)

Project Name	Queen City Farms Phase III
Project Location	17825 Cedar Grove Rd SE, Maple Valley, WA

Downstream Drainage Basins:

Major Basin Name Maple Hills Sub-Basin, Cedar Hills Sub-basin, Main Gravel Pit Sub-basin
 Immediate Basin Name _____

FLOW CONTROL FACILITY:		Basin: Main Gravel Pit Sub-basin	
Facility Name/Number <u>East Pond</u>		<input type="checkbox"/> New Facility	
Facility Location <u>Refer to site improvement plans</u>		<input checked="" type="checkbox"/> Existing Facility	
UIC? <input type="checkbox"/> yes <input checked="" type="checkbox"/> no UIC Site ID: <u>N/A</u>			
Live Storage <input checked="" type="checkbox"/> cu.ft.	Live Storage <input type="checkbox"/> ac.ft.	Volume Factor	
Volume <u>101,103</u>	Depth (ft) <u>3</u>	of Safety <u>1</u>	
Control Structure location: <u>N/A</u>			
Type of Control Structure:	No. of Orifices/Restrictions		
<input type="checkbox"/> Riser in vault	Size of Orifice/Restriction (in.)	No.1	_____
<input type="checkbox"/> Riser in Type II CB	(numbered starting with lowest	No.2	_____
<input type="checkbox"/> Weir in Type II CB	orifice):	No.3	_____
	(inches in decimal format)	No.4	_____
		Dam Safety Regulations (WA State Dept of Ecology):	
		Reservoir Volume	<input type="checkbox"/> cu.ft.
		above natural grade	<input type="checkbox"/> ac.ft.
		Depth of Reservoir	(ft)
		above natural grade	

WATER QUALITY FACILITIES		Design Information	
Indicate no. of water quality facilities/BMPs for each type:		Water Quality design flow (cfs) <u>N/A</u>	
_____ Flow dispersion		Water Quality treated volume (sandfilter) (cu.ft.) <u>N/A</u>	
_____ Filter strip		Water Quality storage volume (wetpool) (cu.ft.) <u>N/A</u>	
_____ Biofiltration swale <input type="checkbox"/> regular, <input type="checkbox"/> wet or <input type="checkbox"/> continuous inflow		<input type="checkbox"/> Landscape management plan <input type="checkbox"/> Farm management plan	
_____ Wetvault <input type="checkbox"/> combined w/detention		_____ High flow bypass structure (e.g., flow-splitter catch basin)	
_____ Wetpond <input type="checkbox"/> basic <input type="checkbox"/> large <input type="checkbox"/> combined w/detention		_____ Oil/water separator <input type="checkbox"/> baffle <input type="checkbox"/> coalescing plate	
_____ Pre-settling pond		_____ Storm filter	
1 _____ Stormwater wetland		_____ Pre-settling structure (Manufacturer: _____)	
_____ Sand filter <input type="checkbox"/> basic <input type="checkbox"/> large <input type="checkbox"/> regular <input type="checkbox"/> linear <input type="checkbox"/> vault		_____ Catch basin inserts (Manufacturer: _____)	
_____ Sand bed depth (inches) _____		_____ Source controls	
• Is facility lined? <input type="checkbox"/> yes <input checked="" type="checkbox"/> no If so, what marker is used above liner? _____			

Facility Summary Sheet Sketch: All detention, infiltration and water quality facilities must include a detailed sketch (11"x17" reduced size plan sheets preferred).

NOTE: Refer to site improvement plans for facility details.

STORMWATER FACILITY SUMMARY SHEET

DPER Permit No. GRDE18-0048

(provide one Stormwater Facility Summary Sheet per *Natural Discharge Location*)

Project Name	Queen City Farms Phase III
Project Location	17825 Cedar Grove Rd SE, Maple Valley, WA

Downstream Drainage Basins:

Major Basin Name Maple Hills Sub-Basin, Cedar Hills Sub-basin, Main Gravel Pit Sub-basin
 Immediate Basin Name _____

FLOW CONTROL FACILITY:		Basin: Main Gravel Pit Sub-basin	
Facility Name/Number <u>South Pond/Bioswale</u>		<input type="checkbox"/> New Facility	
Facility Location <u>Refer to site improvement plans</u>		<input checked="" type="checkbox"/> Existing Facility	
UIC? <input type="checkbox"/> yes <input checked="" type="checkbox"/> no UIC Site ID: <u>N/A</u>			
Live Storage Volume <u>88,460</u>	<input checked="" type="checkbox"/> cu.ft. <input type="checkbox"/> ac.ft.	Live Storage Depth (ft) <u>4</u>	Volume Factor of Safety <u>1.07</u>
Control Structure location: <u>N/A</u>			
Type of Control Structure:	No. of Orifices/Restrictions _____		
<input type="checkbox"/> Riser in vault	Size of Orifice/Restriction (in.) No.1 _____		
<input type="checkbox"/> Riser in Type II CB	(numbered starting with lowest No.2 _____		
<input type="checkbox"/> Weir in Type II CB	orifice): No.3 _____		
	(inches in decimal format) No.4 _____		
		Dam Safety Regulations (WA State Dept of Ecology):	
		Reservoir Volume above natural grade	<input type="checkbox"/> cu.ft. <input type="checkbox"/> ac.ft.
		Depth of Reservoir above natural grade	(ft)

WATER QUALITY FACILITIES		Design Information	
Indicate no. of water quality facilities/BMPs for each type:		Water Quality design flow (cfs) <u>3.38</u>	
_____ Flow dispersion		Water Quality treated volume (sandfilter) (cu.ft.) <u>N/A</u>	
_____ Filter strip		Water Quality storage volume (wetpool) (cu.ft.) <u>N/A</u>	
1 _____ Biofiltration swale <input checked="" type="checkbox"/> regular, <input type="checkbox"/> wet or <input type="checkbox"/> continuous inflow		<input type="checkbox"/> Landscape management plan <input type="checkbox"/> Farm management plan	
_____ Wetvault <input type="checkbox"/> combined w/detention		_____ High flow bypass structure (e.g., flow-splitter catch basin)	
_____ Wetpond <input type="checkbox"/> basic <input type="checkbox"/> large <input type="checkbox"/> combined w/detention		_____ Oil/water separator <input type="checkbox"/> baffle <input type="checkbox"/> coalescing plate	
_____ Pre-settling pond		_____ Storm filter	
_____ Stormwater wetland		_____ Pre-settling structure (Manufacturer: _____)	
_____ Sand filter <input type="checkbox"/> basic <input type="checkbox"/> large <input type="checkbox"/> regular <input type="checkbox"/> linear <input type="checkbox"/> vault		_____ Catch basin inserts (Manufacturer: _____)	
_____ Sand bed depth (inches) _____		_____ Source controls	
• Is facility lined? <input checked="" type="checkbox"/> yes <input type="checkbox"/> no If so, what marker is used above liner? <u>N/A - bioswale is lined with geosynthetic clay/geomembrane liner</u>			

Facility Summary Sheet Sketch: All detention, infiltration and water quality facilities must include a detailed sketch (11"x17" reduced size plan sheets preferred).

NOTE: Refer to site improvement plans for facility details.

STORMWATER FACILITY SUMMARY SHEET

DPER Permit No. GRDE18-0048

(provide one Stormwater Facility Summary Sheet per *Natural Discharge Location*)

Project Name	Queen City Farms Phase III
Project Location	17825 Cedar Grove Rd SE, Maple Valley, WA

Downstream Drainage Basins:

Major Basin Name Maple Hills Sub-Basin, Cedar Hills Sub-basin, Main Gravel Pit Sub-basin
 Immediate Basin Name _____

FLOW CONTROL FACILITY:		Basin: Main Gravel Pit Sub-basin	
Facility Name/Number <u>Cedar Shores Pond 2B</u>		<input type="checkbox"/> New Facility	
Facility Location <u>Refer to site improvement plans</u>		<input checked="" type="checkbox"/> Existing Facility	
UIC? <input type="checkbox"/> yes <input checked="" type="checkbox"/> no UIC Site ID: <u>N/A</u>			
Live Storage Volume <u>337,850</u>	<input checked="" type="checkbox"/> cu.ft. <input type="checkbox"/> ac.ft.	Live Storage Depth (ft) <u>4</u>	Volume Factor of Safety <u>1.02</u>
Control Structure location: <u>Downstream side of pond</u>			
Type of Control Structure:	No. of Orifices/Restrictions <u>1</u>		
<input type="checkbox"/> Riser in vault	Size of Orifice/Restriction (in.) No.1 <u>4.82</u>		
<input checked="" type="checkbox"/> Riser in Type II CB	(numbered starting with lowest orifice): No.2 _____		
<input checked="" type="checkbox"/> Weir in Type II CB	(inches in decimal format) No.3 _____		
	No.4 _____		
		Dam Safety Regulations (WA State Dept of Ecology):	
		Reservoir Volume above natural grade	<input type="checkbox"/> cu.ft. <input type="checkbox"/> ac.ft.
		Depth of Reservoir above natural grade	(ft)

Project Impervious Acres Served	<u>0.38</u>
% of Total Project Impervious Acres Served	<u>25%</u>
No. of Lots Served	<u>N/A</u>

WATER QUALITY FACILITIES		Design Information	
Indicate no. of water quality facilities/BMPs for each type:		Water Quality design flow (cfs) <u>N/A</u>	
<input type="checkbox"/> Flow dispersion		Water Quality treated volume (sandfilter) (cu.ft.) <u>N/A</u>	
<input type="checkbox"/> Filter strip		Water Quality storage volume (wetpool) (cu.ft.) <u>99,090</u>	
<input type="checkbox"/> Biofiltration swale <input type="checkbox"/> regular, <input type="checkbox"/> wet or <input type="checkbox"/> continuous inflow		<input type="checkbox"/> Landscape management plan <input type="checkbox"/> Farm management plan	
<input type="checkbox"/> Wetvault <input type="checkbox"/> combined w/detention		<input type="checkbox"/> High flow bypass structure (e.g., flow-splitter catch basin)	
<u>1</u> <input type="checkbox"/> Wetpond <input type="checkbox"/> basic <input type="checkbox"/> large <input checked="" type="checkbox"/> combined w/detention		<input type="checkbox"/> Oil/water separator <input type="checkbox"/> baffle <input type="checkbox"/> coalescing plate	
<input type="checkbox"/> Pre-settling pond		<input type="checkbox"/> Storm filter	
<input type="checkbox"/> Stormwater wetland		<input type="checkbox"/> Pre-settling structure (Manufacturer: _____)	
<input type="checkbox"/> Sand filter <input type="checkbox"/> basic <input type="checkbox"/> large <input type="checkbox"/> regular <input type="checkbox"/> linear <input type="checkbox"/> vault		<input type="checkbox"/> Catch basin inserts (Manufacturer: _____)	
Sand bed depth (inches) _____		<input type="checkbox"/> Source controls	
● Is facility lined? <input checked="" type="checkbox"/> yes <input type="checkbox"/> no		If so, what marker is used above liner? <u>N/A; pond is lined with a clay liner</u>	

Facility Summary Sheet Sketch: All detention, infiltration and water quality facilities must include a detailed sketch (11"x17" reduced size plan sheets preferred).

NOTE: Refer to "Cedar Shores Refill" plans approved 4/15/09 (Activity Number: L08RE025, Project Number: L03CG141) 4/24/2016

STORMWATER FACILITY SUMMARY SHEET

DPER Permit No. GRDE18-0048

(provide one Stormwater Facility Summary Sheet per *Natural Discharge Location*)

Project Name	Queen City Farms Phase III
Project Location	17825 Cedar Grove Rd SE, Maple Valley, WA

Downstream Drainage Basins:

Major Basin Name Maple Hills Sub-Basin, Cedar Hills Sub-basin, Main Gravel Pit Sub-basin
 Immediate Basin Name _____

FLOW CONTROL FACILITY:		Basin: Main Gravel Pit Sub-basin	
Facility Name/Number <u>Cedar Shores Pond 2C</u>		<input type="checkbox"/> New Facility	
Facility Location <u>Refer to site improvement plans</u>		<input checked="" type="checkbox"/> Existing Facility	
UIC? <input type="checkbox"/> yes <input checked="" type="checkbox"/> no UIC Site ID: <u>N/A</u>			
Live Storage Volume <u>297,150</u>	<input checked="" type="checkbox"/> cu.ft. <input type="checkbox"/> ac.ft.	Live Storage Depth (ft) <u>4</u>	Volume Factor of Safety <u>1.02</u>
Control Structure location: <u>Downstream side of pond</u>			
Type of Control Structure:	No. of Orifices/Restrictions <u>1</u>		
<input type="checkbox"/> Riser in vault	Size of Orifice/Restriction (in.) No.1 <u>5.78</u>		
<input checked="" type="checkbox"/> Riser in Type II CB	(numbered starting with lowest orifice): No.2 _____		
<input checked="" type="checkbox"/> Weir in Type II CB	(inches in decimal format) No.3 _____		
	No.4 _____		
		Dam Safety Regulations (WA State Dept of Ecology):	
		Reservoir Volume above natural grade	<input type="checkbox"/> cu.ft. <input type="checkbox"/> ac.ft.
		Depth of Reservoir above natural grade	(ft)

Project Impervious Acres Served	<u>0.38</u>
% of Total Project Impervious Acres Served	<u>25%</u>
No. of Lots Served	<u>N/A</u>

WATER QUALITY FACILITIES	Design Information
Indicate no. of water quality facilities/BMPs for each type:	Water Quality design flow (cfs) <u>N/A</u>
_____ Flow dispersion	Water Quality treated volume (sandfilter) (cu.ft.) <u>N/A</u>
_____ Filter strip	Water Quality storage volume (wetpool) (cu.ft.) <u>107,400</u>
_____ Biofiltration swale <input type="checkbox"/> regular, <input type="checkbox"/> wet or <input type="checkbox"/> continuous inflow	<input type="checkbox"/> Landscape management plan <input type="checkbox"/> Farm management plan
_____ Wetvault <input type="checkbox"/> combined w/detention	_____ High flow bypass structure (e.g., flow-splitter catch basin)
<u>1</u> _____ Wetpond <input type="checkbox"/> basic <input type="checkbox"/> large <input checked="" type="checkbox"/> combined w/detention	_____ Oil/water separator <input type="checkbox"/> baffle <input type="checkbox"/> coalescing plate
_____ Pre-settling pond	_____ Storm filter
_____ Stormwater wetland	_____ Pre-settling structure (Manufacturer: _____)
_____ Sand filter <input type="checkbox"/> basic <input type="checkbox"/> large <input type="checkbox"/> regular <input type="checkbox"/> linear <input type="checkbox"/> vault	_____ Catch basin inserts (Manufacturer: _____)
Sand bed depth (inches) _____	_____ Source controls
• Is facility lined? <input checked="" type="checkbox"/> yes <input type="checkbox"/> no If so, what marker is used above liner? <u>N/A; pond is lined with a clay liner</u>	

Facility Summary Sheet Sketch: All detention, infiltration and water quality facilities must include a detailed sketch (11"x17" reduced size plan sheets preferred).

Drainage Declaration of Covenant

RECORDING REQUESTED BY AND
WHEN RECORDED MAIL TO:

Stephan Banchemo

7343 East Marginal Way South

Seattle, WA 98108

**DECLARATION OF COVENANT
FOR INSPECTION AND MAINTENANCE OF STORMWATER
FACILITIES AND BMPS**

Grantor: Stephan Banchemo (Queen City Farms)

Grantee: King County

Legal Description: S 1/2 OF SEC LESS CO RDS SUBJ TO ESMT BONNEVILLE
POWER LN

Additional Legal(s) on: _____

Assessor's Tax Parcel ID#: 2823069009

IN CONSIDERATION of the approved King County Clearing & Grading permit
for application No. GRDE18-0048 relating to the real property ("Property") described
above, the Grantor(s), the owner(s) in fee of that Property, hereby covenants(covenant) with King
County, a political subdivision of the state of Washington and its municipal successors in interest and
assigns ("King County" and "the County", or "its municipal successor"), that he/she(they) will observe,
consent to, and abide by the conditions and obligations set forth and described in Paragraphs 1 through 10

below with regard to the Property, and hereby grants(grant) an easement as described in Paragraphs 2 and

3. Grantor(s) hereby grants(grant), covenants(covenant), and agrees(agree) as follows:

1. The Grantor(s) or his/her(their) successors in interest and assigns ("Owners") shall at their own cost, operate, maintain, and keep in good repair, the Property's stormwater facilities and best management practices ("BMPs") identified in the plans and specifications submitted to King County for the review and approval of permit(s) #: GRDE18-0048 . Stormwater facilities include pipes, swales, tanks, vaults, ponds, and other engineered structures designed to manage stormwater on the Property. Stormwater BMPs include dispersion and infiltration devices, native vegetated areas, permeable pavements, vegetated roofs, rainwater harvesting systems, reduced impervious surface coverage, and other measures designed to reduce the amount of stormwater runoff on the Property.

2. King County shall have the right to ingress and egress over those portions of the Property necessary to perform inspections of the stormwater facilities and BMPs and conduct other activities specified in this Declaration of Covenant and in accordance with King County Code ("KCC") 9.04.120 or relevant municipal successor's codes as applicable. This right of ingress and egress, right to inspect, and right to perform required maintenance or repair as provided for in Section 3 below, shall not extend over those portions of the Property shown in Exhibit "A."

3. If King County determines that maintenance or repair work is required to be done to any of the stormwater facilities or BMPs, the Director of the Water and Land Resources Division or its municipal successor in interest ("WLR") shall give notice of the specific maintenance and/or repair work required pursuant to KCC 9.04.120 or relevant municipal successor's codes as applicable. The Director shall also set a reasonable time in which such work is to be completed by the Owners. If the above required maintenance or repair is not completed within the time set by the Director, the County may perform the required maintenance or repair, and hereby is given access to the Property, subject to the exclusion in Paragraph 2 above, for such purposes. Written notice will be sent to the Owners stating the County's intention to perform such work. This work will not commence until at least seven (7) days after such

notice is mailed. If, within the sole discretion of the WLR Director, there exists an imminent or present danger, the seven (7) day notice period will be waived and maintenance and/or repair work will begin immediately.

4. If at any time King County reasonably determines that a stormwater facility or BMP on the Property creates any of the hazardous conditions listed in KCC 9.04.130 or relevant municipal successor's codes as applicable and herein incorporated by reference, the WLR Director or equivalent municipal successors official may take measures specified therein.

5. The Owners shall assume all responsibility for the cost of any maintenance or repair work completed by the County as described in Paragraph 3 or any measures taken by the County to address hazardous conditions as described in Paragraph 4. Such responsibility shall include reimbursement to the County within thirty (30) days of the receipt of the invoice for any such work performed. Overdue payments will require payment of interest at the current legal rate as liquidated damages. If legal action ensues, the prevailing party is entitled to costs or fees.

6. The Owners are hereby required to obtain written approval from the King County WLR Director prior to filling, piping, cutting, or removing vegetation (except in routine landscape maintenance) in open vegetated stormwater facilities (such as swales, channels, ditches, ponds, etc.), or performing any alterations or modifications to the stormwater facilities and BMPs referenced in this Declaration of Covenant.

7. Any notice or consent required to be given or otherwise provided for by the provisions of this Agreement shall be effective upon personal delivery, or three (3) days after mailing by Certified Mail, return receipt requested.

8. With regard to the matters addressed herein, this agreement constitutes the entire agreement between the parties, and supersedes all prior discussions, negotiations, and all agreements whatsoever whether oral or written.

9. This Declaration of Covenant is intended to protect the value and desirability of the real property described above, and shall inure to the benefit of all the citizens of King County and its

municipal successors and assigns. This Declaration of Covenant shall run with the land and be binding upon Grantor(s), and Grantor's(s') successors in interest, and assigns.

10. This Declaration of Covenant may be terminated by execution of a written agreement by the Owners and King County or the municipal successor that is recorded by King County in its real property records.

IN WITNESS WHEREOF, this Declaration of Covenant for the Inspection and Maintenance of Stormwater Facilities and BMPs is executed this 28th day of August, 20 19.

J. Stephan Banchem Queen City Farms Inc
GRANTOR, owner of the Property

GRANTOR, owner of the Property

STATE OF WASHINGTON)
COUNTY OF KING)ss.

On this day personally appeared before me:

J. Stephan Banchem Jr., to me known to be the individual(s) described in and who executed the within and foregoing instrument and acknowledged that they signed the same as their free and voluntary act and deed, for the uses and purposes therein stated.

Given under my hand and official seal this 29 day of AUGUST, 20 19.

Sharyn L Mahoney
SHARYN L MAHONEY

Printed name
Notary Public in and for the State of Washington,
residing at

Renton

My appointment expires 10-2-2023



Drainage Adjustment

Technical Memorandum

TO: Queen City Farms
FROM: Katherine Saltanovitz, PE and Meghan Veilleux, EIT
DATE: August 30, 2019
RE: **Drainage Adjustment Request**
Queen City Farms Phase III Refill
Maple Valley, Washington
Project No. 0992002.050.051

Introduction

For proposed projects subject to drainage review by the Department of Development and Environmental Services (DPER), the Drainage Adjustment process is provided for the occasions when a project proponent desires to vary from one of the core or special requirements, or any other specific requirement or standard contained in the King County Surface Water Design Manual (KCSWDM). Proposed adjustments should be approved prior to final permit approval, but they may be accepted up to the time King County approves final construction or accepts drainage facilities for maintenance.

Adjustments to the requirements in the KCSWDM may be granted provided that granting the adjustment will achieve the following:

- 1) Produce a compensating or comparable result that is in the public interest, AND
- 2) Meet the objectives of safety, function, appearance, environmental protection, and maintainability based on sound engineering judgment.

Queen City Farms (QCF) is applying for Standard Drainage Adjustments for certain elements of the Phase III design that vary from the KCSWDM. The adjustment application form for the Phase III project is attached.

Chapter 1, Core Requirements

An adjustment is requested for the following sections of KCSWDM Chapter 1.

Core Requirement 5, Erosion Control – BMP Requirements

The Erosion control requirements of Core Requirement 5 may be met on the Phase III area using flexible standards that vary from specific erosion and sediment control (ESC) standards but meet the intent of Core Requirement 5 to prevent the transport of sediment to streams, wetlands, lakes, drainage systems, and adjacent properties. Best management practices (BMPs) shall include those contained in the site's Sand and Gravel General Permit. The Technical Information Report (LAI 2019) includes a temporary and permanent erosion and sediment control plan, with appropriate plans and drawings, for review and approval. Erosion and sediment control plans take into consideration that

this site can generally retain stormwater in a closed depression and infiltrate it to groundwater, rather than discharging to surface water.

This approach is consistent with Section D.2.3.5 of the KCSWDM, which states that some projects may meet the intent of Core Requirement 5 while varying from specific construction stormwater pollution prevention (CSWPP) requirements contained in the KCSWDM. If a project is designed and constructed to meet the intent of this core requirement, the County may determine that strict adherence to a specific ESC requirement is unnecessary; an approved adjustment is not required in these circumstances. Certain types of projects are particularly suited to this greater level of flexibility; for instance, projects on relatively flat, well-drained soils, projects that are constructed in closed depressions, or projects that only disturb a small percentage of a forested site may meet the intent of this requirement with very few ESC measures.

This adjustment was previously approved by King County in the Blanket Adjustment to the 1998 and 2005 Surface Water Design Manuals related to projects that include long-term soil disturbance such as a gravel mine or reclamation project.

Core Requirement 8, Water Quality – Definition of Pollution Generating Impervious Surfaces (PGIS)

The following surfaces in the Phase III refill will not be considered PGIS: refill side slopes, noise and visual berms that are not accessed after construction and stabilization, infrequently used maintenance roads, active fill areas within closed depressions where vehicle traffic is limited to fill equipment, and other areas of the refill site without significant vehicle traffic located within closed depressions.

This adjustment was previously approved by King County in the Blanket Adjustment to the 1998 and 2005 Surface Water Design Manuals related to projects that include long-term soil disturbance such as a gravel mine or reclamation project.

Special Requirement #5, Oil Control

The definition of a high-use site for a commercial or industrial site subject to an expected average daily traffic (ADT) count equal to or greater than 100 vehicles per 1,000 square feet (sf) of gross building area is not applicable to the Phase III refill site and shall not be used to determine whether the site is considered high use for purposes of establishing the need for oil controls. The remaining criteria listed in the KCSWDM shall be used to determine if the site, or a portion of the site, is considered a high-use site.

Only those portions of the site considered high use will be required to provide oil control treatment in addition to any other water quality controls required by the KCSWDM. The high-use oil control options detailed in Chapter 6 of the KCSWDM are available for compliance with this requirement. By

definition, the following areas, at a minimum, are considered the high-use portions of the site: fueling stations, petroleum tanks, asphalt and concrete processing areas, hydrocarbon storage tanks, maintenance facilities and associated yards, truck parking areas (for more than twenty-five 10-ton diesel vehicles), scales, tire washes, access roads on which all vehicles must enter or leave, asphalt release agent application areas, and other high-use roads (both graveled or paved). Tire washes shall not discharge to surface water. Structural source controls will be provided for wastewater from tire washes.

If a site has a National Pollutant Discharge Elimination System (NPDES) permit that specifically addresses oil control from the pollution-generating impervious surfaces contained on the site, compliance with the NPDES permit conditions are adequate to meet the oil control requirements of Special Requirement #5. Applicant will provide the stormwater pollution prevention plan (SWPPP) and spill control plans to DPER for confirmation of NPDES compliance.

QCF anticipates that DPER will incorporate the SWPPP and spill control plans as permit operating conditions for compliance with Special Requirement #5.

This adjustment was previously approved by King County in the Blanket Adjustment to the 1998 and 2005 Surface Water Design Manuals related to projects that include long-term soil disturbance such as a gravel mine or reclamation project.

Chapter 3, Hydrologic Analysis and Design

An adjustment is requested for the following sections of KCSWDM Chapter 3.

Section 3.1, Hydrologic Design Standards and Principles

The Talasaea study of Queen City Lake (Lake) wetland (Talasaea 2007), included and approved with the Phase II TIR application (LAI 2007), presented conclusions and recommendations related to impacts of the Phase II Refill Project on wetland vegetation. The evaluation used King County Runoff Time Series (KCRTS) modeling of the Queen City Lake sub-basin to estimate water levels in Queen City Lake and design the outflow structure and associated piping. The Western Washington Hydrologic Model (WWHM) was used to establish wetland hydroperiods.

In 2018, LAI prepared a technical memorandum titled “Queen City Lake Wetland Hydroperiod Analysis” to update the Talasaea study to account for the Phase III project. To provide a direct comparison to the Talasaea study, LAI used KCRTS to model surface water inflows to the Lake. This updated analysis investigated three different model scenarios (Scenario 1: pre-developed, Scenario 2: Phase II developed, and Scenario 3: Phase III developed), to compare the relative magnitude of the hydrologic changes. It concluded that implementation of the Phase III Refill Project will tend to mitigate the impacts of lower water levels somewhat; however, the combined effect of changes on

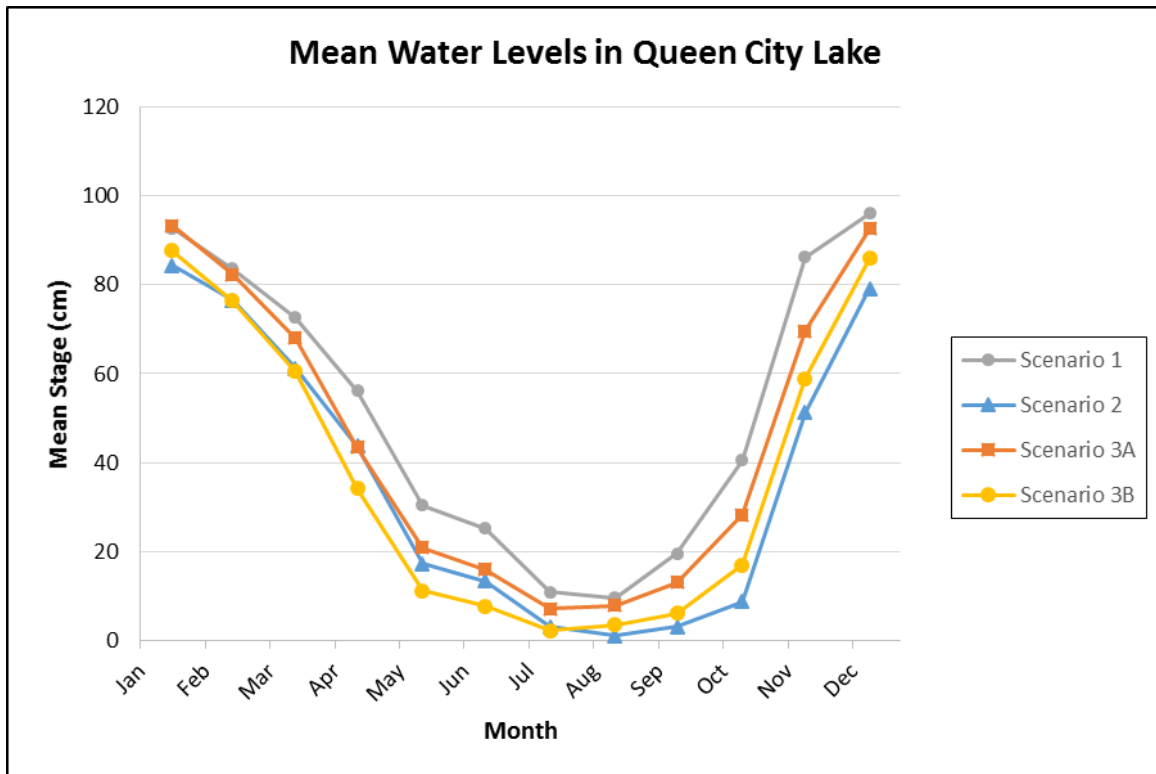
Cedar Hills Regional Landfill and implementation of the Phase II and Phase III Refill Projects is predicted to result in lower lake water levels.

Because KCRTS is not an approved hydrologic model under the 2016 SWDM, LAI performed an analysis to confirm the results of Scenario 3 (with surface water inputs modeled in KCRTS) were at least as conservative as lake level modeling with surface water inputs modeled in WWHM. To do this, LAI calculated the mean monthly water levels based on the WWHM output from the Queen City Lake outlet structure model (presented in Section 6.10 of the 2019 TIR) (LAI 2019). This scenario, designated Scenario 3b, is similar to Scenario 3 from the 2018 technical memorandum, except that the drainage areas flowing to the Lake are modeled in WWHM rather than KCRTS. Also, some of the drainage areas and land types have been updated, as described in Section 6.10 of the 2019 TIR (LAI 2019), and outlet structure discharge was calculated by WWHM instead of manually. Table 1 below is comparable to Table 1 in the 2018 technical memorandum “Queen City Lake Wetland Hydroperiod Analysis”, and shows the summary of modeled drainage areas for the two scenarios. Scenario 3 from the 2018 technical memorandum is relabeled “Scenario 3a” in Table 1.

Table 1 –Summary of Modeled Drainage Areas

KCRTS Land Type	Outwash Forest (acre)	Till Forest (acre)	Till Pasture (acre)	Till Grass (acre)	Impervious (acre)	Total (acre)
Scenario 3a/LAI	145	324	21	0	65.5	555.5
Scenario 3b/LAI	128	333	32	0	46.5	539.5
WWHM Land Type/LAI	A/B, Forest	C, Forest	C, Pasture	none	Roads/Pond	---

The following figure shows the mean monthly water levels in the Lake for pre-2007 conditions (Scenario 1), predicted future conditions with Phase II development (Scenario 2), and predicted future conditions with Phase III development (Scenarios 3a and 3b).



This figure demonstrates that the mean monthly water levels for Scenario 3b (with lake inflows from WWHM) are consistently lower than the levels for Scenario 3a (with lake inflows from KCRTS). Therefore, the modeled lake level data from Scenario 3a is at least as conservative, if not more so, in terms of protecting wetland hydrology compared to Scenario 3b. The use of KCRTS combined with WWHM provides a compensating or comparable result that is in the public interest, and meets the objectives of safety, function, appearance, environmental protection, and maintainability based on sound engineering judgment.

Chapter 5, Flow Control Design

A drainage adjustment is requested for the following elements of Chapter 5.

Infiltration Testing

A drainage adjustment is requested for the infiltration testing procedure described in Section 5.2.1 of the KCSWDM. The previous site infiltration testing was done prior to the adoption of the 2016 KCSWDM, and is judged to be sufficiently conservative for use in the Phase III design.

In addition, due to the accessibility of the Queen City Lake area, the historic lake level analysis and extrapolated infiltration rates used in the hydrologic modeling were not updated for the Phase III project.

Appendix D, Construction Stormwater Pollution Prevention

See the adjustment request under Core Requirement 5.

LANDAU ASSOCIATES, INC.



Meghan Veilleux, EIT
Senior Staff EIT



Katherine Saltanovitz, PE
Senior Associate

MDV/KMS/kjg

\\edmdata01\projects\992\002\FileRm\R\Revised Ph3 TIR\Appendices\I-Drainage Adjustment\I-Drainage Adjustment.docx

Attachments: Attachment 1: Drainage Adjustment Form

References

LAI. 2007. Technical Information Report, Queen City Farms Refill Project, Cedar Grove Road SE, King County, Washington. Landau Associates, Inc. August 13.

LAI. 2019. Technical Information Report, Queen City Farms Phase III Refill Project, Maple Valley, King County, Washington. Landau Associates, Inc. August 30.

Talasaesa (2007). Potential Changes to Plant Communities Resulting from Hydrologic Changes to Queen City Lake, Queen City Farms, King County, Washington, Talasaesa Consultants, Inc.

**King County****Department of Permitting
and Environmental Review**35030 SE Douglas Street, Suite 210
Snoqualmie, WA 98065-9266
206-296-6600 TTY Relay: 711
www.kingcounty.gov**Surface Water Design Manual
Requirements / Standards
Adjustment* Request**

For alternate formats, call 206-296-6600.

Project Name: Queen City Farms Phase III Refill	Permitting Project File No: GRDE18-0048	Permitting Engineer/Planner Name: Amanda Reeck
Project Address: 17825 Cedar Grove Rd SE, Maple Valley, WA, 98038	Design Engineer: Katie Saltanovitz, PE	Phone: 425-329-0268
Applicant/Agent**: Stephan Banchemo	Phone: 206-832-3001	Signature of Design Engineer: <i>[Signature]</i>
Signature of Applicant/Agent: <i>[Signature]</i>	Date: 8/29/19	Date: 8/29/19
Address: 7343 East Marginal Way South Seattle, WA 98108	Engineering Firm Name: Landau Associates, Inc.	Address: 130 2 nd Ave S Edmonds, WA 98020

INSTRUCTIONS TO APPLICANT/DESIGN ENGINEER:

Please be sure to include all materials (Level One Downstream Analysis, Certification of Applicant Status form, sketches, photos, and maps) that may assist in complete review and consideration of this adjustment request. Failure to provide all pertinent information may result in delayed processing or denial of request. Please submit two complete copies of this request, application form, and applicable fee to the Department of Permitting and Environmental Review, 35030 SE Douglas Street, Suite 210 in Snoqualmie, WA 98065-9266. For more information, call 206-296-6600.

****Applicant/Agent is the individual financially responsible for all fees****REFER TO CHAPTER 1, SECTION 1.4 OF THE SURFACE WATER DESIGN MANUAL FOR ADJUSTMENTS**

DESCRIPTION OF ADJUSTMENT REQUEST: Standard Complex Experimental Blanket Pre-application
See attached memorandum.

APPLICABLE VERSION KCSWDM: 1990 (11/95)* 1998 (9/98) 2005 (1/05)
*(Note: the term "variance" replaced by "adjustment")

APPLICABLE SECTION(S) OF STANDARDS:

King County Surface Water Design Manual (2016). See memorandum for specific section references.

JUSTIFICATION PER KCSWDM SECTION 1.4.2: See attachments listed below.

Technical memorandum by Landau Associates dated 8/30/19.

AUTHORIZATION SIGNATURES:

DETERMINATION: <input type="checkbox"/> Approval <input type="checkbox"/> Conditional Approval (see below) <input type="checkbox"/> Denial
<input type="checkbox"/> DNRP/WLRD Approval Signed: _____ Date: _____ (Experimental & Blanket only)
<input type="checkbox"/> Permitting Staff Recommendation Signed: _____ Date: _____
Conditions of Approval: <input type="checkbox"/> See attached memo dated: _____

Permitting DIRECTOR / DESIGNEE:

Permitting, Engineering Review Supervisor: Signed: _____ Date: _____	Permitting, Site Engineering & Planning Supervisor Signed: _____ Date: _____
---	---

Check out the Permitting Web site at www.kingcounty.gov/permits