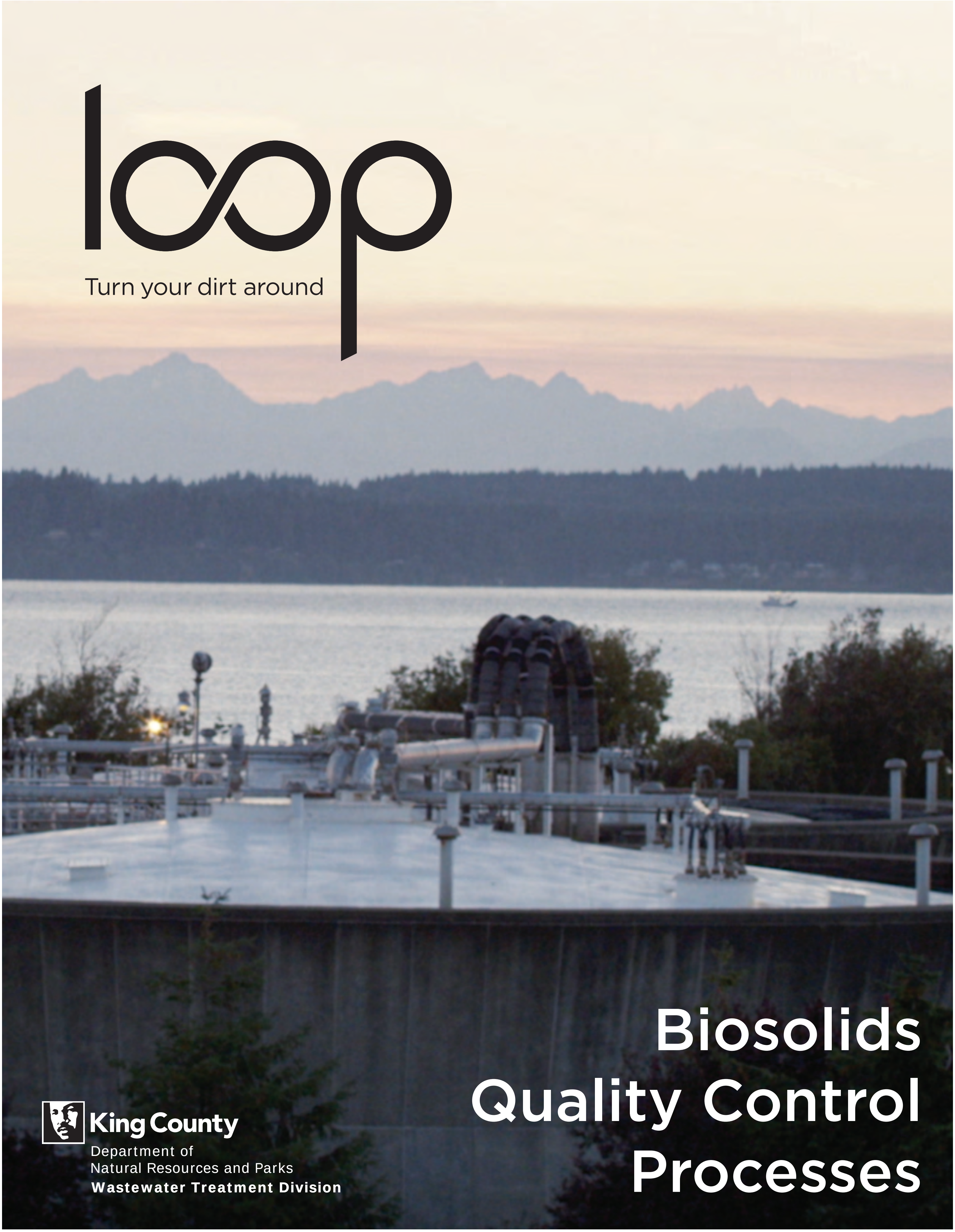

loop

Turn your dirt around

Biosolids Quality Control Processes

King County
Department of
Natural Resources and Parks
Wastewater Treatment Division

Loop® Biosolids
Quality Control Processes

Prepared by

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Contents

Executive Summary

Biosolids are the nutrient-rich organic products of the wastewater treatment process. Biosolids contain water, organic matter, sand, nutrients, as well as microorganisms, trace metals, and trace organic compounds. Because of their moisture content, carbon-rich and humus-like characteristics, essential nutrients for plants, and very low levels of pollutants, biosolids are effective, safe, and sustainable to use as a soil conditioner, fertilizer for forest trees and agricultural crops, and as an ingredient in compost for landscaping.

The King County Wastewater Treatment Division began conducting research and recycling biosolids on land in 1973. The program has grown to beneficially recycle nearly 120,000 wet tons (or approximately 29,500 dry tons) annually in agriculture, forestry, soil reclamation and compost.

King County's biosolids are called Loop® . In February 2012, the Loop brand was launched with a new website www.LoopForYourSoil.com. The product has a name to reflect the nature of biosolids and the benefits of returning carbon and nutrients to the land, and also King County's position in the soil amendment market.

Loop is certified as Class B biosolids. Biosolids are classified as Class A or Class B based on the level of pathogen reduction. Class A biosolids are treated to eliminate pathogens and can be used in landscaping and home garden. Class B biosolids are treated to significantly reduce, but not eliminate, pathogens. Therefore, use of Class B biosolids requires application site permits which include public access and crop harvest restrictions to allow for die-off of pathogens to non-detectable levels after application. These regulatory requirements are intended to make the use of Class A and Class B biosolids equally safe.

To ensure the safety and efficacy of Loop, the physical, chemical, and microbial characteristics are routinely monitored. This monitoring is performed monthly in order to characterize the biosolids, evaluate changes over time, and provide data to determine appropriate application rates for Loop biosolids.

1.0 Introduction

Biosolids are composed of water, sand, organic and inorganic particles, nutrients, microorganisms, trace metals, and trace organic compounds. Biosolids are recycled as a fertilizer and soil conditioner because they contain all essential micronutrients and significant amounts of macronutrients such as nitrogen, phosphorus, potassium, and sulfur, which plants need for growth and development. Their high organic matter content also aids in improving soil structure, moisture holding capacity, and tilth.

King County Wastewater Treatment Division's (WTD) Biosolids Program began recycling its Loop biosolids in 1973. Staff from throughout WTD's operations and source control programs collaborate to ensure that Loop continues to be high in quality, safe, and used beneficially in a variety of projects. An integral part of this effort is the biosolids monitoring program, which has included systematic sampling and analysis of Loop since the early 1980s. Loop is routinely tested for chemicals of health and environmental concern, industrial chemicals, microbes, as well as essential nutrients for plant growth and development.

In 1993, the Environmental Protection Agency (EPA) implemented a federal rule, 40 CFR Part 503, in compliance with the Federal Clean Water Act, which set standards for the use of biosolids to protect public health and the environment. The biosolids rule includes operational standards, monitoring requirements, biosolids quality criteria, and site management requirements. In 1998, the Washington State Department of Ecology (Ecology) implemented a new state biosolids program, and adopted EPA standards in the state rule (WAC 173-308). Under state law, biosolids that meet these state and federal standards are not solid waste and are not subject to solid waste laws.

Among the quality criteria set by state and federal standards are limits for concentrations of metals in biosolids. All biosolids applied to land must contain less than the "ceiling limits" for nine metals (Table 1 in 40 CFR 503.13 and WAC 173-308-160).

Loop samples are analyzed for additional priority pollutant metals and trace organic compounds as part of the National Pollutant Discharge Elimination System (NPDES) permit monitoring of influent, effluent, and biosolids for WTD treatment plants. The County regulates industrial discharges as part of the NPDES permit requirements.

Loop produced at West Point Treatment Plant (WPTP) in Seattle, South Treatment Plant (STP) in Renton, and Brightwater Treatment Plant (BWTP) in Woodinville are monitored for the following constituents:

Conventionals including total solids, total volatile solids, pH, ammonia, organic nitrogen, total phosphorus, total potassium and total sulfur. See Section 5 for a discussion of nutrients found in biosolids.

Microorganisms, including fecal coliforms, *Salmonellae*, parasites and total enteric viruses.

Metals and other elements including arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, zinc, barium, beryllium, boron, calcium, chromium, iron, magnesium, manganese, and silver. The first nine listed are regulated by Ecology and EPA biosolids rules, though King County monitors above and beyond the regulatory requirements.

Trace organic compounds including volatile and semi-volatile compounds, polycyclic aromatic hydrocarbons (PAHs), pesticides, and polychlorinated biphenyls (PCBs) identified by EPA as priority pollutants

1.1 Wastewater Treatment Plant Processes

WPTP, STP, and BWTP all utilize primary and secondary wastewater treatment in their process stream. Preliminary and primary treatment consists of trash screening, grit removal and gravitational settling of solids. Effluent from primary treatment flows to secondary treatment where microbial action and aeration break down and remove more of the dissolved and suspended organic matter, as well as removing additional non-biodegradable solids. Together, primary and secondary treatment removes 85 percent or more of the dissolved and suspended organic matter. At BWTP the secondary effluent is produced using membrane bioreactor (MBR) technology. The MBRs remove 99.9% of the suspended solids from the water.

The solids from primary and secondary treatment are collected, blended, and thickened before being pumped into digesters. In the digesters the solids are treated by mesophilic, anaerobic digestion where microorganisms convert complex organic molecules to methane, carbon dioxide, ammonia, water and other by-products. During digestion the volatile solids are reduced, which lowers the mass of total solids by almost half, and homogenizes the resulting Loop biosolids. The digester contents consist primarily of organic matter and microbes. The organic matter is the source of nutrients including nitrogen, phosphorus and sulfur. It is these elements and the organic matter itself that make Loop a valuable soil amendment and source of nutrients for improved plant growth.

Although the three treatment plants employ similar treatment processes, the influent sewage characteristics differ for each based on the source of wastewater and composition of the conveyance system. STP and BWTP influent is primarily from sanitary sewers in newer communities east of Lake Washington, where most buildings have been equipped with copper piping. On the other hand, WPTP receives wastewater from sanitary and storm sewers (a combined system), which result in large volumes of water surging into the plant during large rain events. These increased flows carry additional sediment along with residues from roads and other impervious surfaces. Furthermore, most of the sanitary flow to WPTP originates from older Seattle neighborhoods, which were historically plumbed with galvanized pipes or copper pipes with leaded solders (containing trace amounts of lead). These differences help explain some of the biosolids quality variations seen between the plants.

1.2 Pathogen Reduction and Stabilization

Under federal and state standards, Loop is certified as Class B biosolids, safe for land application projects. EPA classifies biosolids as Class A or Class B based on the level of pathogen reduction. To meet Class A standards, biosolids are treated to eliminate pathogens. Class B biosolids have been treated to significantly reduce but not eliminate pathogens, so they must be used in accordance with site management and public access restrictions. According to the EPA (1992), the "goal of the Class B requirements is to ensure that pathogens have been reduced to levels that are unlikely to pose a threat to public health and the environment under the specific use conditions." EPA has identified several treatment processes that meet Class B pathogen reduction requirements.

Pathogen reduction of Loop takes place during anaerobic digestion of wastewater solids, which is alternative 2 of 40 CFR 503 [503.32(b)(3)]. The solids are digested at mesophilic temperatures (95° to 131° F) for at least 15 days. WPTP, STP, and BWTP anaerobic digestion processes all meet EPA criteria for a "Process to Significantly Reduce Pathogens" (PSRP) and qualify biosolids as Class B. At all three plants, the anaerobic digestion process reduces the pathogenic microbial concentration by at least 90 percent (i.e., the concentration of pathogens in the finished Loop is at least 90 percent lower than the concentration in the raw solids entering the digesters). Most remaining pathogenic organisms die off soon after land application.

In addition to reducing pathogens, biosolids must be stabilized for vector attraction reduction. Vectors are "any living organisms capable of transmitting a pathogen from one organism to another" (EPA 1992). According to EPA, vectors for pathogens in biosolids would most likely include insects, rodents, and birds. One way to achieve the necessary vector attraction reduction is to reduce the amount of total volatile solids by at least 38 percent during processing, thus reducing odors that might attract vectors. The biosolids then contain biodegradable material that decomposes so slowly that vectors are not attracted (EPA 1992). Volatile solids reduction is measured routinely at each treatment plant, and is typically greater than 50 percent.

2.0 Sampling Methodology and Data Analysis

Loop biosolids from all three regional treatment plants are monitored monthly for metals, conventional constituents, and microorganisms in accordance with federal and state biosolids regulations. Trace organic compounds are monitored twice annually for parameters required under WTD's NPDES permit.

2.1 Sampling Methodology and Sample Analysis

Loop samples are analyzed by the King County Environmental Laboratory as well as the WPTP and STP process laboratories. Testing equipment and protocols at all laboratories comply with those recommended by EPA.

Samples of Loop are collected monthly from WPTP, STP, and BWTP. The monthly sample from STP consists of grab samples taken every three hours over a 24-hour period. The monthly sample from WPTP consists of grab samples collected every two hours during a 24-hour period. The monthly sample from BWTP consists of grab samples taken every two hours during a 12-hour day shift while the dewatering centrifuges are running. At each treatment plant the grab samples are then combined into a composite sample for analysis.

Although collected in a single day, these Loop samples reflect digester solids from a time range typical of their residence time in the digesters. Digester residence time tends to average about 25 days at WPTP, 25-30 days at STP, and 35 days at BWTP. Separate grab samples are collected at all three treatment plants and analyzed for microbiological parameters.

2.2 Data Analysis

Relevant data are compared to state and federal regulatory limits (WAC 173-308-160 and 40 CFR Part 503.13, Tables 1 and 3) for high quality biosolids, and previously reported biosolids quality data. All data are stored and accessed on the King County Environmental Laboratory Information Management Systems database.

2.3 Statistical analysis

Annual data are compared using statistical methods to evaluate year-to-year changes in biosolids quality. The selection of appropriate statistical tests for comparison is strongly dependent on the number of observations and their underlying distribution.

When a constituent was present in a sample in sufficient quantity to be detected with certainty by the laboratory analytical procedure, the detected concentration is reported. This is referred to as a "hit." When constituents were not present in a sample in sufficient concentration to be quantified (i.e., less than the method detection limit), the detection limit for the constituent is reported, which means the lowest concentration that can be detected. These data points are referred to as "undetected." Data sets that contain both hits and undetected values are called "censored." There are several generally accepted ways to compute descriptive statistics for such data sets. The advice of Gilbert (1987) and of Helsel (1990) was followed in the treatment of censored data sets in this report.

The underlying distribution refers to the shape of the frequency plot of all data for a particular constituent. For example, Normal distribution is defined by a specific equation wherein plotted data points create a symmetrical, bell-shaped curve, around a central point (the mean). Environmental data may follow Normal distribution, but often they follow others including skewed or bimodal frequency distributions.

With few exceptions, metals and conventional constituents such as nitrogen and potassium are always detected in biosolids. Some constituents show a reasonably normal distribution, but others do not. In order to compare data sets, a single statistical procedure was chosen that is valid regardless of the distribution and the number of "hits." This test is the Mann-Whitney U Test, also known as the Wilcoxon Rank Sum Test. It permits the use of all data, including detection limits from censored data sets. It tests the hypothesis that the data sets represent two random samples from the same population regardless of the underlying distribution. If the test indicated a statistically significant difference (95% confidence or $p<0.05$) between data sets, it was concluded that they did not represent random samples from the same population.

Summary statistics including means and standard deviations are calculated for conventionals and metals. Since trace organic compounds are tested for twice per year, it is not possible to perform statistical computations on the data sets. Additionally, most trace organic compounds are not detected. In lieu of statistics, the current year's values are compared to historical values for detected organic compounds.

Outlier analysis is performed annually on metals data to identify outliers, or values that lie so far away from the rest of the data that they are likely not accurate measurements. Potential outliers are reported values outside of three standard deviations from the mean. If the outliers cannot be explained by corresponding influent metal concentrations, known discharges or modeling, it is considered not representative of reality, and flagged as an outlier. Such values are reported but excluded from the calculations of averages and statistics.

The King County Environmental Lab also undergoes monthly analysis to identify any data analysis issues. Beginning in April 2015, during monthly analysis of the data, reported values outside three standard deviations are flagged with a DAF, or data anomaly form, and re-analyzed in triplicate to see if the result can be replicated. Generally, the re-analysis results in data values closer to the mean. The original data point is still reported in the database.

Log normal distribution is the distribution that most environmental data follows, including microbiological data. For microbiological data the annual geometric mean is used since the monthly values typically show variable results believed to not be due to the normal distribution of bacteria in a subsample. The geometric mean (GM) was calculated by using the following equation:

$$GM = [e^{(\Sigma \ln x_i / n)}]$$

Where: n = number of times a compound was detected
x_i = the ith value that was detected

Although called a mean, the geometric mean is an estimator of the median for populations with heavily skewed data sets, the median is a robust indicator of central tendency because its position is unaffected by very large or very small values. The median is that value above which 50 percent of the data are situated and below which 50 percent of the data are situated.

3.0 Additional General Information

3.1 Microbial Constituents of Biosolids

Wastewater typically contains many millions of microorganisms per 100 milliliters. Some of these organisms are potentially disease producing, or pathogenic, to humans and other animals, while others are harmless. One of the primary purposes of wastewater treatment is to significantly reduce or eliminate pathogenic microorganisms. The anaerobic digestion processes used to treat wastewater solids at WPTP, STP and BWTP meet the regulatory standard “process to significantly reduce pathogens,” or PSRP. Properly designed and managed land application programs ensure that proper field conditions exist for the elimination of any potentially remaining pathogens in biosolids and thereby prevent them from entry into the food chain and waterways. In Washington, these conditions include warm, dry, sunny environments during at least part of the year.

While there is required process testing to meet PSRP, including time and temperature, laboratory analysis of microorganisms in biosolids is not required. Nonetheless, the King County Environmental Laboratory routinely analyzes Loop for the presence of certain indicator microorganisms and pathogens . A brief description of each follows.

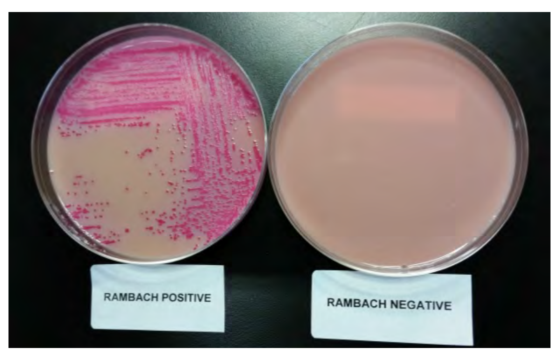
3.1.1 *Fecal Coliform Bacteria*

Fecal coliform bacteria, most of which are nonpathogenic, are common to most warm-blooded animals and include *Escherichia* and *Klebsiella* species. Their presence in high numbers in biosolids suggests, but does not confirm, the possibility of pathogen presence. Fecal coliform bacteria are the most widely accepted, though not the only, indicator of fecal pollution.

3.1.2 *Salmonellae Bacteria*

This genus includes enteric pathogens and are sometimes found in human or animal fecal matter. *Salmonellae* are associated with outbreaks of gastroenteritis and typhoid human diseases usually contracted through consumption of contaminated drinking water or food.

Salmonellae survival in a forest or agricultural field is highly unlikely. Pathogenic microorganisms, including *Salmonellae* do not survive the warm, dry periods and the competition by naturally occurring soil organisms that all biosolids application sites have.



Rambach agar is used to grow *Salmonella* colonies during testing. The dish on the left shows a positive result, with *Salmonella* colonies in pink.

In 2015, the Environmental Lab changed the *Salmonella* analysis method from the Metro Method for *Salmonella* by Most Probable Number (MPN) approach to a modification of the EPA 1682 method for *Salmonella* by MPN approach. The EPA 1682 method has less variability and shorter turnaround time. This new method inhibits growth of other competitive microorganisms, after which motile *Salmonella sp*. are selected for further isolation on Rambach agar and confirmed by serological testing. Side by side comparisons of the two methods indicate that Salmonella results reported for Class B biosolids will be slightly to moderately higher in comparison with the former Metro Salmonella method.

Fecal coliform and *Salmonellae* bacteria analyses are all performed using the MPN approach. This technique results in population counts that are reported as an MPN index. The index is an estimate based on probability formulas and a certain number of replicate tests from the same biosolids sample. Each replicate may give quite different results because of the irregular distribution of bacteria in the subsamples. The results of the test are compared to MPN tables, and the MPN index is assigned.

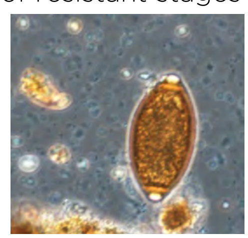
The MPN index is derived from a probability formula and statistics. Associated with each MPN index is a range called the 95% confidence interval. For example, an MPN index of 26 organisms/100 g has a range of 9 to 78 organisms. This means that 95 percent of the replicates analyzed from a particular sample whose index is 26 will have bacterial counts that fall between 9 and 78 organisms/100 g, with a most probable number of 26 organisms/100 g. The salient point is that the MPN index is not a definite number, but rather the most probable number within a range of values.

3.1.3 *Total Enteric Viruses*

Loop produced at WPTP, STP, and BWTP is routinely analyzed for total enteric viruses including polioviruses, Coxsackie viruses, and ECHOviruses. Vaccine-strain polioviruses are commonly found in wastewater as a result of oral polio vaccine use. Viruses multiply only within living cells, so their numbers cannot increase in raw wastewater, wastewater solids, biosolids, or the environment. Processing of wastewater to biosolids further reduces the numbers to very low or undetectable levels.

3.1.4 *Parasites*

Parasites pose a potential risk to human health due to the existence of resistant stages of the organisms and low infective doses. Parasite testing included the following parameters: *Ascaris species, Giardia lamblia*, hookworm, *Hymenolepis species, Taenia species, Trichuris trichiura* and *Toxocara species*. Samples were tested quarterly using a concentration and centrifugation technique.



Trichuris trichiura parasite, as seen under a microscope.

3.1.5 *Recent Research*

Ascaris ova are the most commonly isolated nematode ova, and may be the most resistant of the ova or cysts that could be found in biosolids. As a group, this makes this parasite a good indicator of the presence of other parasites.

A nationwide survey of the incidence of pathogens and indicator organisms was published in 2009 (Pepper 2009). This study suggests that pathogen levels of enteric viruses, *Salmonella* and *Ascaris* ova in mesophilic anaerobically digested Class B biosolids are fairly low in the United States and often times meet Biosolids Class A requirements. No viable *Ascaris* ova were detected in Pepper's 2009 study, equivalent to Class A pathogen reduction performance for this parameter. Emerging pathogens such as Campylobacter and *E. coli* 0157:H7 were never detected, and the authors only detected *Shigella* occasionally. This study suggests that health risks from microbial hazards in biosolids may have been reduced by implementation of the federal 40 CFR 503 biosolids rule.

3.2 Plant-Essential Micronutrients and Macronutrients Found in Biosolids

Two criteria must be satisfied in order to consider an element essential for plant life. First, an element is considered essential if a plant cannot complete its life cycle in the total absence of the element. Second, an element is considered essential if it forms part of any molecule or constituent of the plant that is itself essential (Epstein, 1972). Following these two criteria, 16 elements are considered essential to plant life. These are divided into two groups on the basis of the tissue concentrations observed in most plants. Macronutrients are essential elements found in plants in concentrations greater than or equal to 1,000 ppm dry weight basis (mg/kg dry). Micronutrients, also referred to as trace elements or minor elements, are found in tissue concentrations equal to or less than 100 ppm dry weight basis.

3.2.1 *Macronutrients*

Nine of the sixteen essential elements are considered macronutrients. Arranged in order from greatest to smallest concentration in plant tissue, these are: carbon, oxygen, hydrogen, nitrogen, potassium, calcium, magnesium, phosphorus and sulfur.

The Total Kjeldahl Nitrogen (TKN) method accounts for two forms of nitrogen: readily available ammonia, which accounts for approximately 15 to 20 percent of the total, and bound organic nitrogen which accounts for most of the remainder. Organic N is determined by subtracting the value for ammonia-N from the TKN value. The TKN method is not used to determine nitrate-nitrite nitrogen, as it accounts for less than one one-hundredth of one percent (<0.01 percent) of the total. Also, anaerobically digested biosolids are generally not tested for nitrate-nitrate-N as these constituents are converted to other nitrogen compounds under anaerobic conditions.

The average concentrations of organic and ammonia nitrogen are used to determine site-specific application rates for Loop. All of the ammonia is available for plant uptake but some may be lost by volatilization if biosolids are not incorporated into the soil. Of the bound organic nitrogen, between 10 and 40 percent is mineralized and available for plant use during the first year after biosolids application. These are estimates that vary with the type of biosolids processing, site management practices such as incorporation into the soil, and weather or field conditions. Please refer to Ecology's guidance document for a complete discussion on nitrogen testing, biosolids application rate calculation, and results of field research on nitrogen management (Ecology, 2007).

Carbon, oxygen, hydrogen, nitrogen, phosphorus and sulfur are all constituents of amino acids and proteins including enzymes and some coenzymes, as well as having other critical functions in plant cells. Potassium is essential as an activator of the enzymes involved in protein synthesis and for translocation of anions such as NO_3^- and SO_4^{-2}, from one plant part to another. Magnesium is a constituent of chlorophyll molecules and is responsible for the maximum rates of hundreds of enzymatic reactions involving adenosine triphosphate, for the ability of enzymes to fix CO_2 into organic molecules, and for protein synthesis in cells. Calcium functions to cement plant cell walls together, activates several enzymes, and is important in cell division.

Sulfur, a plant-essential macronutrient, is present in Loop as a constituent of organic and inorganic compounds, which may include sulfide, thiosulfate, and sulfate (SO_4^{-2}) ions, as well as elemental sulfur. This nutrient is slowly released into the soil system as Loop continues to decompose via microbial transformation post land-application. Plants primarily absorb this sulfur as SO_4^{-2}, although several sulfur-containing amino acids may also be directly absorbed and metabolized by soil microorganisms.

3.2.2 *Micronutrients*

Seven elements are currently listed as micronutrients. These include, in descending order of concentration in dry plant tissue: chlorine, iron, boron, manganese, zinc, copper, and molybdenum.

Some, but not all, plant species require other elements in micronutrient concentrations to complete their life cycles. These other elements include cobalt, sodium, silicon, selenium, and nickel. Higher animals whose nutritional requirements are obtained directly or indirectly from plants require additional elements in micronutrient concentrations. These include sodium, iodine, cobalt, selenium, nickel, silicon, chromium, tin, vanadium, and fluorine. These elements may be absorbed and stored by plants even though they are not strictly required for completion of their life cycle. Several other elements that may not be universally essential throughout the plant community, but do contribute to increased growth of some crops, include strontium and barium (Sauchelli, 1969). Barium is another constituent of biosolids.

Loop is routinely analyzed for most of the above elements except iodine, fluorine and silicon. All elements listed above and for which WTD currently tests are detected in Loop.

Except for iron and sometimes manganese, plant essential micronutrients are usually found in low concentrations in soils, and their availability to plants is also low (Brady, 1990). Brady states, "... even though their (micronutrients) removal by plants is small, the cumulative effects of crop production over a period of years may rapidly reduce the limited quantities of these elements originally present in soils." Applications of biosolids, including Loop, to heavily cropped agricultural fields can aid in the replenishment of micronutrients.

Table 3.1 summarizes information from several sources on the importance of micronutrients, their functions in plant growth and development, and known antagonisms. Because Loop contains all these nutrients, it can be thought of as a "complete plant food," especially when compared with commercial fertilizers that focus on providing primarily N-P-K (Nitrogen-Phosphorus-Potassium).

Table 3.1 Essential plant micronutrients

ELEMENT	ESSENTIAL FUNCTION	CROPS HAVING A HIGH REQUIREMENT
IRON	1. Essential component of the catalyst involved in the formation of chlorophyll, 2. Required for oxidation-reduction in respiration processes, 3. Constituent of certain enzymes and proteins.	blueberries, nut trees, cranberries, peaches, rhododendron, grapes
MANGANESE	1. Acts as a catalyst in several enzymatic and physiological reactions in plants, 2. Essential for nitrogen and inorganic acid metabolism, 3. Essential for carbon dioxide assimilation and breakdown of carbohydrates during photosynthesis, 4. Needed for the formation of carotene, riboflavin (vitamin B_2), and ascorbic acid (vitamin C).	beans, soybeans, onions, potatoes, citrus, dates
BORON	1. Essential for protein synthesis, nitrogen and carbohydrate metabolism, 2. Essential for root system development, fruit and seed formation, 3. Maintains correct water relations within plants.	alfalfa, clover, sugar beets, cauliflower, celery, apples, other fruits
ZINC	1. Essential for formulation of growth hormones (auxins), 2. Promotes protein synthesis, 3. Necessary for seed and grain maturation and production, 4. Catalyst for oxidation in plant cells and vital for transformation of carbohydrates, 5. Promotes the absorption of water and prevents stunting.	citrus and fruit trees, soybeans, corn, beans
MOLYBDENUM	1. Required for symbiotic nitrogen fixation and protein synthesis, 2. Required for the synthesis of ascorbic acid (vitamin C), 3. Makes iron physiologically available within plants, 4. Alleviates plant injury caused by the presence of excessive amounts of copper, boron, nickel, cobalt, manganese and zinc.	alfalfa, sweet clover, cauliflower, broccoli, celery
COPPER	1. Catalyst for respiration, 2. Required for chlorophyll synthesis, 3. Required for carbohydrate and protein metabolism, 4. Enzyme constituent. Copper has also been used as a fungicide for more than 100 years to control wheat blunt and smut. Certain compounds of copper are still used in organic farming as pesticides.	citrus and fruit trees, onions, small grains

CHLORINE	1. Role is unclear but it enhances root and top growth of plants, especially when young, 2. Stimulates photosynthesis.	tomatoes, carrots, buckwheat, barley, lettuce, cabbage, sugar beets, corn, cotton, potatoes
SODIUM	1. Improves plant vigor, helps resist disease, 2. Improves the keeping quality of many crops, 3. Imparts color and flavor to vegetable crops, 4. Can substitute for up to 50% of the potassium required by some plants.	celery, sugar beets, Swiss chard, turnips, table beets
COBALT	1. Essential for microorganisms involved with the symbiotic fixation of nitrogen in root nodules of legumes, 2. Constituent of vitamin B_{12} (required by animals, but not by plants).	all legumes, cotton, mustard
VANADIUM	1. May function in biological oxidation-reduction reactions, 2. May substitute for some molybdenum requirement.	asparagus, rice, lettuce, barley, corn
CHROMIUM	Required by higher animals and functions in the action of insulin on cell membranes.	

Known Antagonisms Between Macro and Micronutrients: (from Brady, 1990)

1. Excess copper or sulfate may adversely affect the utilization of molybdenum.
2. Iron deficiency is encouraged by an excess of zinc, manganese, copper, or molybdenum.
3. Excess phosphate may encourage a deficiency of zinc, iron, or copper, but enhances the adsorption of molybdenum.
4. Heavy nitrogen fertilization intensifies copper and zinc deficiencies.
5. Excess sodium or potassium may adversely affect manganese uptake.
6. Excess lime reduces boron uptake.
7. Excess iron, copper, or zinc may reduce the adsorption of manganese.

3.4 Solids

Total solids are measured during sampling because the values are used to convert wet weight lab results to a dry weight basis for uniform comparison to regulatory standards and to enable comparisons of quality parameters over time. Daily total solids samples are also analyzed to monitor treatment plant processes and to monitor the total solids for each truckload of Loop. These numbers are used to calculate averages for biosolids application rates and to make comparisons between products.

The total solids (TS) content of Loop is influenced by many factors, some of which include the proportion of sand and other inert solids in wastewater, the proportion of primary solids to waste-activated solids in the digester feed, the effectiveness of the digestion process at converting solids to gas, the intended use of the product, and the dewatering process employed. Anaerobic digestion, the treatment process that follows thickening of primary and secondary solids, breaks down organic compounds into gases, water, and a more stable organic matrix, and reduces the total volatile solids content. The final step in the production of Loop is dewatering. Centrifuges, with the help of polymers, remove a majority of the water in the matrix after digestion is complete. The finished biosolids product from WPTP, STP, and BWTP is Loop.

3.5 Trace Organic Compounds

Modern society relies on a wide variety of synthetic organic compounds for purposes as diverse as manufacturing, food production, and health care. Because they are so ubiquitous, organic compounds inevitably enter the wastewater stream from stormwater runoff and from residential, commercial, and industrial discharge. King County limits the input of some of these organic compounds through its industrial waste program, which requires many industries to pretreat their wastewater. Some of these compounds are known to be environmentally persistent, to bioaccumulate, or, when present in sufficient concentrations, to be toxic. During wastewater treatment, some compounds may volatilize or partition to the liquid portion of wastewater effluent, while the treatment and biosolids production processes destroy many others. Overall these organic compounds tend not to be found in biosolids. However, some organic compounds remain bound to organic matter and therefore appear in biosolids. Because they are generally observed in very small concentrations in biosolids, they are referred to as trace organics or microconstituents.

Considerable research has been done in recent decades to evaluate the presence, fate, and possible human health and environmental effects of trace organics from biosolids. Many compounds have been observed to degrade readily once biosolids are land-applied, and some are more persistent in the biosolids-soil environment. Persistent compounds tend to be highly lipophilic and bound strongly to organic matter, making the potential for plant uptake and groundwater contamination very low.

In the process of establishing regulations for biosolids, EPA gathered data from a national survey of biosolids and determined that many organic pollutants are only rarely detected in biosolids, while more commonly detected compounds occur at very low concentrations. Thorough risk assessments of these organic compounds led EPA to conclude that their presence in biosolids would not increase risk to public health or the environment, and did not warrant regulation. Therefore, EPA did not set standards for trace organics in biosolids.

3.5.1 *Loop Organics Analysis*

King County regularly tests for trace organic compounds in Loop though such monitoring is not required for land application of biosolids. This testing includes 128 volatile and semi-volatile organic compounds, pesticides, PAHs, and PCBs, many of which are classified as priority pollutants by EPA. While Loop biosolids are not routinely tested for the trace organic compounds found in pharmaceuticals or personal care products, development of analytical methods and research on their presence in biosolids and fate in the environment is ongoing.

This section briefly describes sources of trace organic compounds that may be found in biosolids, their significance and fate in the environment, and how people are typically exposed to these compounds.

3.5.2 *Phthalates*

Phthalates are synthetic chemicals added to plastics to increase their flexibility and transparency. Phthalates are used in the manufacturing of products such as plastic food packaging, PVC piping, paints, adhesives, and cosmetics. Many phthalates are ubiquitous in air, water, soil and biosolids, and high concentrations have been observed in indoor air and house dust. Phthalates may cause endocrine disruption, though their human health and environmental effects have not been conclusively demonstrated. Human exposure occurs primarily via ingestion of foods that have been in contact with plastic packaging, and inhalation of indoor dust. Phthalates then enter the wastewater stream when people excrete them. Research has shown that they biodegrade significantly during anaerobic digestion and composting of biosolids and degrade quickly in soil (Clarke & Smith, 2011). Land application of biosolids is not believed to be a significant exposure pathway for phthalates.

3.5.3 *Surfactants*

A range of surfactants are routinely used in detergents, disinfectants, and industrial processes. Various effects have been identified for individual compounds, including endocrine disruption and toxicity to aquatic organisms. Human exposure occurs primarily through contact with detergents or house dust. These compounds enter the wastewater stream from domestic and industrial sources, depending on the compound and its particular use. Surfactants are partially lipophilic and tend to partition to solids in wastewater treatment. Because they biodegrade rapidly in soil and have not been observed to bioaccumulate, surfactants in land-applied biosolids are not considered a risk for human health or the environment.

3.5.4 *Solvents*

Solvents are common in industrial processes, beauty products, paints, lacquers, adhesives, and cleaning products. Acetone, 2-butanone (MEK), carbon disulfide, toluene, and xylenes are all examples of solvents. In high concentrations, most cause acute toxic effects such as irritation or cognitive impairment, but they are not likely to affect human health in the low concentrations found in biosolids. The most common route of human exposure is use of products containing these solvents (e.g., nail polish, paint). They enter wastewater via human excretion, domestic and industrial discharge, and stormwater runoff. Solvents tend to be more volatile and mobile in soils than other trace organics, though they degrade rapidly in soil. Given that the concentrations in biosolids are not high enough to cause acute effects, and that solvents degrade or volatilize rapidly in soil, biosolids are not considered a significant path of exposure for solvents.

3.5.5 *PCBs*

Polychlorinated biphenyls (PCBs), or aroclors, were widely used in paint, sealants, electrical equipment, and as coolants before US production of these compounds was banned in 1979. However, they remain persistent in the environment. PCBs are known to cause a range of toxic effects from skin irritation to birth defects and cancer. The major routes of human exposure are contaminated food and exposure to air and water at contaminated sites.

Atmospheric deposition and stormwater runoff are believed to be the major sources of PCBs in wastewater and biosolids. PCBs are strongly lipophilic, causing them to partition to solids during wastewater treatment. Because their concentration in biosolids is very low and no evidence has been found that PCBs in biosolids are associated with human health effects, biosolids are not considered a significant source of PCB exposure (WEAO, 2010).

3.5.6 *PAHs*

Polycyclic aromatic hydrocarbons (PAHs) are atmospheric pollutants that result from the combustion of carbon. Volcanic eruptions and forest fires generate them naturally. PAHs from human activities include burning of fossil fuels and biomass, and they are found in petroleum products such as creosote, asphalt, and roofing tar. PAHs are of environmental concern because they are toxic to aquatic life. In sufficient concentrations, PAHs are known to cause developmental effects and cancer in laboratory animals, though human health impacts are uncertain. Humans are exposed to PAHs through ingestion of grilled foods, inhalation of smoke from wood fires and vehicle exhaust.

PAHs enter the wastewater stream mainly via atmospheric deposition, oils and exhaust particulates in road runoff, and human excretion. Most PAHs are lipophilic and will partition to solids during wastewater treatment. In soil, research has demonstrated that PAHs bind strongly to soil particles, exhibit no leaching potential, and show little if any foliar absorption. Degradation rates vary, with soil half-lives ranging from weeks for low molecular weight compounds to 10 years for some high molecular weight PAHs. However, PAH concentrations in biosolids-amended soils are similar to unamended soils. PAHs are rapidly metabolized and do not bioaccumulate if ingested by animals. Biosolids are not considered a major source of exposure to PAHs (WEAO, 2010).

3.5.7 *Pesticides*

Pesticides are commonly used in agriculture, landscaping, and homes to control pests and plant diseases. As a consequence, they are routinely detected in soils, household dust, and in trace concentrations in biosolids. Many pesticides that have long been banned are environmentally persistent and may still be found in the environment although they are no longer in use (e.g., DDT). Human exposure typically occurs via direct exposure to contemporary pesticides, through ingestion of contaminated foods, or exposure to soil and water at contaminated sites. The levels found in biosolids are typically much less than existing levels in soils. Many pesticides are lipophilic and although they tend to be persistent in soil, biosolids may reduce their bioavailability (Hundal et al., 2011). With concentrations of pesticides consistently near method detection limits and lower than levels in soils, biosolids are not considered a significant source of pesticide exposure.

3.5.8 *PBDEs*

Polybrominated flame retardants (PBDEs) were widely used in furniture, textiles, building materials, electronics, and other consumer products, and are ubiquitous in the environment. They bind strongly with lipids and can bioaccumulate in the fatty tissues of animals and humans. Toxic effects are not well established but may include endocrine disruption, neurological and developmental effects, and cancer. In 2007, Washington State banned the manufacture, sale, or distribution of most items containing PBDEs. PBDEs are extremely common indoor pollutants and are routinely detected in household dust at similar or higher concentrations to those found in biosolids. PBDEs may enter wastewater from washing household rags and mops used for cleaning and from industrial sources during manufacturing of consumer products. Ingestion of dust in the indoor environment is the primary route of human exposure to these compounds. PBDEs bind strongly with organic matter in biosolids and are persistent in soil; they have very low leaching potential and have not been found in crops (Hundal et al., 2009). Biosolids are not considered a significant path of exposure to PBDEs.

3.5.9 *Antimicrobials*

Triclosan and triclocarban are examples of antimicrobial agents commonly used in products such as soap, shampoo, and toothpaste. These compounds are toxic to aquatic organisms and have estrogen-mimicking properties. When detected in biosolids, they typically appear at levels less than 50 parts-per-million (ppm). In contrast, they may be found at levels greater than 6,000 ppm in some bar soaps and 3,000 ppm in toothpastes (Hundal et al., 2011). The most important exposure pathways are ingestion and absorption through the skin. Domestic use is the primary source of antimicrobials in wastewater. In biosolids, they have been found to biodegrade quickly and have a low potential for leaching (WEAO 2010). A recent study with edible crops found no absorption of either compound from the soil matrix into plant tissues (Sabourin et al., 2012). Human exposure to antimicrobials via biosolids is therefore extremely unlikely and insignificant in comparison to exposure via use of common consumer products.

3.5.10 *Synthetic Fragrances*

Synthetic fragrances, or musks, are common ingredients in beauty products and other consumer products that contain fragrances. They are estrogenic and accumulate in fat and breast tissue. There are two major types, polycyclic and nitro musks. Use of nitro musks has declined in recent years due to health concerns, so nitro musk concentrations have declined in biosolids. Polycyclic musks are more commonly detected in biosolids. Human exposure occurs through use of consumer products containing these musks, and they enter wastewater from bathing and washing. Musks are degraded to some extent during wastewater treatment. They bind strongly to soil particles and are not believed to be mobile in soil. Observed bioaccumulation in earthworms is minimal. As with antimicrobials, human exposure to musks via biosolids is highly unlikely, particularly in comparison to routine exposure via consumer products.

3.5.11 *Pharmaceuticals and Personal Care Products*

Existing risk assessments and research continue to show little risk to human health and the environment from land application of biosolids. To build upon this data, in 2014-2015, King County and NW Biosolids, in partnership with the University of Washington and Kennedy/Jenks consultants, conducted a risk analysis on trace organic compounds from pharmaceuticals and personal care products, using the general risk assessment methodology outlined by U.S Environmental Protection Agency guidance. The results of the risk analysis suggest that these compounds in biosolids are unlikely to result in adverse health effects from the selected organic compounds for individuals using or coming into contact with biosolids (Kennedy/Jenks, 2015).

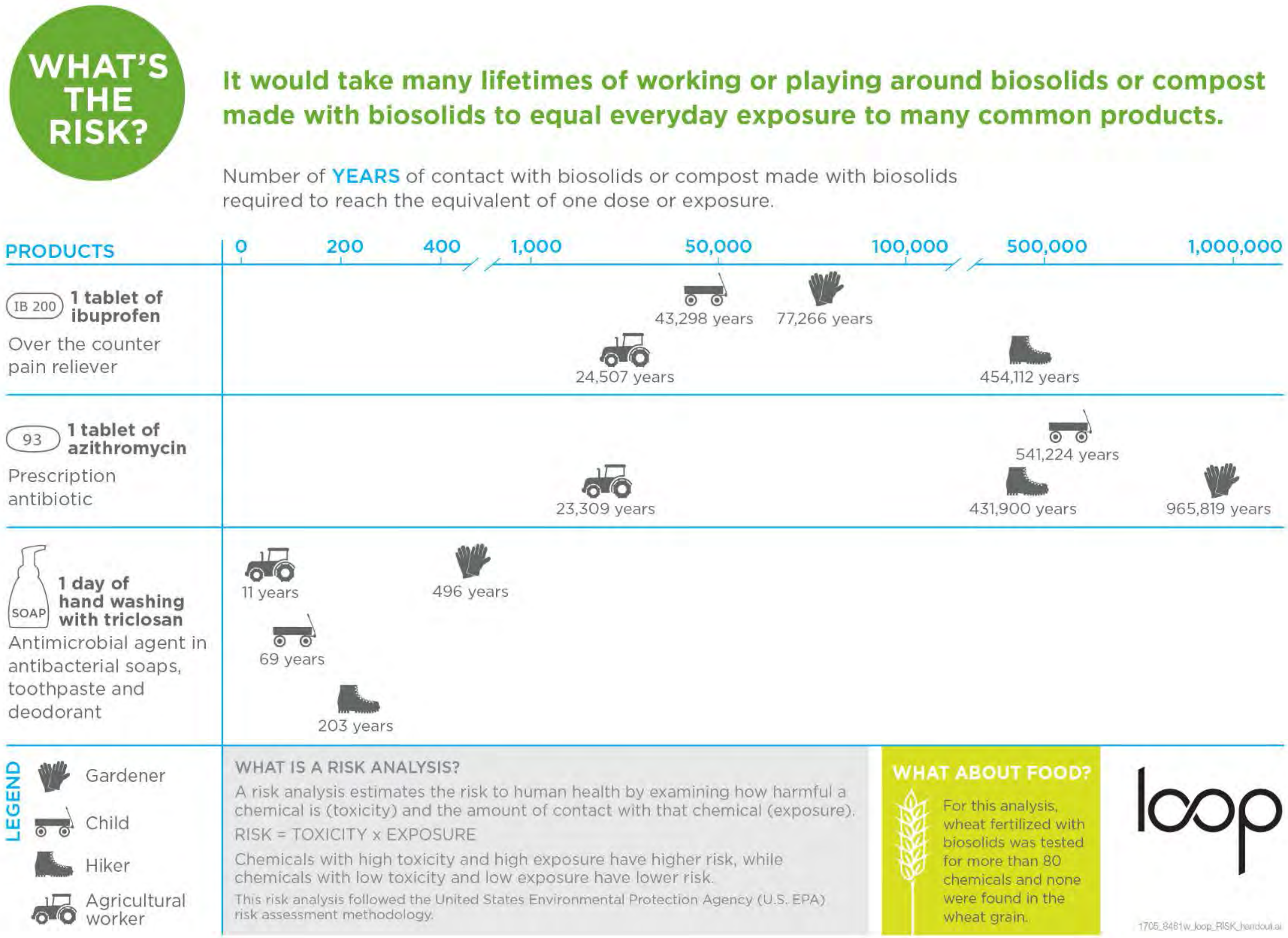
Selected compounds of concern analyzed in the risk analysis represented compounds that have been measured frequently in biosolids, are representative of a larger category of chemicals believed to have a potential human health risk, and are recognizable by the public. The categories included analgesics, antidepressants, birth control, antibiotics, antimicrobials, plasticizers, and flame retardants.

The risk analysis used four exposure scenarios including a child at play and a gardener exposed to compost made with biosolids, and an occupational worker, and a hiker exposed to Class B biosolids.

Results of the risk analysis found concentrations in biosolids are so small, it would take many lifetimes of exposure to biosolids before an individual routinely exposed to biosolids would get the equivalent of a single therapeutic dose of common pharmaceutical and personal care products. Class B biosolids and compost made with biosolids are not a significant exposure pathway for the pharmaceuticals and personal care products analyzed. These results can be seen in Figure 3-1.

In 2016 NW Biosolids, in partnership with the University of Washington, coordinated a survey of organic contaminants in biosolids products to supplement the Kennedy/Jenks study. The study tested 27 biosolids or biosolids product samples for 58 pharmaceutical and personal care products. The results indicated that there is no realistic potential for the trace compounds found in biosolids to harm people. It would take multiple lifetimes for people who regularly work with or garden with biosolids or biosolids products to reach the equivalent of a daily or prescribed dose (Brown, 2017).

Figure 3-1. Infographic displaying results of the Kennedy/Jenks risk analysis



4.0 Glossary

anaerobic digestion: the decomposition of organic matter without the presence of oxygen. Anaerobic digestion of wastewater solids takes place in tanks where 40 to 60 percent of the volatile solids are decomposed by anaerobic bacteria and converted to methane and carbon dioxide. Anaerobic digestion also typically reduces viruses and pathogenic bacterial populations by 90 percent or more. (See also: mesophilic, pretreatment, primary treatment, secondary treatment, tertiary treatment)

available nutrient: that portion of any naturally occurring or fertilizer-borne element or compound in the soil that can be readily absorbed and assimilated by growing plants. (See also: macronutrient, micronutrient)

background level: amounts of nutrients, organisms, or pollutants already existing in the environment before biosolids applications.

bacteria: single-celled microorganisms that lack chlorophyll. Some bacteria are capable of causing human, animal or plant diseases; others are essential for the decomposition of organic matter in soils, in secondary wastewater treatment (see definition below), and in digestive processes in animals. (See also: pathogenic microbe, virus)

base/neutral/acid extractable: The terms base, neutral, and acid refer to the pH conditions of the sample during the extraction process. Also referred to as BNA or semi-volatile organic compounds (SVOCs). (See also: volatile organic compounds)

biosolids: (Water Environment Federation definition) - "primarily organic product produced from the wastewater treatment plant process, that can be beneficially recycled". It contains water, sand, organic matter, microorganisms, trace metals and other chemicals. (See also: Class A Biosolids, Class B Biosolids)

ceiling concentrations: refers to federal regulation 40 CFR Part 503.13 (EPA, 1992) Table 1 concentrations of metals in biosolids. The ceiling limit is the maximum concentration of a metal allowed in biosolids in order to be considered safe for land application. (See also: pollutant concentration)

Class A biosolids: the EPA designation for biosolids that have been treated to reduce pathogens to below detectable levels. Federal regulations require this level of quality for biosolids that are sold or given away in a bag or other container, or applied to lawns or home gardens. (See also: biosolids, class B biosolids)

Class B biosolids: the EPA designation for high quality biosolids that have been treated to significantly reduce pathogens to levels that are safe for beneficial use in land application. Federal regulations require site management, crop harvest, and access restrictions when biosolids of this quality are land applied. (See also: biosolids, class A biosolids)

dewatering: any of several processes used to remove water from biosolids in order to reduce its volume and weight prior to recycling. These processes may include evaporation, passage through belt filter presses that squeeze water out of biosolids, or centrifuging which drives water out by spinning, much as water is driven out of clothes during the "spin" cycle of a clothes washing machine.

essential element: an element that is required by all organisms in order to complete their life cycles. (See also: macronutrient, micronutrient, heavy metal, trace metal, available nutrient)

heavy metal: metallic elements whose densities are equal to or greater than 5.0 g/cm^3 including, but not limited to chromium, lead, zinc, copper, cadmium, mercury, nickel, silver, and iron. Some heavy metals are required in trace concentrations for all animal and plant life. These include manganese, iron, copper, zinc, and molybdenum. Others like cadmium, mercury, and lead can be toxic to living organisms. Still others have no known effects on living organisms. (See also: micronutrient, trace metal)

Loop: Loop® is the biosolids produced by King County's wastewater treatment plants. Loop is a natural soil amendment and endlessly renewable resource that restores carbon and nutrients to the land for the good of plants, people, and Puget Sound.

mg/kg: milligram per kilogram; equivalent to a part per million.

macronutrient: an essential element needed in large amounts by a plant or animal in order to complete its life cycle. Macronutrients are found in dry tissue in concentrations greater than 1,000 ppm. Plant macronutrients include nitrogen, phosphorus, potassium, sulfur, calcium, magnesium, carbon, hydrogen and oxygen. (See also: micronutrient, trace metal)

mesophilic digestion: Biological degradation process where the temperature in the digester is maintained within the range of 85-100ºF (30-38ºC). (See also: anaerobic digestion, primary treatment, secondary treatment)

micronutrient: (also called trace element) an essential element needed in extremely small amounts by a plant or animal in order to complete its life cycle. Micronutrients are found in dry tissue in concentrations less than 100 ppm. Plant micronutrients include iron, boron, manganese, zinc, copper, chloride, cobalt, and molybdenum. Micronutrients are often depleted or unavailable in soils that have been cropped continuously and that have received only applications of nitrogen fertilizers. (See also: macronutrient, trace metal)

pathogenic microbe: any microorganism that has the potential to cause disease. These may include certain bacteria, fungi, and viruses. (See also: bacteria, virus)

"pollutant concentration limit": refers to the 40 CFR Part 503.13 (EPA, 1993) Table 3 concentrations of metals in biosolids. Municipalities whose biosolids meet this limit are exempt from certain recordkeeping and reporting requirements.

ppm: part per million, equivalent to a milligram per kilogram dry weight

pretreatment: use of processes to remove or reduce pollutants from non-domestic wastewater before discharging it to the wastewater conveyance system. Also referred to as source control. (See also: primary treatment, secondary treatment, tertiary treatment)

primary treatment: the first phase of wastewater treatment in which solids are removed through gravitational settling. (See also: pretreatment, secondary treatment, tertiary treatment)

priority pollutants: a group of chemicals specifically listed in the Code of Federal Regulations (40 CFR 423, Appendix A; 40 CFR 122 Appendix D) given priority for regulatory control.

secondary treatment: the second phase of wastewater treatment that uses aeration and the biological action of bacteria to further remove dissolved and suspended organic matter remaining in wastewater after primary treatment. (See also: pretreatment, primary treatment, tertiary treatment)

tertiary treatment: a third phase of wastewater treatment in which most of the remaining pollutants are removed from effluent following secondary treatment. The processes used include among others, sand filtration and membrane filtration. (See also: pretreatment, primary treatment, secondary treatment)

tilth: Physical condition of soil, especially in relation to its suitability for planting or growing a crop. Factors that determine tilth include the formation and stability of aggregated soil particles, moisture content, degree of aeration, rate of water infiltration, and drainage. The tilth of a soil can change rapidly, depending on environmental factors such as changes in moisture. The objective of tillage (mechanical manipulation of the soil) is to improve tilth, thereby increasing crop production; in the long term, however, conventional tillage, especially plowing, often has the opposite effect, causing the soil to break down and become compacted.

trace metal: any metallic element detected in biosolids in extremely low concentrations (equal to or less than 100 ppm). The term is also commonly used as a synonym for micronutrient, although not all micronutrients are metals. (See also: essential element, heavy metal, macronutrient, and micronutrient)

trace organic: any organic compound detected in biosolids in extremely low concentrations, usually several parts per million (mg/kg) or less.

virus: the smallest of the microorganisms, these are obligate parasites composed of a nucleic acid (RNA or DNA) core and a protein coat. They cannot grow or reproduce outside a host organism. (See also: pathogenic microbe, bacteria)

volatile organic compounds (VOC's): VOC's are emitted as gases from certain solids or liquids found in a wide array of products, including fuels, solvents, and degreasers; paints, paint strippers, and wood preservatives; household products, cleansers and disinfectants. (See also: base/neutral/acid extractable)

wastewater: water that has been previously used in homes, businesses or industry and requires treatment before it can be discharged to surface waters (i.e., Puget Sound) or reused.

5.0 References

Brady, Nyle C. The Nature and Properties of Soils, 10th ed. New York: MacMillan Publishing Company, Inc., 1990.

Brown, Sally. 2017. Trace Organics Voluntary Survey. Seattle, WA: NW Biosolids

Clark, B.O. and S.R. Smith. 2011. Review of 'emerging' organic contaminants in biosolids and assessment of international research priorities for the agricultural use of biosolids. Environment International. 37: 226-247.

Ecology. Biosolids Management, WAC 173-308. Olympia, WA: Washington State Department of Ecology, 2007.

_______. Dangerous Waste Regulations, WAC 173-303. Olympia, WA: Washington State Department of Ecology, 2009.

EPA. Environmental Regulations and Technology: Control of Pathogens and Vector Attraction in Sewage Sludge (Including Domestic Septage) Under 40 CFR Part 503. Washington, D.C.: Environmental Protection Agency, Office of Research and Development, 1992.

_______. Standards for the Use or Disposal of Sewage Sludge, 40 CFR 503. Washington, D.C.: Environmental Protection Agency, 1993.

_______. EPA Administered Permit Programs: The National Pollutant Discharge Elimination System, 40 CFR Part 122. Washington, D.C.: Environmental Protection Agency, 1985.

_______. Priority Pollutants, 40 CFR Part 423, Appendix A. Washington, D.C.: Environmental Protection Agency, 1996.

_______. Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions, 40 CFR Part 761. Washington, D.C.: Environmental Protection Agency, 1996.

Epstein, Emanuel. Mineral Nutrition of Plants, Principles and Perspectives. New York: John Wiley & Sons, Inc., 1972.

Gilbert, Richard O. Statistical Methods for Environmental Pollution Monitoring. New York: Van Nostrand Reinhold Company, 1987.

Helsel, D. "Less Than Obvious." Environmental Science Technology, Vol. 24, No. 12 (1990).

Hundal, L., Xia, K., Kumar, K., Cox, A., and Granato, T. 2009. Long-Term Assessments of Microconstituents Fate in Biosolids-Amended Soils. Residuals and Biosolids 2009, Water Environment Federation Specialty Conference on CD-ROM

Hundal, L.S., K. Kumar, N. Basta, and A.E. Cox. 2011. Evaluating Exposure Risk to Trace Organic Chemicals in Biosolids. BioCycle, August 2011, 31–36.

Kennedy/Jenks Consultants. 2015. Biosolids Risk Analysis (K/J Project No. 1476009.0). Seattle, WA: NW Biosolids

Pepper, Ian L., John Brooks, Ryan Sinclair, Patrick Gurian, Charles P. Gerba. Biosolids and Indicators in United States Class B Biosolids: Temporal and Spatial Distributions. A Research Progress Report, Water & Environmental Technology Center, December 2009.

Pepper, Ian L., John Brooks, Ryan Sinclair, Patrick Gurian, Charles P. Gerba. Biosolids and Indicators in United States Class B Biosolids: Temporal and Spatial Distributions. A Research Progress Report, Water & Environmental Technology Center, December 2009.

Sauchelli, Vincent. Trace Elements in Agriculture. Van Nostrand Reinhold Co., Inc., 1969.

WEAO. 2010. Assessing the Fate and Significance of Microconstituents and Pathogens in Sewage Biosolids: Update on the 2001 WEAO Report on Fate and Significance. Water Environment Association of Ontario.

6.0 Appendix A

Table A-1. List of Organic Compounds Analyzed in King County Biosolids

Pesticides and PCBs	Volatiles	Semivolatiles (Bases/Neutrals/Acids	
4,4-DDE	1,1-Dichloroethane	1,2-Dichlorobenzene	Benzyl Alcohol
4,4-DDD	1,1-Dichloroethylene	1,2-Diphenylhydrazine	Bis(2-chloroethoxy) methane
4,4-DDT	1,2-Dichloroethane	1,3-Dichlorobenzene	Bis(2-chloroethyl)ether
Aldrin	1,2-Dichloropropane	1,4-Dichlorobenzene	Bis(2-chloroisopropyl)-ether
Alpha-BHC	1,2-Trans-Dichloroethylene	1,2,4-Trichlorobenzene	Bis(2-ethylhexyl)phthalate
Alpha Chlordane	1,1,1-Trichloroethane	2-Chloronaphthalene	Benzyl Butyl Phthalate
Total Aroclors[†]	1,1,2-Trichloroethane	2-Chlorophenol	Carbazole
Beta-BHC	1,1,2-Trichloroethylene	2-Methylnaphthalene	Chrysene *
Delta-BHC	1,1,2,2-Tetrachloroethane	2-Methylphenol	Di-n-Butyl Phthalate
Dieldrin	1,3-Trans-Dichloropropene	2-Nitroaniline	Di-n-Octyl Phthalate
Endosulfan 1	2-Butanone (MEK)	2-Nitrophenol	Dibenzo(a,h)anthracene *
Endosulfan Sulfate	2-Chloroethylvinyl Ether	2,4-Dichlorophenol	Dibenzofuran
Endosulfan11	2-Hexanone	2,4-Dimethylphenol	Diethyl Phthalate
Endrin	4-Methyl-2-Pentanone (MIBK)	2,4-Dinitrophenol	Dimethyl Phthalate
Endrin Aldehyde	Acetone	2,4-Dinitrotoluene	Fluoranthene *
Gamma-BHC	Acrolein	2,6-Dinitrotoluene	Fluorene *
Heptachlor	Acrylonitrile	2,4,5-Trichlorophenol	Hexachlorobenzene
Heptachlor Epoxide	Benzene	2,4,6-Trichlorophenol	Hexachlorobutadiene
Methoxychlor	Bromodichloromethane	3-Nitroaniline	Hexachlorocyclopentadiene
Toxaphene	Bromoform	3-,4-Methylphenol	Hexachloroethane
Trans Chlordane	Bromomethane	4-Bromophenyl Phenyl Ether	Indeno(1,2,3-c,d)pyrene *
	Carbon Disulfide	4-chloro-3-methylphenol	Isophorone
	Carbon Tetrachloride	4-Chloroaniline	N-Nitroso-di-n-propylamine
	Chlorobenzene	4-Chlorophenyl Phenyl Ester	N-Nitrosodimethylamine
	Chlorodibromoethane	4-Nitroaniline	N-Nitrosodiphenylamine
	Chloroethane	4-Nitrophenol	Naphthalene *
	Chloroform	4,6-Dinitro-O-Cresol	Nitrobenzene
	Chloromethane	Acenaphthene *	Pentachlorophenol
	Cis-1,3-Dichloropropane	Acenaphthylene *	Phenanthrene *
	Ethyl Benzene	Aniline	Phenol
	Methylene Chloride	Anthracene *	Pyrene
	Styrene	Benzoic Acid	
	Tetrachloroethylene	Benzo(a)anthracene *	
	Toluene	Benzo(a)pyrene *	
	Total Xylenes	Benzo(b,j,k)fluoranthene *	
	Trichlorofluoromethane	Benzo(g,h,i)perylene *	
	Vinyl Acetate		
	Vinyl Chloride		

* Polynuclear Aromatic Hydrocarbons (PAHs)
[†] Polychlorinated Biphenyls (PCBs)

Rev: 20180801