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Memo

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Suncrest Septic System Phosphorus Loading Analysis

As part of the Bi-State Nonpoint Source Phosphorus Study, a preliminary analysis to estimate the phosphorus loading from onsite wastewater disposal systems (referred to as septic systems) in the Suncrest area was performed (Figure 1). Suncrest is an unincorporated community in Stevens County, Washington located along Lake Spokane, northwest of Spokane, Washington. The study area is generally bounded by Lake Spokane to the south, State Route (SR) 291 to the north, Little Sandy Canyon to the west, and Sandy Canyon to the east.

The objective of this analysis was to estimate the phosphorus load from septic systems in the Suncrest area to groundwater and surface water. Based on the proximity of these septic systems to Lake Spokane, the hydraulic gradient data in Soltero, et.al (1992), and the relatively coarse-grained sediments within the unconsolidated aquifer underlying the Suncrest area, phosphorus loads to groundwater in this area likely affect water quality within Lake Spokane. Quantifying the septic system phosphorus load is a first step to understanding the magnitude of the load and the potential reduction of this load to the river. Quantifying and reducing septic system phosphorus loads is one of the recommendations in the Nonpoint Source Phosphorus Reduction Plan (GeoEngineers, HGC, and HDR, 2011). The steps required to quantify the phosphorus load include 1) estimating the phosphorus load to the soils, 2) estimating the phosphorus breakthrough to groundwater, and 3) estimating the phosphorus discharge to surface water.

Hydrogeology

Basement rocks in the vicinity of Suncrest generally consist of metasedimentary rocks of the Precambrian Belt Supergroup (age greater than about 570 million years [Ma]). These rocks were intruded by granitic plutonic rocks during the Mesozoic (245 to 65 Ma) and Tertiary (65 to 1.5 Ma) (Stoffel et al. 1991). Groundwater occurs in basement rocks in fractured and/or weathered zones. Porosity and permeability are generally low.

Basement rocks are stratigraphically overlain by basalt flows associated with the Columbia River Basalt Group (CRBG). The CRBG was deposited during an extended period of Miocene (23 to 5 Ma) volcanism that extruded a series of very fluid lava flows. The lava flowed from north-northwest trending fissures as much as 90 miles long which were located primarily in northeastern Oregon and southeast Washington (Hooper 1982). The resulting basalt deposits are hundreds to thousands of feet thick and extend throughout the Columbia Plateau. The Suncrest area is located along the margin of the Columbia Plateau and, as such, CRBG distribution is discontinuous and thickness is relatively low. The CRBG has been subdivided into five formations that include, from oldest to youngest, the Imnaha Basalt, Picture Gorge Basalt, Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt. Two of these formations, the Grande Ronde and Wanapum, have been identified within the Suncrest area (Drost and Whiteman 1986). The CRBG consists of a series of individual basalt flows. Groundwater is most readily transmitted through the broken vesicular and scoriaceous interflow zones that characterize the top of each flow. The interflow zones are separated by the less porous and less transmissive entablature and colonnade, which comprise 90 to 95 percent of the total flow volume (Whiteman et al. 1994). The flows are locally interlayered with sedimentary deposits of the Latah Formation. This system of multiple flows and interlayered sedimentary deposits creates multiple stacked confined to semi-confined aquifers.

The CRBG is overlain by Pleistocene-age glaciofluvial (flood) deposits that consist of unsorted mixtures of silt, sand, gravel, cobbles and boulders. Flood deposits are frequently interbedded with glaciolacustrine sediments that were deposited in a low-energy depositional environment (such as a lake); these deposits typically consist of clay, silt, or silty fine sand. Quaternary (less than about 1.5 Ma) alluvium and loess (wind-blown clay, silt and fine sand) frequently overlie the glaciofluvial and glaciolacustrine deposits, and, in some areas, directly overlie the CRBG. Unconsolidated surficial deposits consist primarily of glaciofluvial and glaciolacustrine deposits. The glaciofluvial deposits typically consist of relatively free-draining sand and gravel with relatively high permeability that in places forms an unconfined aquifer, perched on the underlying bedrock surface. The unconfined aquifer water quality is relatively susceptible to degradation from point and non-point sources of contamination because of the lack of an overlying confining unit and the generally shallow depth to the groundwater table. Recharge to the unconfined aquifer is primarily from precipitation, applied irrigation, septic systems and potentially through leakage from underlying bedrock aquifers.

Glaciofluvial deposits constitute the near shore unconsolidated aquifers adjacent to Lake Spokane that are in hydraulic connection with Lake Spokane and directly underlie near shore residential septic systems. These deposits form the uppermost aquifer underlying the Suncrest area. Key characteristics of the glaciofluvial aquifer underlying the Suncrest area are adapted from information provided by Soltero, et.al (1992) and include the following:

- The aquifer is unconfined and consists of sand and gravel with cobbles and boulders and minor silt content.
- Saturated aquifer thickness ranges from about 20 to 40 feet.
- Hydraulic conductivity is on the order of about 500 feet per day.
- Groundwater flows toward, and presumably discharges to, Lake Spokane.
- Hydraulic gradient is about 5×10^{-4} feet per foot in magnitude.

The geometry and flow characteristics of near shore unconsolidated aquifers adjacent to Lake Spokane is complicated by numerous zones of shallow bedrock and/or other low-permeability formations, creating numerous hydraulically distinct unconsolidated aquifers on both the north and south sides of Lake Spokane. Soltero, et.al (1992) reports significant variation in groundwater flow direction depending on location and reservoir stage.

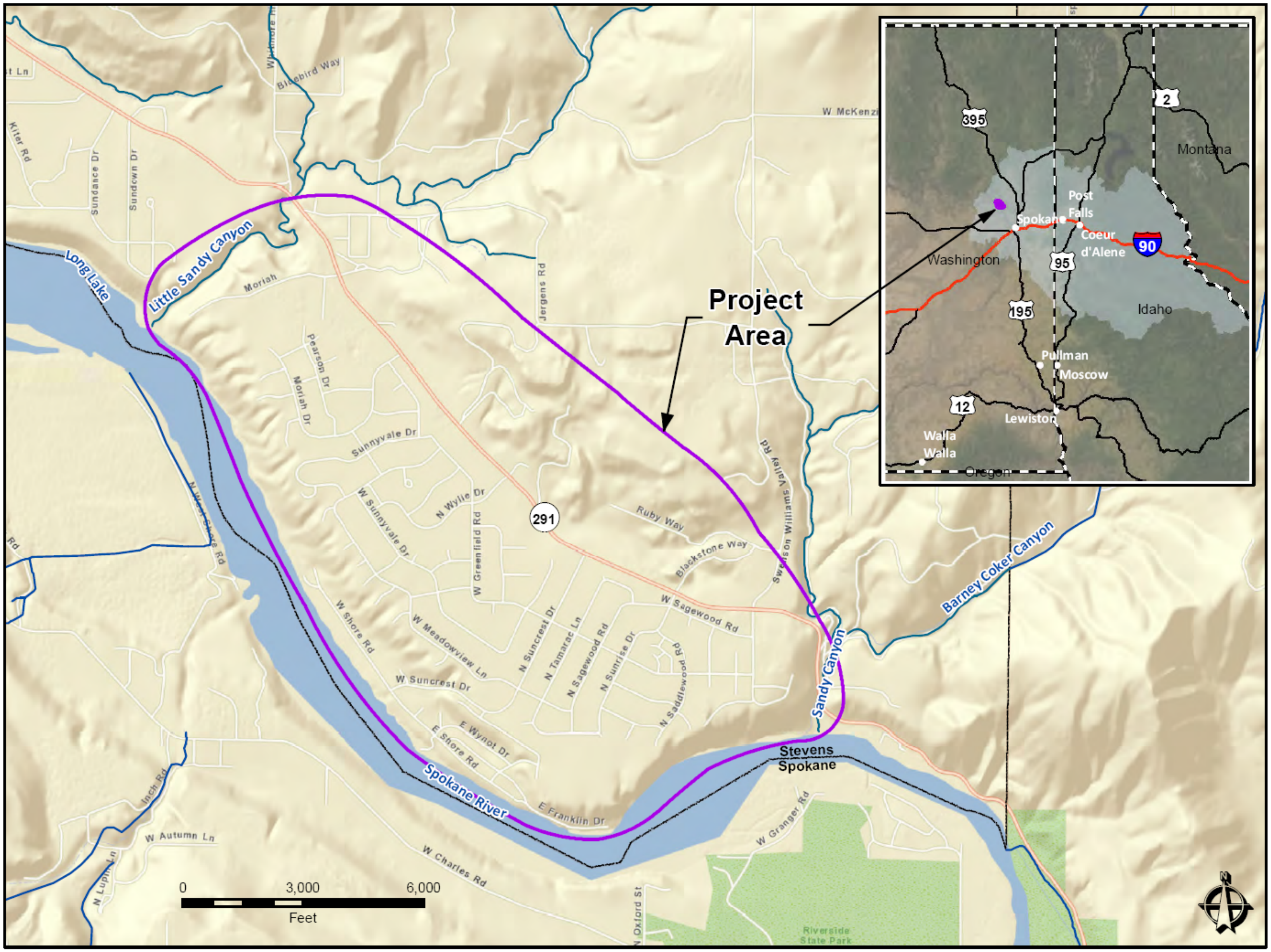

Figure 1. Suncrest Location Map

Method and Approach
The method for estimating the phosphorus loading from septic systems is based on the breakthrough calculations presented by the Montana Department of Environmental Quality (MDEQ, 2009), the guidance presented by the Idaho Department of Environmental Quality (IDEQ, 2008), and fundamental physical principles regarding the fate and transport of phosphorus. The approach was to estimate the loads in a stepwise manner from the drainfield through the soils to groundwater and through groundwater to surface water.

The phosphorus loading analysis consists of three components:

1. Estimate the phosphorus load from the septic system drainfield to soils.
2. Estimate the phosphorus load from the soils (unsaturated zone) to groundwater.
3. Estimate the phosphorus loads in groundwater to surface water.

Wastewater from residential and other uses is discharged to a septic tank where the solids settle and the liquid discharges to a drainfield. Estimating the phosphorus load from the drainfield requires estimating the effluent discharge rate and phosphorus concentration. The effluent that discharges to the drainfield receives biological and physical treatment in the soil system. However, for phosphorus the treatment efficiency, or percent removal, can vary from 0 to 100 percent depending upon the loading rate and the soil characteristics (HDR, 2007). From this information, phosphorus loads to the soil were estimated (**Step 1: Estimate Phosphorus Loads to Soils**).

Phosphorus in the soil system is subject to sorption mechanisms (adsorption, precipitation, desorption, and dissolution). Collectively, these mechanisms are referred to as “sorption”. The fate and transport of phosphorus in the soil was estimated using a sorption coefficient, where the higher the coefficient, the greater the relative amount of phosphorus that can be adsorbed to soils. The sorption coefficient represents the maximum value of phosphorus that soil can adsorb. Once that finite capacity is exceeded, the phosphorus will begin to be transported with water in the soil to groundwater. From this information, a time estimate and load for phosphorus to reach groundwater was estimated (**Step 2: Estimate Phosphorus Breakthrough to Groundwater).**

The phosphorus loads that have reached breakthrough to groundwater were then used to estimate the phosphorus load to surface water. Phosphorus that has entered the groundwater is subject to advection, diffusion, sorption mechanisms (i.e., phosphorus binding with geologic materials), withdrawal through pumping, and discharge to surface waters. From this information, the phosphorus load to surface was estimated, (**Step 3: Estimate Phosphorus Discharge to Surface Water).**

Residential Phosphorus Loading Analysis

Step 1: Estimate Phosphorus Loads to Soils
The phosphorus load to soils was estimated using the phosphorus concentration discharge to the drainfield and the effluent flow rate. Literature reviews indicated the range of effluent phosphorus concentrations from septic systems to be 1 to 25 milligrams per liter (mg/L) (HDR, 2007). An effluent phosphorus concentration of 12 mg/L was used for this analysis. This is consistent with previous septic system analyses associated with Spokane River valley sediments within the Spokane Valley area and completed by HDR (2007).

The design of septic systems and the applicable regulations impacting these systems have evolved over time. Wastewater flows have decreased due to decreased water use and regulations governing the installation of more efficient fixtures and conservation. Wastewater flow estimates range from 156 gallons per day (gpd) per household (using 60 gpd per person and the U.S. Census average of 2.6 people per household) to 300 gpd per household (DOH, 1992 and IDEQ, 2002). Montana DEQ recommends a flow value of 200 gpd per household for phosphorus breakthrough analysis (MDEQ, 2009). While wastewater flows were likely higher prior to water efficiency upgrades, an average flow of 200 gpd per household was used for this evaluation because it is based on current studies and incorporates water efficiency upgrades.

The phosphorus load to soils is calculated as:

Estimation of phosphorus Load (pounds [lbs])/year) = effluent flow (gpd) x phosphorus concentration (mg/L) x 365 days/year x conversion factor

The estimated residential phosphorus load is 0.02 lbs/day (7.3 lbs/year) per household.

Step 2: Estimate Phosphorus Breakthrough to Groundwater
The time for phosphorus to travel to the underlying aquifer is known as breakthrough. Calculation of the breakthrough time used the following parameters:

- Effluent phosphorus load – Result from Step 1.
- Drainfield area.
- Soil phosphorus sorption coefficient.
- Depth to the groundwater table.

These parameters are described below.

Drainfield Area
An estimate of the drainfield area was used to estimate the soil mass between the septic system and the ground water. The soil mass is required to estimate the potential amount of phosphorus adsorbed by the soil.

The Northeast Tri County Health District (NETCHD) oversees individual septic systems. The drainfield area was calculated using the following equation (NETCHD, unknown):

Drainfield area = Number of bedrooms x design flow / loading rate

The number of bedrooms per residence was generally available in the Stevens County Assessor's parcel data in the residential characteristics information. When the data did not include a number of bedrooms, a bedroom size of 2.5 was assumed for these properties. The design flow is the number of bedrooms multiplied by 120 gpd with a minimum design flow for any septic system of 240 gpd (NETCHD, 2010). The loading rate is based on the soil textural classification as shown in Table 1. Soils in the area are predominantly coarse-grained sediments (see **Hydrogeology**), so a loading rate of 1.0 gallon per square foot per day was used.

Table 1. Maximum Hydraulic Loading Rate

Soil Type	Soil Textural Classification Description	Loading Rate for Residential Effluent Using Gravity or Pressure Distribution (gal/sq ft/day)
1	Gravelly and very gravelly coarse sands, all extremely gravelly soils except where soil types 5 and 6 make up the non-gravel component	1.0
2	Coarse sands	1.0
3	Medium sands, loamy coarse sands, loamy medium sands.	0.8
4	Fine sands, loamy fine sands, sandy loams, loams.	0.6
5	Very fine sands, loamy very fine sands; or silt loams, sandy clay loams, clay loams and silty clay loams with a moderate structure or strong structure (excluding a platy structure).	0.4
6	Other silt loams, sandy clay loams, clay loams, silty clay loams.	0.2
7	Sandy clay, clay, silty clay and strongly cemented firm soils, soil with a moderate or strong platy structure, any soil with a massive structure, any soil with appreciable amounts of expanding clays.	Not Suitable

NETCHD, 2010

Soil Phosphorus Sorption Coefficients

Phosphorus sorption coefficients may vary through the soil profile for different depths below ground surface. Unsaturated sediment beneath the Suncrest area generally consists of coarse-grained sand and gravel (see **Hydrogeology**). Much of the rest of the aquifer is comprised of cobbles, and boulders that are not expected to adsorb significant amounts of phosphorus. The Suncrest septic system analysis was completed using the following sorption capacities, which are consistent with those previously used for the Spokane Valley area (HDR, 2007).

- Upper 3 feet, sorption capacity of 200 mg/kg.
- 3 feet to 13 feet, sorption capacity of 150 mg/kg.
- 13 feet and below, sorption capacity of 50 mg/kg.

Depth to Groundwater

The depth to groundwater for the Suncrest area was estimated using available data sources including Geographic Information Systems (GIS) data. Approximate contours of the depth to groundwater for this preliminary analysis were estimated but not refined to smooth all the edges (Figure 2). The U.S. Geological Survey (USGS) 10-meter National Elevation Dataset (NED) was used for the ground surface elevation. The aquifer elevation was estimated using the ground surface elevation minus the depth to water based on well logs in Ecology's well drilling database. Well logs primarily from approximately 30 domestic water wells in the area were used. The elevation of the top of the well was assumed to represent the ground surface.

The Stevens County Assessor appraisal data was used to identify if a parcel had a septic system. All residential parcels were assumed to have a septic system. The type of lot was identified from the Stevens County Assessor's parcel data. Approximately 1,380 residential parcels were identified in the Suncrest area. The depth to groundwater was calculated at the center of each parcel, using the parcel data, the ground surface elevation and aquifer elevation.

Breakthrough Analysis

The parameters calculated in the previous sections were used to estimate the time to breakthrough to the groundwater. The amount of total phosphorus that can be sorbed was calculated using the sum of the soil weight for each depth segment multiplied by the respective phosphorus sorption coefficients for the depth of soil below each drainfield (see example in Table 2).

The time to breakthrough was calculated as the total phosphorus that can be adsorbed divided by the estimated phosphorus load per household. The time to breakthrough ranged from approximately 3 to 190 years per residence. If the breakthrough time was less than the length of time the system has been in service, then phosphorus breakthrough to the groundwater is assumed to have occurred. The years in service was estimated as the same as the age of the home (Figure 3). The year the home was built was in the Stevens County Assessor appraisal data. Approximately 150 of the 1,380 septic systems are estimated to have reached breakthrough by 2011. However, in 20 years the number of septic systems that are estimated to have reached breakthrough will more than double, at 440 septic systems.

The years of breakthrough were multiplied by the estimated phosphorus load to calculate the total phosphorus mass to the groundwater. The number of septic systems at breakthrough was multiplied by the estimated phosphorus loads to calculate the total phosphorus load to groundwater each day. The estimated phosphorus load is approximately 3.0 lbs/day under current conditions.

Groundwater Phosphorus Loading

Approximately 1,380 septic systems were evaluated (Figure 4). Of these systems, approximately 11 percent were calculated to have reached phosphorus breakthrough. The septic systems with greater depth to groundwater generally have a longer breakthrough time. The properties near Lake Spokane generally had the lowest depth to groundwater and were typically the oldest, built in the 1970's. As a result, most of the septic systems within about 1,000 feet of Lake Spokane have reached breakthrough. The phosphorus load reaching groundwater in 2011 is estimated to be 3.0 lbs/day from the Suncrest area.

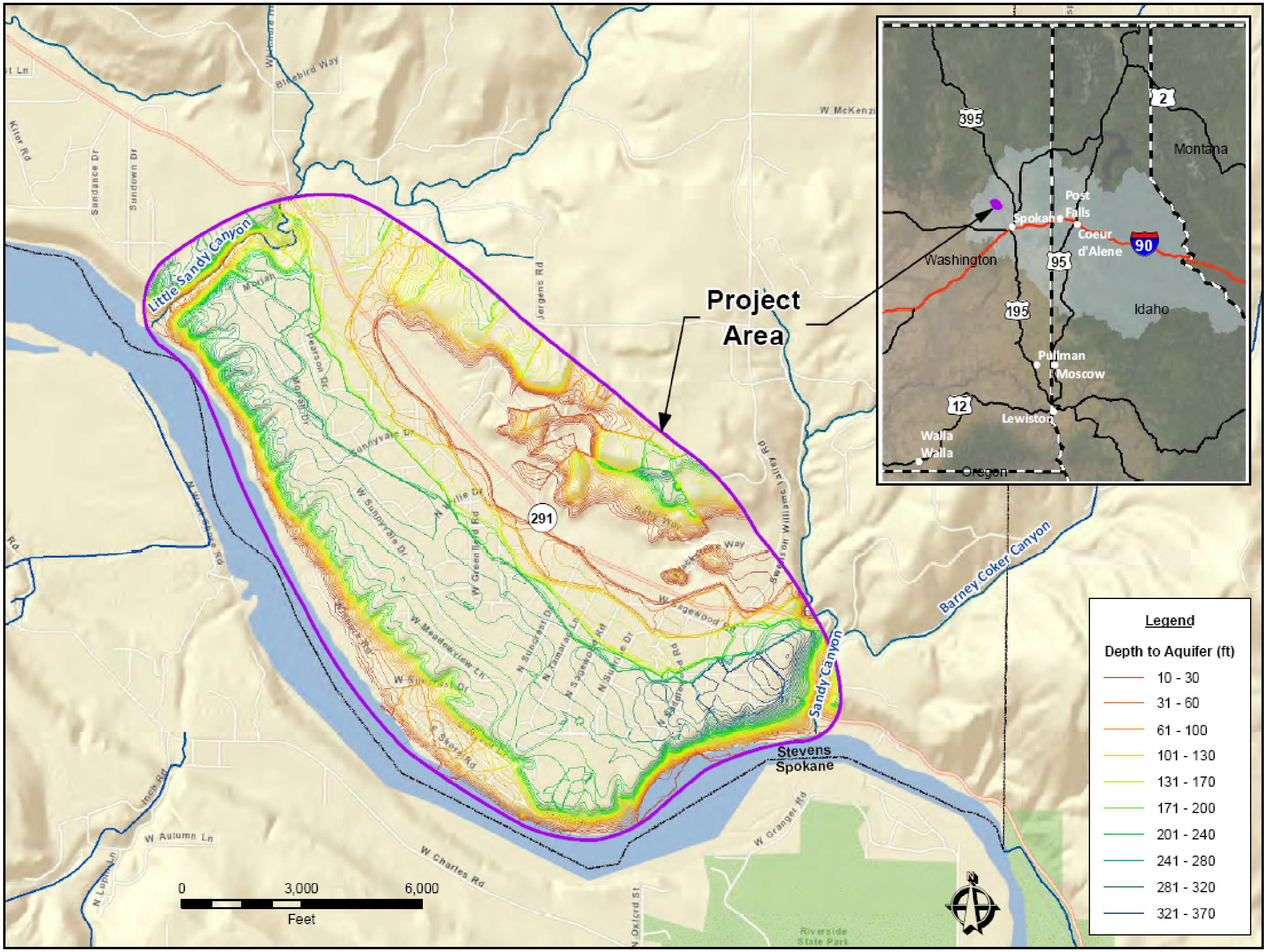

Figure 2. Suncrest Area Approximate Contours of the Depth to Groundwater

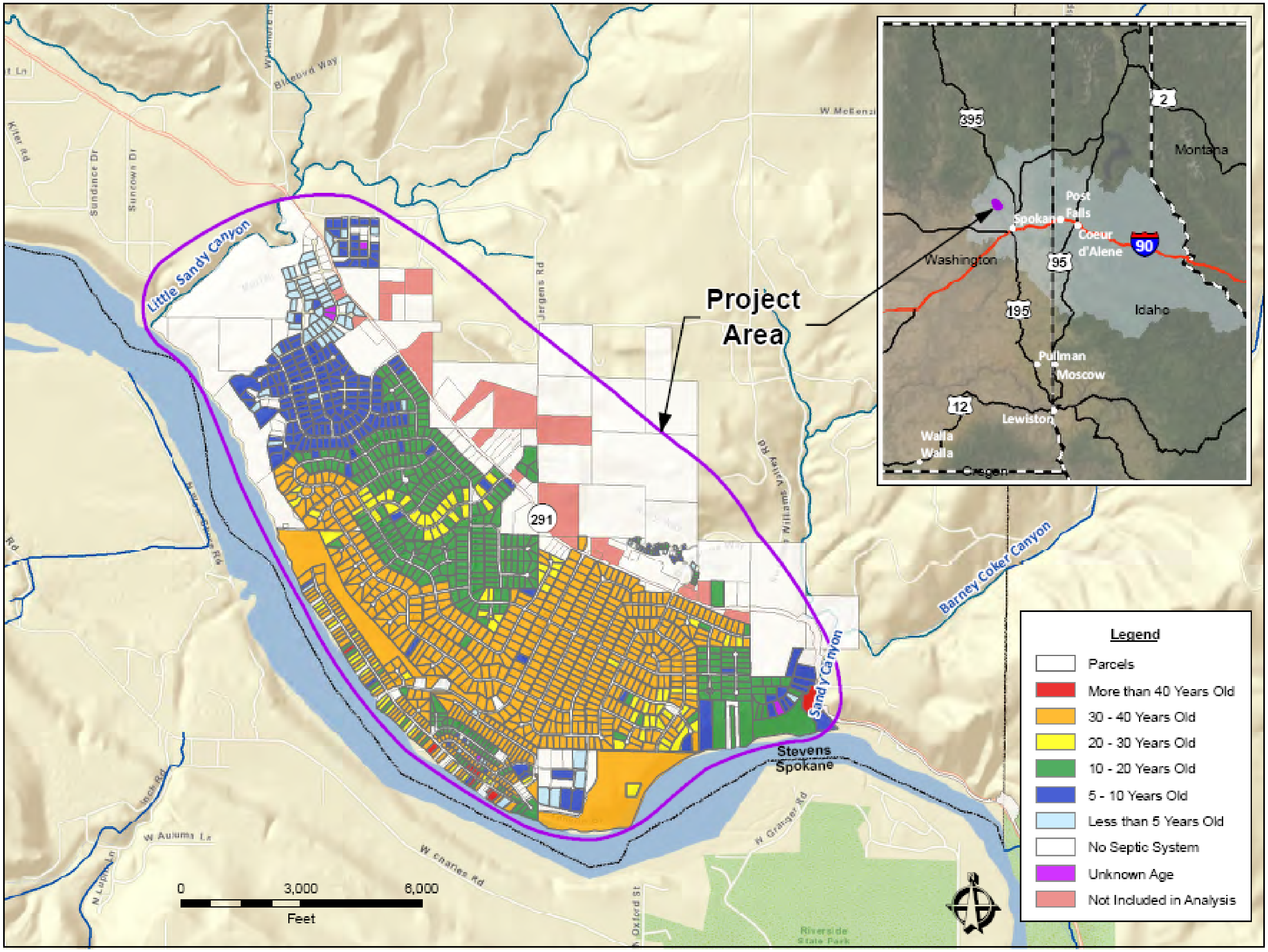

Figure 3. Suncrest Estimated Age of Septic Systems

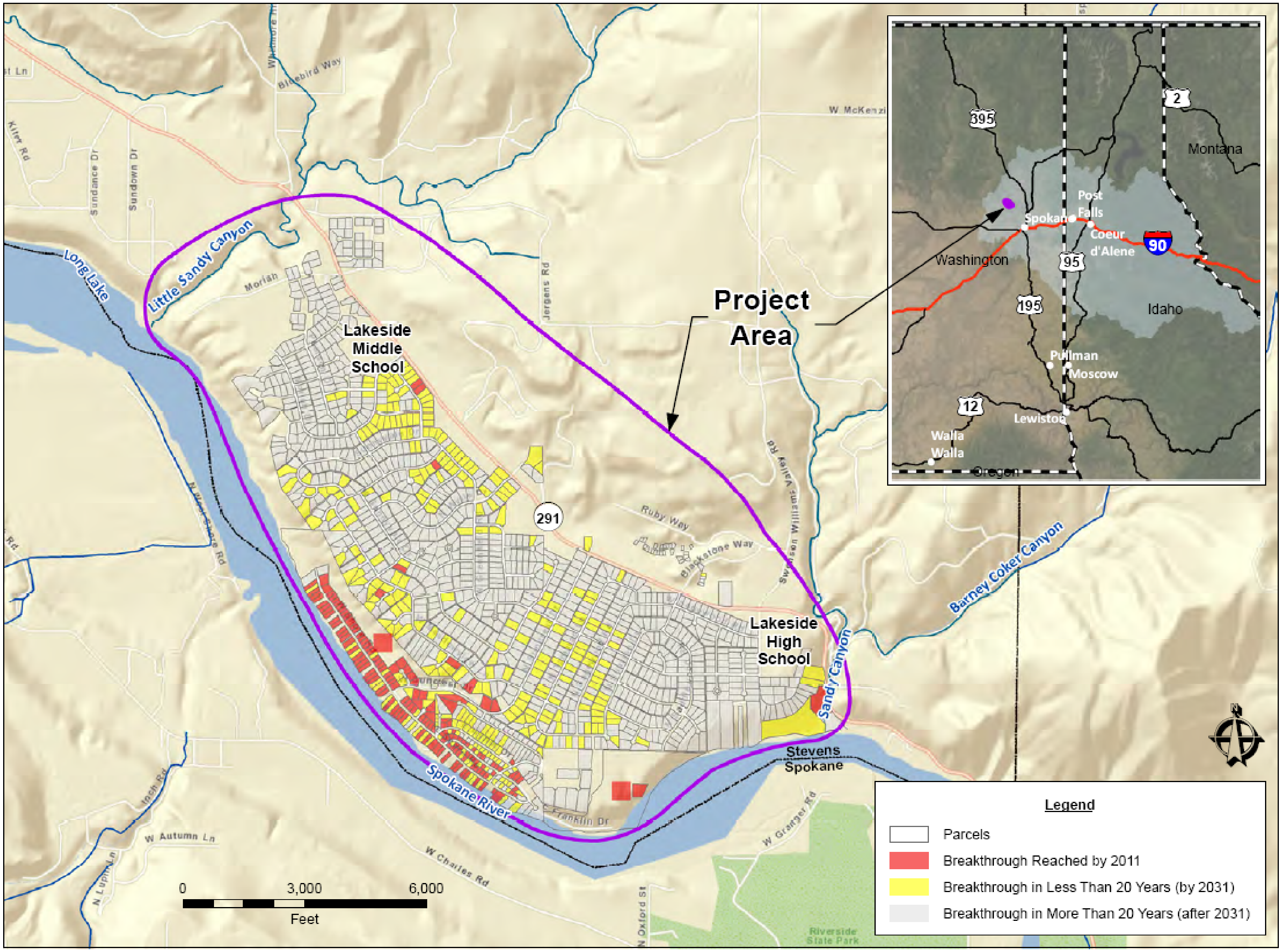

Figure 4. Suncrest Septic Systems Breakthrough Estimates

Step 3: Estimate Phosphorus Discharge to Surface Water

Groundwater and surface water in the Spokane River watershed are hydraulically connected. Throughout most of the length of Lake Spokane (and within the Suncrest area) the unconsolidated aquifer system discharges (provides baseflow) to Lake Spokane. In addition, the uppermost unconsolidated aquifer underlying the Suncrest area is also almost entirely comprised of relatively coarse grained particles – sand, gravel, cobbles, and boulders – that have little to no phosphorus adsorptive capacity. The travel time from groundwater to surface water was not estimated, since Suncrest is located along Lake Spokane and the travel time is relatively short, likely on the order of a few years or less based on hydraulic conductivity and hydraulic gradient information presented by Soltero, et.al (1992).

Not all of the phosphorus that enters the groundwater will reach Lake Spokane. The estimate of the groundwater phosphorus load that contributes to the surface water includes an aquifer retention factor to account for phosphorus adsorbed in the aquifer. An aquifer retention factor of 0.5 was used to estimate the surface water load (HDR, 2007). While phosphorus is not expected to strongly sorb to the geologic material in the aquifer, which are primarily sands low in iron and clay, this conservative literature value for the aquifer retention factor was used. The phosphorus load to Lake Spokane was estimated to be 1.5 lb/day from septic systems.

An example calculation for a single septic system is shown in Table 2.

Table 2. Example Calculation of Phosphorus Loading from a Single Septic System

Scenario:
Residential site with a 3 bedroom home
Residence built and septic system installed in 1978
Depth to groundwater 55 feet

Input Parameters:

- Phosphorus loading to soil = 7.3 lb/year (Step 1)
- Drainfield area = 3 bedrooms X 120 gpd/1 gal/ft^2/day = 360 ft^2 (Step 2)
- Phosphorus sorption to soil (Pa) = 200 mg/kg 0 to 3 feet; 150 mg/kg 3 to 13 feet; 50 mg/kg 13 to 55 feet (Step 2)
- Depth to groundwater = 55 feet (Step 2)

Calculations:
Calculate the weight for three depth intervals beneath the drainfield:

$$W = A \times D \times Sw$$

Where:
A is the drainfield area
D is the depth (feet)
Sw is the soil density, assumed to be 100 lb/ft^3

W1 (0 to 3ft) = 360 ft^2 x 3 ft x 100 lb/ft^3 = 108,000 lbs of soil
W2 (3 to 13ft) = 360 ft^2 x 10 ft x 100 lb/ft^3 = 360,000 lbs of soil
W3 (13 to 55ft) = 360 ft^2 x 42 ft x 100 lb/ft^3 = 1,512,000 lbs of soil

Calculate the total mass of phosphorus (Ps) sorbed by soils

$$P = (W \times Pa)/10^6$$

Ps1 = 108,000 lbs soil x 200 mg/kg /10^6 = 21.6 lbs
Ps2 = 360,000 lbs soil x 150 mg/kg/10^6 = 54 lbs
Ps3 = 1,512,000 lbs soil x 50 mg/kg/10^6 = 75.6 lbs

The soil beneath the system can adsorb 151.2 pounds of phosphorus before breakthrough to the groundwater.

Calculate the breakthrough time

BT = phosphorus adsorbed/phosphorus loading

BT = 150.2 lbs of phosphorus/ 7.3 lbs phosphorus per year = 20.7 years

Interpretation:
Thus, it will take 20.7 years for phosphorus breakthrough to groundwater to occur at this site. It is estimated that breakthrough occurred in 1999.

Non-Residential Phosphorus Loading Analysis

Two non-residential septic systems in the Suncrest area were identified in the Washington State Department of Health records. These were for the middle and high schools. There were an additional 21 sites identified that may potentially have septic systems. The types of septic systems and loading rates from these could not be identified and these septic systems were not included in the loading estimate.

For nonresidential onsite wastewater disposal systems, MDEQ recommends using the following equation to estimate phosphorus load (MDEQ, 2009):

Nonresidential phosphorus Load = Nonresidential effluent rate (gpd)/(200 gpd) x 7.3 lb/year

The average flow for the middle and high school septic systems is 13,000 gpd. The estimated nonresidential phosphorus load to the aquifer was estimated to be:

Nonresidential phosphorus load = 13,000 gpd/(200 gpd) x 7.3 lb/year = 1.3 lbs/day (475 lb/year)

This phosphorus load was used to complete the breakthrough analysis for the two schools. The same methodology was used to calculate the soil weight, phosphorus adsorption capacity, and breakthrough time as was used for residential systems. These septic systems are estimated to have not yet reached breakthrough.

Summary of Phosphorus Loading Estimates

The total phosphorus load to Lake Spokane was estimated based on the combined breakthrough load from aging septic systems with a soil/aquifer retention coefficient. The current and projected phosphorus loads to Lake Spokane are summarized in Table 3. These range from about 1.5 lbs/day in 2011 to more than 11 lbs/day by 2061. The mass of phosphorus entering Lake Spokane would be significantly reduced by the removal of Suncrest septic systems. This would benefit the water quality of Lake Spokane and be beneficial with respect to the goal of complying with the Dissolved Oxygen Total Maximum Daily Load (TMDL) (Ecology, 2010). Conversely, if these septic systems are not removed, the associated phosphorus loading to Lake Spokane will increase with time as more septic systems reach breakthrough.

Table 3. Estimated Phosphorus Loads from Suncrest Residential Septic Systems

Year	Estimated Number of Systems at Breakthrough	Percent of Systems at Breakthrough	Loading to Groundwater (lbs/day)	Loading to Surface Water (lbs/day)
2011	148	11%	3.0	1.5
2031	447	32%	8.9	4.5
2061	943	68%	18.9	9.4

Table 4. Estimated Phosphorus Loads from Suncrest Large Septic Systems[1]

Year	Estimated Number of Systems at Breakthrough	Percent of Systems at Breakthrough	Loading to Groundwater (lbs/day)	Loading to Surface Water (lbs/day)
2011	0	0%	0	0
2031	1	50%	2.6	1.3
2061	2	100%	3.9	2.0

[1]Middle school and high school septic tanks

Table 5. Estimated Phosphorus Loads from Suncrest Septic Systems

Year	Loading to Groundwater (lbs/day)	Loading to Surface Water (lbs/day)
2011	3.0	1.5
2031	11.5	5.8
2061	22.8	11.4

Analysis Limitations and Uncertainty

The general approach used for this preliminary analysis assumes that phosphorus does not breakthrough to groundwater until the sorption sites are used. The approach underestimates the loading as it has been well documented in the literature that phosphorus will leach in the soil system prior to breakthrough occurring. The approach used for this preliminary analysis for estimating the phosphorus loading includes a generous underestimate of the load by not including non-residential septic systems, by underestimating historic phosphorus concentrations in effluent, underestimating historic hydraulic loading, overestimating phosphorus sorption capacity of soils, ignoring phosphorus movement into the groundwater system prior to full sorption capacity of the soil being reached, and the use of a 50 percent aquifer retention coefficient.

As described in this document and the referenced Spokane County analysis (HDR, 2007), the calculations are based on a number of assumptions and variables. Where available, the uncertainty in these variables was reduced by using site or area specific information. These variables, such as depth to groundwater and septic system location, have low levels of uncertainty. For variables with a greater level of uncertainty, estimates were used that included a generous underestimation. Parameters used for the phosphorus loading estimate and uncertainty associated with these parameters are summarized in Table 6.

Table 6. Parameter Uncertainty for Suncrest Septic Systems Phosphorus Breakthrough Analysis

Parameter	Value	Comments
Phosphorus Loading to Drainfield		
Phosphorus Concentration	12 mg/L	Phosphorus concentrations can be variable. Historical concentration is appropriate since these loadings consumed phosphorus sorption sites in the soil. Used median value in literature.
Effluent Discharge	200 gal/day	This value reflects current uses and efficient fixtures which were implemented in 1994. The flow rate underestimates historic flow rates.
Septic System Information		
Location of System	Physical Location	Stevens County parcel data and assessor information for system locations. Data are readily accessible and reliable.
Depth to Groundwater	Variable	Based on USGS NED topography and Ecology well logs to calculate the depth in GIS. Data are readily accessible and reliable.
Sizing of Drainfield	Variable	Based on County and site specific information on dwellings size and county rules on sizing of drainfield. This represents location specific information and is based on data assessor data.
Soil Sorption		
Sorption	200, 150 and 50 (Varies with depth with higher sorption values assumed for the drainfield and lower values with depth through gravelly soils	Utilized literature information on sorption value for sand as well as the recommended default value by MDEQ. Also relied on soil information for Spokane area for soil type and adjusted sorption values based on lithology. Based on soil type, there is little sorption capacity in the soil types in the area.
Load to Surface Water		
Aquifer Retention Factor	50%	A retention factor of 50% was used to represent phosphorus not entering Lake Spokane. This value was based on general literature values for retention factors for watershed studies where all septic systems were used in the calculation.

References

Drost, B.W. and K.J. Whiteman, 1986. Surficial geology, structure and thickness of selected geohydrologic units in the Columbia Plateau: U.S. Geological Survey Water Resources Investigations Report 84-4326.

Ecology, 2010. Spokane River and Lake Spokane Dissolved Oxygen Total Maximum Daily Load, Water Quality Improvement Report. Washington State Department of Ecology, Eastern Regional Office, Spokane, WA. Publication No. 07-10-073 (Revised).

GeoEngineers, HGC, and HDR, 2011. Spokane River Watershed, Nonpoint Source Phosphorus Reduction Plan. Spokane County, Spokane, WA and Washington State Department of Ecology, Eastern Regional Office, Spokane, WA.

HDR, 2007. Spokane County Onsite Sewage Disposal Systems Phosphorus Loading Estimate Technical Memorandum. June 27, 2007.

Hooper, P.R., 1982. The Columbia River basalts: Science, v. 215, n. 4539, p. 1463-1468.

IDEQ, 2008. State of Idaho Technical Guidance Manual for Individual and Subsurface Sewage Disposal Systems. Idaho Department of Environmental Quality.

MDEQ, 2009. How to Perform a Nondegradation Analysis for Subsurface Wastewater Treatment Systems (SWTS) under the Subdivision Review Process. Montana Department of Environmental Quality. February 2009.

NETCHD, unknown. Northeast Tri County Health District, What You Need to Know to Submit an On-Site Sewage System Design.

NETCHD, 2010. Northeast Tri County Health District, Regulation 01-2007, On-Site Sewage Systems with February 3, 2010 Amendment (Resolution 05-2010).

Soltero, R.A. et al. 1992. Assessment of Nutrient Loading Sources and Macrophyte Growth in Long Lake (Lake Spokane), WA and the Feasibility of Various Control Measures. Eastern Washington University Departments of Biology and Geology.

Stoffel, K.L., Joseph, N.L., Waggoner, S.Z., Gulick, C.W., Korosec, M.A., and B.B. Bunning, 1991. Geologic map of Washington – northeast quadrant: Washington Division of Geology and Earth Resources, Geologic Map GM – 39.

Whiteman, K.J., Vaccaro, J.J., Gonthier, J.B., and Bauer, H.H., 1994. The hydrogeologic framework and geochemistry of the Columbia Plateau aquifer system, Washington, Oregon, and Idaho: U.S. Geological Survey Professional Paper 1413-B, 73 p.