Lake Loma Phosphorus Screening-Level Assessment

October 2013

Publication No. 13-03-031

DEPARTMENT OF ECOLOGY
State of Washington

Publication and Contact Information

This report is available on the Department of Ecology's website at
https://fortress.wa.gov/ecy/publications/SummaryPages/1303031.html

The Activity Tracker Code for this study is 12-009.

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Lake Loma Phosphorus Screening-Level Assessment

by

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Water Resource Inventory Area (WRIA):

- 7 – Snohomish

Hydrologic Unit Code (HUC) number:

- 17110011

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Abstract

Lake Loma (Snohomish County) has exhibited high chlorophyll levels and is on the Washington State Department of Ecology's 303(d) list of impaired waters for total phosphorus. Total phosphorus levels will require a 48% reduction to achieve a concentration of 20 ug/L in the surface waters. The purpose of this phosphorus assessment is to identify the relative contributions of total phosphorus sources to ensure that management activities focus on dominant sources. Because the relative source contribution may shift as a result of seasonal processes, loading rates were estimated for both annual average and peak seasonal conditions. The screening-level estimates are based on the best available information and best professional judgment.

The three dominant sources are onsite sewage systems (OSS), animals, and lake sediments, whether analyzed on an annual average or peak seasonal basis, and both with and without considering attenuation. Management actions should focus on the two external sources, OSS and animals, because they represent 90 to 95% of the total phosphorus load generated or delivered to the lake. While lake sediments represent 8% of the annual average loads, they produce 65% of the peak seasonal loads. Management actions should focus on reducing dominant external sources, although internal loading may not reflect reductions for years to decades.

Fertilizer applications and atmospheric deposition represent secondary sources of phosphorus. Fish stocking and recreational use of Lake Loma produce even lower loads of phosphorus.

Stormwater contributes 60-70% of the residential loads. Potential sources include enhanced transport from OSS, any runoff from surfaces piped to the lake, fertilizer applications, pet waste, and land clearing.

Acknowledgements

The author of this report thanks the following people for their contributions to this study:

- Marisa Burghdoff, Snohomish County Surface Water Management, provided invaluable local data on the conditions within the Lake Loma watershed that were critical to refining relative load contributions.
- Gene Williams, Snohomish County Surface Water Management, reviewed materials and provided local knowledge on managing sources within the Lake Loma watershed.
- Washington State Department of Ecology staff:
    - Tricia Shoblom and Ralph Svrjcek, Water Quality Program-Northwest Regional Office, provided oversight and project direction.
    - Scott Collyard, Environmental Assessment Program, peer reviewed the draft report.
    - Dustin Bilhimer, Helen Bresler, Karol Erickson, Dave Garland, and Will Kendra, Water Quality Program and Environmental Assessment Program, reviewed the initial draft report.
    - Barb Carey and Joe Joy, Environmental Assessment Program, provided animal contribution references.

Introduction

Lake Loma is on the Washington State Department of Ecology's 2008 303(d) list of impaired waters for total phosphorus based on monitoring conducted by Snohomish County Public Works Surface Water Management and others. Ecology is addressing the total phosphorus listing by identifying the relative contribution of dominant phosphorus sources. This document describes the total phosphorus load estimates and load reduction target to support the implementation of pollution-control activities. Because management will be through direct actions, these are screening-level estimates to quantify the relative importance of various identified sources to ensure that the most likely sources are managed.

Lake Loma is a shallow, eutrophic lake in Snohomish County (Figure 1). The 22.6-acre lake averages 3.4 meters in depth (Snohomish County Public Works, Surface Water Management, 2003) with a volume of 230 acre-ft (284,000 m^3). Seasonal runoff and groundwater from the 134-acre watershed feed the lake, which has no perennial tributaries and one outflow stream to a wetland located west of the lake. The watershed consists of primarily low-density residential development with 76 documented dwellings served by onsite sewage systems based on best available information on the watershed boundary and facility locations. Some forest patches and fields remain as well. The number of nearshore dwellings (<75 m from the shoreline) increased from 0 in 1940 to 10 in 1950, 19 in 1960, and 47 in 1970 (Gilliom, 1983).

Potential phosphorus sources include septic systems, fertilizer, land clearing, runoff piped to the lake, and pet waste (Williams and Burghdoff, 2011), as well as waterfowl, recreational users, boat launch activities, groundwater, and atmospheric deposition. Sediment releases within the shallow lake represent an internal loading source of phosphorus.

The watershed is not within an Urban Growth Area (UGA) but is within the area covered by the Snohomish County Phase 1 National Pollutant Discharge Elimination System (NPDES) municipal stormwater permit area. Grassy swales along the Snohomish County roadway infiltrate much of the stormwater.

The Quality Assurance Project Plan (Roberts, 2012) describes several ongoing and previously completed monitoring and assessment efforts for Lake Loma and its watershed. Snohomish County Public Works, Surface Water Management (Snohomish County, 2003) noted that summer water clarity worsened between 1992-94 and 1999-2000 as Secchi depths decreased from 2.0-2.2 m to 0.8-1.0 m. Chlorophyll a concentrations were below 10 ug/L in 1973, 1981, 1983, and 1994. Recent monitoring in 2010 and 2011 indicates concentrations of 37 and 28 ug/L, respectively. Summer epilimnetic total phosphorus averages ranged from 23 to 37 ug/L with no trend but high interannual variability (Snohomish County, 2011).

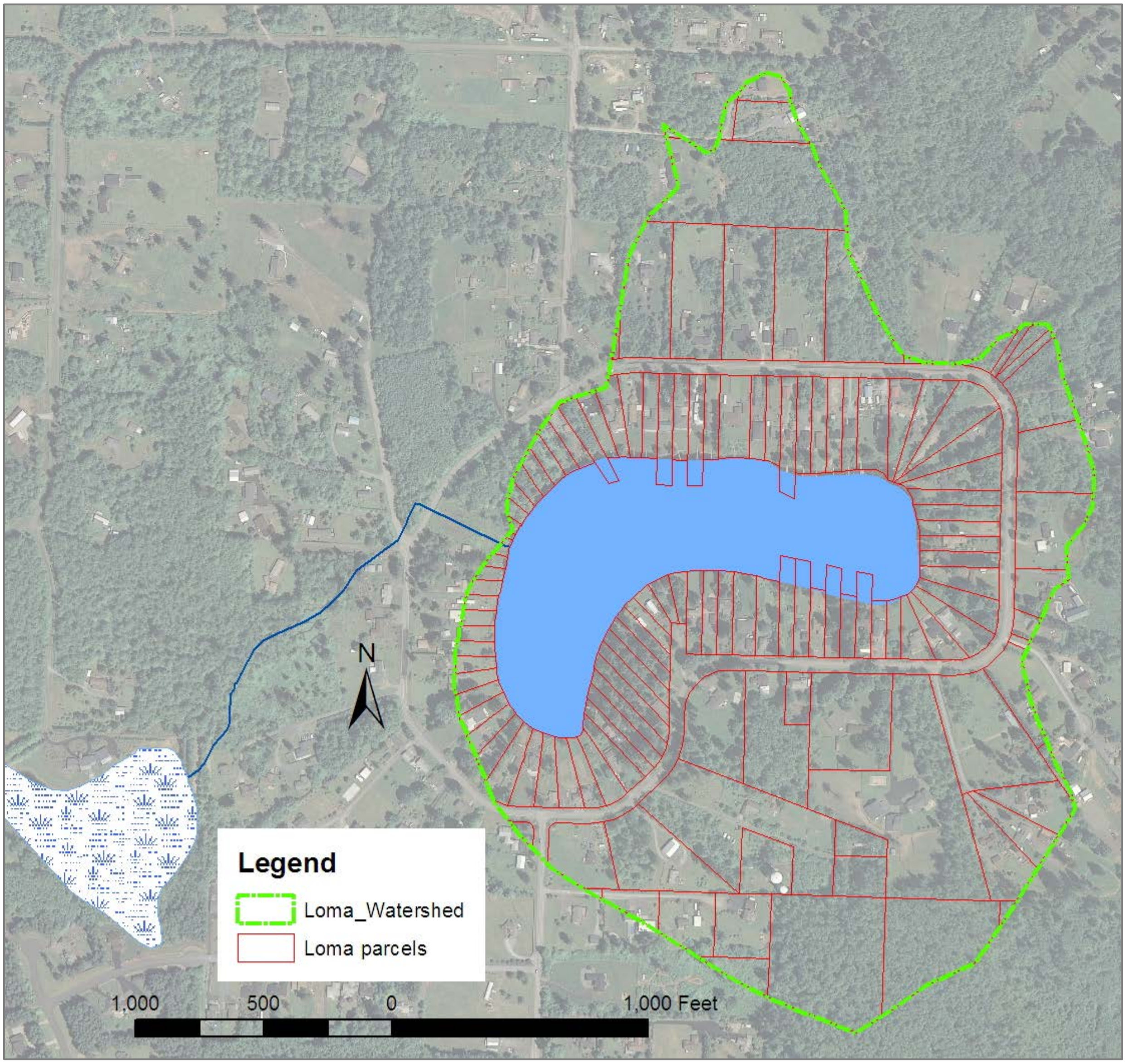


Figure 1. Lake Loma watershed in Snohomish County.

Methods

The Quality Assurance Project Plan (Roberts, 2012) describes the approach for estimating total phosphorus loads and loading reduction targets. Because the potential attenuation strongly influences relative contributions, results are included for both loads generated from the watershed without attenuation and for loads delivered to Lake Loma with attenuation. Total phosphorus load estimates were based on the best available information and best professional judgment for the following potential sources:

- Onsite Sewage Systems – Loads were estimated based on the number of onsite sewage systems within the watershed. These relied on Snohomish County Health Department's web site as well as per-capita loading rates. In addition, we used best available information to estimate a failure rate and assumed attenuation for functioning and nonfunctioning systems.
- Fertilizer Applications – Fertilizer applications were based on regional commercial application rates and an assumed proportion of residential land where fertilizer is applied.
- Animal Contributions – Per-animal rates were multiplied by estimates of the number of domesticated animals and wildlife in the Lake Loma watershed with an assumed attenuation rate.
- Fish Stocking – The load was estimated based on the number and mass of fish stocked by the Washington Department of Fish and Wildlife in Lake Loma multiplied by typical phosphorus concentrations in fish. Removal by fishing was not included because this assesses sources to the lake.
- Recreation – Loads from recreational users were estimated based on the number of users, amount of time spent on or near the lake, and proportion of people not managing human waste properly. No attenuation was assumed for a worst-case load.
- Lake Sediment – Internal loads of phosphorus were based on monitoring data for Lake Loma and literature values from shallow lakes.
- Atmospheric Deposition – Atmospheric deposition of phosphorus to the lake surface was estimated from nearby rainfall monitoring data. Atmospheric deposition to the watershed was included in other estimates.
- Permitted Sources – No other permitted sources beyond the Snohomish County stormwater permit occur in the watersheds.
- Other Sources – No other load estimates were developed. Groundwater contributions are included with land cover contributions.

In addition, we used unit-area total phosphorus loading rates by land cover type developed by Herrera Environmental Consultants (2011) to calculate the loads expressed as 25th, 50th, and 75th percentile values for both baseflow and stormwater. Because these capture sources already estimated for onsite sewage systems (OSS), fertilizer, and animals, they were used only as a check and not as additional source load estimates. The stormwater estimates are attributed to the Snohomish County Phase 1 NPDES permit in lieu of site-specific data.

We developed both annual average and peak seasonal load estimates and compared them using equivalent daily rates. The primary purpose of this assessment is to identify dominant sources by establishing relative loads among sources. Several sources exhibit seasonality, which may shift the relative contributions. Therefore, peak seasonal load estimates were used to check for a shift in dominant sources. Load estimates are based on best available information and best professional judgment and are most appropriate to assess relative patterns. While annual average loads per year are included for completeness, the magnitudes are subject to large uncertainty and should be consulted for guidance but were not intended to establish specific load reduction targets.

The load target is based on the action level identified in the state water quality standards. For Puget Lowland lakes, the action level is a summer average epilimnetic phosphorus concentration of 20 ug/L. This does not establish a lake-specific standard. The load reduction is based on this target and current monitoring data. Reductions also use lake-specific concentrations to characterize current conditions.

Load Estimate Results

Each section describes parameter values used to estimate total phosphorus contributions by source.

Land Cover

Loads from the Lake Loma watershed were estimated two ways. This section assigns unit-area loads by land cover type as a check on the subsequent estimates for OSS, fertilizer, and animals. The approach provides guidance on proportional contributions from stormwater not available in the other estimates.

Two recent studies quantified unit-area loads of total phosphorus and other pollutants based on measured stream concentrations within small watersheds representing forested, residential, agricultural, and commercial lands (Herrera, 2011; Herrera et al., 2007). Unit-area loads for both baseflow and stormwater from Herrera (2011) were applied to the land cover distribution (National Land Cover Dataset, 2006). Table 1 summarizes the values used to estimate total phosphorus loads by land cover type. No agricultural or commercial land occurs in the watershed. Residential land covers 0.348 km^2 and forested land covers 0.140 km^2.

The higher unit-area loads for stormwater translate to a higher proportion of phosphorus delivered during storms than during baseflow conditions. Overall, stormwater contributes 60-70% of the phosphorus load by land cover depending on which percentile is used. Because summer months have fewer storms than in the winter, the baseflow values were used to represent summer contributions in this region with no perennial streams. Total load ranges from 9 to 25 kg/yr, with a best estimate of 14 kg/yr. Figure 2 illustrates the interquartile range for equivalent daily load estimates. Residential land contributes more phosphorus than forested lands and exhibits greater variability.

Land cover-based estimates could be biased low. Herrera (2011) used stream concentrations from watersheds that averaged 4.4 km^2, about 10 times the size of the Lake Loma watershed, to establish the unit-area loads. Therefore, those loads likely include more attenuation and storage of total phosphorus than occur between active sources and Lake Loma. The study characterized uncertainty as 25th, 50th, and 75th percentile values, and the 75th percentile loads are about three times those estimated from the 25th percentile. This indicates the general level of uncertainty due to variability within the source data.

Table 1. Land cover-based total phosphorus load estimates.

Factor	25th percentile	50th percentile	75th percentile
Baseflow unit-area loads (kg-TP/km²-yr)			
Forest	6.41	10.1	17.1
Agriculture	16.1	25.8	39.2
Residential	6.65	7.83	20.7
Commercial	4.46	9.34	12.2
Stormwater unit-area loads (kg-TP/km²-yr)			
Forest	7.65	15.3	22.8
Agriculture	46	75.2	98.4
Residential	13.3	20.9	35.4
Commercial	18.5	23.8	32.2
Baseflow loads (kg/yr)			
Forest	0.90	1.42	2.40
Agriculture	0.00	0.00	0.00
Residential	2.31	2.73	7.20
Commercial	0.00	0.00	0.00
Stormwater loads (kg/yr)			
Forest	1.07	2.15	3.20
Agriculture	0.00	0.00	0.00
Residential	4.63	7.27	12.32
Commercial	0.00	0.00	0.00
Total loads (kg/yr)			
Forest	1.97	3.56	5.60
Agriculture	0.00	0.00	0.00
Residential	6.94	10.00	19.52
Commercial	0.00	0.00	0.00
Total loads (kg/yr)	**8.92**	**13.56**	**25.12**
Total loads (kg/d)	***0.024***	***0.037***	***0.069***

TP: Total phosphorus

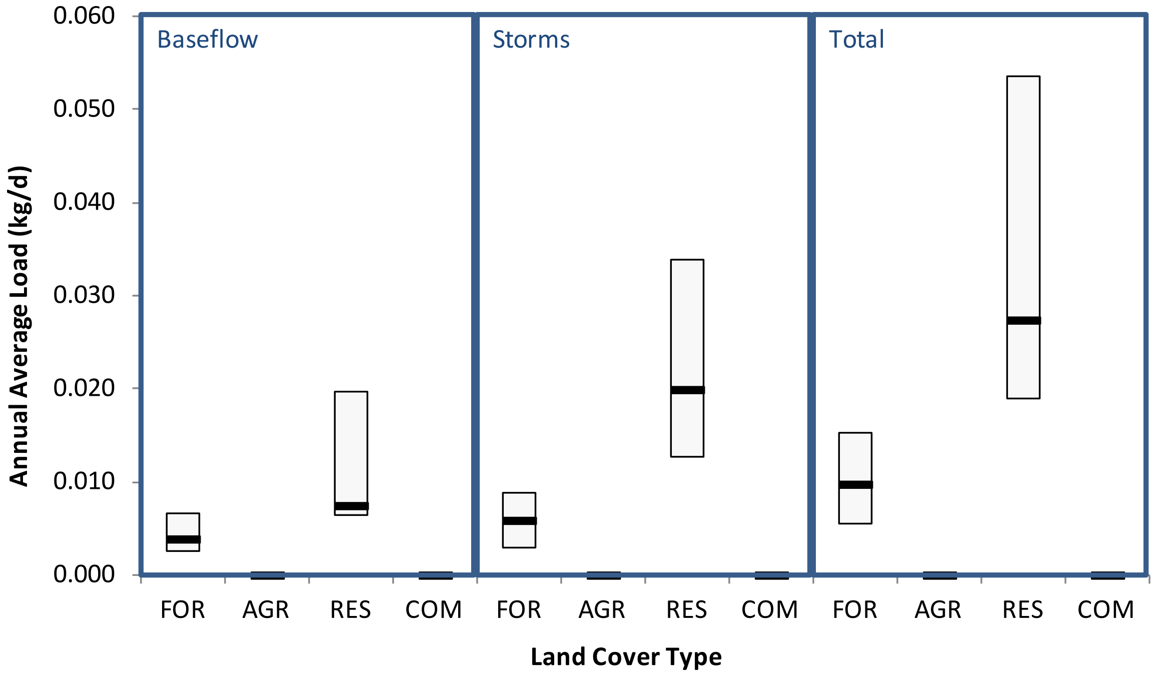


Figure 2. Load contributions by land cover type using the 25th and 75th percentiles for the box and 50th percentile as the best available estimate.

Onsite Sewage Systems

The Snohomish Health District records indicate that 76 onsite sewage systems occur within the Lake Loma watershed (http://ww2.snohd.org/shdcontactcore/CMSDisclaimer.aspx). The number of systems for each type is listed in Table 2 and shown in Figure 3. In addition, 12 parcels have no information, system type is blank, or the system type is listed as "repair denied" with no further information. An additional 11 parcels in the watershed are unoccupied. From aerial imagery, several unoccupied parcels share common ownership with adjacent parcels that have dwellings with OSS. In addition, Snohomish County records include the age of the system. Currently 11 were built after 2000, 34 between 1985 and 2000, 15 between 1970 and 1985, and 15 before 1970. Others have no age information available.

Table 2. System type for onsite sewage systems in the Lake Loma watershed

System Type	Description	Number in Watershed
ATU-DRIP	Alternative Treatment Unit – DRIP	2
ATU-LPD	Alternative Treatment Unit – Low Pressure Distribution	2
Gravity	Gravity fed	47
Holding tank	Holding tank; no discharge	1
LPD	Low Pressure Distribution	13
Mound	Mound System	1
SF-Gravity	Sand Filter plus Gravity	1
SF-LPD	Sand Filter plus Low Pressure Distribution	9
(none)	Blank, no information, or repair denied	12
(none)	Unoccupied parcels with no onsite sewage systems	11

Load estimates were calculated based on an occupancy rate of 2.2 people per dwelling (Paulson et al., 2006), per capita contributions of 1 kg-P/capita-yr (equivalent to 70 gal/capita-day [USEPA, 2002, Table 3-1] and checked with a septic effluent concentration of 9 mg/L [McCray et al., 2005]). The assumed failure rate was 15% of all systems (USEPA, 2002). The phosphorus attenuation rate was estimated to be 90% for functioning systems and 50% for failing systems (USEPA, 2002). Although watershed soils are Alderwood gravelly sandy loam (Hydrologic Soils Group C), the specific soil types were not used to estimate the attenuation rates. Table 3 summarizes the steps to develop the attenuated OSS load estimate of 27 kg/yr or 0.073 kg/d, including the effects of attenuation. No seasonal summer peak factor was incorporated. The total load released within the watershed is 167 kg/yr without attenuation.

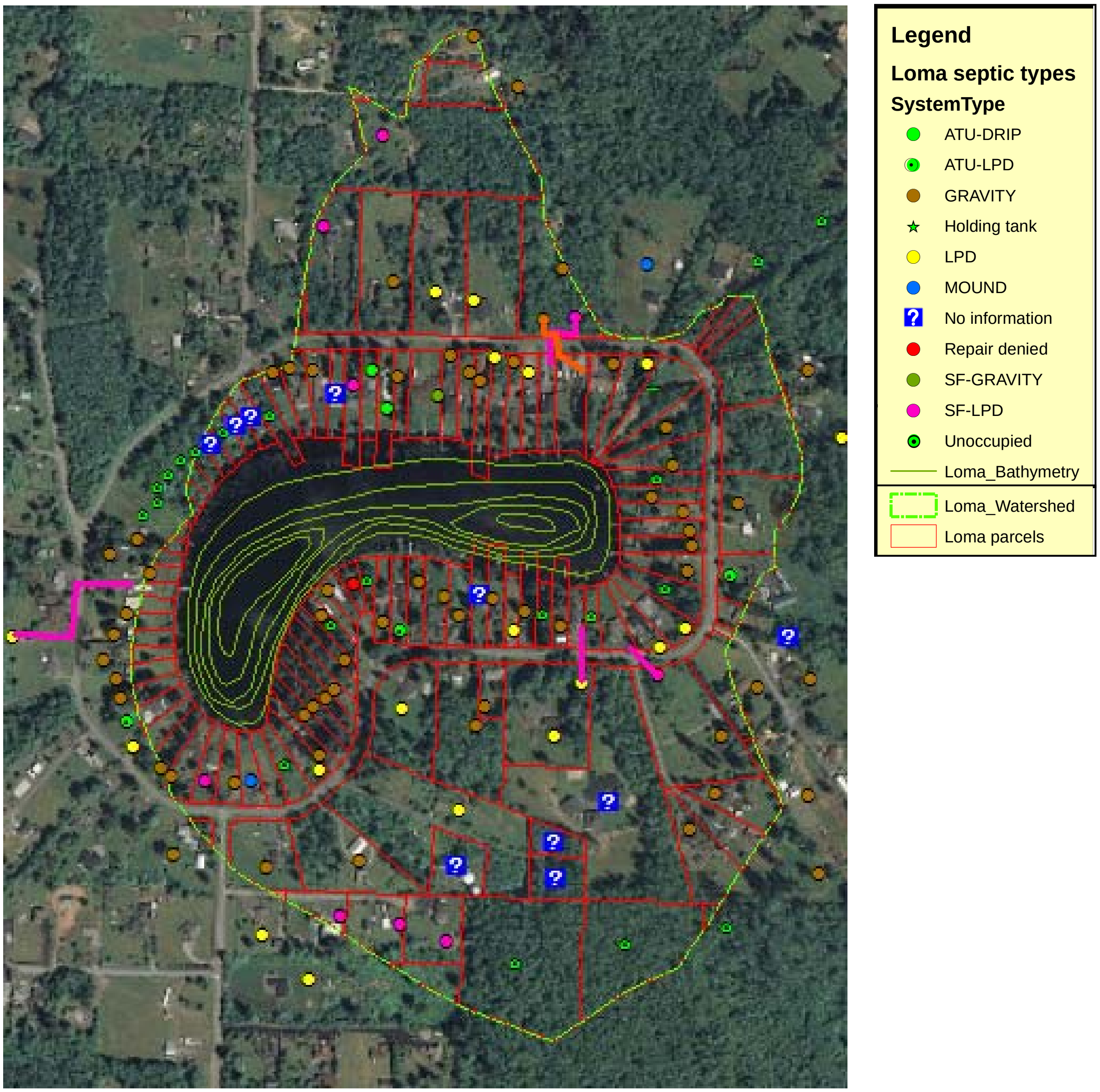


Figure 3. System type for onsite sewage systems within parcels at least partially within the Lake Loma watershed.

Table 3. Annual average onsite sewage system total phosphorus load estimates.

Factor	Value
Dwelling units (#)	76
Occupancy rate (people/dwelling unit)	2.2
Proportion served by OSS (%)	100
OSS failure rate (%)	15
Per-capita contribution (kg-P/person-yr)	1
Phosphorus attenuation for functioning OSS (% retained)	90
Phosphorus attenuation for failing OSS (%retained)	50
Total phosphorus sources in watershed before attenuation (kg/yr)	*167*
Total phosphorus delivered from functioning systems (kg/yr)	14
Total phosphorus delivered from failing systems (kg/yr)	13
Total phosphorus delivered from all OSS (kg/yr)	**27**
Total phosphorus delivered from all OSS (kg/d)	***0.073***

While the table represents best available information, the OSS load estimates include several sources of uncertainty. First, the true number of facilities may be different than indicated in the records depending on where facilities are sited relative to the drainage divide. Second, USEPA (2000) reports septic failure rates are typically 10 to 20%. We assumed a value in the middle of the range, but better information could improve this number. It is also possible that no systems are currently failing in the watershed. Third, several factors influence the amount of attenuation that occurs before the phosphorus reaches the lake, including distance from the shoreline, the flow path, height above groundwater table, plant uptake, and soil sorption and precipitation processes that vary with soil type. Attenuation is likely quite variable. The selected attenuation factors are intended as screening-level estimates in lieu of specific values for the Lake Loma watershed.

Fertilizer Applications

Loads from fertilizer applications were estimated based on commercial application rates (Embrey and Inkpen, 1998), residential land area, and assumed proportions of residential land fertilized and how much is retained and not delivered to the lake itself. In 2011, Washington restricted phosphorus in turf fertilizers. However, we were unable to identify loading rates that account for the restrictions or actual loading rates for residential lands. Table 4 lists the factors used to develop the loading estimates from fertilizer applications. Fertilizer applications could deliver 4.6 kg/yr to Lake Loma, with about 9.2 kg/yr applied in the watershed without considering attenuation. These estimates are screening-level estimates only. While the residential land acreage is well known, the proportion fertilized, the fertilizer application rate, and the percent retained are highly uncertain. In addition, fertilizer effects could be included in the land cover-based load estimates described above.

Table 4. Annual average fertilizer total phosphorus load estimates.

Factor	Value
Residential land (ac)	86
Proportion of residential land fertilized (%)	30
Fertilizer application rate (lb-P/1000 ft^2-yr)	0.06
Fertilizer application rate (kg-P/km^2-yr)	293
Annual fertilizer load applied (kg-P/yr)	*9.2*
Proportion of applied fertilizer retained (%)	50
Annual fertilizer load delivered (kg-P/yr)	**4.6**
Annual fertilizer load delivered (kg-P/d)	***0.013***

Animal Contributions

Limited information exists for the number of animals (livestock, pets, and wildlife) in the watershed, and the load estimates were developed for screening-level purposes only. A road survey in early 2013 did not identify any cows or horses in the watershed (Shoblom, personal communication, June 24, 2013 call). Previous surveys by Snohomish County indicate that the households in the Lake Loma watershed may have 28 to 49 dogs (Burghdoff, personal communication, November 13, 2012 email). We assumed no horses or cows, but did estimate numbers of chickens, deer, and raccoons, typical animals in the region.

Figure 4 summarizes bird counts from volunteer monitoring and staff records at Lake Loma from 1994 through 2012 (Burghdoff, personal communication, November 13, 2012 email). The counts are conducted between 10:00 am and 3:00 pm and may miss evening roosting. Some observations distinguish geese and ducks, while others provide a total number only. Assuming the proportions of ducks and geese hold for the counts where the birds were not distinguished, there are on average 10 ducks and 6 geese at Lake Loma, and the 90th percentiles are 19 ducks and 20 geese for the months with counts. The averages were used for annual average conditions, although winter bird counts may be higher or lower, while the 90th percentiles were used for summer peak seasonal counts.

Table 5 summarizes the steps in estimating average annual animal contributions within the Lake Loma watershed, while Table 6 summarizes the calculations for peak seasonal contributions. Although there may be few domesticated animals in the watershed, they likely produce most of the phosphorus load generated compared with less from wildlife. Even 1 or 2 horses or cows would dominate the loads generated, mostly due to higher per-animal contributions associated with larger body size. Peak seasonal counts were only available for dogs, geese, and ducks. Incorporating high-season contributions from birds and dogs increases the load but domesticated animals still produce most of the phosphorus generated during these periods.

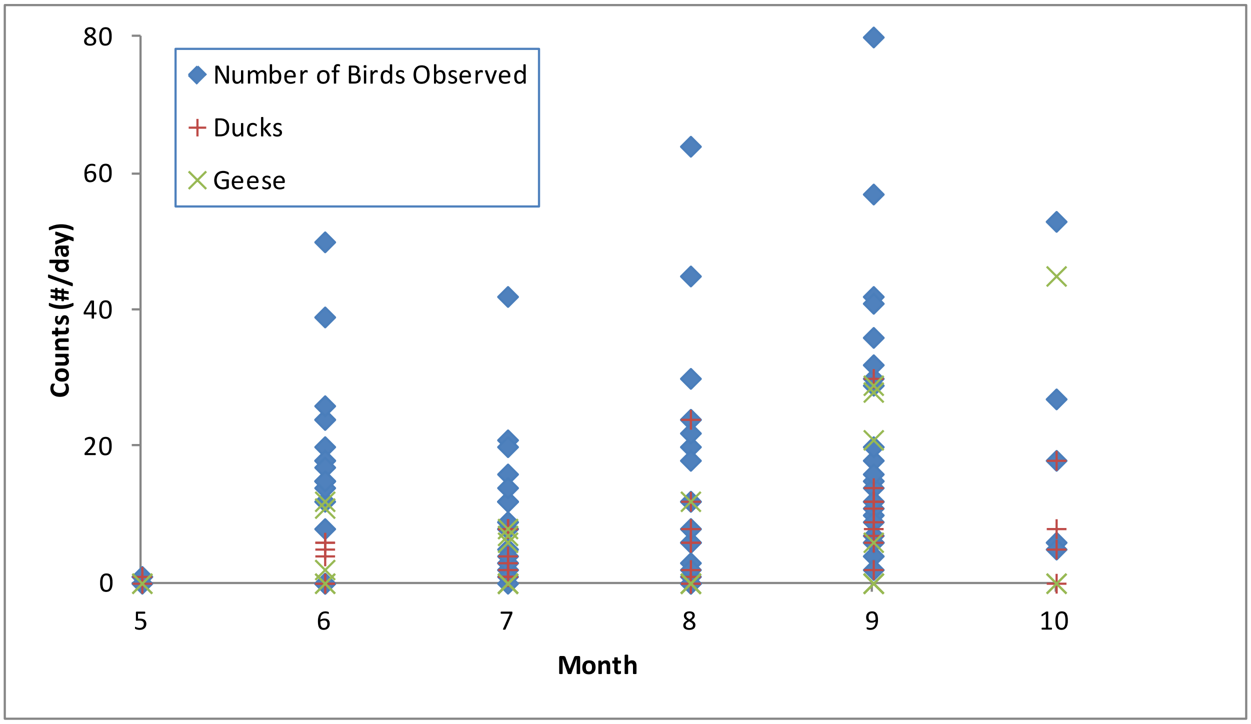


Figure 4. Bird counts at Lake Loma.
Source: Burghdoff, personal communication, November 13, 2012 email.

Table 5. Annual average domesticated animal and wildlife total phosphorus load estimates.

Animal	Number of animals (annual)	Contribution (mg-TP/ animal-day)	Notes	Load (g/d)	Load (%total)
Domesticated animals				*66 g/d*	*66%*
Dogs	28	1,500	1	41	41%
Horses	0	13,200	2	0	0%
Cows	0	31,700	3	0	0%
Chickens	5	5,000	2	25	25%
Wildlife				*33 g/d*	*34%*
Deer	10	2,500	4	25	25%
Raccoons	10	700	5	7.3	7.3%
Geese	6	80	6	0.5	0.5%
Ducks	10	60	7	0.6	0.6%
Seagulls	0	60	8	0	0%
Total phosphorus from animals (g/d)				99 g/d	
Total phosphorus from animals (kg/d)				*0.099 kg/d*	
Attenuation (%)				*50%*	
Total phosphorus from animals with attenuation (kg/d)				***0.049 kg/d***	

Notes:
1- Barr (2005)
2- American Society of Agricultural Engineers (2005)
3- Viers et al. (2012)
4- Emmons & Olivier Resources, Inc. (2010)
5- Estimated as 50% of dog contribution
6- Kear (1963) and Manny et al. (1975)
7- Estimated as equivalent to gull
8- Gould and Fletcher (1978)

Table 6. Peak seasonal domesticated animal and wildlife total phosphorus load estimates.

Animal	Number of animals (annual)	Contribution (mg-TP/ animal-day)	Notes	Load (g/d)	Load (%total)
Domesticated animals				*96 g/d*	*73%*
Dogs	49	1,500	1	71	54%
Horses	0	13,200	2	0	0%
Cows	0	31,700	3	0	0%
Chickens	5	5,00	2	25	19%
Wildlife				*35 g/d*	*27%*
Deer	10	2,500	4	25	19%
Raccoons	10	700	5	7.3	5.5%
Geese	20	80	6	1.6	1.2%
Ducks	19	60	7	1.1	0.9%
Seagulls	0	60	8	0	0%
Total phosphorus from animals (g/d)				131 g/d	
Total phosphorus from animals (kg/d)				*0.131 kg/d*	
Attenuation (%)				*50%*	
Total phosphorus from animals with attenuation (kg/d)				***0.065 kg/d***	

TP: Total phosphorus

The above animal load estimates are based on the number of animals and the per-animal contribution. The number of animals is a screening-level estimate, with site-specific information for dogs, geese, and ducks only and no obvious cows or horses during a road survey. While the per-animal contributions are reasonably well documented, the greater uncertainty is in the amount of attenuation and the proportion delivered to Lake Loma. Waterfowl may use the lake surface itself, with no attenuation. Dog waste management is highly variable. No residences next to the lake are known to have horses or cattle but some may exist in the watershed. Attenuation could be estimated based on proximity to the lake, although this would still include significant loading assumptions.

As a sensitivity analysis, we considered attenuation rates of 0%, 50%, and 90%. Figure 5 presents the range of daily loads domesticated animals and wildlife would provide with each assumed attenuation rate. If contributions were attenuated by 50% or 90%, then the annual average loads delivered to Lake Loma would be 18 or 3.6 kg/yr, equivalent to 0.049 or 0.010 kg/d, respectively.

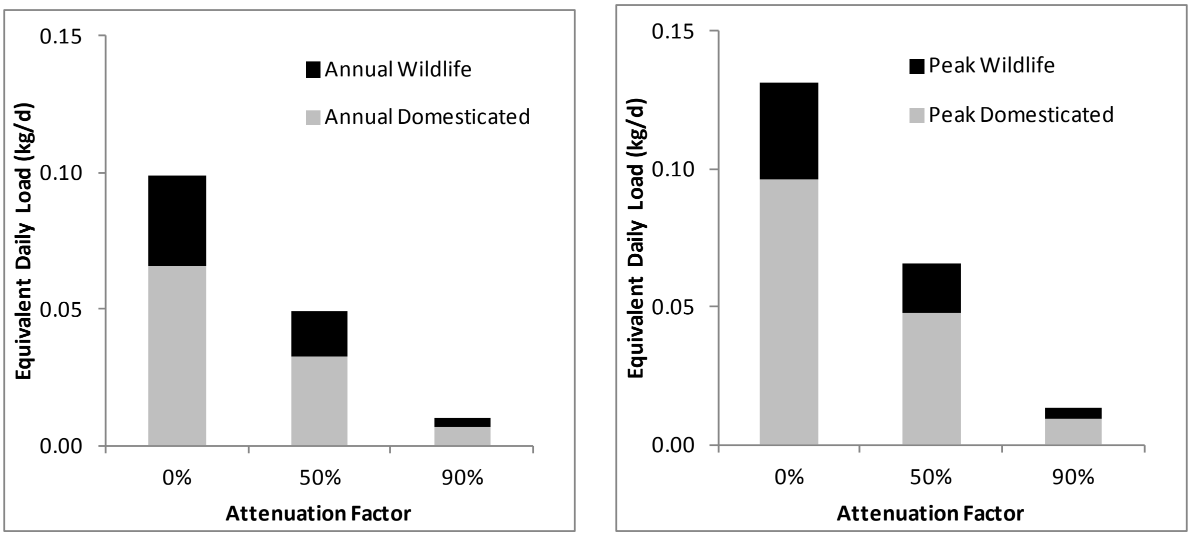


Figure 5. Effect of increasing attenuation on total animal loads for annual average and peak seasonal conditions.

Fish Stocking

The Washington Department of Fish and Wildlife stocks Lake Loma with rainbow trout (http://wdfw.wa.gov/fishing/plants/weekly/), most recently on March 19, 2013. Table 7 provides background for an estimate of 1.6 kg/yr for the phosphorus introduced in the mass of the fish. This could be improved with a verification of phosphorus content for whole rainbow trout. Because stocked fish grow and are likely caught and removed from the lake, fishing may result in a net loss of nutrient mass or no net change. If all fish survive and double in size, fishing could remove 3.2 kg/year or 0.009 kg/d. Since fish are added directly to the lake, no attenuation is expected.

Table 7. Annual stocked fish total phosphorus load estimate.

Factor	Value
Number of fish (#)	1,715
Average size (kg)	0.181
Phosphorus content (%)	0.5
Total phosphorus from stocked fish (kg/yr)	**1.6**
Total phosphorus from stocked fish (kg/d)	***0.0043***

Recreation

Most homes have docks on the lake itself, and a public boat ramp allows access to other users as well. Table 8 provides a screening-level estimate of the highest potential phosphorus load associated with recreational users. These estimates are highly uncertain. No attenuation is included as a worst-case scenario.

Table 8. Annual average and peak seasonal recreational users total phosphorus load estimate.

Factor	Annual Average	Peak Seasonal (Summer)
Number of people using the lake (#/day)	2	20
Phosphorus contribution per capita (kg/person-yr)	1	1
Proportion of time on lake (%)	10%	30%
Proportion of people urinating in or adjacent to lake (%)	50%	50%
Proportion of people defecating in or adjacent to lake (%)	5%	5%
Total phosphorus load from recreational users (kg/d)	***0.000027***	***0.00082***

Lake Sediment

Lake sediments accumulate organic matter that enters from the watershed or grows within the lake itself as plant matter. Phosphorus in these sediments is released to the water column through biogeochemical cycling that varies with conditions near the sediments. Table 9 summarizes the steps to estimate internal loads. The depth of the thermocline distinguishes the surface layer (epilimnion) from the bottom layer (hypolimnion) changes over the summer, but a typical value is about 7.5 ft (Snohomish County, 2011). We estimate the lake volume below this depth as 131,000 m^3. Snohomish County 2012 monitoring data (Burghdoff, personal communication, 11/13/12 email) indicate an increase in hypolimnetic concentration from 55.3 ug/L on August 6 to 135 ug/L on October 8, equivalent to a mass increase of 10.5 kg of phosphorus. Assuming this occurs from the sediment area below the 7.5-ft contour (50,300 m^2), sediments release 3.3 mg-P/m^2-day. Averaged over the entire year, this is equivalent to a phosphorus flux of 0.57 mg-P/m^2-d.

Table 9. Annual and summer sediment total phosphorus loads released from sediments (internal loads).

Factor	Annual Average	Peak Seasonal (Summer)
Total phosphorus flux from sediments (mg-P/m^2-d)	0.57	3.3
Lake sediment area (ac)	22.6	22.6
Internal total phosphorus load (kg/yr)	**19**	NA
Internal total phosphorus load (kg/d)	***0.052***	***0.302***

A similar approach was used to develop sediment releases to Cottage Lake. The value developed from Cottage Lake data (7.5 mg-P/m^2-d) was reduced to 4.5 mg-P/m^2-d to calibrate a lake model (Whiley, 2004). Chamber measurements of benthic fluxes were part of a study of Capitol Lake in Olympia (Roberts et al., 2012). Capitol Lake is an impounded estuary with chlorophyll a values of up to 20-40 ug/L and Secchi depths of 1.5-2 m (Thurston County, 2008). Average depth is similar to Lake Loma at 3.4 m, although the south and middle basins are <2 m and the north basin is >2 m. The average of all basins is 29 mg-P/m^2-d, but the north basin produced fluxes of 7 mg-P/m^2-d and may be more comparable to Lake Loma peak seasonal estimates.

Sediment flux calculations are uncertain, although they are based in part on monitoring data. They could be improved with a more detailed assessment of hypolimnetic total phosphorus mass. The approach ignores near-bottom gradients that could affect sediment-water flux and does not consider vertical diffusion across the thermocline. Internal loading of phosphorus from sediments peaks in the summer months with biological activity. No sediment flux data exist for Lake Loma.

Atmospheric Deposition

Snohomish County records rainfall less than a mile west of Lake Loma and reports annual precipitation of 36.35, 37.28, and 40.26 inches for the last three years (Burghdoff, personal communication, November 13, 2012 email). These average to 38.0 inches, which was used to estimate annual rainfall volumes to the lake surface. Studies indicate a range of rainfall phosphorus concentrations (Table 10) that are generally higher in more recent years. The average of the most recent three studies (24 ug/L) was used to develop load estimates in Table 11. These use the best available information to estimate loads deposited directly on the water surface, equivalent to 0.0058 kg/d. Unit-area loads derived from these values (23.2 kg-P/km^2-yr) are consistent with those estimated by Embrey and Inkpen (1998) for the Puget Sound region. Atmospheric deposition to the watershed surface is included in other estimates, but could account for an additional 10.45 kg/yr of phosphorus.

Table 10. Phosphorus concentrations in rainfall from nearby locations.
Source: Burghdoff, personal communication, November 13, 2012 email.

Value (ug/L)	Location	Years	Citation
20	Lake Ketchum	1970s	Welch, unpublished data
8	Bellevue	1979-82	Ebbert et al. (1985)
23	Blackmans Lake	1994	KCM Inc. (1995)
33	Cottage Lake	2004	Ecology (2004)
17	Pine Lake	2009	Sammamish (2009)

Table 11. Annual average atmospheric deposition total phosphorus load estimates to the Lake Loma water surface.

Factor	Value
Lake surface area (ac)	22.6
Total phosphorus in rain water (ug/L)	24
Annual average precipitation (in/yr)	38
Annual volume of precipitation to lake surface (m^3)	88,300
Total phosphorus load from atmospheric deposition (kg/yr)	**2.12**
Total phosphorus load from atmospheric deposition (kg/d)	***0.0058***

Total phosphorus concentrations reported in recent studies differ by a factor of 2, which induces uncertainty in the value selected. No comprehensive assessment exists for nutrients delivered by atmospheric deposition to waters in the Puget Sound region. The National Atmospheric Deposition Program provides excellent characterization of nitrogen in regional atmospheric deposition but does not include phosphorus. Therefore, better estimates of rainfall phosphorus could improve these load estimates.

Permitted Sources

Except for the Snohomish County Phase I municipal stormwater National Pollutant Discharge Elimination System (NPDES) permit coverage, no other NPDES-permitted sources are located in the Lake Loma watershed.

Other Sources

Groundwater is another potential source of phosphorus to Lake Loma. We did not develop this estimate at this time, given that the same sources would influence both surface water and groundwater quality. This could be estimated in the future by a water balance to get the flow volume and typical phosphorus concentrations in regional groundwater.

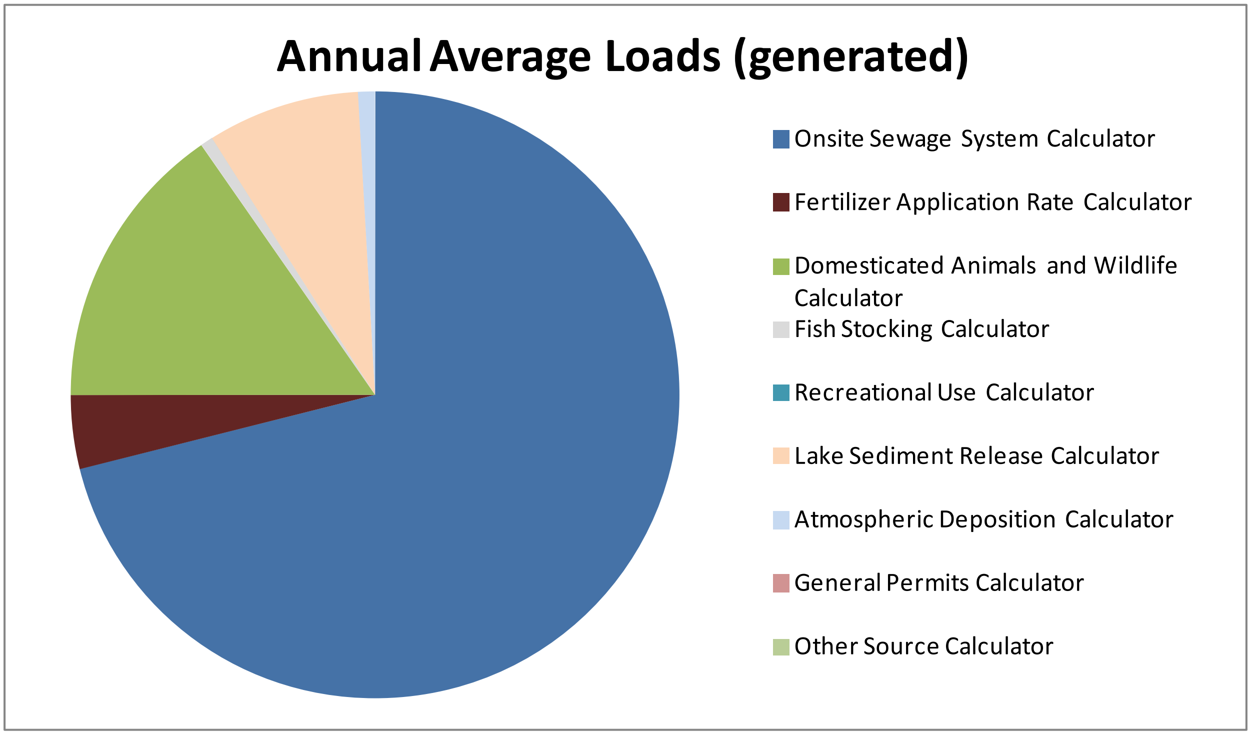
Total Phosphorus Loads in the Lake Loma Watershed

Total phosphorus sources include activities within the watershed itself or delivered to the watershed from external sources such as atmospheric deposition. Not all of the generated total phosphorus reaches the lake itself. Sources directly to the lake do not undergo attenuation. Sources with an overland or underground flow path can have high or low attenuation such that a small or large fraction of total generated actually reaches the lake. However, attenuation rates are highly variable and uncertain for the various sources within and to the Lake Loma watershed. We present results both as loads generated without attenuation and as loads that reach Lake Loma with varying attenuation.

The three highest total phosphorus generators within the Lake Loma watershed include OSS, animals, and lake sediments (Table 12 and Figure 6) based on either annual average or peak seasonal contributions. Human wastewater treated by OSS generates the largest single total phosphorus load in the watershed, both on an average annual and peak seasonal basis. Domesticated animals and wildlife and lake sediments constitute the second and third highest sources, although the relative rank shifts when considering either annual average or peak seasonal contributors. Together the top three sources generate more than 90% of the annual or peak seasonal total phosphorus loads within the Lake Loma watershed. Atmospheric deposition and fertilizer applications generate 6 to 9% of the annual or peak seasonal loads, while fish stocking and recreational use generate less than1% of the annual or peak seasonal loads. This analysis does not include land cover-based loads since they likely double-count OSS, fertilizer, and animal contributions

Table 12. Annual average total phosphorus loads generated in the Lake Loma watershed without attenuation, based on best available information.

Potential Source	Annual Average			Peak Seasonal	
	(kg/d)	(kg)	(% total)	(kg/d)	(% total)
Onsite Sewage System	0.458	167	71.1%	0.458	49.4%
Fertilizer Application	0.025	9.2	3.9%	0.025	2.7%
Domesticated Animals and Wildlife	0.099	36	15.3%	0.131	14.1%
Fish Stocking	0.0043	1.6	0.7%	0.0043	0.5%
Recreational Use	0.000027	0.01	0.004%	0.00082	0.09%
Lake Sediment Release	0.052	19	8.1%	0.302	32.6%
Atmospheric Deposition	0.0058	2.1	0.9%	0.0058	0.6%
General Permits	0	0	0.0%	0	0.0%
Other Source	0	0	0.0%	0	0.0%
Total	**0.64**	**235**		**0.93**	



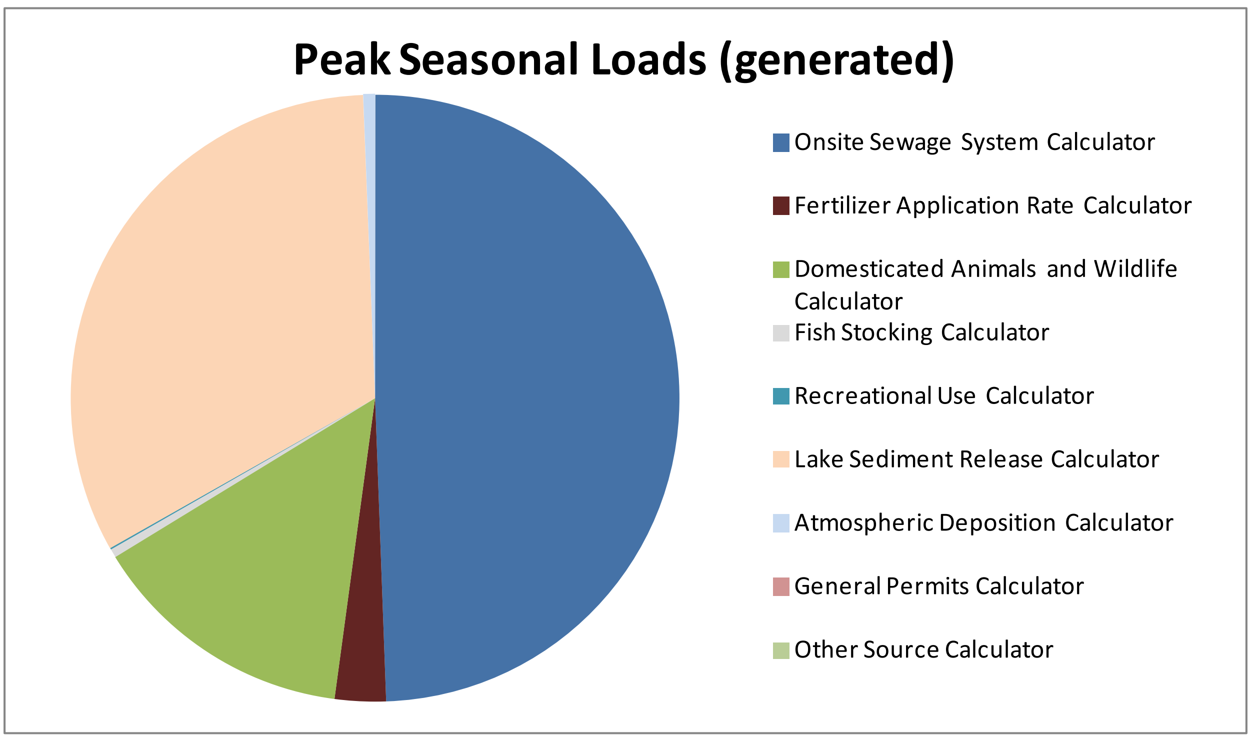


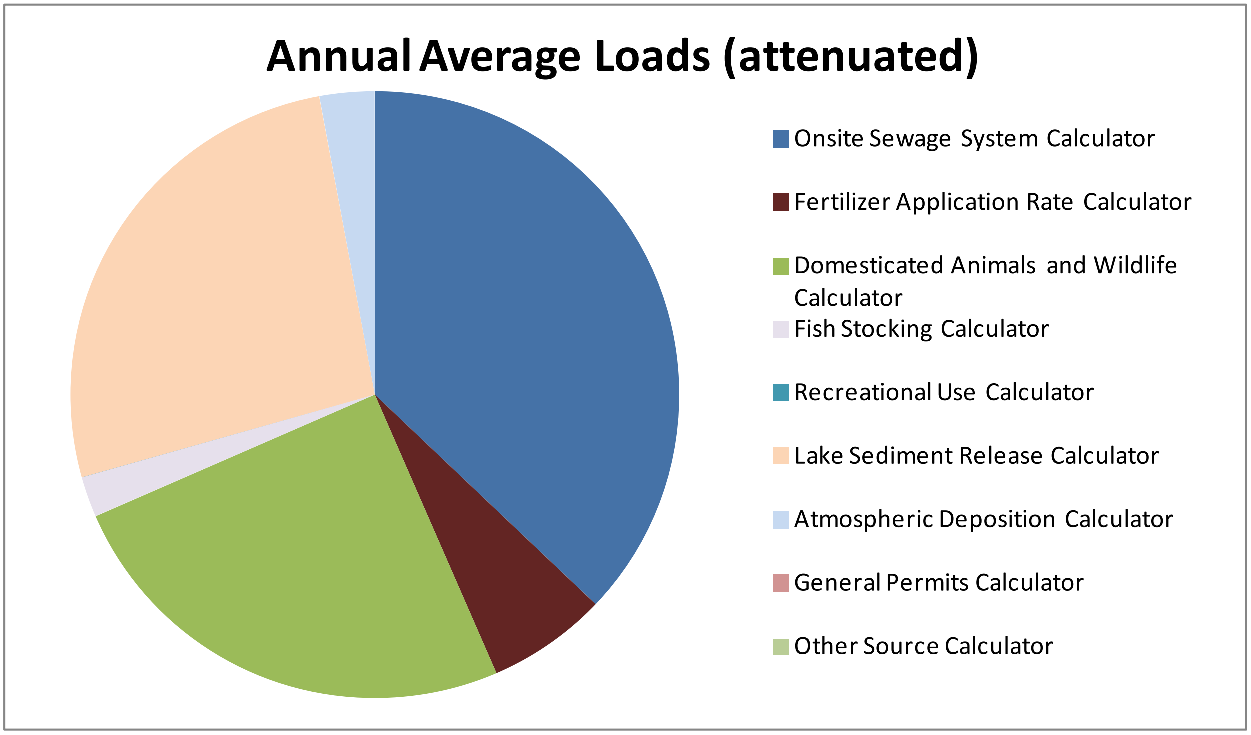
Figure 6. Proportional contributions of phosphorus generated within the Lake Loma watershed (without attenuation).

The contributions among the top three sources shift when attenuation is accounted for (Table 13 and Figure 7), but they still constitute 90 to 95% of the loads delivered to Lake Loma. Human wastewater treated by functioning and properly sited OSS likely goes through more attenuation in an underground flow path than animal waste that may have an overland flow path during rainfall events. The relative contribution of releases from lake sediment grows both for annual average and peak because the releases are direct sources to the lake. Fish stocking and recreational contributions remain <2% even though they were not subject to attenuation. Fertilizer applications and atmospheric deposition produce the remaining loads to Lake Loma.

Table 13. Annual average total phosphorus loads (attenuated) to Lake Loma based on best available information.

Potential Source	**Annual Average**			**Peak Seasonal**	
	(kg/d)	**(kg)**	**(% total)**	**(kg/d)**	**(% total)**
Onsite Sewage System	0.073	27	37.1%	0.073	15.8%
Fertilizer Application	0.013	4.6	6.4%	0.013	2.7%
Domesticated Animals and Wildlife	0.049	18	25.0%	0.065	14.1%
Fish Stocking	0.0043	1.6	2.2%	0.0043	0.9%
Recreational Use	0.000027	0.01	0.014%	0.00082	0.18%
Lake Sediment Release	0.052	19	26.4%	0.302*	65.0%
Atmospheric Deposition	0.0058	2.1	2.9%	0.0058	1.3%
General Permits	0	0	0.0%	0	0.0%
Other Source	0	0	0.0%	0	0.0%
Total	**0.20**	**72**		**0.46**	

* Applied to 2 months



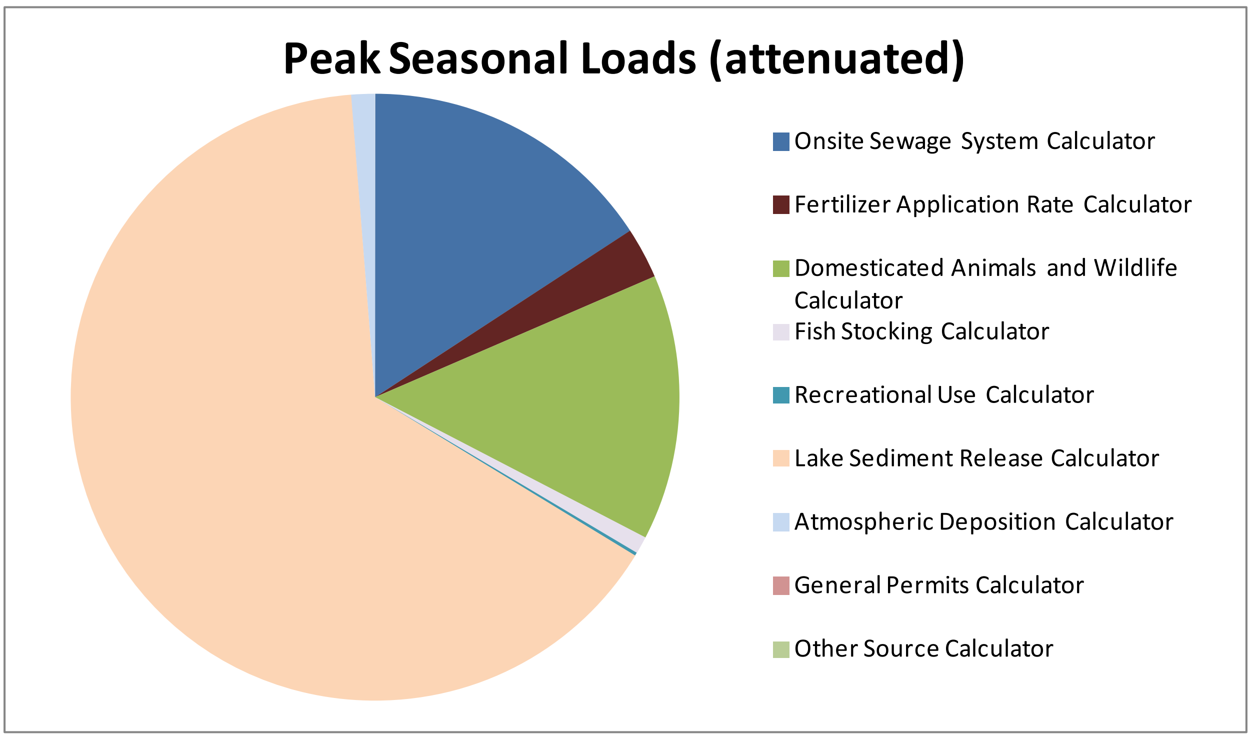


Figure 7. Proportional contributions of phosphorus loads delivered to Lake Loma (with attenuation).

Load Reduction Targets

Snohomish County (2011) compiled average summer epilimnetic total phosphorus concentrations since 1996. These range from 23 to 49 ug/L with no significant trend (Table 14). To establish a protective load reduction target, the 90th percentile of these values was used to describe current conditions (38.5 ug/L). A reduction of 48% is needed to achieve an average summer epilimnetic total phosphorus concentration of 20 ug/L in the long term, calculated from the equation:

$$\text{Percent Reduction} = 1 - (TP_{target} / TP_{current})$$

Given that internal loads dominate in the summer months, achieving the target concentration in the epilimnion could require years to decades before the phosphorus in the sediments decreases to background concentrations.

Table 14. Average summer epilimnetic total phosphorus concentrations for Lake Loma.

Date	Average TP at surface (ug/L)	Range (ug/L)	Number of samples
1996	33	24-41	2
1997	23	19-26	4
1998	35	20-58	4
1999	32	30-36	4
2000	29	12-37	4
2001	35	25-61	4
2002	37	32-42	4
2003	26	4-35	4
2004	35	32-38	4
2005	40	29-60	4
2006	33	28-39	4
2007	33	28-44	4
2008	24	23-24	4
2009	35	28-47	4
2010	49	27-90	4
2011	30	25-33	4

TP: total phosphorus

Discussion

The primary sources of total phosphorus to Lake Loma reflect its watershed land cover. The three largest sources include OSS, animals, and lake sediments. While sediment sources may include some groundwater contributions through advection, sediment loads are not external loads that may be controlled through watershed management. Instead, sediment loads reflect cycling of phosphorus that has accumulated from external sources and in-lake plant growth (phytoplankton, macrophytes) for many years followed by release through biochemical processes. The two dominant external loads are OSS and animal contributions.

Each source experiences some level of attenuation before reaching the waters of Lake Loma. However, attenuation is highly variable in space and time and not known for the Lake Loma watershed. We evaluated ranges of attenuation for each source, based on best available information or best professional judgment. Even with attenuation, the dominant sources are onsite sewage systems (external), animals (external), and lake sediments (internal).

The Land Cover Calculator is an aggregated approach to estimate the same residential sources. The sum of best estimates of OSS, animals, and fertilizer is 0.135 kg/d, which is higher than the 75^{th} percentile range from the unit-area loads. The Lake Loma watershed is 10 times smaller than those watersheds from which data were gathered to develop the unit-area loads with fewer attenuation opportunities. However, the land cover estimates do provide insight regarding the mechanism of delivery, and stormwater is expected to be a large contributor. The other load calculations do not distinguish proportional stormwater contributions.

Uncertainty in Load Estimates

The load estimates were developed to identify dominant sources through screening-level analyses. The calculations are based on a combination of site-specific information and assumptions as described above. Some load estimates are more certain than others because of the specificity of available information. The fish stocking loads are fairly certain, whereas the recreational user contributions are less certain. However, both are likely to be of secondary importance even with conservative assumptions for maximum likely recreational inputs.

The lake sediment internal loads are uncertain but likely to be the single dominant source in the summer months. These do not represent new loads to the lake from the watershed. Controlling new watershed sources is the highest priority. Once those are controlled, internal loads could decrease over time, although slowly.

The largest source of uncertainty to the onsite sewage system estimates is the attenuation before phosphorus reaches Lake Loma. Attenuation is highly variable and difficult to quantify for individual systems and even more difficult to extrapolate to the OSS within the Lake Loma watershed. Attenuation is likely characterized within an order of magnitude and is not expected to be 9% or 99%. Even within reasonable ranges, however, OSS represent one of the dominant sources within the watershed both as a load generated and load delivered to Lake Loma.

Attenuation also represents the largest source of uncertainty in animal contributions. Properly managed animal waste from domestic animals could receive substantial attenuation. While included, wildlife likely represents less than 20% of the animal contributions, even though birds may contribute directly to the lake surface. The number of large animals such as horses and cows is unknown at this time, but even a few would become the dominant source. Management varies widely, however, and better information could refine these estimates.

Fertilizer represents an important, though less dominant, source of phosphorus. The greatest areas of uncertainty are attenuation and application rates, particularly on residential lands with the 2011 fertilizer phosphorus restrictions.

Summary and Recommendations

Lake Loma has exhibited high chlorophyll levels and is on the Washington State Department of Ecology's 303(d) list of impaired waters for total phosphorus. Snohomish County's water quality monitoring indicates that total phosphorus levels will require a 48% reduction to achieve a concentration of 20 ug/L in the surface waters from today's concentration of 38.5 ug/L. The purpose of this phosphorus assessment is to identify the relative contributions of potential total phosphorus sources to ensure that management activities focus on dominant sources. Because the relative source contribution may shift as a result of seasonal processes, loading rates were estimated for both annual average and peak seasonal conditions. The screening-level estimates are based on the best available information and best professional judgment.

The three dominant sources are OSS, animals, and lake sediments, whether analyzed on an annual average or peak seasonal basis, and both with and without considering attenuation. Management actions should focus on the two external sources, OSS and animals, because they represent 90 to 95% of the total phosphorus load generated or delivered to the lake. While lake sediments represent 8% of the annual average loads, they produce 65% of the peak seasonal loads. Therefore, management actions should focus on reducing dominant external sources, although internal loading may not reflect reductions for years to decades.

Fertilizer applications and atmospheric deposition represent secondary sources of phosphorus. The Washington fertilizer restrictions could reduce this contribution in the future, although management actions may consider education on proper fertilizer applications as part of a larger program to manage residential phosphorus sources. Fish stocking and recreational use of Lake Loma produce even lower loads of phosphorus. While good sanitation practices are important, additional management is not warranted to control phosphorus from these sources.

Based on land cover calculations, stormwater contributes 60-70% of the residential loads. Potential sources include enhanced transport from OSS, any runoff from surfaces piped to the lake, fertilizer applications, pet waste, and land clearing.

We did not develop separate estimates of groundwater. The same potential sources would affect both groundwater and stormwater. However, groundwater pathways likely enhance phosphorus retention in soils and reduce delivery of those sources to Lake Loma.

Seasonal monitoring of epilimnetic phosphorus should continue in order to document lake nutrient levels over time.

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Appendix. Glossary, Acronyms, and Abbreviations

Glossary

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the Total Maximum Daily Load (TMDL) program.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

Total Maximum Daily Load (TMDL): Water cleanup plan. A distribution of a substance in a waterbody designed to protect it from not meeting (exceeding) water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants.

These are water quality-limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

Acronyms and Abbreviations

Ecology	Washington State Department of Ecology
NPDES	(See Glossary above)
OSS	Onsite sewage systems
TP	Total phosphorus
USEPA	U.S. Environmental Protection Agency

Units of Measurement

acre	acre, a unit of area equal to 43,560 square feet
acre-ft	acre –feet, a unit of volume equal to 43,560 cubic feet
ft	feet
g	gram, a unit of mass
g/d	grams per day
in/yr	inches per year
kg	kilograms, a unit of mass equal to 1,000 grams
kg/d	kilograms per day
kg/yr	kilograms per year
kg-P/km^2-yr	kilograms phosphorus per square kilometer per year
kg-P/person-yr	kilograms phosphorus per person per year
km	kilometer, a unit of length equal to 1,000 meters
km2	square kilometers
lb	pound
lb-P/1000 ft^2-yr	pound of phosphorus per 1,000 square feet per year
m	meter
m^3	cubic meters
mg	milligram
mg-P/animal-day	milligrams phosphorus per animal per day
mg-P/m^2-d	milligrams phosphorus per square meter per day
ug/L	micrograms per liter (parts per billion)