WRIA 41 LOWER CRAB CREEK
2006 – SUMMARY OF WATER SAMPLING FOR MOSES LAKE

MARCH 2007

Prepared for:
Moses Lake Irrigation and Rehabilitation District
1053 West Broadway Avenue
PO Box 98
Moses Lake, Washington, 98837

WATER QUALITY ENGINEERING

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WATER
QUALITY
ENGINEERING

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EXECUTIVE SUMMARY

In 2006 the sampling effort was focused on evaluating sources of phosphorus that may be entering Moses Lake. The disposal of wastewater to groundwater at the Larson Wastewater Treatment and from residential septic systems was the primary source evaluated. These were chosen as the point of focus for 2006 since they are known sources of relatively high loads of phosphorus to the groundwater that if necessary can be controlled with available wastewater treatment technology. The goal of the effort was to estimate phosphorus loads to the lake from these sources and compare them to load reductions recommended in the Washington State Department of Ecology TMDL assessment.

The Larson Wastewater Treatment Plant is permitted to treat and discharge a maximum wastewater flow of 750,000 gallons per day (gpd). In 2006 the average flow treated at the facility was 324,000 gpd. The infiltration basins discharge the wastewater into coarse sandy and gravelly soils laid down during glacial floods. Wastewater has been discharged at this site since the 1970's. The wastewater is disposed into rapid infiltrations basins that are located one mile from western lakeshore and about 3 miles from southwestern lakeshore. The groundwater flow is towards the lake in a southwestern direction. During the 2006 sampling, concentrations of phosphorus in the groundwater below the infiltration basins averaged 2079 ug/L TP. Total phosphorus (TP) concentrations in wastewater effluent averaged 2614 ug/L. The 20% reduction in TP concentration in the groundwater is due either to dilution from groundwater or removal in the soil matrix.

Removal of phosphorus in the sandy gravels in the soil and aquifer is expected to be low because 1) the sands and gravels are coarse and calcareous and 2) long term loading to the site, more than 25 years, has probably exhausted the limited removal capacity. Low removal implies that there should be an identifiable plume of wastewater mixed with groundwater moving southwest from the WWTP towards Moses Lake. A network of documented wells was organized to help locate a plume. The network was originally put together in 2001 and used to develop a surficial groundwater model to evaluate TCE contamination in the Cascade Valley. Unfortunately regular access to the wells is not permitted due to a lawsuit over the TCE contamination. The limited number of wells that were sampled in 2006 indicated that the phosphorus is not migrating into the basalt and is in the upper part of the surficial aquifer where it can discharge into Moses Lake.

A maximum load from the current WWTP can be estimated if it is assumed that there is no significant removal of TP between the wells and Moses Lake. In this scenario, the estimated groundwater load for April through September that may flow into Moses Lake from the Larson WWTP was 601 kg. This load could reach the lake in a couple of months to a couple of years depending on the groundwater seepage velocities.

Septic systems in the rapidly growing Cascade Valley area are predominantly installed in very gravelly (Type 1A) soils. These soils are generally calcareous and coarse grained and are not expected to remove significant amounts of phosphorus. Currently there are about 3,156 acres of land available for residential development in the Cascade Valley. About 917 acres of that total has more than 490 dwelling units with septic systems. The estimated load from existing septic systems to Moses Lake is 466 kg TP. This estimate is based on an "average" wastewater, 20-30% removal in the septic tank, 20% removal in the drain field, and 10% removal in the groundwater matrix. These assumptions could be strengthened with more extensive field sampling. At this time, this is a ball park estimate of the loads from existing septic systems in the

area. This is probably a low load estimate since septic systems installed prior to 1993 were not accounted for because they were not in the Grant County electronic database. If the Cascade Valley is developed to allowable densities without a sewer system, the loads from septic systems and impacts to Moses Lake will be much greater.

Disposal of municipal and residential wastewater appears to be a very significant source of groundwater phosphorus entering Moses Lake. The total estimated load in 2006 from the two sources is 1067 kg TP over a six month period. The estimated load is 142% of the recommended groundwater load reduction from the Moses Lake TMDL and about 32% of the total load recommended by WA DOE for all of Moses Lake. Installation of phosphorus removal technology at the Larson Wastewater Facility, a sewer collection system in Cascade Valley, and/or requirements for removal of phosphorus in residential septic systems will result in a significant load reduction to Moses Lake. Implementation of methods to reduce phosphorus loads will improve the long term quality of Moses Lake.

In addition to groundwater sampling, the lake was also sampled in July and September 2006. The dilution flow added to Moses Lake via Rocky Coulee Wastewater for the year was 194,800 acre feet. Eighty-six percent of the dilution flow was added before the end of May. The relatively low dilution flows in July and August, the hottest months of the summer, appears to have contributed to low lake water quality in the late summer. In September, the average surface water concentration in the lake was 54 ug/L TP. Concentrations were equal to or greater than 60 ug/L in the lower portion of Rocky Ford Arm and in the south end of the lake. These high concentrations supported large blooms of toxic blue green algae that concentrated in the south end of the lake.

The concentrations of toxic blue green algae were at levels considered to be a moderate to high risk by the World Health Organization. When concentrations are this high, health districts or lake associations are recommended to post signs, restrict access to the lake, and make measurements of cyanotoxins to clarify concerns about toxicity.   The primary concerns would be for: residents that have drinking water wells in hydraulic continuity with the lake, risks to pets and livestock drinking the lake water, and swimmers itch or rashes to anyone swimming in the lake.

In August 2006 the United States Bureau of Reclamation began evaluation of the use of Crab Creek as a supplemental route for feed water to Potholes Reservoir. There were concerns that expected additional flow rates of 150 cfs would erode soil and transport large loads of sediment and nutrients into Parker Horn. Sample results from August through December revealed no significant changes in water quality entering Parker Horn during the supplemental flow study.

The entire supplemental feed flow from Brooks Lake was not accounted for in surface water flows at the Road 7 USGS flow gage on Crab Creek. Flows in Crab Creek peaked in mid December at about 95 cfs. This is about 75 cfs greater than expected base flows in Crab Creek for this time of year. The significant change in the hydrograph in December implies that a new flow condition for Crab Creek was developing. If supplemental flows had continued past December 15 it appears that a significant percentage, certainly greater than 50%, of the supplemental flow would have entered Moses Lake via Crab Creek.

During the flow study a dairy on Crab Creek was flooded. The resultant pond that formed had up to 500 ppb TP. The land had been used for land application of dairy wastewater. If this pond had breached a natural dike and reconnected to the main channel of Crab Creek the phosphorus load would have been significant.

All the supplemental feed flow was expected to flow into Moses Lake, if not by Crab Creek, then via alternative subterranean routes. Rocky Ford Creek flows increased significantly during the test period.

Future work for 2007 should focus on development of a Water Pollution Control Plan for control of phosphorus loads into Moses Lake. This area is growing rapidly with no control of phosphorus loads into the lake from municipal, residential, or agricultural wastewater disposal. The lake will become more eutrophic if a planning and action strategy is not developed and implemented. This study makes it clear that there is a high risk of phosphorus loading from the disposal of wastewater at the Larson treatment Plant and from unsewered areas around the lake. The City should be encouraged to begin planning for a phosphorus removal system at Larson WWTP. The County and City should begin planning for either 1) A collection system in the Cascade Valley and other unsewered areas or 2) Requiring phosphorus removal systems for residential septic systems in the Cascade Valley. If these actions are taken about one third or more of the total TP load reduction recommended by Department of Ecology's TMDL assessment could be achieved. More importantly, the long term recreational benefits of Moses Lake will be protected and/or enhanced.

1.0 INTRODUCTION

In 2006 the Moss Lake Irrigation and Rehabilitation District (MLIRD) contracted with Water Quality Engineering to start a phosphorus assessment for Moses Lake. A source assessment was recommended for the following reasons:

1. 2005 lake water sampling showed elevated phosphorus concentrations (>50 ppb) in several locations around the lake.
2. It was agreed that water pollution control planning would be beneficial for the lake due to concerns about municipal, residential, and agricultural wastewater pollution in the Moses Lake drainage basin.
3. Development of a water pollution control plan can be completed and be approved by WA DOE as an alternative to the Total Maximum Daily Load (TMDL) process.
4. The assessment would serve as a foundation for a water pollution control plan
5. A water pollution control plan can be approved as an alternative to the Total Maximum Daily Load (TMDL) process.

2.0 MOSES LAKE AREA BACKGROUND

Moses Lake is a shallow warm water lake covering an area of approximately 6800 acres (10.6 square miles). The watershed to Moses Lake encompasses approximately 2,450 square miles, principally within the Crab Creek drainage. The lake and adjacent watershed lands are shown on Figure 1. Physical characteristics of Moses Lake are provided in Table 1.

The City of Moses Lake and adjacent urban areas occupy much of the southeastern shoreline including areas within the lake known as Parker Horn and Pelican Horn. Crab Creek waters enter the lake at the upper end of Parker Horn; USBR dilution water releases from the East Low Canal enter Crab Creek via Rocky Coulee Wasteway approximately one mile north of Parker Horn. A portion of the diluted water within Parker Horn is pumped across a narrow peninsula to Pelican Horn in order to dilute nutrients and improve local water quality. In years past the City of Moses Lake sewage effluent discharged into Pelican Horn. This major source of nutrients was removed in 1979 when sewage was transferred to a new treatment plant with effluent disposal to lands east of Moses Lake.

The northern or main arm of Moses Lake is fed by a small spring fed tributary known as Rocky Ford Creek. See upper left hand corner of Figure 1. In 1987 a small dam was constructed at the lower end of Rocky Ford Creek as part of the Moses Lake Clean Lake Project. This dam was designed to prevent upstream migration of carp into the creek system as part of a program to enhance water quality within the creek and Moses Lake. High phosphorus concentrations are associated with the Rocky Fork Creek system and were aggravated by carp activity within the creek. The carp barrier provided a detention pond and made subsequent rehabilitation of the creek feasible. Carp had eroded the banks and uprooted vegetation within the creek. Carp remaining in the Creek were eradicated by the Department of Wildlife and a trout fishery was established. During 1996 stop logs were removed by vandals who compromised the structures water quality control features by lowering the detention pond water surface and allowing carp to migrate upstream into Rocky Ford Creek. The State Department of Fisheries and Wildlife repaired the structure and rehabilitated Rocky Ford Creek during 1998.

Table 1. Physical Characteristic of Moses Lake (Bain 1990) (based on water surface elevation of 1046 ft).

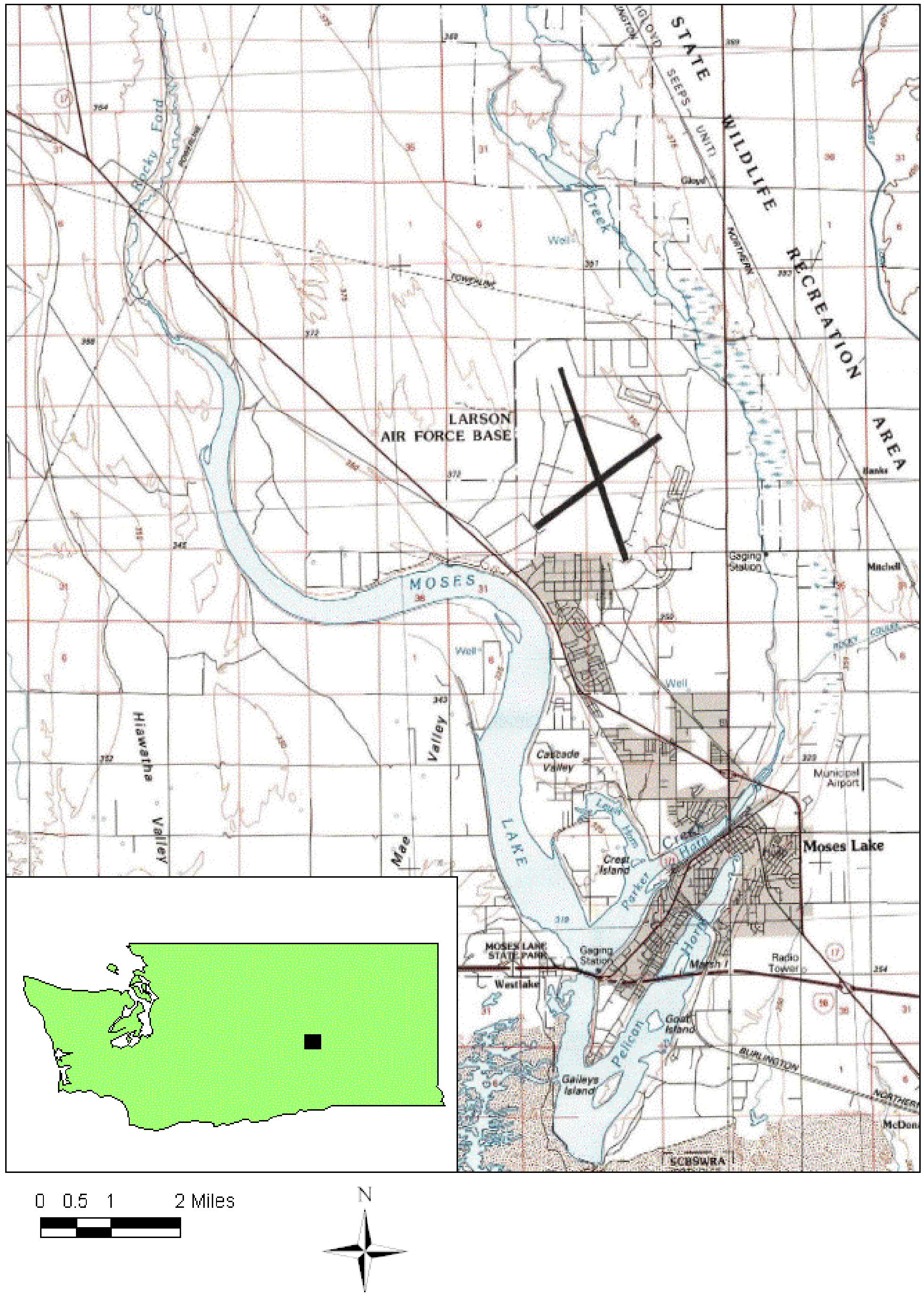
Moses Lake	
Surface Area	6,800 acres
Maximum Depth	38 feet
Mean Depth	18.5 feet
Volume	126,000 acre-feet
Total Length	20.5 miles
Parker Horn	
Mean depth	12.6 feet
Area	758 acres
Volume	9,520 acre-feet
Pelican Horn	
Mean Depth	15.6 feet
Area	1,600 acres
Volume	25,000 acre-feet

The Moses Lake Clean Lake Project also focused on nitrogen sources, particularly the deep percolation of nitrates from irrigation of agricultural lands within Blocks 40 and 41 of the USBR Columbia Basin Project. The project provided on-farm assistance to local irrigators which included cost share assistance for irrigation system upgrades and for irrigation water management programs. These major on-farm activities resulted in funding of improvements on 36 farms and directly involved 5,346 cropland acres. Subsequent project spin-offs occurred benefiting approximately 7350 cropland acres by the 1989 irrigation season. Nutrient loss savings and overall benefits of the Clean Lake Program were summarized in a March 1990 Final Report (Bain 1998). Since completion of the Clean Lakes Project, lake and surrounding well have been monitored on a 5 year cycle to provide a historical data base and records on water quality in the lake since completion of the Clean Lakes project.

2.1 WATER QUALITY STATUS

Moses Lake is classified as a Lake class under Washington State water quality standards (Chapter 173-210A WAC). Rocky Ford Creek is classified as Class A, and Crab Creek as Class B. Lake class and Class A waters are required to meet or exceed the requirements for all or substantially all, of the following characteristic uses: domestic, industrial, and agricultural water supply, stock watering; salmonid and other fish migration, rearing, spawning, and harvesting; wildlife habitat; recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment); and commerce and navigation. Class B water are required to meet or exceed the requirements for most of the preceding uses (Carroll 2006).

Figure 1. Moses Lake Watershed



Despite all the work and benefits of the Clean Lakes Project (Bain 1990) Washington State Department of Ecology placed Moses Lake, Rocky Ford, and Crab Creek on the 2004 303(d). The Lake was listed with a Category 5 listing for Total phosphorus. The lake outlet was also placed on the 303(d) for pH based on samples collected from 1993 – 2001. In addition to the water quality listings the lake was listed for elevated concentrations of 2,3,7,8 TCDD and PCBs in fish tissue (WA DOE 2005). Crab Creek was listed for high pH and temperature at several locations (mouth to Moses Lake, at USGS gage station, Road 16 crossing) (WA DOE 2005).

Washington State Department of Ecology published the results of its 2001 water quality assessment with recommendations for reducing phosphorus loads to Moses Lake (Carroll 2006). Final load reduction recommendations for bringing Moses Lake into compliance with water quality goals are shown in Table 2. The water quality goal is that Moses Lake will have an average concentration of 50 ug/L Total Phosphorus. This standard applies from May through September. The hydraulic conditions for the critical flow conditions are 90th percentile inflows from Rocky Ford Creek and Crab Creek and a 10th percentile flow or feed water through Rocky Coulee Wasteway)based on flow records from 1977-2001).

Development of a Total Maximum Daily Load (TMDL) and reduction strategy was initiated with public hearings in 2002 but was discontinued in 2003. The TMDL process for the lake may be reconsidered in 2007 (Peeler 2004).

Table 2. External TP load contributions to Moses Lake (May through September) during critical load conditions and TP loads following 35% load reductions (Carroll 2006).

External Source	TP load, kg	TP load after 35% reduction(kg)	TP Load reduction (kg)
Crab Creek	1765	1147	591
Rocky Coulee Wasteway	687	447	240
Groundwater	2150	1398	752
Columbia Basin Hatchery[1]	77	50	22
Columbia Basin Hatchery Spring	1582	1028	554
Troutlodge Hatcheries[1]	398	259	139
Rocky Ford Creek	3089	2008	1081
TOTAL			3379

[1]Hatcheries contributions based on 2001 production levels.

3.0 MOSES LAKE AREA GEOLOGY AND HYDROGEOLOGY

3.1 GEOLOGY OF THE MOSES LAKE AREA

The subsurface stratigraphy of the Moses Lake area consists of a series of thick Miocene-age basalt lava flows and interbedded sediments is known as the Columbia River Basalt Group (CRBG). The most recent basalts underlying most of the Moses Lake area are Roza Member of the Wanapum Basalt formation of the CRBG.

Throughout much of the area, the basalts are overlain by finer-grained deposits known as the Ringold Formation. Ringold sediments in the Moses Lake area are composed of lacustrine clay, silt, and fine sand. These sediments are thicker to the west and pinch out east of the lake approximately one mile west of Crab Creek. Previous research indicates the Ringold sediments separate Moses Lake from the underlying basalt units for much of the area between the airport and the city.

Overlying the Ringold sediments are a sequence of Pleistocene-age flood deposits that surround the majority of the lake. These flood deposits, known as the Hanford Formation, consist of large, well-stratified boulder to granule-sized basaltic gravel with some deposits of sand, silt, and non-basalt gravel.

3.2 HYDROGEOLOGY

The finer-grained deposits of the Ringold Formation act as an aquitard, separating groundwater in the Hanford flood deposits from groundwater in the underlying basalt units. This position and distribution of the Ringold sediments with respect to the lake bed indicate that the majority of groundwater interacting with Moses Lake moves through the coarse grained Hanford flood deposits with limited interaction from the basalt units. Groundwater moving into the lake along the southeastern shore of Pelican Horn and in the area of the big bend may be transported through the Ringold deposits (Pitz 2003).

The Hanford Formation flood deposits are highly permeable and can allow rapid groundwater movement. Reported hydraulic conductivities in this formation range from 2,800 to 28,000 ft/day. In addition, because of the coarse nature of these deposits, infiltration rates through the vadose zone are considered to be quite rapid with little attenuation capacity for pollutants (Pitz, 2003; MWH, 2003).

Hanford Formation flood deposits are highly permeable and can allow rapid groundwater movement.

Moses Lake has been described as a regional discharge feature for shallow groundwater within the Columbia Basin. Groundwater elevation data in the Hanford and Ringold deposits just east of the lake indicate the main direction of groundwater flow in this area is in a south to southwest direction, with groundwater discharging to the lake along the eastern shoreline (Figure 2). Groundwater discharge volumes to the lake from the lower permeability Ringold deposits is limited but significant (Pitz, 2003; MWH, 2001).

Recharge for both the unconsolidated aquifers and the basalt aquifer is primarily from irrigation. Primary creeks entering Moses Lake, Rocky Ford Creek and Crab Creek are both groundwater discharge areas. The recharge to the Rocky Ford stream area comes from the northwest (Ephrata), and north (Soap Lake), and the northeast (Adrian). Recharge to the portion of Crab Creek between Adrian and Moses Lake is primarily from the east and northeast. Direct groundwater recharge to Moses Lake is from both east and west (Figure 2).

3.3 GROUNDWATER QUALITY

A historical median TP concentration of 20 ug/L has been reported from wells sampled between 1942 and 1992 in the central Columbia Plateau (Pitz, 2003). These data showed no clear trend in TP concentration with depth as might be expected from a buried geologic source. Reported TP concentrations averaged 35 ug/L as P in groundwater from wells less than 150 feet in the Moses Lake area since 1980 (Pitz 2003).

3.3.1 Natural Condition of Phosphorus in Area Groundwater

The existence of surface or subsurface geologic deposits containing phosphate minerals were suggested to cause the elevated phosphorus concentrations in the groundwater in the Moses Lake area. Detailed mineralogical descriptions of the Hanford and Ringold Formations are limited in the literature but there are no references to the presence of significant phosphate mineral deposits in these formations in published geologic reports of the area. In addition, the sediments of the Ringold Formation underlying Moses Lake are thought to originate from granitic and volcanic regions located northeast of the Columbia basin. Such sediments are not likely to be a significant source of phosphorus-rich sediments.

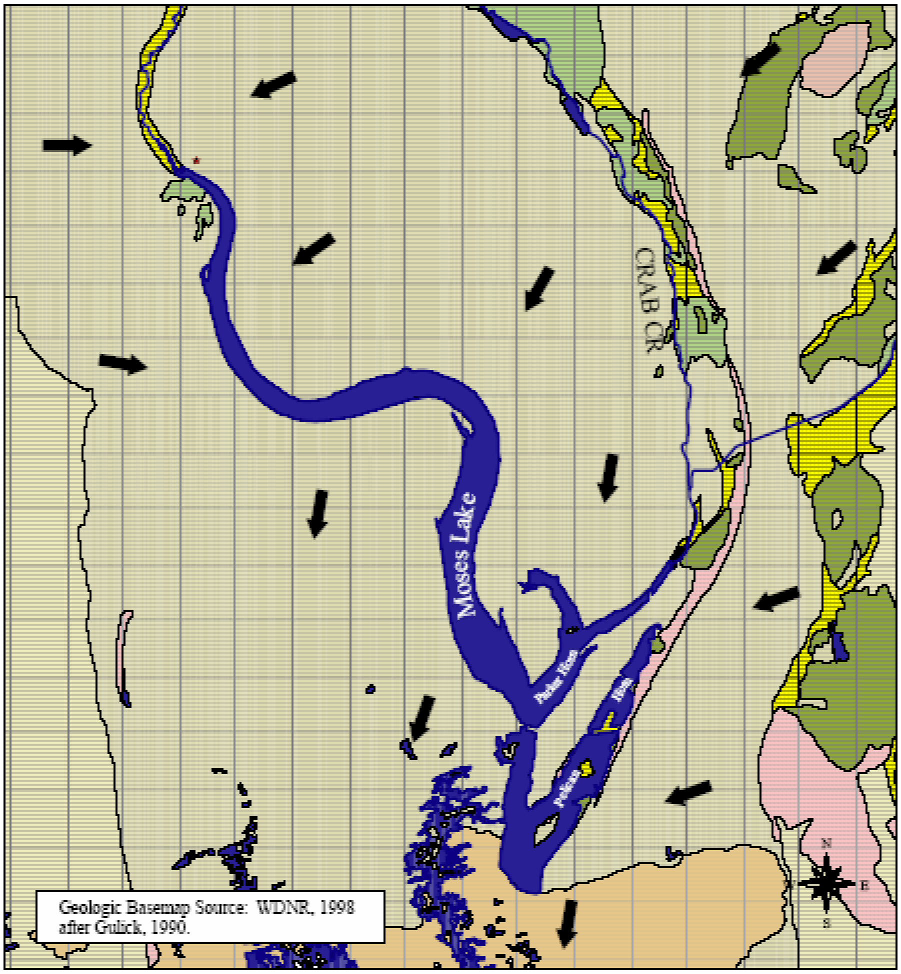


Figure 2. Groundwater flow direction in Moses Lake basin (arrows). Tan areas around lake are Pleistocene gravel and sand flood deposits (from Pitz 2003).

The slightly higher OP concentrations in the Moses Lake area (35 ug/L) compared to the central Columbia Plateau (20 ug/L) may possibly be due to a natural mineral contribution; however previous research suggests human impacts (Pitz, 2003).

Rocky Ford Creek presents an anomaly to the presumed groundwater phosphorus levels of 35 ug/L. Rocky Ford Creek is fed by a spring that historically has elevated levels of phosphorus. Carroll (2006) reported an average concentration of 91 ug/L TP in the spring water. Pitz (2003) and Bain (2002, 1997, 2002) speculate that the spring is fed with shallow groundwater originating from the flood deposits northeast of the springs. Using trilinear analysis of water samples and historical geological evaluations, reasoned that the spring water was not connected to Soap Lake (a lake north of the springs which has phosphorus concentrations as high as 6300 ug/L TP).

Bain (1987) determined that phosphorus may originate from Brook Lake and Round Lake. Nutrients in these lakes apparently originate from agricultural activities in the upper Crab Creek Basin and upper Grant and Lincoln Counties. Bain found no available evidence for a natural stratigraphic source of phosphorus that could explain the elevated concentrations present in the groundwater. Pitz (2003) speculates that the source may be low density rural development combined with agricultural practices. However, the phosphorus load from Rocky Ford Creek (Table 2) is equivalent to the amount that may produced by a population of about 6000 people discharging wastewater directly into the Creek (assuming 80 gallons wastewater/person/day with 6 mg/L TP). This large of a community is difficult to find between Moses Lake and Spokane.

3.3.2 Anthropogenic Sources of Phosphorus Contributing to Groundwater

Common sources of phosphorus in groundwater are disposal of municipal, residential, and agricultural wastewater. The focus of the 2006 source evaluation is municipal and residential wastewater disposal in the Cascade Valley area.   This area and sources were given high priority for evaluation because many circumstances imply that they may be significant source of groundwater phosphorus. These circumstances are: the hydrogeology, gravelly soils, the rapid increase in development, the close proximity to the lake, and the long term disposal of wastewater in to the area.

4.0 PURPOSE AND GOALS

This sampling program is the initiation of efforts to develop a Water Pollution Control Plan for Moses Lake. The goal of the Plan will be to better identify sources and implement programs to reduce loads of phosphorus into Moses Lake. The assessment entails sampling groundwater, the lake, evaluating septic systems, and monitoring creeks flowing into Moses Lake. General goals for 2006 sampling are discussed below.

4.1 LAKE SAMPLING GOALS

Lake sampling in 2006 was done to monitor lake water quality following a wet winter. The USBR does not normally run a lot of water through the lake after a wet year. The low dilution flows were expected to have negative impacts on lake water quality.

4.2 GROUNDWATER SAMPLING GOALS

Wastewater disposal from the Larson Wastewater Treatment Plant (WWTP) and septic systems be a source of groundwater phosphorus that enters Moses Lake. The objectives of 2006 sampling are to determine if there is:

1. Elevated concentration of phosphorus in groundwater at monitoring wells surrounding the Larson WWTP disposal area,
2. A groundwater gradient towards Moses Lake or Crab Creek and,
3. A significant phosphorus load to Moses Lake from the wastewater disposal site.

4.3 SEPTIC SYSTEM EVALUATIONS

This task involves evaluation of the current status of septic systems in the Moses Lake area. The objective of the task is to quantify the existing and future status of septic systems around the Lake.

4.4 CRAB CREEK SAMPLING

The Columbia River Water Management Program is evaluating alternative methods to develop new water supplies for the Columbia River basin. One of the alternative methods is to move water from Brooks Lake down Crab Creek and into Potholes Reservoir (WA DOE 2006). An early implementation study was started by United States Bureau of Reclamation in August 2006. A sampling program was established in 2006 to monitor impacts of additional flows in Crab Creek.

5.0 SAMPLING METHODS AND SITES

Phosphorus is reported as either Total Phosphorus (TP) which includes organic and inorganic phosphorus; or the soluble form referred to as ortho-phosphorus (OP) which is the form that is most available for biological growth. All phosphorus data is reported in the units of ug/L or parts per billion (ppb). The TMDL target for phosphorus is 50 ppb TP.

A Quality Assurance Project Plan was developed for lake sampling in 2005 (MLIRD 2005). Sites and protocol were selected to assure consistency with the Moses Lake Phosphorus TMDL Study QAPP (Carroll and Cusimano 2001). The QAPP was amended in 2006 to include groundwater sampling from area wells. Some of the Groundwater Management Association (GWMA) sampling procedures were adapted to provide continuity with the tri-county regional sampling program developed by GWMA. In some cases the procedures adapted for the QAPP are the same or similar. Since phosphorus is the item of primary concern in these evaluations procedures were modified where more exact sampling techniques are required for phosphorus. The GWMA QAPP has been approved by the United States Department of Environmental Protection (US EPA).

5.1 QUALITY CONTROL FOR SAMPLE ANALYSIS

Sample quality control measures were implemented in the field and the laboratory. One replicate sample was collected in the field and analyzed for all water quality parameters. A duplicate sample was randomly selected in the laboratory and analyzed for each set of monthly samples. A spike sample, blank and known standard were also analyzed in the lab for one random sample for each set of monthly samples.

Differences between the replicates, duplicates, and known standards were compared using relative percent difference (RPD). Relative percent difference is calculated by the equation below:

RPD = absolute value of: $[(X_1 - X_R)/(X_1 + X_R)/2)]$,

X_1 is the value of sample and X_R the value of the parameter for the replicate or duplicate of X_1. The RPD gives an understanding of the sampling error from variability in the field and during laboratory analysis.

6.0 RESULTS AND DISCUSSION

6.1 LAKE SAMPLE STATISTICS

The RPD for each set of lake samples is presented in Table 3. All data reported by Soil Test Consultants, Inc are available in Appendix 1. During analysis of the July samples the RPD of 10% was exceeded for ortho P during analysis of the known standard and for Total N during analysis of the sample spike. These two exceedances also resulted in the average laboratory RPD being greater than the 10% target. During September the average RPD for the laboratory analysis were all less than the 10% target (Table 3).

Table 3. Summary of QA|QC Statistics (relative percent difference, RPD) for the two sets of lake samples.

	Ortho P	Total P	Total N	pH
July Sample				
Lab Duplicate	4%	8%	0%	FM
Sample spike	6%	3%	**79%**	FM
Known standard	**29%**	3%	2%	FM
Average RPD	**13%**	5%	**27%**	FM
September Sample				
Lab Duplicate	0%	**14%**	0%	3%
Sample spike	3%	3%	0%	na
Known standard	0%	3%	0%	1%
Average RPD	1%	6%	0%	2%

FM = Field measurement

6.2 GROUNDWATER SAMPLE STATISTICS

The average RPD summaries for groundwater samples are presented in Tables 4 through 6. These include samples collected from wastewater effluent and monitoring wells at the

Table 4. Summary of Average RPD for Larson Wastewater Effluent Samples.

Date	Total P	Ortho P	Sodium	Chloride	Boron
7/19/2006	4%	6%	3%	2%	5%
7/26/2006	4%	**13%**	3%	9%	5%
8/2/2006	4%	1%	3%	3%	3%
8/9/2006	4%	1%	3%	3%	3%
8/16/2006	5%	2%	1%	1%	4%
8/23/2006	5%	1%	1%	1%	4%
8/30/2006	3%	2%	2%	2%	4%
9/6/2006	3%	1%	2%	2%	4%
9/13/2006	6%	2%	2%	0%	4%
9/20/2006	6%	**25%**	2%	0%	4%
9/27/2006	4%	1%	2%	3%	4%
10/4/2006	3%	1%	1%	2%	5%
10/11/2006	**12%**	9%	1%	1%	5%
10/18/2006	5%	2%	1%	1%	4%
11/8/2006	1%	2%	2%	1%	4%

12/6/2006	3%	1%	2%	1%	4%

Larson Wastewater Treatment Plant and those collected from domestic private wells.

Appendix 2 contains the groundwater summary statistics for the remaining parameters (lab duplicate, sample spike, and known standard) and all data reported by Soil Test Consultants. The average laboratory RPD was less than the 10% target for the majority of sampling dates and groundwater constituents.

Table 5. Summary of Average RPD for Larson Monitoring Wells.

Date	Total P	Ortho P	Sodium	Chloride	Boron
6/13/2006	na	na	na	na	na
7/11/2006	na	na	na	na	na
8/8/2006	na	na	na	na	na
9/12/2006	6%	2%	2%	2%	3%
10/10/2006	3%	2%	1%	1%	5%
11/7/2006	6%	1%	3%	5%	3%
12/5/2006	3%	3%	2%	1%	4%

na - not available

Table 6. Summary of Average RPD for Domestic Wells.

Date	Total P	Ortho P	Sodium	Chloride	Boron
10/30/2006	6%	ns	3%	**10%**	3%
12/5/2006	3%	3%	2%	1%	4%
12/21/2006	2%	**14%**	3%	4%	7%

ns - not sampled

6.3 LAKE SAMPLING

The 2005/2006 winter was very wet and consequently dilution flows from Rocky Coulee Wastewater were expected to be very low in 2006. Since the critical season for the TMDL is for low flow years the plans were to sample the lake during this critical time. However, the flows from USBR to Rocky Coulee Wasteway were relatively normal so samples were only collected twice.

6.3.1 Lake Sampling

Lake sampling sites are shown in Figures 3 and 4. These sites are consistent with the 2001 TMDL lake assessment and other historic sampling records (MLIRD 2005)

6.3.2 Dilution Flows

Diversion of Columbia River water via Rocky Coulee Wasteway into Moses Lake is managed by United States Bureau of Reclamation. Dilution flow began in 1976. Flow delivery to Moses Lake is based on irrigation needs south of Moses Lake. Consequently flows are provided regularly in the spring and fall to fill the Potholes Reservoir. Flows are intermittently released in the summer. Figure 5 shows dilution flows from Rocky Coulee Wasteway into Moses Lake throughout 2005 and also through July 2006. This figure shows the general pattern of flow; large flows in spring and fall and less in the summer and winter.

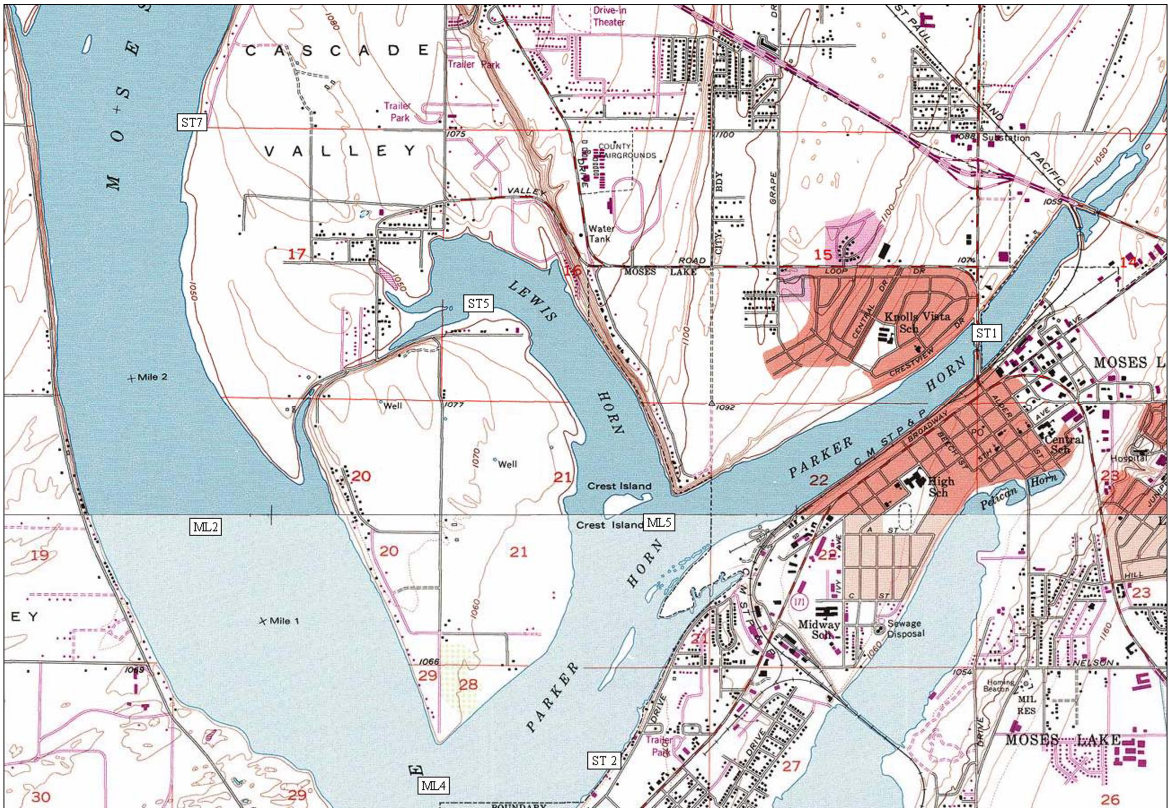


Figure 3. Detail - Vicinity Map of Cascade Valley and Lake Sampling Stations.

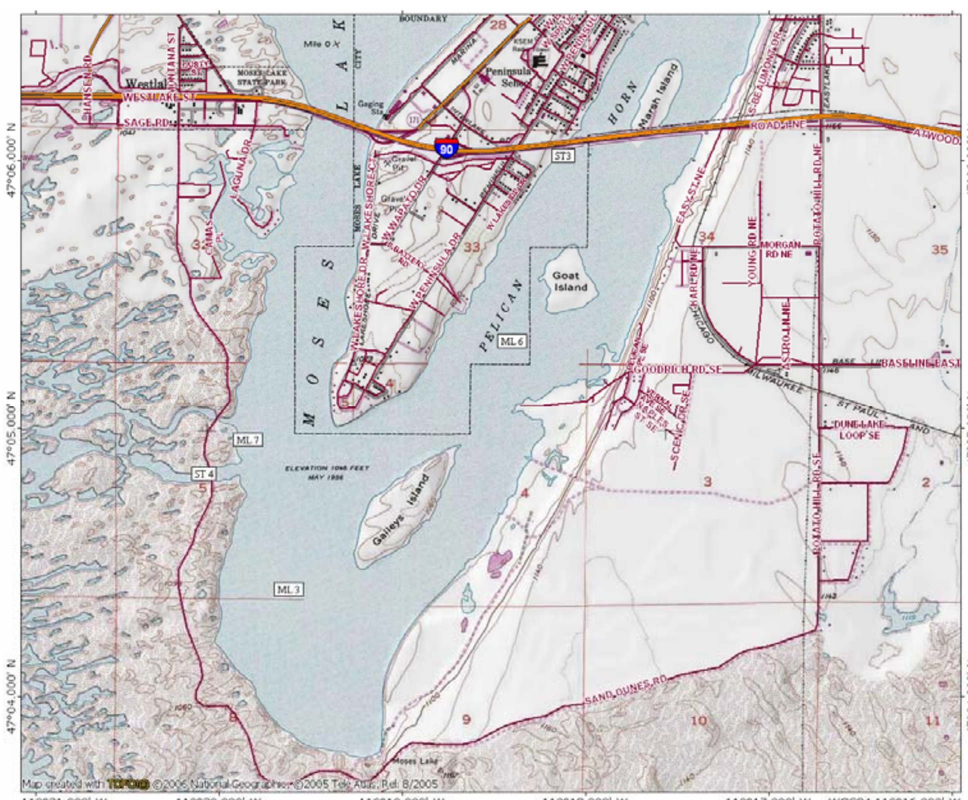


Figure 4. Detail Vicinity Map of Pelican Horn and Lake Sampling Stations.

Flows from Rocky Coulee have significant impacts on nutrient levels and water quality in the lake. Total flow to Moses Lake in 2006 was 194,802 acre-feet. This was significantly less than flow added in six previous years (Table 7). From 2002 through 2005 total annual flow was greater than 316,900 ac-ft for each year.

Year	Dilution Release (ac-ft)
1976	64,070
1977	150,630
1978	81,840
1979	214,540
1980	19,540
1981	56,050
1982	144,180
1983	73,250
1984	0
1985	154,350
1986	106,230
1987	137,770
1988	207,300
1989	207,300
1990	229,980
1991	286,098
1992	267,846
1993	120,976
1994	289,356
1995	132,211
1996	60,685
1997	25,886
1998	111,026
1999	117,928
2000	***243,072***
2001	***242,039***
2002	***316,900***
2003	***340,418***
2004	***372,315***
2005	***326,875***
2006	194,802
90th percentile	316,900
75th percentile	***242,556***
50th percentile	150,630

Table 7. Moses Lake Dilution Water Release Record.

Total annual flow is not always a good indicator of lake quality during the summer because significantly less dilution flow is available in the summer months. Figure 5 shows that in 2006 most of the dilution flow were added before July 1; of 194,000 acre-ft added in 2006 only 87% of the annual flow was released before July 1. Therefore dilution flows in July, August, and September were very low in 2006. This was a major factor in high concentrations of TP and algae in the September lake samples.

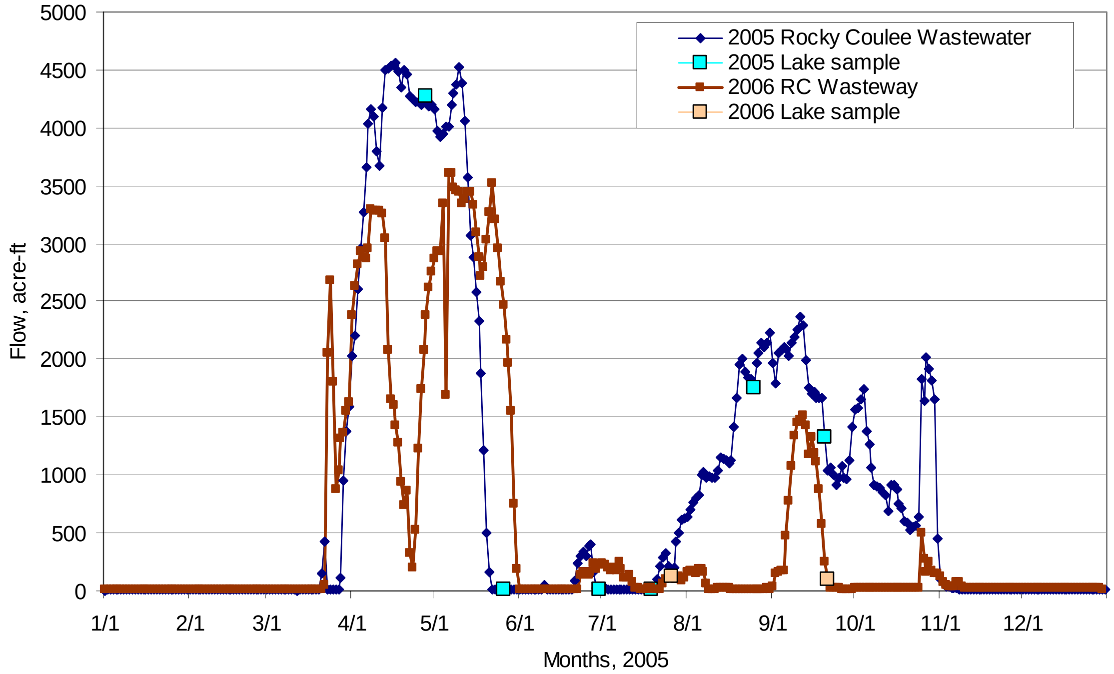


Figure 5. Comparison of Dilution flows from Rocky Coulee Wasteway in 2005 and 2006.

6.3.3 Lake Water Quality - Phosphorus

The lake was sampled on July 26th and on September 21st. On both days surface water grab samples were collected at all lake stations (Table 8). Surface water concentrations of TP were less than 40 ug/L at all locations in July. In September surface water samples were greater than 50 ug/L TP at three stations. The average surface water concentration for the entire lake was 26 ± 12 ug/L TP in July and 54 ± 14 ug/L TP in September.

The elevated TP in September occurs for several reasons, 1) TP release from the sediment increase in the summer due to development of anoxic sediment conditions, 2) a uniform temperature gradient facilitates mixing of the entire water column, and 3) dilution flow was low in August and September. These three conditions combined resulted in elevated TP concentrations and the eutrophic conditions observed.

6.3.4 Lake Water Quality – Algae, Chlorophyll, and Visibility

Lake Sampling Results

Surface water samples were sent to Water Management Laboratories and analyzed for algae type and chlorophyll a. The algae densities (Table 9) and chlorophyll a (Table 8) were much higher in September than in July. The algae populations were dominated by toxic blue green algae during both July and September. Concentrations were highest in September and toxic blue green algae were at levels that have moderate to high probability of adverse health effects. The World Health Organization considers concentrations greater than 100,000 counts/100 mL a moderate risk (WHO 2006). During this type of condition, the WHO recommendations are to discourage swimming and post on-site risk advisory signs. The risks are greatest from the toxic blue-green algae Microcystis sp. This alga was at elevated concentrations throughout the lake in September. Concentrations in the southern part of the lake were highest, reaching concentrations of 554,000 at ML3.0 and 704,000 counts/mL at ML7.0 (Figure 4 and Table 9). It is common for these algae species to drift with the winds and get concentrated in down wind sections of a lake. The high concentrations in September are most likely due to strong northerly winds the day before sampling. The day before sampling, September 20, the winds were blowing to the south at an average speed of 3.6 mph; significantly higher than the monthly average of 2.1 mph.

Table 8. Summary of lake sampling during 2006.

	MLCC0	ML2.0	ML2.5	ML3.0	ML4.0	ML5.0	ML6.0	ML7.0
TP, ug/L								
7/26/06	35	12	46	39	9	17	32	15
9/21/06	29	**59**	**ns**	**69**	**49**	37	**47**	**62**
Ortho - P, ug/L								
7/26/06	34	5	0	17	4	5	18	5
9/21/06	6	9	ns	13	9	5	8	12
Total N, mg/L								
7/26/06	<0.7	<0.7	1.95	1.3	<0.7	<0.7	0.7	<0.7
9/21/06	<0.7	<0.7		<0.7	<0.7	<0.7	<0.7	<0.7
pH								
7/26/06	8.3	8.76	7.98	8.6	8.55	8.61	8.77	8.71
9/21/06	7.9	8.6	ns	8.7	8.5	8.8	8.7	6.99
Temperature, oC								
7/26/06	23.3	26.1	23.8	25.9	26.7	27.5	27	26.3
9/21/06	13.8	18.0	ns	18.1	17.8	16.2	17.5	18.0
Dissolved oxygen, mg/L								
7/26/06	7.15	9.16	7.98	8.2	8.67	10.56	7.99	8.03
9/21/06	8.3	10.7	ns	8.4	10.4	10.0	9.7	9.5
Secchi depth, ft								
7/26/06	5.2	6.8		12.2	6.3	4.5	6.5	10.8
9/21/06	7.0	3.3	ns	2.3	3.9	5.2	ns	2.3
Chlorophyll a, ug/L								
7/26/06	ns	5	ns	5	6	7	5	14
9/21/06	4	20	ns	29	16	12	27	9

Table 9. Densities of algae in the lake in July and September.

	21-Jul-06		9/21/2006	
	ML2.0		**ML2.0**	
Phytoplankton	counts/mL		counts/mL	
Total	220,400		544,000	
Bluegreen (Toxic)	220,000	Aphanizomenon (87%), Microcystis (13%)	500,000	Microcystis (59%), Lyngbya (33%), Aphanizomenon (3%), Anabaena (5%)
	ML3.0		**ML3.0**	
Phytoplankton	counts/mL		counts/mL	
Total	4,100		800,400	
Bluegreen (Toxic)	2,000	Microcystis (100%)	730,000	Microcystis (76%), Lyngbya (6%), Aphanizomenon (3%),
	ML4.0			
Phytoplankton	counts/mL		counts/mL	
Total	61,900		625,900	Ulothrix
Bluegreen (Toxic)	59,500	Aphanizomenon (66%), Microcystis (30%), Anabaena (4%)	600,000	Anabaena (58%), Microcystis (31%), Lyngbya (3%), Aphanizomenon (8%),
	ML5.0		**ML5.0**	
Phytoplankton	counts/mL		counts/mL	
Total	31,800		626,100	
Bluegreen (Toxic)	7,100	Anabaena	600,000	Anabaena (65%), Microcystis (28%), Aphanizomenon (6%), Lyngbya (1%)
	ML6.0		**ML6.0**	
Phytoplankton	counts/mL		counts/mL	
Total	14,600		269,600	
Bluegreen (Toxic)	10,100	Microcystis (100%)	200,000	Microcystis (87%), Anabaena (9%), Aphanizomenon (4%)
	ML7.0		**ML7.0**	
Phytoplankton	counts/mL		counts/mL	
Total	160,000		867,300	
Green	<200		<200	
Bluegreen (Toxic)	160,000	Aphanizomenon (93%), Microcystis (7%)	800,000	Microcystis (88%), Anabaena (11%), Lyngbya (1%)
	CC 0		**CC 0**	
Phytoplankton	counts/mL		counts/mL	
Total	ns		7,100	
Bluegreen (Toxic)	ns		700	Microcystis (100%)

ns = no sample

The liver toxins from these algae can cause skin irritations, gastrointestinal illness, and potential long term illness. Pets are most vulnerable due to potential ingestion from drinking or licking the algae off their fur.

These blue green algae are associated with lakes with elevated concentrations of phosphorus. In September, the average concentration of TP in the surface water of the lake was 54 ug/L. Elevated concentrations of phosphorus contribute to the elevated concentrations of blue green algae.

General Background on Blue Green Algae

Blue-green algae are ubiquitous in ponds and lakes around the world. There are numerous species of blue-green algae; most do not produce toxins. Four primary genera grow in Washington and produce toxins. These four genera are *Microcystis sp*., *Anabaena sp*., *Aphanizomenon sp*., and *Gloetrichia sp*. All genera are capable of producing microcystin, a hepato (liver) toxin, but Microcystis is to be the major producer of microcystin.

Microcystin and other cyanotoxins have not been directly related to deaths of humans from recreation in ponds or lakes. However, there have been links to skin rashes on swimmers and closure of swimming areas is common. The toxin presents the greatest danger to people when it occurs in drinking water reservoirs. The World Health Organization has set an allowable cyanotoxin concentration of 1 μg/L (1 part per billion) for drinking water. This is the concentration that theoretically could be consumed in drinking water by a human being every day for 70 years without ill effect (Newcombe and Burch, 2003). Concentrations recorded in western Washington lakes, have been as high as 32 μg/L in Green Lake (Seattle Department of Parks 2003) and 43 ug/L in Lake Sammamish (Jacoby 2003). In ponds and lakes used strictly for recreation the primary concern is consumption of water by to pets and livestock. There have been deaths of pets attributed to cyanotoxins.

No attempt was made to measure cyanotoxins in Moses Lake in 2006. Future sampling should monitor microcystins especially in public swimming and livestock watering areas.

6.3.5 Lake Trophic Status

Washington State Department of Ecology regulates nutrient loads to water bodies in order to maintain the lake trophic status (WAC 173-201A-010(6)). Critical months for determination of the trophic status index (TSI) are June through September. Trophic status classifications for ponds are oligotrophic, mesotrophic, and eutrophic. Oligotrophic ponds are low in nutrients (i.e. Lake Chelan); eutrophic systems are high in nutrients.

Eutrophication is a natural process of accumulation of nutrients that causes a change in the trophic status of a water body. This process can be greatly accelerated by human activities. Eutrophication may result in excessive growth of aquatic plants, loss of fish habitat, and in worst-case large fish kills.   In the last couple of decades, toxic blue green algae have also become more problematic in eutrhophic lakes.

Trophic Status Index (TSI) is calculated for the average summer (June through September) concentrations of TP. Chlorophyll a, and secchi depth disk. The following equations from Carlson (1977) are used to calculate the TSI.

TSI for Total Phosphorus: TSI_{TP} = 14.42 * ln (TP, ug/L) + 4.15

TSI for Chlorophyll a: TSI_{CHL}= 9.81 * ln (Chl a, ug/L) + 30.6

TSI for secchi depth: TSI_{SD} = 60 – 14.41*ln (SD, m)

A TSI greater than 40 indicates mesotrophy and a TSI greater than 50 indicates eutrophy (Carlson 1977). In order for Moses Lake to be in a mesotrophic condition the average TP would need to be less than 23 ug/L.

During 2006, the average TSI for all indices were above 50 indicating a eutrophic condition; the TSI_{TP} = 56, the TSI_{CHL} = 54, and the TSI_{SD} = 53.

The elevated TP and eutrophic state of the lake is not surprising considering the small dilution feed going to the lake in July – September (Figure 5). The data exemplify the importance of regular dilution flow throughout the summer months.

6.4 LAKE SEDIMENT SAMPLING

Under the direction of Don Beckley, sediment samples and depths were taken from Laguna and Wild Goose Inlets on September 21, 2006. The depth of the sediment above cobbles was measured with a long steel rod. It was pushed into the sediment until it would stop with two men pushing on it. The point at which it stopped was considered to be the depth of the cobbles. The sites and depths are shown in Table 10. The samples were both taken from Laguna. The sample taken in the Laguna channel was a silt loam; with 65% silt and 15% clay. This sample had strong sulfide odors when it was collected implying anoxic sediments. Anoxic sediments will increase release of phosphorus from the sediment. Phosphorus levels in the sediment were 1000 mg/kg. The sample collected at the inlet of the Laguna channel was a loamy sand which also had about 1000 mg/kg of total phosphorus. This sample was not anoxic. Sediment analysis is in Appendix 3.

6.5 CRAB CREEK SAMPLING

The United States Bureau of Reclamation initiated the supplemental feed study (WA DOE 2006) in August 2006. Sampling of Crab Creek and Rocky Ford Creek started in August 2006 and collected until December 2006. Supplemental flows ended December 15^{th}, 2006.

The expected flow path for the supplemental feed water was from Brooks Lake through the Town of Stratford and down the Crab Creek drainage into Moses Lake. There were several fallow fields and open ground that the water could run through so erosion, sediment, and nutrient transport into Moses Lake was a concern. A sampling plan was initiated to monitor the impact of the expected flows on Crab Creek and its discharge into Moses Lake. Sample locations and descriptions are shown in Table 11.

The USBR report for the supplemental flow study has not been released. Therefore the actual flows are not known at this time. Verbal reports are that 100 to 150 cfs of water was diverted during the study. Figure 6 shows that flows in Crab Creek did not increase until early October. The flow into Crab Creek increased by 20 to 40 cfs in October and November then increased dramatically again in December. The peak December flow of 95 cfs was about 75 cfs greater than the seasonal average. It appears that if the supplemental flow study had continued a significant portion of the flow would have run from Crab Creek into Moses Lake.

Table 10. Sediment sampling sites in Laguna and Wild Goose Inlets on 9/21/06.

Site	Description	Coordinates			
1	Laguna/Pier 4 Channel	47	6.051		
		119	19.717		
	Water Depth		3.8	ft	
	Probe depth (to water surface)		12	ft	
	Depth of sand and silt sediment		8.2	ft	
	One sediment sample collected	ponar grad, strong sulfide smell, fine sediment and roots, OM?			
2	Laguna/Pier 4 Channel - west of dock	47	6.057		
		119	19.653		
	Water Depth		2.6		
	Probe depth (to water surface)		12		
	Depth of sand and silt sediment		9.4		
	No sample				
3	Laguna/Pier 4 Channel - east of end of dock	47	6.058		
		119	19.601		
	Water Depth		3		
	Probe depth (to water surface)		7.6		
	Depth of sand and silt sediment		4.6		
	No sample				
4	Laguna/Pier 4 Channel - between east end of dock and inlet	47	6.051		
		119	19.54		
	Water Depth		3		
	Probe depth (to water surface)		7		
	Depth of sand and silt sediment		4		
	No sample				
5	Laguna/Pier 4 Channel - south side of inlet	47	6.048		
		119	19.52		
	Water Depth		2.8		
	Probe depth (to water surface)		12		
	Depth of sand and silt sediment		9.2		
	One sediment sample				no odor from sample, coarse
6	Wild Goose	na	na		
		na	na		
	Water Depth		3		
	Probe depth (to water surface)		6		
	Depth of sand and silt sediment		3		
	No sample, DO less than 1 mg/L				

Table 11. Crab Creek sampling locations.

ID	N	W
CC0	47.14160	-119.26838
CC1	47.18964	-119.26401
CC2	47.22517	-119.27743
RF17	47.26155	-119.45596
DL-10	47.23401	-119.29666
DL-AFP	47.22470	-119.28835
DL-AFD	47.22285	-119.28063

ID	Description
CC0	W bank of Crab Creek, S side of Hwy. 17 bridge at mouth
CC1	E bank of Crab Creek, S side of Rd. 7-NE bridge, at USGS gauging station
CC2	W (S) bank of Crab Creek, E side of Stratford Rd bridge
RF17	W (N) bank of Rocky Ford Creek, W side of Hwy. 17 bridge, adjacent to bridge pillar with staff gage
DL-10	Dairy Lake at Rd 10-NE, along fence line N side of Rd. 10 approx 25 ft W of cement drain access pipe
DL-AFP	Dairy Lake at Paved Air Force Rd to old Nike site--D/S end of culvert under road
DL-AFD	Dairy Lake at Dirt Air Force Rd to NE exit—no culvert, W edge of road; installed staff gage

Although flows increased significantly for the season they were not greater than peak flows that have been measured in Crab Creek (Carroll 2006). The peak flows of 75 - 95 cfs did not result in significant changes in water quality in Crab Creek (Table 12).

Supplemental feed flow also increased flows in Rocky Ford Creek. The flow increase was most significant in December 2006 and January 2007 and has continued into March 2007 (Figure 7). There are no continuous flow gages but staff gage readings were provided by USGS and USBR for Rocky Ford Creek below the hatchery (Appendix 5).

The increased groundwater flows to Rocky Ford Creek could have one of two results; it could 1) decrease the TP concentrations by dilution or 2) it could have no change on TP.

Concentrations of both forms of phosphorus (TP and OP) and nitrates increased significantly in Rocky Ford Creek during October, November and December (Table 12). This appears to be a normal trend for Rocky Ford Creek (Carroll 2006, Cusimano and Ward 1998) and cannot be directly attributed to the supplemental flow study.

The elevated TP and increased flows will result in increased loads of TP to Moses Lake. This may be a transient condition and needs more consideration when the final report from USBR is available.

Land surrounding a dairy on Crab Creek became flooded during November. Fields that were regularly used for land application of dairy waste became flooded. A pond that formed was sampled and had elevated levels of phosphorus (Table 13). The pond that was formed threatened to breach a natural levee and flood Crab Creek. The pond did not breach the levee and slowly disappeared after the study was completed. The water percolated back into the soil but the fate of the phosphorus is unknown. This dairy would need to be closed or moved in order to minimize impacts of a supplemental feed route down Crab Creek.

Table 12. Crab Creek water quality results prior and during flow augmentation study by USBR.

Total Phosphorus, ug/L (ppb)							
	Crab Creek Sampling Sites						
Date	CCO	CC1	CC2	CC3	CC4 - E Cross	CC4 - W cross	RF17
8/11/06	30	28	28	26	ns	ns	139
9/26/06	31	39	46	35	64	130	ns
10/13/06	47	32	57	ns	ns	ns	ns
10/26/06	26	45	55	ns	ns	ns	174
11/2/06	31	42	44	ns	ns	ns	192
12/5/06	65	51	27	ns	ns	ns	191
Ortho Phosphorus, ug/L (ppb)							
8/11/06	12	13	12	10	0	0	74
9/26/06	22	18	21	27	21	37	ns
10/13/06	24	23	20	ns	ns	ns	ns
10/26/06	11	33	30	ns	ns	ns	109
11/2/06	26	35	19	ns	ns	ns	168
12/5/06	28	<2	2	ns	ns	ns	89
Total Suspended Solids, mg/L							
8/11/06	8	9	12	9	1	0	22
9/26/06	<1	<1	<1	<1	<1	<1	<1
10/13/06	<1	<1	<1	ns	ns	ns	ns
10/26/06	<1	<1	2	ns	ns	ns	13
11/2/06	<1	<1	<1	ns	ns	ns	2
12/5/06	7	5	1	ns	ns	ns	20
Nitrate and Nitrite, mg/L							
8/11/06	1.31	1.1	1.07	0.08	ns	ns	1.34
9/26/06	1.33	0.93	1.16	0.54	1.12	0.053	ns
10/13/06	0.85	1.38	0.79	ns	ns	ns	ns
10/26/06	0.44	0.74	0.69	ns	ns	ns	2.08
11/2/06	0.89	1.02	0.96	ns	ns	ns	2.17
12/5/06	1.93	1.49	0.95	ns	ns	ns	1.79

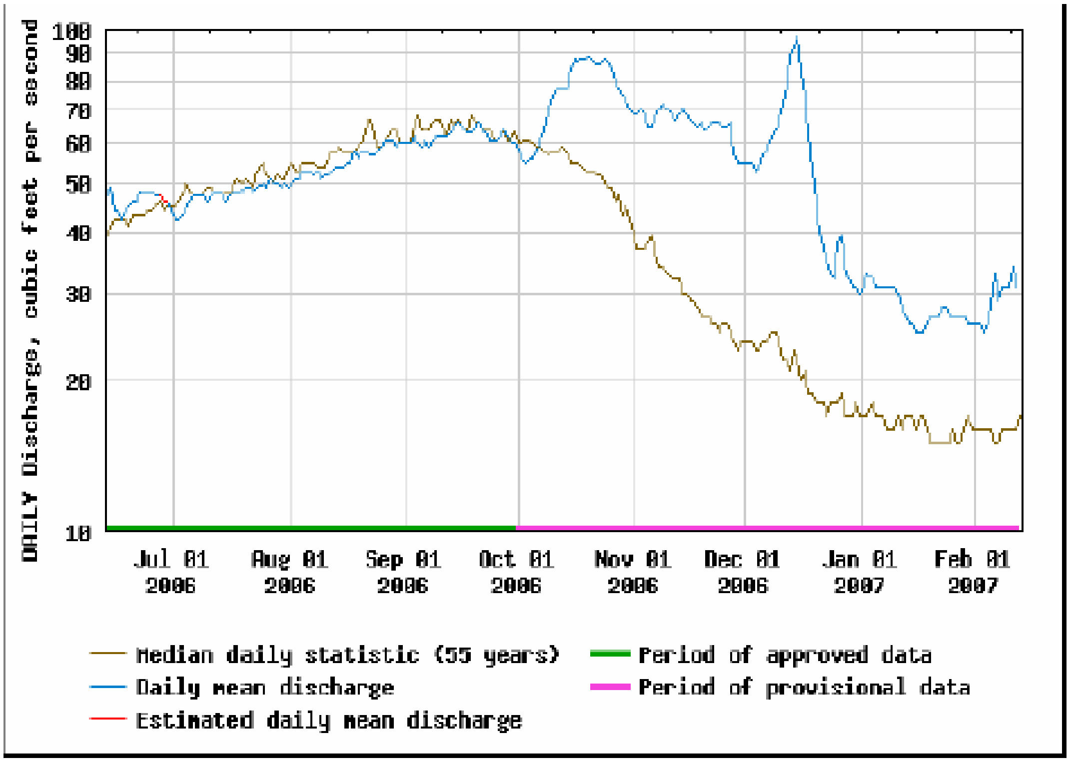


Figure 6. Crab Creek flows during USBR flow augmentation from Brooks Lake. Flow augmentation occurred from early August to December 15th 2006.

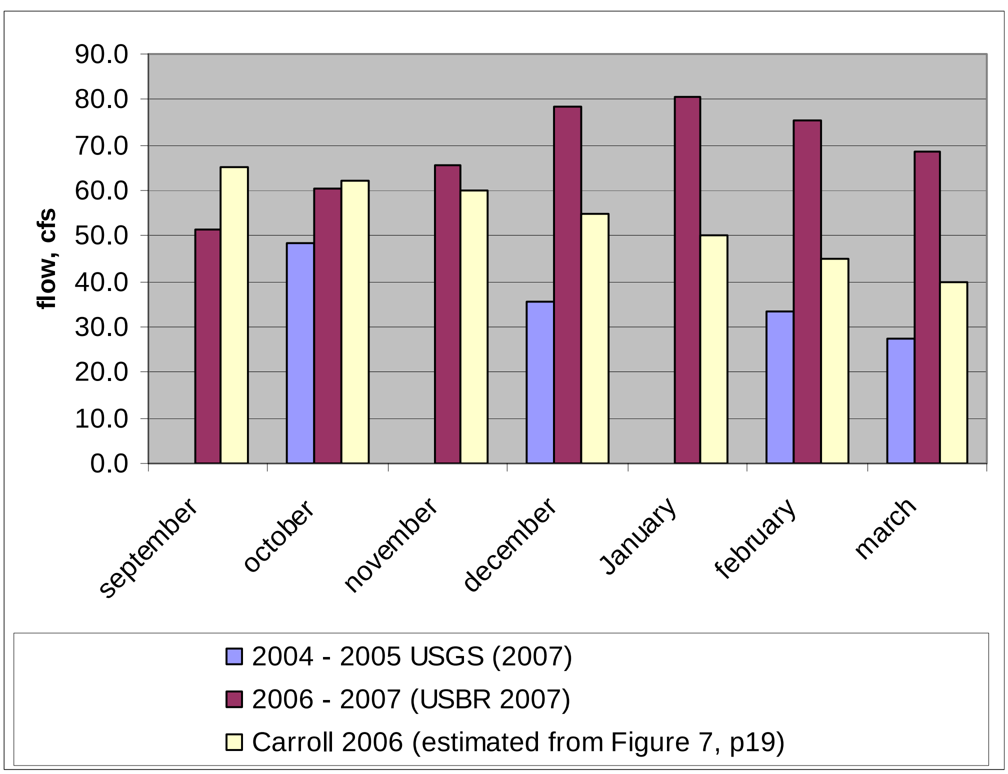


Figure 7. Comparions of Rocky Ford flow during supplemental feed study (2006-2007) with previous flow records.

7.0 GROUNDWATER

Groundwater samples were collected from monitoring wells located at the Larson Wastewater Treatment Plant (WWTP), private domestic wells, and wells sampled by Bain (2002) (Figure 9). WWTP monitoring wells are identified by MW-1, MW-2, MW-3, and MW-4 (MW-1 was not sampled because this well is often too dry), private domestic wells are identified by the Washington DOE six-digit well identifier, and wells and sites previously sampled by Bain (2002) are identified by the designations G-1 through G-8. Table 14 presents more detailed information for each well including the well identifier, depth, geologic material, and the specific parcel or address.

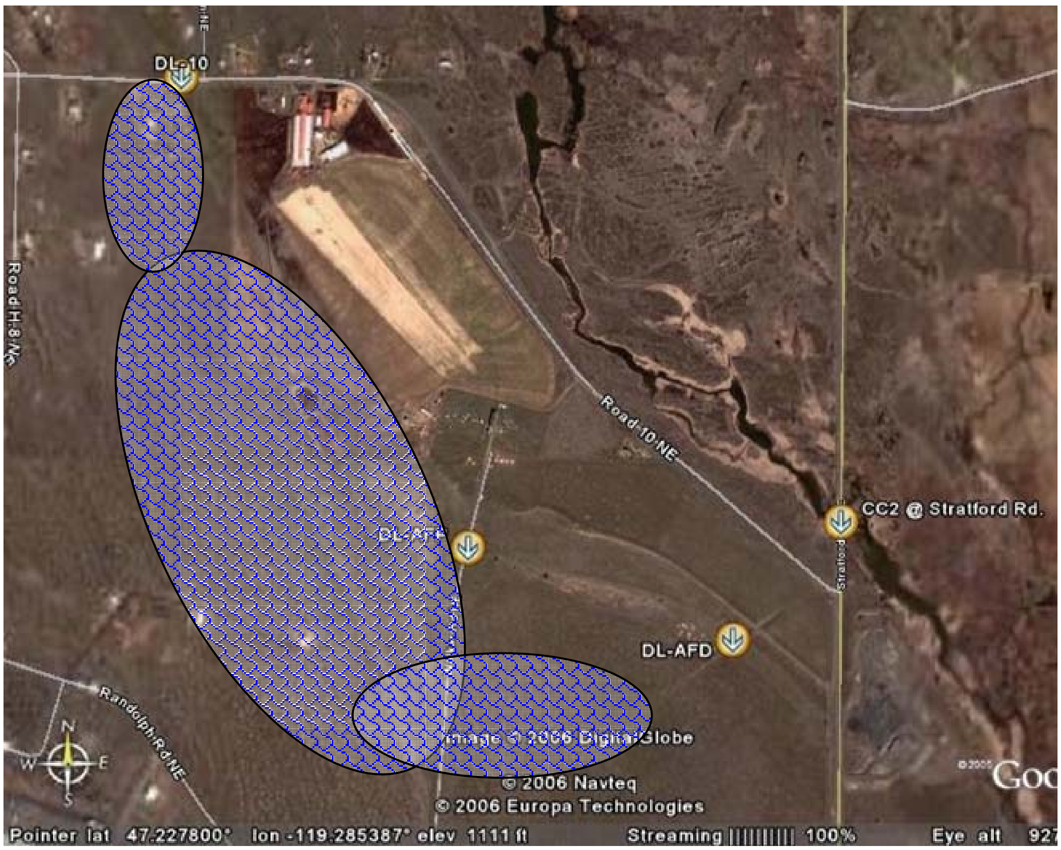


Figure 8. Sampling sites on Rd 10 Dairy during flow augmentation study. Approximate flooded area is shown (map from Google Earth).

7.1 PHOSPHORUS IN MUNICIPAL WASTEWATER EFFLUENT

Larson WWTP is located on a 34 acre site southeast of the Grant County Airport (Figure 9). There is a long history at this site of wastewater disposal into rapid infiltration basins. In 1943, a primary treatment plant was constructed on the site to serve the Larson Army Air Corp Base including base housing. In the early 1970's the city upgraded the original primary wastewater treatment facility and constructed the current Larson WWTP (WA DOE 2001).

The WWTP serves approximately 5000 residents. Between July and December 2006 this facility disposed of 350,000 to 400,000 gallons per day. Concentrations of phosphorus, chloride, sodium, and boron from the wastewater effluent are shown in Table 15. The average daily flow for the year was 324,000 gpd.

There is concern that phosphorus loading to groundwater from WWTP results in a net load of phosphorus to Moses Lake. Sampling during 2006 found that groundwater from all the WWTP monitoring wells have elevated levels of TP (Table 16). Chloride, sodium, and boron were also all very high and at concentrations similar to those found in the wastewater.

Well MW-3 mean groundwater TP and OP concentrations are by far the highest and compare closely to the mean Larson WWTP wastewater effluent concentrations (Tables 15 and 16): 2614 ug/L TP wastewater and 2079 ug/L TP at MW-3; 2299 ug/L OP wastewater and 1934 ug/L OP at MW-3. This is due to the location of MW-3, which is the most down-gradient well in the main southwest groundwater flow direction from the WWTP wastewater infiltration ponds.

Table 13. Water quality from flood pond around dairy on Road 10.

Date	Dairy Lake at RD 10 (DL-10)	USAF Paved Rd at CULVERT (DL-AFP)	USAF Dirt Rd LEVEE (DL-AFD)
Total phosphorus, ug/L			
11/2/06	267	570	350
12/5/06	199	469	347
Ortho phosphorus, ug/L			
11/2/06	247	459	73
12/5/06	106	360	146
Total Suspended Solids, mg/L			
11/2/06	<1	<1	15
12/5/06	<1	<1	7
Nitrate + Nitrite, mg/L			
11/2/06	<0.15	0	<0.15
12/5/06	0	0	1
Dissolved Oxygen, mg/L			
11/2/06	13.8	19.8	14.0
12/5/06	Ns	ns	ns
Temperature, ^{o}F			
11/2/06	38.5	37.0	38.8
12/5/06	ns	ns	ns
pH			
11/2/06	7.5	8.2	7.9
12/5/06	8.3	8.3	8.4

Shannon and Wilson (1989) also reported groundwater phosphorus concentrations in the monitoring wells in the same concentration ranges that are reported for 2006. This shows that the soils beneath this site have been heavily loaded for more than two decades. The average concentration difference between the wastewater and MW-3 ground water is 535 ug/L TP. This represents about a 20% reduction in TP. Long term use of this site for wastewater disposal and the coarse highly permeable gravels is expected to have significantly reduced any capacity for adsorption or precipitation. The reduction is probably due to dilution in the groundwater rather than removal in the soil column. The estimated potential load to the groundwater during the six month sampling was about 601 kg TP (Table 14).

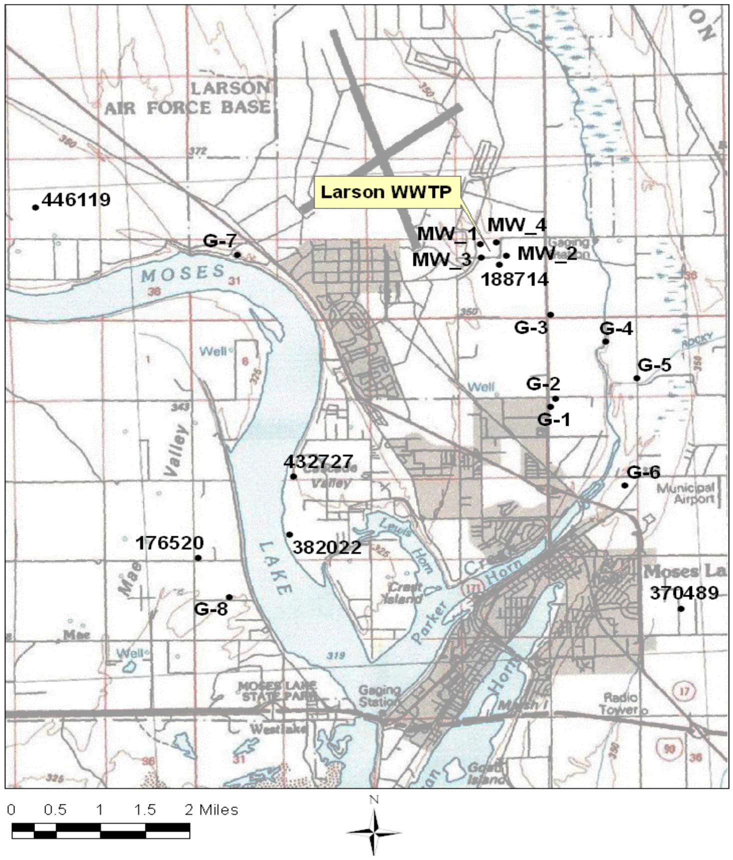


Figure 9. Wells and Groundwater Sampling Locations.

Table 14. Estimated monthly loads to groundwater from the Larson WWTP in 2006.

Month (2006)	Monthly Total Flow (million gal)	Monthly Total Flow (million L)	Monthly Avg. Total P Con-centration (ug/L)	Monthly Total P Load (kg)
January	9.670	36.60	ns	ns
February	8.844	33.48	ns	ns
March	9.279	35.12	ns	ns
April	9.308	35.23	ns	ns
May	9.763	36.96	ns	ns
June	10.155	38.44	ns	ns
July	10.188	38.57	3415	132
August	10.033	37.98	3354	127
September	9.936	37.61	1995	75
October	9.959	37.70	1750	66
November	10.289	38.95	1550	60
December	10.828	40.99	3440	141
			Six-Month Total (kg)	**601**

ns - not sampled.

7.2 PHOSPHORUS ANALYZED FROM DOMESTIC AND OTHER AREA WELLS

Groundwater phosphorus behavior in the Moses Lake area can be further analyzed by examining groundwater phosphorus concentrations from the domestic wells and those wells sampled by Bain (2002). Table 18 summarizes groundwater data collected in 2006 from the domestic wells. Specific data for wells and sites G-1 through G-8 can be found in Bain (2002). A spatial perspective of TP and OP groundwater concentrations from these wells is displayed in Figures 10 and 11 respectively (TP concentration data only are available for sites sampled by Bain (2002)).

Domestic wells 188714, 176520, and 446119 are shallow-depth wells (<100 ft) or are completed in the more permeable upper flood sediments, or both. Groundwater samples show mean TP and OP concentrations in the mid to higher ranges above background levels (>40 ug/L, Table 18, Figures 10 and 11). Well 188714 is located in the main direction of groundwater flow just south of WWTP. The high mean groundwater TP and OP concentrations (>110 ug/L OP and TP) may be due to proximity to the wastewater disposal site.

Table 15. Individual Well Information

Well Identifier	Well Tag or Label for Positive Field ID	Depth to Mid Screen or Open Hole (ft)	Geologic Material / Formation of Contributing Aquifer	Well Location (Parcel or Address)
MW-1[a]	MW-1	59	Hanford/Ringold	110412005
MW-2	MW-2	70	Hanford/Ringold	190324000
MW-3	MW-3	70	Hanford/Ringold	110412005
MW-4	MW-4	71	Ringold	110412005
432727	ALE617	109	Basalt	120947000
382022	AKL565	119	Basalt	121126410
176520	ACW245	59[b]	Gravel	122107000
370489	AHJ844	100	Sandstone, Basalt	190495000
188714	ACK712	73	Sand, Gravel, Clay	190325010
446119	APC819	119	Brown, Blue Clay	121822417
G-1	Identified from Bain, 2002	na	Upper Alluvium	170516000
G-2	Identified from Bain, 2002	na	Upper Alluvium	170481000
G-3	Identified from Bain, 2002	na	Upper Alluvium	PUD Well, Rd 7 east of Stratford Rd
G-4 (Spring)	Identified from Bain, 2002	na	Upper Alluvium	Columbia Basin Hatchery Spring
G-5	Identified from Bain, 2002	na	Upper Alluvium	120903000
G-6	Identified from Bain, 2002	na	Upper Alluvium	170611011
G-7	Identified from Bain, 2002	na	Upper Alluvium	Connelly Park
G-8	Identified from Bain, 2002	na	Upper Alluvium	141698000

[a] MW-1 not sampled; well is too dry.
[b] Represents total well depth.
na – not currently available.

Table 16. Concentrations of phosphorus, chloride, sodium, and boron in Larson WWTP effluent.

	Total Phos-phorus (TP) (ug/L)	Ortho-Phosphate (ug/L)	Chloride (Cl) (mg/L)	Sodium (Na) (mg/L)	Boron (B) (ug/L)
Minimum	1340	1220	42.9	74.4	156
Maximum	4560	4090	59.1	92.2	248
Mean	**2614**	**2299**	**48.4**	**82.9**	**184**
Median	2680	2140	47.9	82.3	179
Standard Dev	981	849	3.55	5.18	21.1

Domestic wells 432727, 382022, and 370489 are deeper wells (>100 ft) completed in the basalt rock units. Groundwater from these wells contains mean TP and OP concentrations in the lower ranges near or below background levels (<20 ug/L TP, <40 ug/L OP, Table 18, Figures 10 and 11).

Table 17. 2006 Summary of Groundwater Parameters from WWTP monitoring wells.

Groundwater Parameters		Wells MW-2	Wells MW-3	Wells MW-4
Total Phosphorus (ug/L)	Range	80 - 210	1720 - 2660	43 - 107
	Mean	135	2079	59.5
	Median	133	1980	52
	Number of Samples	n = 7	n = 7	n = 7
Ortho-Phosphorus (ug/L)	Range	59 - 220	1520 - 2700	18 - 119
	Mean	120	1934	67
	Median	105	1830	58
	Number of Samples	n = 7	n = 7	n = 7
Sodium (mg/L)	Range	14.8 - 43.3	80.6 - 94.4	30.8 - 34.2
	Mean	24.1	89.7	31.7
	Median	18.9	91.9	31.4
	Number of Samples	n = 7	n = 7	n = 7
Chloride (mg/L)	Range	2.4 - 31.2	43.4 - 49.9	8.9 - 11.4
	Mean	11.0	46.5	9.6
	Median	4.1	45.8	9.4
	Number of Samples	n = 7	n = 7	n = 7
Boron (ug/L) [a]	Range	<2.08 - 78.7	140 - 194	<2.08 - 23.9
	Mean	26.7	165	16.8
	Median	19.7	168	20.2
	Number of Samples	n = 7	n = 7	n = 7
pH	Range	6.50 - 7.11	6.88 - 7.03	7.30 - 7.62
	Mean	6.90	6.95	7.53
	Median	7.00	6.92	7.55
	Number of Samples	n = 6	n = 6	n = 6
Temperature (C)	Range	15.0 - 16.0	15.9 - 19.0	11.8 - 16.6
	Mean	15.7	17.3	14.4
	Median	15.9	17.0	14.6
	Number of Samples	n = 6	n = 6	n = 6

[a] Soil Test Laboratory reports <2.08 ug/L on 6-13-2006; 2.08 ug/L used in calculations.

The groundwater flow direction in the upper aquifer (in the Hanford/Ringold deposits) from WWTP is in a south-southwest direction toward Moses Lake (MWH, 2001). Two domestic wells sampled are located in this flow direction from WWTP: wells 432727 and 382022 (Figure 10). These wells are completed in the basalt. Low TP concentrations in these wells imply that phosphorus is not moving in to the basalt. Pitz (2003) sampled groundwater entering the lake in this area and reported concentrations of 100 to 178 ug/L TP. Data collected to date imply that the wastewater plume does not reach the deep aquifer and may remain more concentrated in the upper levels of the aquifer. Additional sampling of wells in the shallow aquifer needs to be completed to quantify the phosphorus transport to the lake.

For the sites sampled by Bain (2002), Figure 10 shows sites G-2, G-4, G-5, G-7, and G-8 with mean groundwater TP concentrations in the mid to higher ranges above background levels (>40 ug/L). The remaining wells (G-1, G-3, and G-6) show mean groundwater TP concentrations in the lower ranges near or below background levels (<40 ug/L). Detailed depth and hydrogeologic information for sites G-1 through G-8 was not supplied by Bain (2002) and is currently not known at this point. However, Bain (2002) reports these wells and sites were selected to characterize groundwater in the upper level alluvium.

7.3 SODIUM, CHLORIDE, BORON, PH, AND TEMPERATURE

Sodium, chloride, and boron were all measured as indicators that may help distinguish the between municipal wastewater and agricultural or natural phosphorus.

Groundwater from WWTP well MW-3 consistently shows some of the highest mean concentrations of sodium, chloride, and boron (Table 16). Wells MW-2 and MW-3 are also slightly acidic with groundwater pH values of 6.90 and 6.95 respectively, while pH values from most other area domestic wells are in the slightly basic range (between 7.0 and 8.0, Figures 12 - 15). Infiltration of WWTP wastewater may therefore be influencing the sodium, chloride, and boron constituents and pH in groundwater since MW-2 and MW-3 are located at the most down-gradient points from the infiltration ponds at WWTP.

Boron appears to be the constituent that most closely reflects the TP and OP concentration patterns for the other wells (Figure 14). Most of the shallow wells and those completed in the upper flood sediments aquifer (wells MW-2, MW-3, 188714, 446119, and 176520) have the higher mean groundwater concentrations of boron (>23 ug/L). The exception is MW-4 (<20 ug/L), but it should be noted this well is located most up-gradient of the WWTP infiltration ponds. Groundwater from wells completed in the deeper basalt rock (432727, 382022, and 370489) contains lower mean boron concentrations (<23 ug/L). This pattern is very similar to the TP and OP concentrations for the study area wells.

Groundwater concentration patterns for sodium and chloride from other wells in the area are less well defined with no clear pattern based on well depth or geologic formation (Figures 12 and 13): sodium concentrations are in the same range (40 – 60 mg/L) from deep wells 432727 and 382022 (>100 ft) and shallow well 176520 (59 ft). The lowest chloride concentrations (<7 mg/L) are from deep well 370489 (100 ft) and shallow well 188714 (73 ft); however, high chloride concentrations (15 – 20 mg/L) are also from deep wells 432727 and 382022. Chloride concentrations from the remaining area wells are in the mid to higher ranges (>7 mg/L).

Table 18. Summary of Groundwater Parameters from Domestic Wells.

Groundwater Parameters		Wells					
		432727	382022	188714	370489	176520	446119
Total Phosphorus (ug/L)	Range	10	19	134 - 141	16 - 17	85 - 89	62
	Mean	10	19	138	16.5	87	62
	Median	10	19	138	16.5	87	62
	Number of Samples	n = 1	n = 1	n = 2	n = 2	n = 2	n = 1
Ortho-Phosphorus (ug/L)	Range	14	17	129	6	74	72
	Mean	14	17	129	6	74	72
	Median	14	17	129	6	74	72
	Number of Samples	n = 1	n = 1	n = 1	n = 1	n = 1	n = 1
Sodium (mg/L)	Range	51.1	52.8	27.1 - 29.1	151 - 161	55.4 - 57.2	33.1
	Mean	51.1	52.8	28.1	156	56.3	33.1
	Median	51.1	52.8	28.1	156	56.3	33.1
	Number of Samples	n = 1	n = 1	n = 2	n = 2	n = 2	n = 1
Chloride (mg/L)	Range	16.6	17.1	4.9 - 7.5	0.6 - 2.6	11.5 - 12.1	7.9
	Mean	16.6	17.1	6.2	1.6	11.8	7.9
	Median	16.6	17.1	6.2	1.6	11.8	7.9
	Number of Samples	n = 1	n = 1	n = 2	n = 2	n = 2	n = 1
Boron (ug/L)	Range	20.2	20.2	34.8 - 37.5	19.5 - 21.0	32.9 - 34.5	23.1
	Mean	20.2	20.2	36.2	20.3	33.7	23.1
	Median	20.2	20.2	36.2	20.3	33.7	23.1
	Number of Samples	n = 1	n = 1	n = 2	n = 2	n = 2	n = 1
pH	Range	7.24	7.34	7.5	8.0	7.7	7.9
	Mean	7.24	7.34	7.5	8.0	7.7	7.9
	Median	7.24	7.34	7.5	8.0	7.7	7.9
	Number of Samples	n = 1	n = 1	n = 1	n = 1	n = 1	n = 1
Temperature (C)	Range	11.9	13.7	11.7	14.8	12.9	12.9
	Mean	11.9	13.7	11.7	14.8	12.9	12.9
	Median	11.9	13.7	11.7	14.8	12.9	12.9
	Number of Samples	n = 1	n = 1	n = 1	n = 1	n = 1	n = 1

Mean groundwater temperatures are generally higher at the WWTP wells than the other wells. However, this may be because of seasonal influence; the WWTP wells include groundwater temperatures recorded during the summer months while temperatures for the other wells were recorded during the fall and winter (Figure 16).

Elevated concentrations of phosphorus in shallow wells is due to greater susceptibility of these wells to surface sources of phosphorus, particularly in the highly permeable upper soil and alluvial zones in the area. Higher concentrations of phosphorus (100 - 250 ug/L ortho-phosphorus) in shallow groundwater have also been reported by Pitz (2003) in samples from two piezometers installed in lake sediments on the east shore of the lake north of, and within Cascade Valley. Anthropogenic sources located up-gradient of the piezometers such as municipal wastewater, leachate from septic drain fields, and leakage from sewer systems have been identified as the primary sources of phosphorus in groundwater discharging to the lake.

Figure 10. Total Phosphorus Concentrations – Domestic, WWTP Monitoring wells, and Bain (2002) Wells.

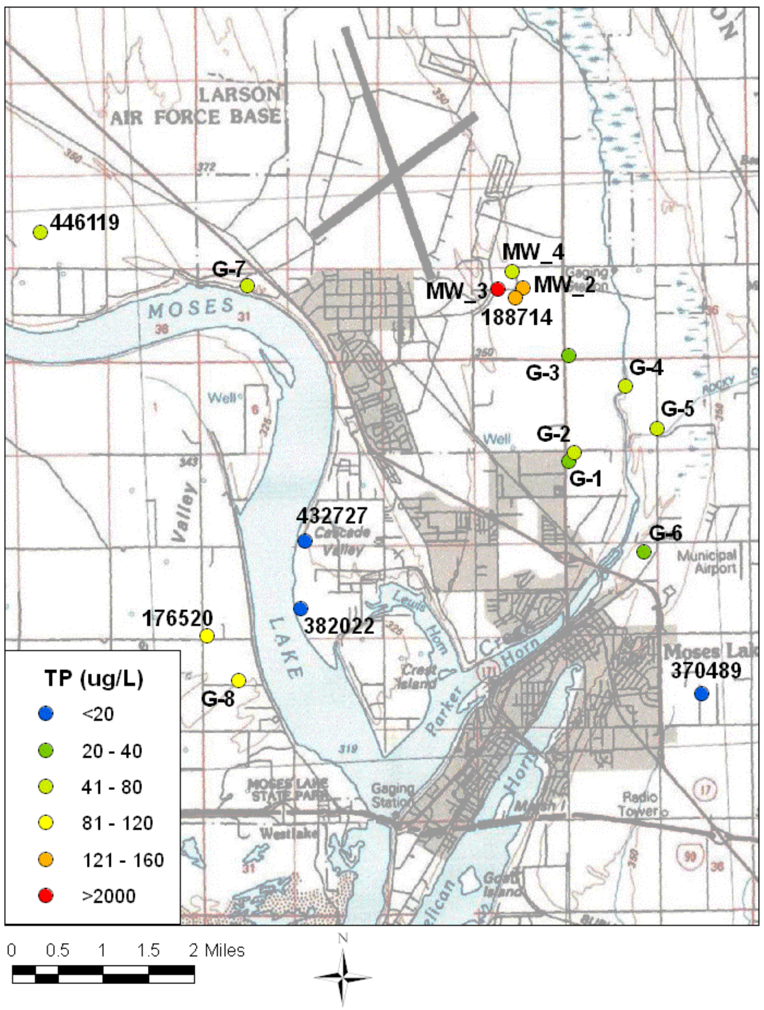


Figure 11. Ortho-Phosphorus Concentrations – Domestic and WWTP Monitoring Wells.

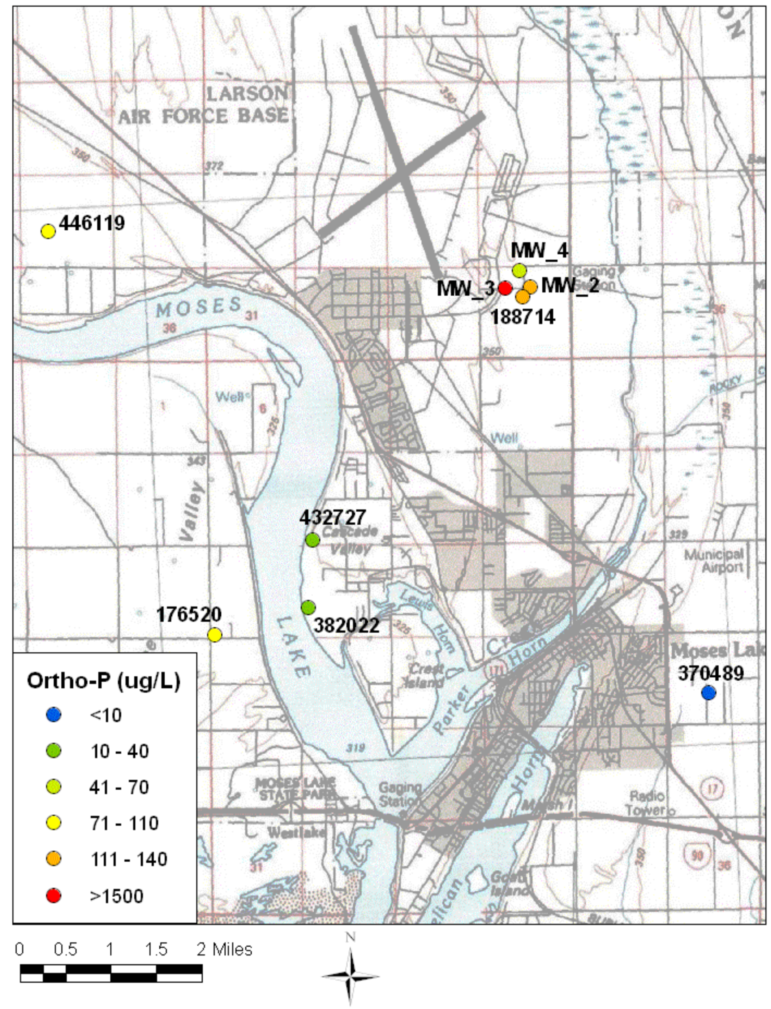


Figure 12. Sodium Concentrations – Domestic and WWTP monitor wells.

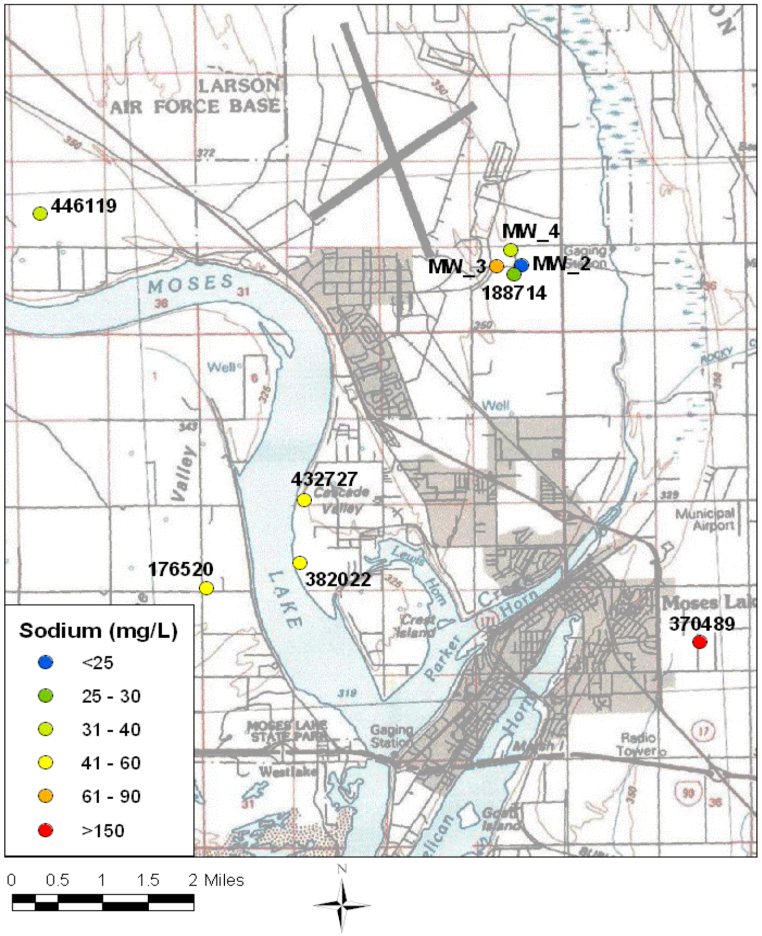


Figure 13. Chloride concentrations - Domestic and WWTP Monitoring wells.

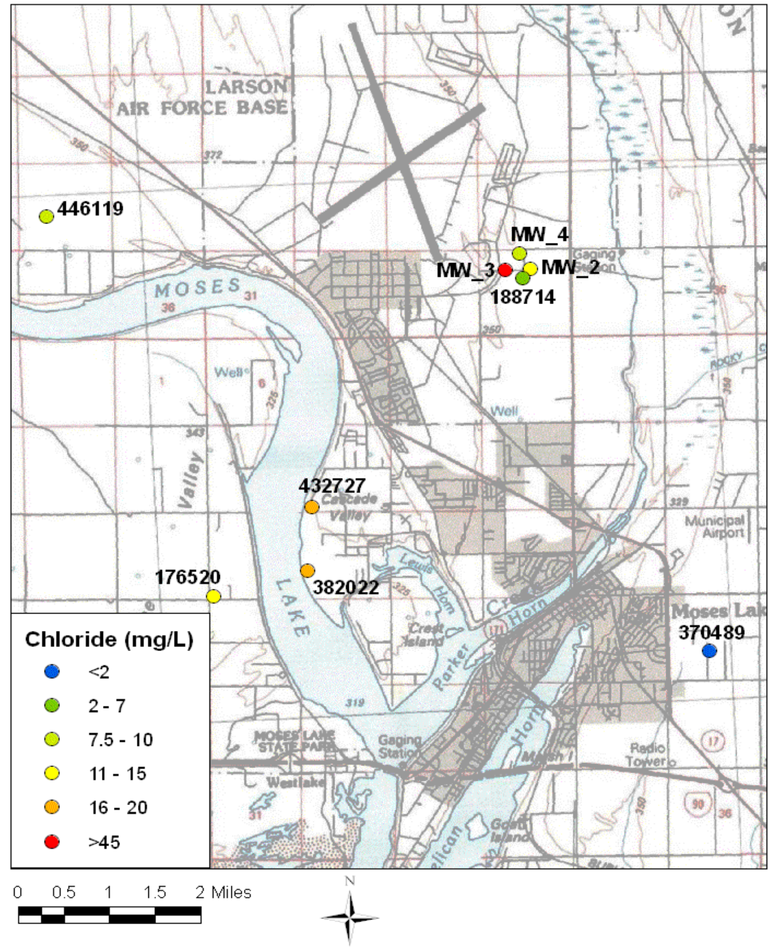


Figure 14. Boron Concentrations – Domestic and WWTP Monitor Wells.

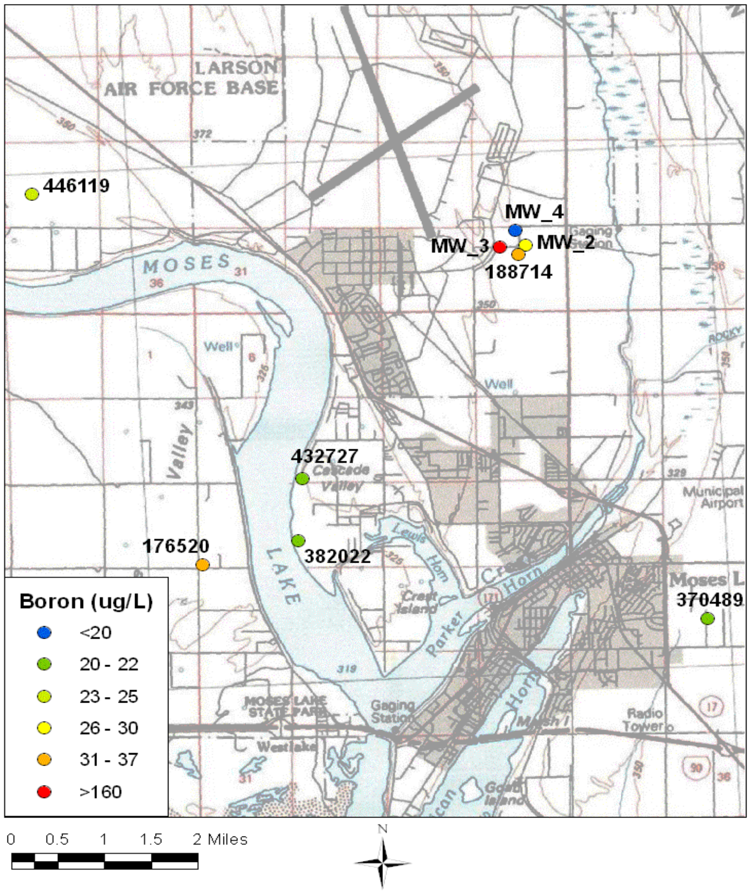


Figure 15. pH Values - Domestic and WWTP Monitor Wells.

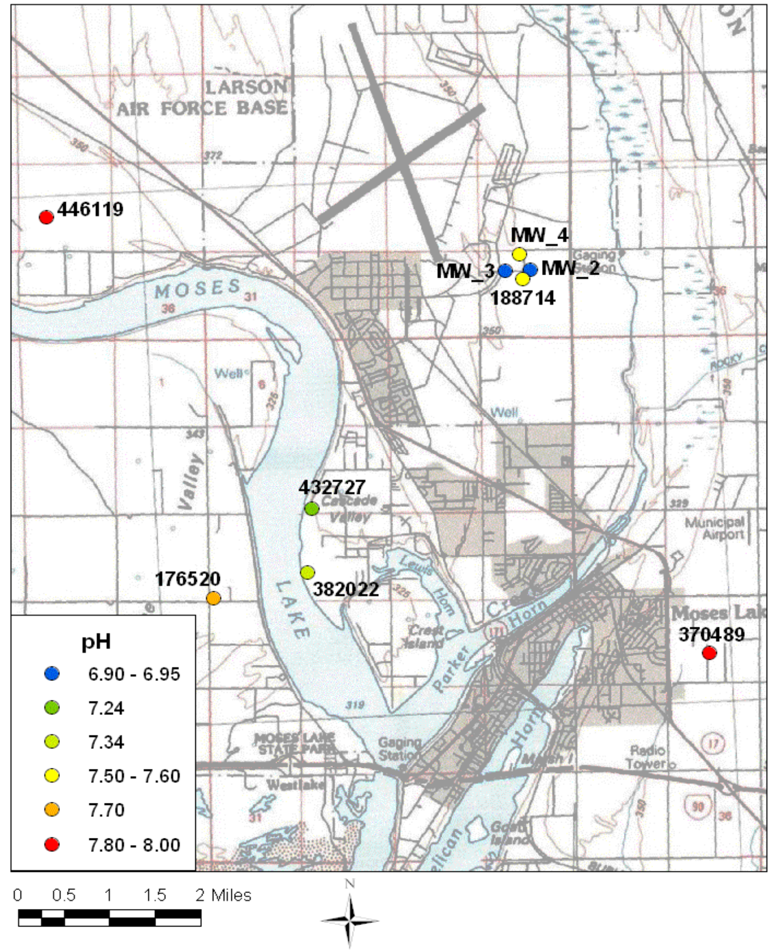
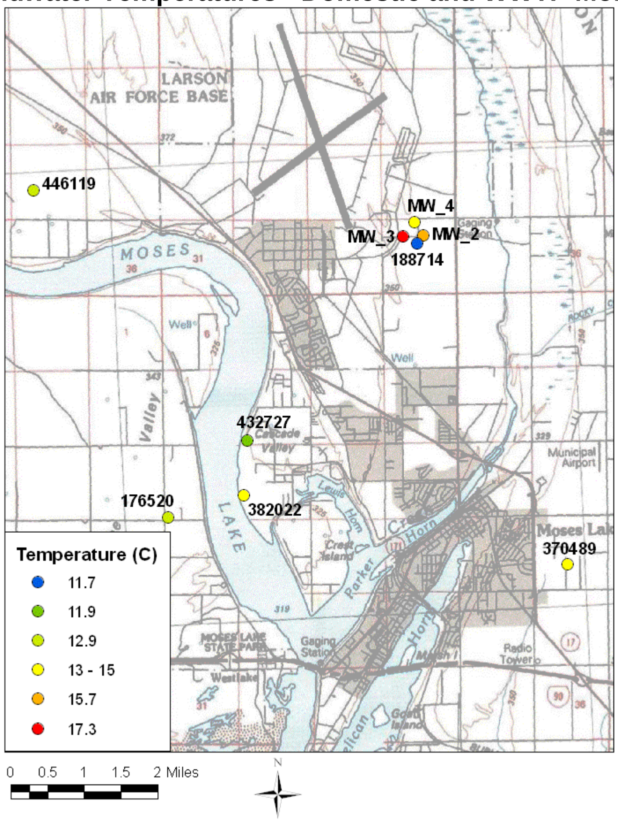


Figure 16. Groundwater Temperatures - Domestic and WWTP Monitor Wells.



Groundwater from the deeper basalt wells contain concentrations of 10 – 19 ug/L total phosphorus, 6 – 17 ug/L ortho-phosphorus, both near or below background concentrations. Two of the three deeper wells sampled are also located on the east shore of the lake in Cascade Valley, down-gradient from the main phosphorus sources to groundwater. Phosphorus transport in groundwater is primarily occurring in the shallow upper flood sediments (Hanford/Ringold Formations) that are in direct contact with the lake.

7.4 SEPTIC SYSTEMS IN THE REGION

Residential growth in the Moses Lake has increased 12.3% in the last five years. This represents an increase of about 2000 people. A significant potion of the growth is occurring in the Cascade Valley and on the eastern shore of Moses Lake, south of interstate 90. Both areas are outside the City limits but inside the Urban Growth Boundary. Figure 17 shows the areas in the Urban Growth Area (UGA) that are not currently on the City Sewer system. Currently there are about 3,156 acres of land available for residential development in the Cascade Valley. About 917 acres of that total has 491 dwelling units with septic systems. There may be more septic systems than this since Grant County Health District does not have systems installed prior to 1993 in their electronic data base.

These areas of that are inside the Urban Growth Boundary are zoned Urban Residential 2 (R2) or 3 (R3). These land use designations allow for one to four dwelling units per acre for R2 or four to eight dwelling units per acre for R3 (Grant County 1999). Total Urban Residential lots in Cascade Valley that do not have sewer service available are approximately 3,156 acres. Currently at least 917 of the total acres have 491 septic systems. This area is developing rapidly.

The City will annex parcels and provide sewer upon request from the owners (personal communication, Grant County Planning 2006). The loads of phosphorus from septic systems could increase significantly as the available lakeside land is developed prior to annexation and installation of a sewer collection system.

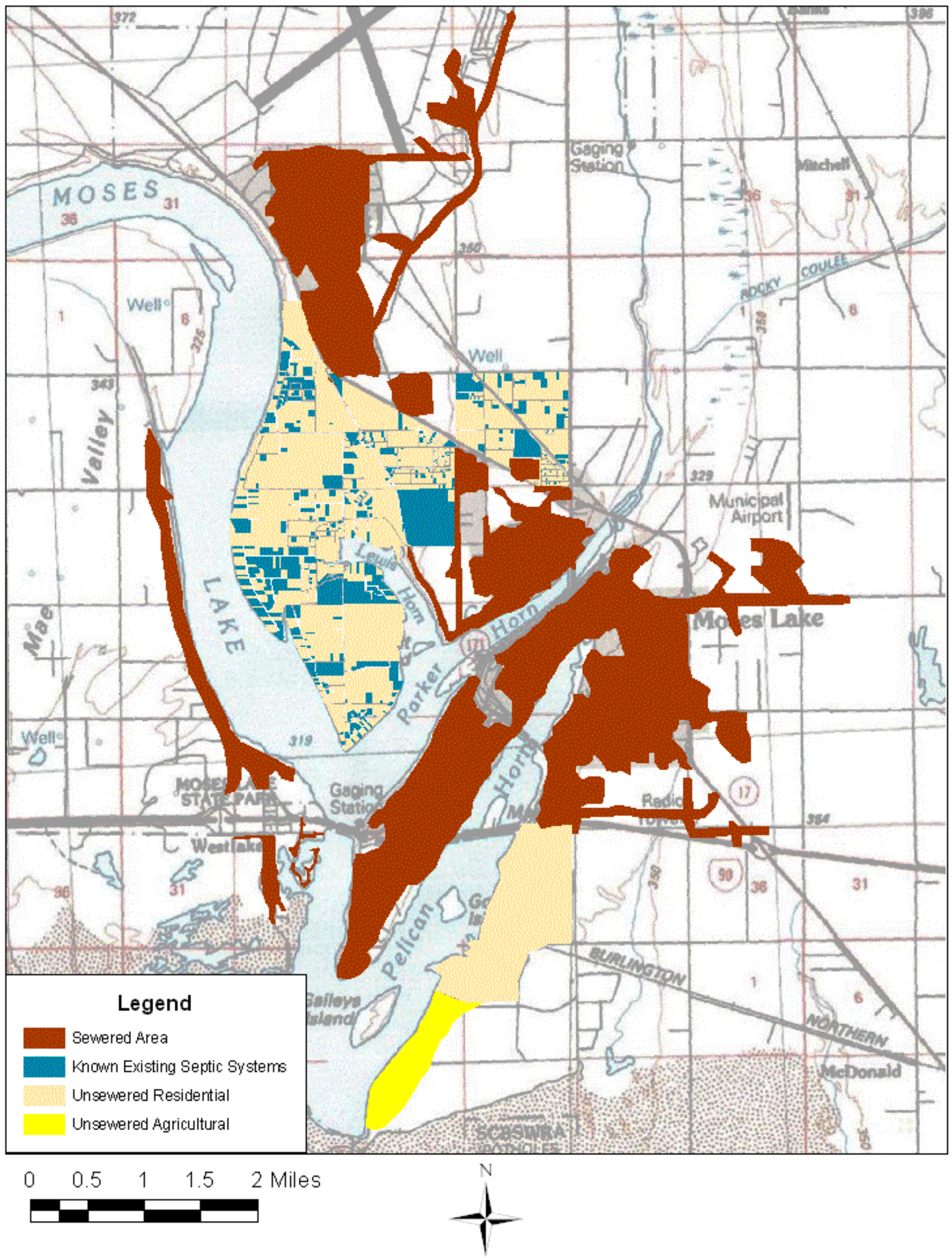


Figure 17. Current and potential development of Cascade Valley using drain fields for disposal of residential wastewater.

Soils in the area are in the Ephrata and Malaga soil types. Both soils were formed in glacial outwash that is mixed with loess in the upper horizon and gravelly fine sandy loam below. Soils at depths greater than 19 -23 inches vary from gravelly to extremely gravelly with permeability greater than 20 inches per hour (USDA SCS 1978). The soil reaction pH for Ephrata and Malaga soils is in the alkaline range with pH from 7.4 – 8.4. The soils are calcareous in the substratum (USDA SCS 1978)

Residential drain fields are installed two to three feet deep in the very gravelly soils. The Washington State Department of Health (WA DOH) classifies these soils a Type 1A soils. The WA DOH guidance for deign of septic system in Type 1 A soils recommends a maximum loading rate of 1.2 gal/ft^2/day. This is the highest loading rate allowable in septic systems. The high loading rate results in less reaction time with the soil and more rapid saturation of available adsorption sites in the soil.

Adsorption of phosphorus in soils below the drain fields varies depending on texture (sand, silt or clay content) and chemistry. Predicting removal is complicated due to the variable distribution of soils and non equilibrium removal processes (Harris 2002). The least effective removal of phosphate occurs in gravelly calcareous soils (Lombardo 2006).

Phosphorous in septic system effluent can be expected to average about 8,000 ug/L TP. Approximately 20 – 30% of the phosphorus is removed in the septic tank (Lombardo 2006). A conservative load estimate to groundwater from septic systems in Cascade Valley can be estimated. Assuming an average septic tank wastewater, the approximate load to the drain field from 491 houses with an average of 3 people per house and 80 gpd/person is 648 kg phosphorus in six months (April through September). If 20% removal occurs in the drain field the load to the ground water would be about 518 kg TP. The removal in the groundwater matrix is expected to be low due to the low iron content in soils (2-8 mg/kg soil, Dan Nelson, Soil Test Consultants, Inc) and very high content of gravel in the substratum. If we assume a 10% removal in the groundwater matrix the total load from existing septic systems (in the Grant County Health District electronic database) is estimated to be 466 kg TP.

7.5 GROUNDWATER LOADS FROM WASTEWATER DISPOSAL

The total groundwater load reduction recommended in the TMDL is about 752 kg TP (Table 2, Carroll 2006). The estimated six month load from the Larson Wastewater facility is 601 kg. The estimated load from the existing septic systems is about 466 kg. The combined load from wastewater disposal in Cascade Valley is estimated to be 1067 kg TP over a 6 month period. If it is assumed that all this wastewater TP is able to reach the lake, then removal of TP at the Larson Facility and installation of a sewer would result in very significant load reductions to Moses Lake. .

The time for benefits to occur in the lake from control of wastewater TP sources depends on the travel time in the aquifer. Estimated seepage velocity for the groundwater is 5 to 600 feet/day (MWH 2003). The southwest flow path is about 17,307 feet; therefore, the time it takes wastewater to reach lake may be from 9 years to as short as 30 days. Given that the wastewater has been applied daily for more than 20 years there may be a delay in benefits due to the potentially large reserve of phosphorus in the aquifer.

8.0 CONCLUSIONS

8.1 LAKE WATER QUALITY

Low dilution flows from Rocky Ford Coulee in July, August, and September contributed to development of large blooms of toxic blue green algae in the lake. Water quality was good in July, but TP concentrations were greater than 60 ug/L in the southern end of the lake in September. Concentrations of toxic blue green algae were in a range that the World Health Organization considers a moderate to high risk. This condition can be expected to continue when wet winters create conditions such that less water in needed in the summer for irrigation south of Moses Lake. The USBR should be encouraged to move greater amounts of dilution water through Moses Lake in July and August to reduce this problem. Reduction of external phosphorus load to the lake will also reduce eutrophication problems in the lake.

8.2 GROUNDWATER

Disposal of municipal and residential wastewater appears to be a very significant source of groundwater phosphorus entering Moses Lake. The groundwater wells immediately down gradient of the wastewater disposal site have concentrations of TP, Na, Cl, and B that are similar to the wastewater effluent. There is about a 20% reduction in concentration that appears due to dilution from groundwater. The total estimated TP load of groundwater in 2006 that may reach Moses Lake from residential septic systems and municipal wastewater sources is 1067 kg TP over a six month period. The estimated load is 142% of the recommended groundwater load reduction from the Moses Lake TMDL and about 32% of the total load recommended by WA DOE for all of Moses Lake.

Installation of phosphorus removal technology at the Larson Wastewater Facility, a sewer collection system in Cascade Valley, and/or requirements for removal of phosphorus in residential septic systems will result in a significant load reduction to Moses Lake. Implementation of methods to reduce phosphorus loads will improve the long term quality of Moses Lake.

9.0 RECOMMENDATIONS

Future sampling should continue to focus on sources of TP in the watershed. Evaluation requires moving the sampling effort out of the lake and on to the land. Recommended actions for 2007 are:

- No lake sampling is recommended for 2007. In 2008 the lake should be sampled to maintain the data base developed by MLIRD with whole lake assessment once every 5 years.
- Organize a one time sampling of all shallow wells completed in the upper flood deposits and used in the TCE pollution study. WQE has been given access for a one time sampling, but regular sampling on a periodic basis has not been permitted.
- These data along with modeling information from the TCE pollution control study will be used to better identify groundwater conditions and transport through Cascade Valley into Moses Lake.

- Collect and integrate field and sampling data into a groundwater model to quantify the phosphorus load from groundwater into the lake. Much of the field and geologic data required by a modeling effort is already available.
- Make an estimate of the adsorption capacities of the subsurface soils and gravels for phosphorus. This will provide valuable model input and also help determine if groundwater will be a long-term source of phosphorus loading to the lake.
- Complete identification of septic systems within City Limits that are not on the sewer system and may be too close to Moses Lake.
- Identify septic systems of concern in the Crab Creek drainage
- Discuss concerns about Larson WWTP and sewers with City of Moses Lake and Grant County.
- Encourage assistance and cooperation with development of Water Pollution Control Plan for Moses Lake
- Pursue sources of grants to continue work and planning in the watershed.

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APPENDIX 01 – LAKE SAMPLE DATA

APPENDIX 02 – LARSON WWTP EFFLUENT, WWTP MONITORING WELLS, AND GROUND WATER DATA FOR RESIDENTIAL MONITORING WELLS

APPENDIX 03 – SEDIMENT DATA

APPENDIX 04 – CRAB CREEK WATER DATA

APPENDIX 5 - ROCKY FORD FLOW DATA