2009 ROCK ISLAND LAKE NUTRIENT LOADING ASSESSMENT

January 6, 2010

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WATER
QUALITY
ENGINEERING

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1 SUMMARY AND RECOMMENDATIONS

Hammond Lake has very high concentrations of phosphorus that cause thick blooms of blue green algae. The shallow water, lack of submerged aquatic plants and abundant sunlight and phosphorus (P) create ideal conditions for the growth of the algae. This study was completed to evaluate the sources of phosphorus that are causing the hypereutrophic conditions in the lake.

Finding of the study are:

- ❖ Wells on the east end of Rock Island have soluble phosphorus concentration in excess of 0.1 mg/L and nitrate nitrogen in excess of 10 mg/L. These high concentrations of nutrients are from septic systems and/or misuse of agricultural and residential fertilizer.
- ❖ Putters Ponds are deep and intercept polluted groundwater flow from Rock Island before it reaches Hammond Lake.
- ❖ Groundwater P entering Putters Pond is diluted and results in significantly lower P concentrations.
- ❖ Putters Ponds are stratified ponds and develop a deep anoxic layer (20 to 70 feet deep) in the summer.
- ❖ Loading of P into Putters Ponds does not result in excessive blooms of algae or create conditions that negatively impact the warm water fishery.
- ❖ During the summer irrigation season, Hammond Lake is down gradient from and receives low phosphorus groundwater from both Putters Ponds and the Columbia River.
- ❖ Groundwater P entering Hammond Lake has P concentrations less than 0.01 mg/L and is of significantly better quality than groundwater in Rock Island wells and Putters Pond..
- ❖ There are low permeability layers of sediment and/or bedrock that limit dilution of Hammond Lake from groundwater entering the lake.
- ❖ Hammond Lake does not receive enough flushing from groundwater or the Columbia River to dilute the lake P concentrations.
- ❖ Fertilizer application of the golf course may result in high loading of P and nitrogen (N) into Hammond Lake.
- ❖ Careful management of fertilizer application from the golf course and surrounding orchards should be encouraged. It is common to manage established turf with fertilizer with no phosphorus.
- ❖ The old burn site has phosphorus levels that are optimum for plant growth. These concentrations may be from burning trash on the site or fertilizer application.
- ❖ About 33% of phosphorus in the Hammond Lake sediment is associated with organic material and fine particulate matter. A very small portion is in iron precipitate; about 67% is bound to aluminum and calcium.
- ❖ Internal loading of P is the most significant source of P in the lake.
- ❖ External loading from fertilizer use on the golf course is most likely the largest external source of P entering Hammond Lake.
- ❖ Annual external loads of P to Hammond Lake accumulate in the lake because there is minimal flushing of the lake combined with high evaporation rates.

Phosphorus is available in the lake from internal (within the lake) and external sources (from outside of the lake). This lake will not recover without efforts to eliminate both internal and external loads of phosphorus. Control of external phosphorus loading

should result in long and short term improvements in the lake. External loads in order of priority are:

1. Fertilizer applications at the golf course,
2. Septic system from the golf course and surrounding community,
3. Old community burn site on north side of the lake,
4. Fertilizer from orchard production.

Concentrations of P in the lake from internal loading are very high and must be eliminated to create an aesthetic and healthy warm water fishery in Hammond Lake. Internal loads are from particulate bound phosphorus in the water column which stays suspended in the shallow lake and remains available to algae. There is also a very high concentration of soluble reactive phosphorus (srp) in the water column year round. The high concentrations of srp have increased significantly in the last couple decades and are associated with the particulate phosphorus and most likely fertilizer applications to the golf course.

The internal loads can be controlled with application of aluminum sulfate and/or dredging. The options to consider are:

1. Application of aluminum sulfate to precipitate the phosphorus and bind it in the sediment.
2. Dredge the bottom of the lake to remove 6 – 12 inches of fine sediment from the bottom of the lake. Sediment would need to be land applied as a soil amendment.
3. Dredge the bottom of the lake to remove 6 – 12 inches of sediment and sand and gravel to create a deep (>20 feet) lake. This third option for control of internal phosphorus would be the best alternative for improving the fishery and potentially producing sand and gravel for sale.

2 INTRODUCTION

Hammond Lake has a history of hypereutrophic conditions (Water Quality Engineering, Inc 2008). Hypereutrophic conditions have been indicated by phosphorus concentrations in excess of 0.500 mg/L, extensive blooms of blue green algae, and some fish kills. The lake is down gradient of the community of Rock Island which has does not have a sewer system and is the suspected source of phosphorus in the lake. The problem appears more complex than suspected because none of the other lakes in the area exhibit the problems commonly seen in Hammond Lake. This study was conducted to better understand the sources of phosphorus that are causing the hypereutrophic conditions in the lake.

The community of Rock Island wants to improve the trophic status of the lake for recreation and aesthetics. Hammond Lake is used as a recreational fishery and irrigation source supporting numerous warm water fishes such as blue gills, largemouth bass, channel catfish, brown bullheads, black crappie, and yellow perch (Osborne and Peterson 2005). There is a public boat launch that is open for fishing year round.

2.1 GOALS AND OBJECTIVES

This project was designed to evaluate sources of phosphorus that may be contributing to the elevated levels of phosphorus in Hammond Lake. Objectives were to evaluate:

1. Potential benefits of a public sewer in the community of Rock Island,

2. Internal phosphorus loading from lake sediment,
3. Estimate phosphorus loads from septic system on golf course,
4. Estimate phosphorus loads from agriculture and golf course, and
5. Evaluate influence of old landfill on lake water quality.

3 METHODS AND MATERIALS

The Quality Assurance Project Plan (QAPP) (ref) defined approximate sample locations and approaches for sample collection and methods for analysis. A brief summary of methods are provided for each sample type along with any deviations from the QAPP. All sediment and water samples were analyzed by Aquatic Research, Inc, a Washington State certified laboratory that specializes in analysis of low concentrations of nutrients.

3.1 Lake Sampling

Water and sediment samples were collected from Hammond Lake and Putters Pond throughout the Spring into Fall 2009.

3.1.1 Lake Water Sampling

Water samples were collected from the epilimnion and hypolimnion in both Hammond Lake and Putters Pond. In general samples were collected two times per month from Hammond Lake and once per month from Putters Pond. Figure 2 shows the approximate location of the sample stations.

Samples were collected, shipped, and analyzed in the laboratory for total phosphorus (TP), soluble reactive phosphorus (srp), total nitrogen (TN), nitrate and nitrite nitrogen (NO3-N) and chlorophyll a. In the field water was analyzed for pH, temperature, dissolved oxygen (DO), turbidity, and salinity.

3.1.2 Sediment

Sediment samples were collected from two stations in the middle of Hammond Lake (Figure 2). The water depth at the sampling location was about 9 feet. Samples were collected using a 15 by 15 cm Ponar Grab as specified in the QAPP. At each station three grab samples were composited, homogenized and then placed in the sample bottle. Sediment was analyzed for % water, % solids, total phosphorus, phosphorus fractionation, and gradation.

3.2 Groundwater Sampling

Groundwater was collected from shallow wells in the community and from piezometers installed in the littoral zone of both lakes.

3.2.1 Groundwater from Irrigation or Drinking Water Wells

Three shallow cased wells on the eastern edge of the community of Rock Island (Figure 4) were sampled for nutrients. One shallow uncased well on the golf course (Figure 4) was also sampled. For cased wells, outdoor taps were opened and run for 10 minutes prior to sampling. A flow cell was used to measure DO, pH and temperature and to verify stabilization of parameters. Samples were shipped and analyzed according to the QAPP (WQE 2009).

The shallow uncased well had a 50 hp irrigation pump withdrawing water twenty four hours a day seven days a week. A van Dorn bottle was lowered three feet into the well for sampling.

3.2.2 Groundwater from Piezometers

Six piezometers were installed in about three feet of water in Hammond Lake and Putters Ponds (Figure 4). After installation, each piezometer was purged to remove sediment, lake water, algae, and any other materials that may have entered the perforations during installation. Sampling of piezometers was initiated four weeks after installation.

Piezometers were sampled three times using a peristaltic pump and flow cell. Samples were collected after pumped water had run clear for at least 10 minutes. A flow cell was used to monitor change in temperature, pH, and DO for each sample. Temperature, pH, and DO were recorded after parameters had stabilized and a sample was collected. Samples were stored, shipped, and analyzed per the QAPP (2009).

The piezometers were sampled in July, August, and September 2009. During the summer sampling months, the golf course irrigation system was operating twenty fours hours a day seven days per week (24/7). The QAPP had specified collecting piezometer samples only after the irrigation pump had been off for several hours and groundwater elevations had returned to equilibrium. It was assumed that the 24/7 operation established a unique equilibrium and so samples were collected each sampling day with the irrigation pump in operation.

3.3 Elevations of Water Surfaces and Piezometers

On the same morning that piezometers were sampled, a licensed professional surveyor (Fitzpatrick Surveying, Inc) recorded the elevations of water surfaces in Hammond Lake, Putters Pond, and the Columbia River. The river elevation was selected behind Rock Island Dam, at a point between Hammond and Putter Lakes. Surface elevations of Hammonds Lake, Putters Pond and the Columbia River were used to quantify the hydraulic relationships between water bodies.

The surveyor also recorded the elevation of the top of each piezometer each morning prior to sampling. This provided a metric to determine if the piezometers had been moved (by vandals or accident) between sampling events. The elevations of the piezometers were essentially identical at the beginning and end of the project (Appendix A).

3.4 Soil Sampling

Three soil samples were collected to evaluate Total Phosphorus (TP) and water soluble phosphorus (bicarbonate extraction) in soils at the old burn site on the north side of Hammond Lake east of the golf course (Figure 2). Soils were collected with a hand auger at a depth of one foot and mixed thoroughly in a stainless steel bowl. A composite sample composed of three sub samples was taken at each location in the burn site. Samples were analyzed at Cascade Analytical Lab; a Washington State certified laboratory.

4 RESULTS AND DISCUSSIONS

4.1 Relative Percent Differences for Water Samples

Relative Percent Differences (RPDs) for laboratory duplicates were all within the target RPD established in the QAPP (Appendix – Laboratory Data from Aquatic Research). Relative Percent Difference of field replicates for lake samples (Table 1)

and wells and piezometers (Table 2) show relatively low variation between samples. There were a few sampling times when variation was large (80%) but in general variability was low and samples appear representative of the system (Table 1).

4.2 Nutrients and Lake Trophic Status

4.2.1 Results

Sample stations were located in nine to ten feet of water on two ends of the lake (Figure 2). The center of lake was measured with a depth finder and the depth was consistently between nine to eleven feet.

During the past four years Hammond Lake has exhibited very high phosphorus concentrations and eutrophic conditions (WQE 2007). This sample year, 2009, was no exception, epilimnetic TP levels averaged 0.644 mg/l and soluble reactive phosphorus (srp) averaged 0.322 mg/L (Table 3). Algae blooms in Hammond were dense (Figure 3) throughout the season and secchi visibility was less than 2 feet (Table 3). All trophic status indicators were greater than 70 indicating hypereutrophic conditions (Table 3).

Throughout the sampling season the average hypolimnetic TP and srp concentrations were larger than the epilimnetic TP and srp concentrations in Hammond Lake (Table 3). Temperature did not differ significantly between the top and bottom of Hammond Lake. Dissolved oxygen was significantly lower in the bottom of the Hammond Lake, in particular in late July and throughout August. The west end of the lake had DO less than 1 mg/L (Table 3) while the east end appeared well oxygenated. The temperature and TP concentrations imply mixing in this shallow lake and hypolimnetic release of P. The severe anoxia on west end of the lake implies that the lake is not completely mixed from east to west

Total nitrogen concentrations averaged 2.4 mg/l in the Hammond Lake epilimnion. Total N was not measured in the hypolimnion. The TN concentration was more than twice the average concentration in Putters Pond (Table 4). In 2007 when Hammond was sampled throughout the season the TN averaged 3.0 mg/L which was significantly greater than the average TN in the other lakes (Big Bow, Hideaway, and Pit Pont). In 2007, the average TN in the other lakes ranged from 0.79 to 1.64 mg/l N (WQE report reference). Hammond has had significantly higher concentrations of both TN and TP than other Rock Island Lakes during 2007 and 2009. These elevated concentrations indicate a regular external source of N.

Putters Pond has a central, presumably porous berm that splits it into two lakes. The Putters Pond stations were located on different sides of the berm; PT1S was located in the south section and PT2N was located in the north section. Each half of Putters Pond had significantly different concentrations of TP, chlorides and chlorophyll a (Table 3). Most importantly the TP is significantly higher in the shallower southern portion of the lake. There was no significant difference between the srp concentration in the epilimnion and hypolimnion of the Putters Pond stations. Elevated TP and chlorides in the south section of the lake is probably from the very fine minerals solids that are rinsed off the mined material and discharged into the lake. The pump for the operation is located in the south section of the lake and appears to stir up the fine sediments on a regular basis.

Often the southern section of the lake was brown and cloudy. On August 17th this resulted in TP concentration in the hypolimnion of 0.132 mg/L which is significantly higher than during other sampling times (Appendix Table 9 A.4).

Hypolimnetic samples were collected from Putters Pond at depths of 21-24 feet at the south station (PT 1 S) and 62-70 feet at the north station (PT 2 N) (Figure 2) At station PT 1 S a thermocline developed with anoxic conditions below 24 feet (Table 3).

Putters Pond(s) had average TP and srp concentrations that were one order of magnitude lower than those measured in Hammond Lake (Table 4); average epilimnetic TP was 0.024 mg/l and average srp was 0.003 mg/L. There were no significant algae blooms and visibility averaged 9 feet in Putters Pond. The TSI for Putters Pond indicates a lake at the low end of eutrophic scale and upper end of mesotrophic scale (Table 4); conditions generally good for warm water fishes and similar to the other Rock Island lakes.

4.2.2 Discussion

Putters Pond is directly down gradient from the community of Rock Island and was expected to show elevated P since it should be in the flow path of leachate from all the septic systems in Rock Island. As discussed below in **Section 4.3.1** area wells are impacted by the septic systems and have elevated concentrations of both P and NO3-N; the average srp in groundwater wells was 0.156 mg/L; NO3-N averaged 9 mg/L. There are no elevated concentrations of srp in the either section of Putters Pond that indicates heavy P loading into Putters Pond from septic systems. The loading must be low enough that it is diluted to relatively low concentrations.

Putters Pond(s) are two to seven times deeper than Hammond Lake and should intercept the groundwater flow from Rock Island towards Hammond Lake. Based on the water quality of Putters Pond and proximity to the Columbia River, Hammond Lake would be expected to have good water quality. Conversely, Hammond has very high levels of TP and TN and is hypereutrophic. The elevated levels of TP and TN may be related to fertilizer use around the golf course.

In general shallow lakes such as Hammond Lake are either dominated by submerged aquatic plants and relatively clear water or dominated by algae with turbid waters (Cooke et al. 2005). Prior to a weed management program in Hammond Lake (Envirovison 2003), the lake was completely full of submerged aquatic plants. With the use of grass carp (*Ctenophryngodon idella*) and aquatic herbicides the submerged aquatic plants have been essentially eliminated (City of Rock Island 2008). The lake is now dominated by dense blue green algae blooms with high turbidity levels (Appendix Table 9.6 A6). The elevated P concentrations increase the problem of blue green algae blooms, turbidity, and frequency of anoxia in the lake.

The water elevation in the “tea cup” lakes in Rock Island increased about four feet in 1978 when the second powerhouse was installed on Rocky Reach Dam (WSU ref). This helped change the eutrophic wetland sloughs (WSU 1982) into shallow lakes. Putters, Big Bow, and Hideaway Lakes have developed into

mesotrophic slightly eutrophic (WQE 2007) lakes that support a good recreational warm water fishery. This most likely occurred due to past dredging operations that increased the depth of these lakes (personal communication, Whitey Evenhus).

In 1979, after the increase in water levels, the mean srp concentrations were about 0.18 mg/L in the sloughs that are now Hammond Lake (WSU 1982) versus 0.380 mg/L in 2009. The TP was not measured in the WSU (1982) study so there is not way to determine the increase in TP in the lake. Based on available date it is clear that srp concentrations in Hammond Lake have doubled over the last 30 years. This could only occur from external loads of P to the lake. The estimated increased P load between 1979 and 2009 based only on changes in srp concentration is about 390 lbs of P. This is most likely coming from septic systems, agriculture, golf course fertilization, and/or an old burn area near the lake.

The annual rate would be about an increase of 13 lbs/P per year. This is misleading since it assumes a linear increase which may not be the case. The P concentration may have increase very rapidly over the last 5 – 10 years as land management changed or the P retention capacity of the soils may have become saturated after many years of fertilizer use.

A review of data collected in the past three years shows that P concentrations increased significantly but not linearly. The average summer TP concentrations for 2007, 2008, and 2008 were 0.48, 0.23, and 0.67 mg/L TP. Total phosphorus in the summer has increased significantly and to levels that will cause dense blue green algae blooms, aesthetic problems, and at times a lethal environment for fish.

4.3 Groundwater P and Hydraulic Gradient around Hammond Lake

Groundwater P was tested in shallow irrigation wells and from piezometers placed in Putters Pond(s) and Hammond Lake. Water surface elevations were measured to understand directions of groundwater flow during sampling events. Results are discussed below.

4.3.1 Shallow well sampling to evaluate nutrients in groundwater up gradient of Hammond Lake and Putters Pond

Shallow cased irrigation wells on the eastern edge of the community (Figure 4) were sampled to help evaluate the concentration of NO3-N, TP, and srp in groundwater up gradient of Putters and Hammond Lakes.

Wells had average concentrations of TP and srp of 0.197mg/L and 0.157 mg/L respectively. (Table 4) Nitrate N was often greater than 10 mg/L. These concentrations are an order of magnitude greater than the P concentration measured in the south section of Putters Pond(s). The well P concentrations are much lower than concentrations measured in Hammond Lake (Tables 3 and 4).

Chlorides, P, and NO3-N are highest in the Barnett and Evenhus wells; elevated srp, NO3-N, and chloride levels indicate of contact with treated septic tank effluent. This is expected considering the high porosity and hydraulic conductivity of soils in the area. The porous soils in the area allow effluent from

septic systems to infiltrate rapidly before complete microbial removal or chemical reactions with soil particles. The high porosity and limited adsorptive capacity of the soil allow soluble nutrients such as srp to pass through soil particles without binding. In more ideal conditions, the reactive surface of soil particles binds soluble nutrients in septic effluent removing them from the wastewater before it enters the underlying aquifer.

4.3.2 Groundwater P and hydraulic gradient around piezometers

During all piezometer sampling events, the Rock Island Golf Course irrigation well was running continuously. According to John Roberts, grounds manager for Rock Island Golf Course, this is to irrigate the golf course and to help establish new turf on a recently renovated area. Since the irrigation pump was on 24/7 throughout June, July, and August, all piezometer samples were taken while the pump was on.

Water samples collected from all the piezometers had srp concentrations that were much lower than srp concentrations in Hammond Lake and shallow wells in Rock Island (Tables 3, 4, and 5). The TP concentrations in the piezometers were high due to the high content of silt in some of the samples. DO concentrations below 1.0 mg/L and pH significantly less than lake levels implied that samples collected were groundwater not lake water (Tables 5 and 9.A6).

Elevations of water surfaces on the Columbia River, Putters Pond, and Hammond Lake measured during each sampling day show that the hydraulic gradient was consistently towards Hammond Lake. Hammond Lake water surface was 0.8 to 0.9 feet lower than the Columbia River and about 0.2 feet lower than Putters Pond (Table 6) during the three sampling events.

The significant difference in elevation between the lakes and the Columbia River imply that there is no direct connection (i.e. culverts) between the lakes and the river. The berms under the railroad must be semi permeable and allow only slow water exchanges. This could also be deduced from the elevated levels of P in the lakes relative to the Columbia River.

Elevations were also measured on the inside and outside of each piezometer on the morning of each sampling event. Flow direction, either into or out of the lake, predicted from these elevation differences also showed that Hammond Lake should be gaining water from Putters Pond and the Columbia River (Table 7). The hydraulic gradient was small (< 1 inch) but consistent.

Figure 5 shows the general hydraulic gradient that was established during the summer sampling events. This gradient is consistent with hydraulic gradients measured during summer irrigation season during earlier studies of this area (WSU 1982).

All the elevation and water quality data shows that Hammond Lake is the low point in the drainage basin and has limited water exchanges with the Columbia River. Hammond Lake may be isolated from Putters and the Columbia River due to clay and/or bedrock below the lake. Both are present on the east end of the lake but the extents are not clear. A well at the east end of Hammond Lake shows a clay confining unit several feet (QAPP 2009) deep which could extend

beneath the lake limiting groundwater movement. Evaporation being the primary water loss would then concentrate nutrient levels in the lake over time.

Putters pond receives the groundwater from Rock Island before it flows into Hammond Lake but being much deeper with a cobble/sandy bottom it is also constantly diluted by the influx of river water. Hammond Lake with a very silty high organic bottom has limited groundwater movement and exchanges with the Columbia River.

4.4 External Loads of P Entering Hammond Lake and Putters Ponds

There are no surface water streams entering these lakes so the only potential external source is stormwater runoff (and snowmelt) and groundwater contaminated by agricultural use of P, septic systems, or an old burn site north of Hammond Lake. Rock Island, located up gradient of both lakes, is an agricultural community with orchards throughout town and does not have a centralized sewer system. The sandy gravel soils in the area are conducive to pollution of groundwater from septic systems and residential and agricultural use of fertilizers. Historically wells around Rock Island have had elevated concentration of nitrates and srp (WSU 1982).

4.4.1 Evaluation of an old burn site

An old community burn site is located about 100 yards north of Hammond Lake (Figure 2). The land is currently maintained as open non irrigated land which has not been used for burning for several decades; it was an area commonly used for disposing and burning trash (personal communication, Whitey Evenhus 2009). Total phosphorus, water soluble P (bicarbonate extractable), and pH were on end of the optimum range for orchard soils Chelan and Douglas County (Table 9). Water soluble phosphorus concentrations between 8 – 20 mg/kg are considered optimum for orchards and natural for Chelan and Douglas Counties (personal communication, Tim Smith).

Since nutrients are in a good range for plant growth it may be beneficial to raise a crop of hay so the nutrients could be beneficially harvested from the site. Hay would also provide a cover crop that would minimize runoff from the site.

4.4.2 Impacts of golf course septic system

Rock Island Golf Course has a gravity fed septic drainfield for the Clubhouse which has a restaurant and restrooms for golfers and employees. The design (4 – 85 foot long drainfields) permitted and built in 1980 was for the clubhouse and restaurant with a seating capacity for 40 people and serving approximately 100 meals. The design flow and soil assessment is not available in the Chelan Douglas Health District records; Per the County Soil Survey (NRCS 2007), the soil in the drainfield is probably a fine sandy loam (Cashmont series) or a sandy fine loam (Quincy Series). The drainfield was probably designed for a maximum daily flow of about 600 gallons per day.

The load from the septic system is estimated assuming an average of 450 gallons per day, an average TP concentration of 6 mg/L in septic tank effluent, and retention of at least 50% of the daily phosphorus load (ref Pio Lombardo for P retention in alkaline soils). With these assumptions the net annual load would be approximately 1.7 lbs of P per year. This would result in a net annual increase of about 0.002 mg-P/L in Hammond Lake. The fine soils around

Hammond Lake probably retain more phosphorus than is estimated. Assuming 50% retention is a reasonable estimate for this area. Annual loads have a relatively small impact on an annual basis but in the long term annual loading may be significant.

4.4.3 External P loads from fertilizer applications to orchards and golf course

4.4.3.1 Orchard Fertilizer Management

Aerial photo analysis was conducted to estimate the land area in orchards in Rock Island. Orchards were identified using Google Earth and acreage was calculated using the NRCS Web Soil Survey program. (http://websoilsurvey.nrcs.usda.gov/) A total of 491 acres of orchard land was estimated within the Rock Island watershed area (Figure 1). Tim Smith of the WSU Extension Service does not recommend any application of P to the orchards but he is aware that some orchards apply small amounts in leaf feeding programs. He estimated that these amounts would be 1-2 lbs/acre/year. Assuming that every orchard utilized leaf feeding, and that the trees had minimal uptake, this would add up to 500-1000 lbs of P per year. Mr. Smith also suggested that very occasionally, orchards might apply upwards of 100 lbs/year to an area. Such applications are not encouraged by WSU and only occur in areas that have sandy soil with few nutrients.

Leaves are not harvested from orchards so presumably applied P stays in the soils and is recycled and/or leaches to groundwater. The majority of the orchards are west of Hammond Lake and Putters Pond(s). Any impact from fertilizer use is assumed to be measured in wells on the east end of town. The groundwater moving east under town does have elevated P, some of which is from agriculture, and causes and increase in P concentrations in Putter(s) Ponds.

Overuse of P fertilizer may have a significant impact on the lakes in the Rock Island area. The orchards directly north of Hammond may have the greatest impact on Hammond Lake (Figure 1). The owner of those orchards should be encouraged to sample the soil regularly to avoid excess use of fertilizer. If or when the land is converted to housing, stormwater should not be directly discharged to the lake and P fertilizer should be used sparingly around the lake.

4.4.3.2 Golf Course Fertilizer Management

Golf Course grounds manager, John Roberts, reported that fertilizers containing 3 percent phosphorus (P) are applied to the greens and the fairways. The fertilizer is applied at a rate of 850 total lbs a year to the greens and 10,000 total pounds to the fairways. This is equivalent to application of about 325 pounds of P in the drainage area around Hammond Lake. This correlates to application rates of 10.2 lbs P/acre/yr to the greens and 12 lbs P/ac/yr to the fairways. In 2009, however, the usual fairways fertilizing regiment was suspended while 4 acres of new turf was established at the Rock Island Golf Course. The new turf had a spring application of 10% P fertilizer corresponding to 23.7 lbs P/acre/year.

Where homeowners and agricultural applications will often apply a large amount of fertilizer once or twice per year, golf courses often apply smaller doses more regularly throughout the growing season. This should minimize the danger of losing nutrients N to runoff during storm events or snow melt. The Rock Island Golf Course applies fertilizer every 4-6 weeks indicating that they are most likely following this form of management.

Soil tests for this area generally show that there is sufficient P in the soils. In addition there is no collection of grass clipping so all P applied to the soils are staying in the soil to decompose and leach into the groundwater and lake. The shallow groundwater and heavy application of P fertilizer is most likely resulting in significant P loads to Hammond Lake.

If it is estimated that 25% of the fertilizer P enters Hammond Lake then increase in lake concentration is estimated to be 0.097 mg/L P; which is equivalent to 81 lbs P/yr. It is not unreasonable to estimate that 50% of the P ends up in Hammond Lake. In this case the increase in P concentration would be about 0.195 mg/L; which is equivalent to 163 lbs P/yr. The net load is uncertain but it is clear that fertilizer management has potential to cause significant impact to the lake water quality.

An incidental load from the golf course is from the flocks of Canada geese that use the golf course for food, refuge, and a large litter box. Over wintering geese leave large amount of feces that can be washed into the lake during late winter and spring snow melt. These impacts can have significant impacts on water quality (Fleming and Fraser 2001).

4.5 Internal Phosphorus Loading from Resuspension of Sediment

In general P entering a lake settles to the sediment where it becomes isolated from the water column. It is generally stored in residual organic compounds or in low solubility chemical complexes. The P may become available by biological and chemical processes that cause the release of the phosphorus. The anaerobic or aerobic processes that cause the release of P from the sediment also cause the internal loading to a lake. These processes commonly results in elevated concentrations of P in the water column.

Internal loading from anaerobic release of P occurs in lakes that become thermally stratified. Thermal stratification develops a deep cooler portion of the lake without dissolved oxygen which leads to dissolution of iron phosphates. In late July and early August 2009, the west end of Hammond Lake did have DO concentrations less than 0.18 mg/L and srp was greater in the hypolimnetic samples indicating hypolimnetic release. In general, Hammond Lake is a shallow lake that was not thermally stratified and was generally well oxygenated throughout the water column (Table 3). Both anaerobic release and aerobic release may be occurring in the lake.

Significant amounts of phosphorus can still be released from sediments in shallow, well mixed, aerobic lakes (Cooke and Welch 2005). The primary mechanism for internal loading in Hammond Lake is most likely aerobic release since the lake was not thermally stratified, was generally well oxygenated and had very high concentrations of srp throughout the water column for the entire sampling season. Although P release rate from aerobic sediment is less than that from anaerobic

sediment, all of the P released is available to algae in the photic zone. This appears to be occurring in Hammond Lake.

The approximate annual internal load, based on lake volume (estimated to be 380,360 m^3) and P concentration (using 0.6 mg/m^3) is 502 lbs P. This is larger than any of the external load estimates. However it is important to recognize the internal P loads will increase with each annual external P load.

The sediment is very fine; more than 70% of all solids pass the number 200 sieve (Table 8). That means that the majority of the sediment is fine silt or clay that can be easily resuspended. About 2/3 of the P is bound in the sediment in aluminum and calcium precipitates. The remaining 1/3 is most likely bound in organic matter and fine mineral particles that are easily resuspended. The organic fraction may be relatively high based on the 13% volatile fraction in the sediment (Table 8) and the recent lake wide elimination of submerged aquatic plants (City of Rock Island 2008). The aquatic plants were not removed from the lake will represent a significant source of organic bound P in the lake.

The sediment in Hammond Lake has very low levels of loosely bound and iron bound phosphorus (Table 9). Normally these two forms of sediment P are significant sources of internal loading that can be remedied with addition of aluminum sulfate (alum). Since these forms of sediment P are so low, alum may have minimal effect on internal loading from sediment P release but alum addition would be useful for precipitating P out of the water column and binding the P in the sediment.

If alum were applied high concentrations of P would be required to form large rapid settling floc. Jar tests should be done on the lake water to determine the optimal dose of alum and potential for resuspension of the floc. Resuspension is a concern because it may allow continued aerobic internal loading.

5 RECOMMENDATION FOR MANAGEMENT OF EXTERNAL AND INTERNAL LOADS OF P

A public sewer and treatment facility for Rock Island is planned for construction in 2010. Therefore any long term loads from the community septic systems will be eliminated. This should improve water quality in Putters Ponds and Hammond Lake. It may take a decade or more for the P to flush out of the soils and groundwater in the area.

Other actions should be taken to reduce external loads to the lakes. Remaining sources and recommendations for reducing the external load is discussed below.

5.1 Reducing External Loads from Golf Course Fertilizer

Golf course fertilizer and geese feces are large source of P entering Hammond lakes and may be relatively easily reduced.

A management technique used by many golf courses is only applying fertilizer where it is needed in an effort to save money. The logic of this strategy is that if the turf does not need phosphorus it will cost less money to apply a P-free fertilizer to the turf. Soil tests should be conducted across the Rock Island Golf Course to establish whether the fertilizers need to include P or if the soil currently has adequate levels of P for the turf.

Also turf grass generally needs very little P to maintain growth. While phosphorus applications can be very useful in establishing turf, the University of Illinois Turfgrass Extension service indicates that once established, turf needs little to no P input. At this point, it could be worthwhile for the Rock Island Golf Course to switch to a P-free fertilizer. Lake Oswego Lake Association in Oregon markets their own P free fertilizer to residents to minimize residential P loads.

Efforts should be taken to minimize use by the Canada geese. Course managers should talk with local Washington State Wildlife personnel to find out what techniques have been tried in this area and which are successful. There are also numerous sites on the internet with advice and techniques.

5.2 Reducing External Loads from Golf Course septic system

The septic system drain field is a long term concern as a P source. The drainfield should be relocated and replaced with a pressurized drain field that will optimize the soils capacity to remove phosphorus. Alternately a treatment unit could be installed that will remove P prior to discharge to the drain field.

5.3 Reducing External Loads from Old Burn Site

Concentrations of water soluble P are on the high end of the optimum range (Table 9) in these soils. A cost effective method to reduce P in these soils would be to raise a crop of alfalfa or other hay. The hay will take up P that can be removed from the site with harvest. It will also provide a cover crop that may reduce runoff from the site. Irrigation water should be well managed to minimize flushing P to groundwater or causing runoff.

5.4 Reducing Internal Loads by Dredging Hammond Lake

Dredging removes P rich sediments from the bottom of the lake so they are no longer available for internal recycling. This is a permanent solution that combined with reduction of external P loads will have significant long term impacts on water quality.

Dredging Hammond Lake, a thirty four acre lake, would be a large project. At a minimum a dredging operation would need to remove the top 6 – 12 inches deep of fine lake sediment. This is equal to about 17 - 34 acre-feet (27,000 - 55,000 cubic yards) that would need to be removed. The very fine sediment would need to be dewatered to reduce haul costs and may be best used as a soil amendment for land application.

Given the proximity to a sand and gravel pit it may be cost effective to dredge sand and gravel from the west end of Hammond Lake. Deeper excavation of the lake bottom would create better fish habitat and may provide useful building materials. Well logs on the west end of the lake (Appendix A.8) show that at least the west end of Hammond Lake may has potential for sand and gravel mining.

Additional planning should be completed to develop a detailed evaluation of the costs and benefits that may be involved in dredging the lake.

5.5 Reducing Internal Loads by Addition of Aluminum Sulfate (Alum)

Alum is a chemical that forms low solubility precipitates of P and aluminum. With an application the majority of the P is removed from the water column and settles to the bottom where it is no longer bioavailable. Jar tests should be done to determine the

optimum concentration of alum. The laboratory tests can also be used to determine the amount of chemical required to buffer the water against the natural reduction in pH that occurs in poorly buffered water. The alum and buffer can be applied to a lake from the back of a boat.

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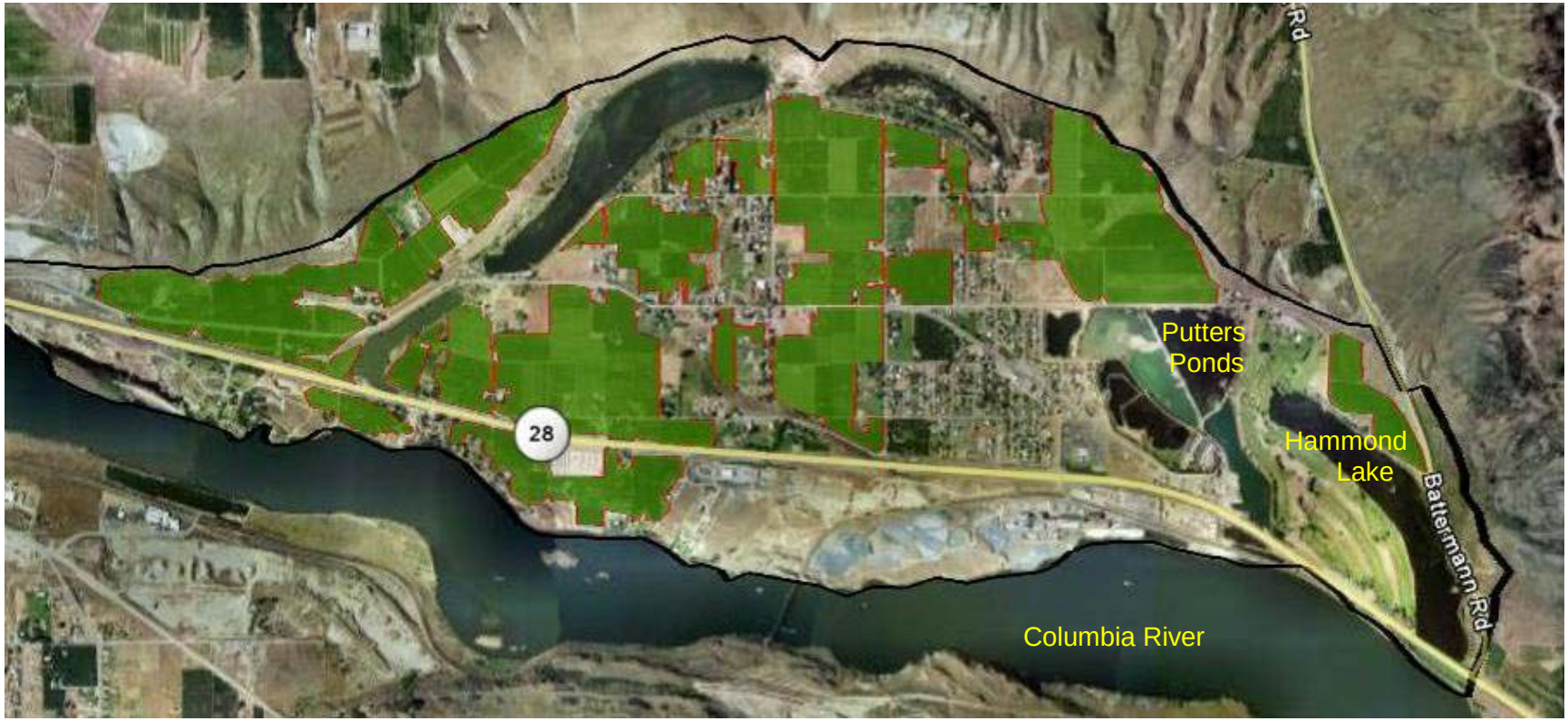
7 FIGURES

Figure 1. Aerial photo of the City of Rock Island, Washington and location of lakes and ponds sampled in this study.



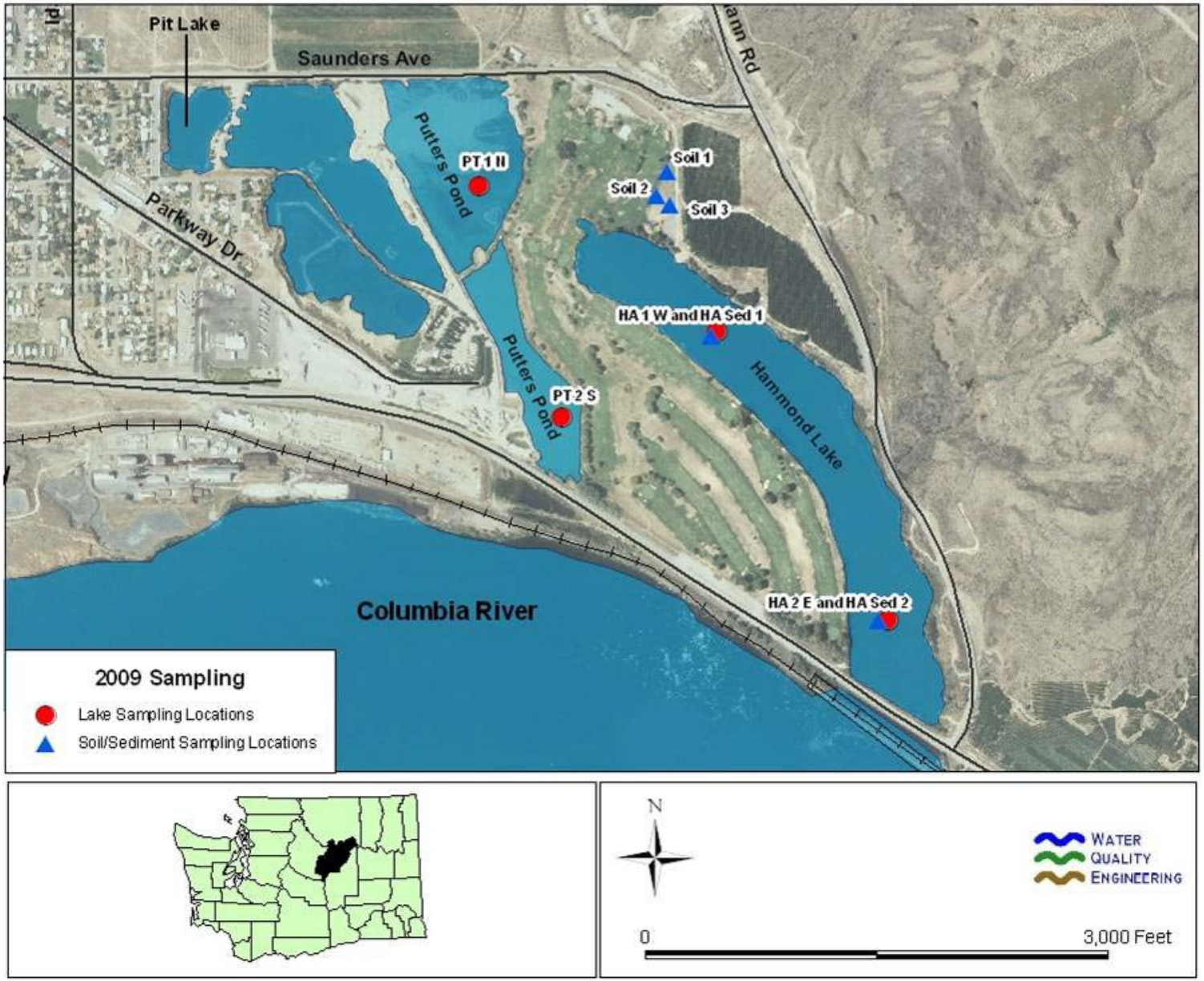


Figure 2. Water and sediment sample sites in Hammond Lake and Putters Ponds and soil sample site at old burn site.

Figure 3. Dense blooms of blue green algae were common throughout the summer in Hammond Lake.

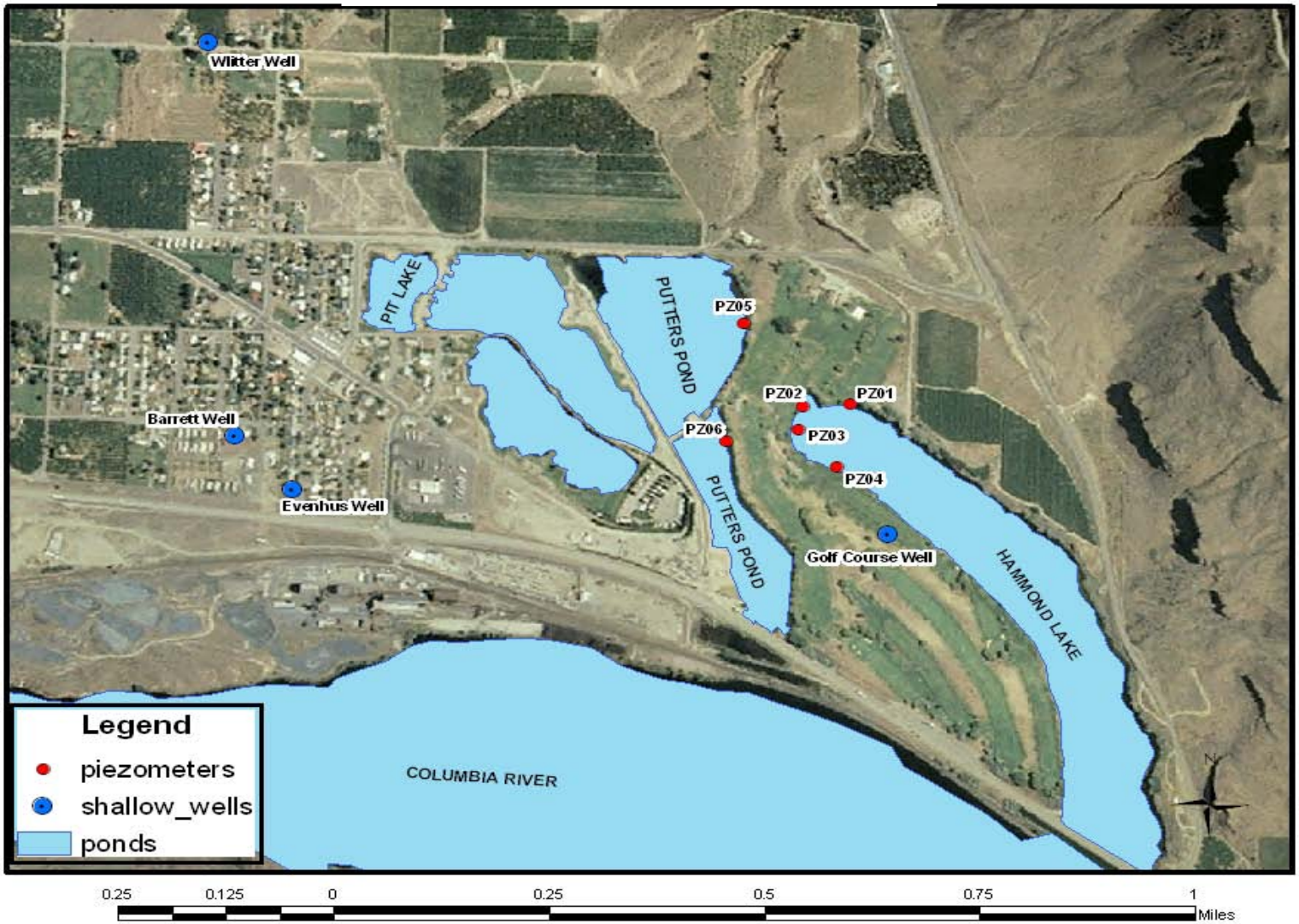


Figure 4. Location of piezometers and wells sampled in 2009

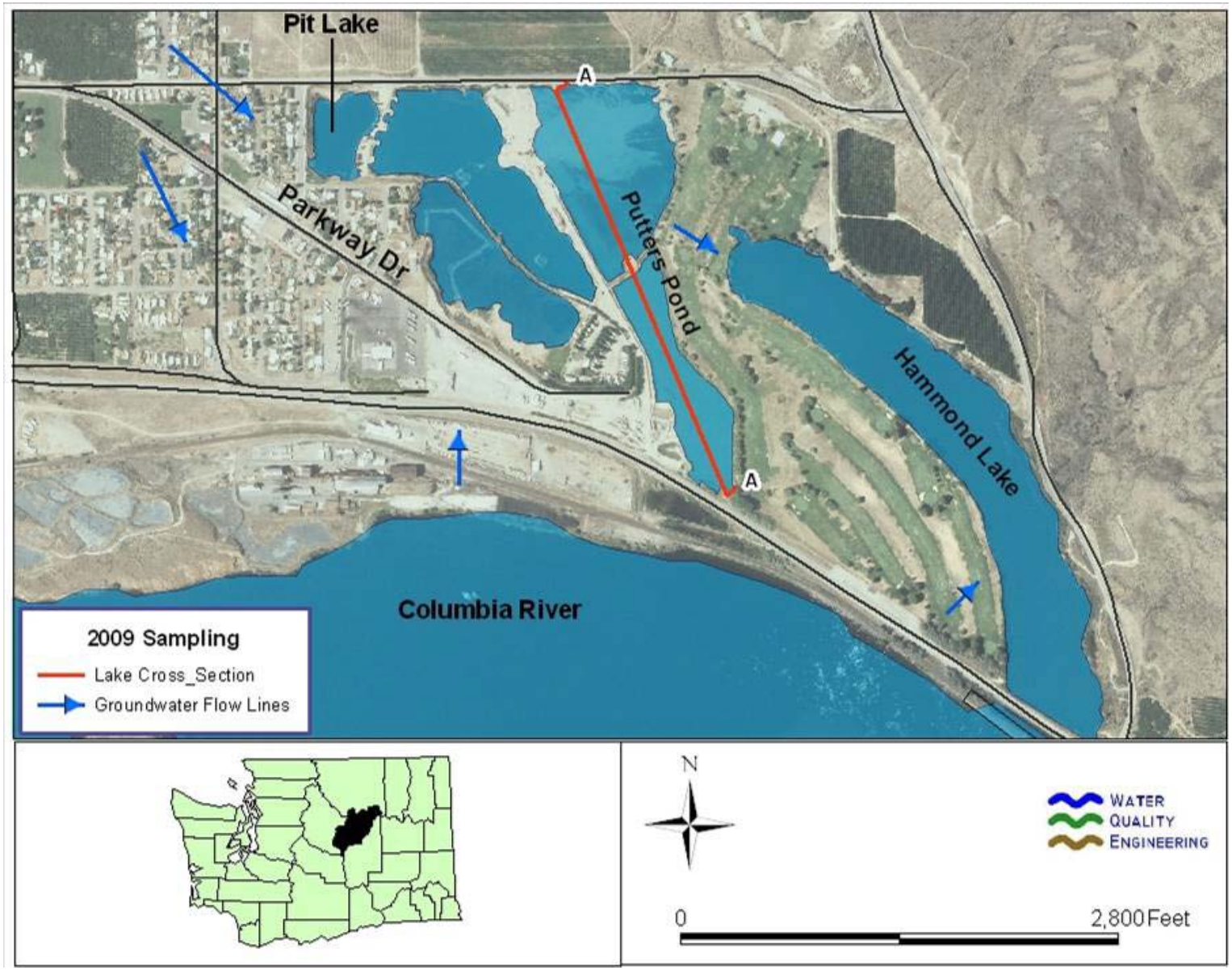


Figure 5. General direction of hydraulic gradient between City of Rock Island, the Columbia River, Putters Ponds, and Hammond Lake.

8 TABLES

Table 1. Relative Percent Difference (RPD) for field replicates for lake water samples.

Sample	Total P	SRP	Total N	Cl	Chl-a	Phaeo-a
Reporting Limit (RL)	10 ug/L	1 ug/L	50 ug/L	0.5 mg/L	0.1 ug/L	0.1 ug/L
Hammonds Lake						
6/11/2009	0.9%	17.4%	11.0%	1.1%	ns	ns
7/2/2009	11.1%	10.7%	ns	0.6%	ns	ns
7/23/2009	16.0%	3.8%	ns	1.6%	ns	ns
8/4/2009	7.1%	4.8%	ns	1.6%	ns	ns
9/9/2009	0.1%	1.8%	ns	ND	1.9%	13.9%
9/21/2009	3.3%	7.4%	ns	3.5%	ns	ns
10/1/2009	6.2%	2.2%	3.8%	1.2%	ns	ns
Putters Pond						
6/23/2009	2.5%	ns	0.3%	0.9%	ns	ns
7/13/2009	0.0%	ns	4.4%	4.4%	ns	ns
8/17/2009	80.9%	40.0%	ns	1.2%	ns	ns
8/27/2009	25.0%	ns	ns	2.5%	ns	ns
10/13/2009	0.0%	66.7%	1.7%	1.1%	7.7%	8.7%

Table 2. Relative Percent Difference (RPD) for replicate water samples from wells and piezometers.

Sample	Total P	SRP	N03+N02	Cl	DO	pH	Temp
Date	mg/L	mg/L	mg/L	mg/L	mg/L		C
Piezometers							
7/23/2009	35.9%	0.0%	NA	1.8%	3.6%	0.1%	0.9%
8/13/2009	9.1%	20.0%	1.6%	3.4%	7.3%	0.6%	0.5%
9/1/2009	9.2%	2.5%	6.6%	7.4%	2.2%	1.0%	0.5%
Rock Island Wells							
7/30/2009	1.7%	1.1%	11.4%	6.9%	4.3%	1.3%	1.0%
8/27/2009	2.6%	4.8%	8.9%	9.5%	1.3%	1.0%	0.7%

Table 3. Average nutrients and field parameters for Hammonds Lake and Putters Pond (Putters Pond is presented as north and south sections since depth and water quality differed significantly; alpha =0.05).

	Total P	SRP	Total N	Cl	Chl-a	DO	pH	Temp	Secchi
	mg/L	mg/L	mg/L	mg/L		mg/L	ug/L	C	ft
Hammonds Lake									
Epilimnion									
Average	0.644	0.322	2.41	17.7	101.4	8.1	9.0	19.6	1.7
STD	0.072	0.063	0.52	0.6	81.3	2.1	0.2	3.5	0.2
TSI	97	--	--	--	75.9	--	--	--	70
Hypolimnion									
Average	0.696	0.360	ND	17.7	ND	5.6	8.9	20.5	ND
STD	0.08	0.07	ND	0.6	ND	3.6	0.2	2.3	ND
North Putters Pond									
Epilimnion									
Average	0.013	<0.001	0.93	18.5	3.1	9.6	8.8	21.7	6.3
STD	0.005	<0.001	0.41	0.8	2.0	0.4	0.2	1.5	2.3
TSI	41	--	--	--	41.8	--	--	--	51
Hypolimnion									
Average	0.019	0.005	ND	16.5	ND	2.1	7.5	9.4	ND
STD	0.007	0.004	ND	0.3	ND	1.6	0.4	0.5	ND
South Putters Pond									
Epilimnion									
Average	0.035	0.003	0.75	25.0	13.6	8.5	8.4	20.8	2.0
STD	0.013	0.002	1.00	1.4	10.7	0.6	0.1	1.7	0.9
TSI	55	--	--	--	56.2	--	--	--	66
Hypolimnion									
Average	0.060	0.004	ND	23.9	ND	1.0	7.6	17.1	ND
STD	0.032	0.005	ND	0.4	ND	0.7	0.1	1.8	ND

Trophic Status Index calculated with following equations (Wetzel 2001)

TSI(TP) = 14.42 ln(TP) + 4.15, units, ug/L

TSI(CHL) = 9.81 ln(CHL) + 30.6, units ug/L

TSI(SD) = 60 - 14.41* ln(SD), units, meters

Table 4. Water quality data from wells sampled in Rock Island area.

Sample ID	Sample Date	Total P mg/l	SRP mg/l	NO3+NO2 mg/l	Cl mg/l	DO mg/L	pH	Temp C
Barrett Well	7/30/2009	0.233	0.184	11.6	23.3	4.8	7.2	18.7
Barrett Well	8/27/2009	0.251	0.206	12.0	24.4	4.1	7.3	21.1
Evenhus Well	7/30/2009	0.263	0.193	12.3	28.3	6.7	7.3	14.7
Evenhus Well	8/27/2009	0.268	0.222	13.2	29.9	5.6	7.2	15.0
Golf Course Well	7/30/2009	0.116	0.083	1.2	18.0	3.5	7.5	17.8
Golf Course Well	8/27/2009	0.207	0.156	0.6	18.2	0.6	7.0	16.5
Witter Well	7/30/2009	0.119	0.094	9.1	8.2	4.8	7.1	19.2
Witter Well	8/27/2009	0.130	0.121	10.3	8.8	3.7	7.3	17.0

Table 5. Water quality data from piezometers.

Sample ID	Sample Date	Total P mg/l	SRP mg/l	N03+N02 mg/l	Chloride mg/l	DO mg/L	pH	Temp C
PZ 01	7/23/2009	5.510	0.002	<0.010	13.9	0.8	6.6	23.8
PZ 01	8/13/2009	9.990	0.003	0.079	12.8	1.4	6.4	21.9
PZ 01	9/1/2009	4.010	0.005	0.077	10.8	0.9	6.7	20.8
Average		**6.503**	**0.003**	**0.078**	**12.5**	**1.0**	**6.6**	**22.2**
PZ 02	7/23/2009	2.430	0.007	0.044	70.5	0.5	6.8	20.8
PZ 02	8/13/2009	2.410	0.003	0.062	63.8	0.6	6.9	20.5
PZ 02	9/1/2009	1.900	0.005	0.070	70.3	0.5	6.9	20.5
Average		**2.247**	**0.005**	**0.059**	**68.2**	**0.5**	**6.9**	**20.6**
PZ 03	7/23/2009	0.511	0.057	0.556	14.2	0.6	7.2	18.6
PZ 03	8/13/2009	0.724	0.044	0.564	14.8	0.6	7.1	18.3
PZ 03	9/1/2009	0.436	0.039	0.442	15.5	0.5	7.3	18.6
Average		**0.557**	**0.047**	**0.521**	**14.8**	**0.5**	**7.2**	**18.5**
PZ 04	7/23/2009	0.530	0.009	2.560	10.6	0.8	7.2	20.1
PZ 04	8/13/2009	0.021	0.011	2.440	11.9	0.9	7.7	20.7
PZ 04	9/1/2009	0.110	0.010	2.680	11.2	0.6	7.4	20.1
Average		**0.220**	**0.010**	**2.560**	**11.2**	**0.7**	**7.4**	**20.3**
PZ 05	7/23/2009	0.476	0.013	0.035	20.3	0.6	7.2	23.4
PZ 05	8/13/2009	0.472	0.007	0.038	18.3	0.5	7.0	21.1
PZ 05	9/1/2009	0.386	0.008	0.014	17.7	0.4	7.2	22.4
Average		**0.445**	**0.009**	**0.029**	**18.8**	**0.5**	**7.1**	**22.3**
PZ 06	7/23/2009	1.780	0.005	0.010	38.8	0.6	6.8	21.4
PZ 06	8/13/2009	2.100	0.003	0.050	35.4	0.5	7.1	23.1
PZ 06	9/1/2009	1.210	0.007	0.048	27.8	0.5	7.1	20.9
Average		**1.697**	**0.005**	**0.036**	**34.0**	**0.5**	**7.0**	**21.8**

Table 6. Surveyed elevations of water surfaces of Hammond Lake, Putters Pond, and Columbia River during piezometer sampling in June, July and August.

Date	Water Body/	Elevation	Difference in elevations
7/10/2009	Columbia River	616.74	0
	Putters Pond	616.04	-0.7
	Hammond Lake	615.82	-0.92
8/23/2009	Columbia River	616.49	0
	Putters Pond	615.96	-0.53
	Hammond Lake	615.74	-0.75
9/1/2009	Columbia River	616.7	0
	Putters Pond	616.01	-0.69
	Hammond Lake	615.79	-0.91

Table 7. Relative elevation in and outside of piezometers and recharge condition at piezometers during sampling.

Date	Piezometer Number	DTW, in	D, in	dh, inches	Loosing/ Gaining
Hammond Lake					
7/10/2009	PZ01	18.63	18.38	0.25	Loosing Water
8/13/2009	PZ01	19.88	19.63	0.25	Loosing Water
9/1/2009	PZ01	19.50	19.13	0.38	Loosing Water
Average		**19.33**	**19.04**	**0.29**	**Loosing Water**
7/10/2009	PZ02	21.13	21.13	0.00	
8/13/2009	PZ02	21.88	22.00	-0.13	Gaining Water
9/1/2009	PZ02	21.25	21.25	0.00	
Average		**21.42**	**21.46**	**-0.04**	**Gaining Water**
7/10/2009	PZ03	22.38	22.75	-0.38	Gaining Water
8/13/2009	PZ03	23.00	23.75	-0.75	Gaining Water
9/1/2009	PZ03	22.50	23.13	-0.63	gaining Water
Average		**22.63**	**23.21**	**-0.58**	**Gaining Water**
7/10/2009	PZ04	21.88	23.50	-1.63	Gaining Water
8/13/2009	PZ04	21.75	23.88	-2.13	Gaining Water
9/1/2009	PZ04	21.25	23.06	-1.81	Gaining Water
Average		**21.63**	**23.48**	**-1.85**	**Gaining Water**
Putters Pond					
7/10/2009	PZ05	21.75	21.25	0.50	Loosing Water
8/13/2009	PZ05	22.13	22.25	-0.13	Gaining Water
9/1/2009	PZ05	22.13	22.25	-0.13	Gaining Water
Average		**22.00**	**21.92**	0.08	**Loosing Water**
7/10/2009	PZ06	32.00	32.00	0.00	
8/13/2009	PZ06	32.75	32.44	0.31	Loosing Water
9/1/2009	PZ06	32.25	32.25	0.00	
Average		**32.33**	**32.23**	0.10	**Loosing Water**

DTW = Depth to water surface inside piezometer
D = Depth to lake water surface (outside of piezometer)
dh = DTW - D

Table 8. Sediment samples from Hammond Lake – Solids content and volatile fraction.

Sample ID		Date	%Solids	%Water	%VS
HA 1.08 SED		7/30/2009	16.24	83.76	13.28
HA 1.08 SED	Replicate	7/30/2009	15.61	84.39	16.25
HA 2.09		7/30/2009	21.37	78.63	14.94

Table 9. Sediment samples from Hammond Lake – Total phosphorus and forms of predominant phosphorus compounds in sediment.

Sample ID	Sample Date	TP mg/kg	NH4CL mg/kg Loosely Bound P	DITHIONATE mg/kg FE Bound P	NAOH mg/kg AL Bound P	HCL mg/kg CA Bound P
HA 1.08 SED	7/30/2009	1013	<2.00	4.07	134	501
HA 1.08 SED	7/30/2009	1003	<2.00	3.9	153	536
HA 2.09	7/30/2009	990	<2.00	12	137	572

Table 10. Data from analysis of soils from old burn site on the north side of Hammond Lake.

Sample ID	pH	TP mg/kg	Bicarbonate P mg/kg	As mg/kg
1	7	845	19.9	29.1
2	7.6	740	16.3	24.2
3	7	795	14.3	32

9 APPENDIX

9.1 Table A1. Surveyed elevations of piezometers and surface waters.

Sample	Water Body/	With/Without	Cap		Gradient to
Date	Piezometer	Cap	Thickness	Elevation	Columbia River
7/10/2009	Columbia River			616.74	0
	Putters Pond			616.04	-0.7
	Hammond Lake			615.82	-0.92
	PZ01	Without		617.35	
	PZ02	Without		617.57	
	PZ03	Without		617.71	
	PZ04	Without		617.82	
	PZ05	Without		618.69	
	PZ06	Without		617.82	
8/23/2009	Columbia River			616.49	0
	Putters Pond			615.96	-0.53
	Hammond Lake			615.74	-0.75
	PZ01	With		617.39	
	PZ02	With		617.62	
	PZ03	With		617.74	
	PZ04	With		617.79	
	PZ05	With		617.74	
	PZ06	With		617.85	
9/1/2009	Columbia River			616.7	0
	Putters Pond			616.01	-0.69
	Hammond Lake			615.79	-0.91
	PZ01	With		617.39	
	PZ02	With		617.62	
	PZ03	With		617.74	
	PZ04	With		617.79	
	PZ05	With		618.74	
	PZ06	With		617.85	

9.2 Table A2. Hammond Lake epilimnion data

Sample ID	Sample	Total P	SRP	Total N	Cl	Chl-a	Phaeo-a	Secchi
	Date	mg/L	mg/L	mg/L	mg/L	ug/L	ug/L	ft
Epilimnion								
HA 1.03 W	6/11/2009	0.579	0.33	1.83	17.3	75	1.7	3.0'
HA 1.03 W	6/23/2009	0.541	0.277	2.71	17.1	155	2.1	2.5'
HA 1.03 W	7/2/2009	0.505	0.274	2.18	17.9	73	4	2'
HA 1.03 W	7/13/2009	0.587	0.296	2.54	17.8	78	8.6	1.5
HA 1.03 W	7/23/2009	0.66	0.407	2.34	17.9	55	7.4	9'
HA 1.03 W	8/4/2009	0.75	0.329	3.22	18.2	88	16	1.25'
HA 1.03 W	8/17/2009	0.638	0.26	2.35	18.2	107	11	1.5'
HA 1.03 W	8/27/2009	0.706	0.316	ND	17.7	94	5.4	1.8
HA 1.03 W	9/9/2009	0.673	0.193	1.96	17.9	66	2.7	2'
HA 1.03 W	9/21/2009	0.724	0.404	2.16	16.7	60	4.1	1.8
HA 1.03 W	10/1/2009	0.719	0.44	2.09	16.5	61	6.5	1.8
HA 1.03 W	10/13/2009	0.64	0.361	2.01	16.7	72	4.3	1.5'
HA 2.03 E	6/11/2009	0.61	0.292	2.05	17.6	174	1.4	2.0'
HA 2.03 E	6/23/2009	0.686	0.283	3.88	17.8	428	<0.1	1.5'
HA 2.03 E	7/2/2009	0.578	0.286	3.39	17.9	91	5.5	1.83
HA 2.03 E	7/13/2009	0.64	0.279	2.42	18.7	113	4.5	1.2
HA 2.03 E	7/23/2009	0.602	0.347	2.23	18	42	6	10'
HA 2.03 E	8/4/2009	0.607	0.29	2.34	18.2	ND	ND	1.5
HA 2.03 E	8/17/2009	0.563	0.256	2.12	17.9	83	10	1.75'
HA 2.03 E	8/27/2009	0.694	0.349	ND	18.7	83	3.8	1.75
HA 2.03 E	9/9/2009	0.683	0.381	2.07	17.7	53	4.7	3.3'
HA 2.03 E	9/21/2009	0.792	0.432	2.38	16.8	79	4.3	1.8
HA 2.03 E	10/1/2009	0.731	0.439	2.08	16.8	69	6.7	1.8
HA 2.03 E	10/13/2009	0.662	0.414	1.78	16.2	66	4.1	1.5'
Average		**0.649**	**0.331**	**2.37**	**17.59**	**98.48**	**5.67**	**1.67**

9.3 Table A3. Hammond Lake hypolimnion data

Sample ID	Sample	Total P	SRP	Total N	Cl	Chl-a	Phaeo-a	Secchi
Hypolimnion								
HA 1.09 W	6/11/2009	0.611	0.382		17.7			
HA 1.08 W	6/23/2009	0.55	0.29		17.7			
HA 1.08 W	7/2/2009	0.56	0.339		17.8			
HA 1.08 W	7/13/2009	0.644	0.328		18.8			
HA 1.08 W	7/23/2009	0.836	0.555		17.7		Max TP&SRP	
HA 1.08 W	8/4/2009	0.786	0.373		17.7			
HA 1.08 W	8/17/2009	0.701	0.27		18			
HA 1.08 W	8/27/2009	0.796	0.369		18			
HA 1.08 W	9/9/2009	0.808	0.375		17.9			
HA 1.08 W	9/21/2009	0.732	0.426		17.2			
HA 1.08 W	10/1/2009	0.744	0.43		17.4			
HA 1.09 W	10/13/2009	0.678	0.404		16.3			
HA 2.09 E	6/11/2009	0.619	0.294		17.9			
HA 2.09 E	6/23/2009	0.672	0.283		17.7			
HA 2.09 E	7/2/2009	0.598	0.326		17.3			
HA 2.09 E	7/13/2009	0.655	0.288		18.1			
HA 2.09 E	7/23/2009	0.722	0.35		18.4			
HA 2.09 E	8/4/2009	0.802	0.386		18.4			
HA 2.09 E	8/17/2009	0.621	0.277		17.4			
HA 2.09 E	8/27/2009	0.708	0.346		18.4			
HA 2.09 E	9/9/2009	0.686	0.393		17.1			
HA 2.09 E	9/21/2009	0.789	0.439		17.1			
HA 2.09 E	10/1/2009	0.748	0.453		17.2			
HA 2.10 E	10/13/2009	0.667	0.416		16.7			
	Average	**0.697**	**0.366**		**17.66**			

9.4 Table A4. Putters Pond – South section data

South Putters Pond Nutrient Data

Sample ID	Sample Date	Total P mg/L	SRP mg/L	Total N mg/L	Cl mg/L	Chl-a ug/L	Phaeo-a ug/L	Secchi Depth ft
Epilimnion								
PT 1.03 S	6/11/2009	0.017	<0.001	2.85	23.4	2.1	2.3	3.5
PT 1.03 S	6/23/2009	0.039	<0.001	0.304	23.1	3.7	4.1	1.25
PT 1.03 S	7/13/2009	0.038	0.002	0.319	25.1	8.5	5.7	1.5
PT 1.03 S	7/23/2009	0.056	0.002	0.43	25.2	9.6	5	2.2
PT 1.03 S	8/17/2009	0.029	0.002	0.516	27	26	2.8	1.5
PT 1.03 S	8/27/2009	0.022	<0.001		25.9	28	2.3	3.5
PT 1.03 S	9/9/2009	0.04	0.005	0.439	25.5	21	3.1	1.6
PT 1.03 S	10/13/2009	0.039	0.003	0.421	24.9	9.6	4.6	1.25
Average		**0.035**	**0.003**	**0.754**	**25.0**	**13.6**	**3.7**	**2.**
Hypolimnion								
PT 1.20 S	6/11/2009	0.036	<.001		23.3			
PT 1.25 S	6/23/2009	0.049	0.002		23.2			
PT 1.23 S	7/13/2009	0.051	0.002		24.1			
PT 1.21 S	7/23/2009	0.057	0.001		23.9			
PT 1.21 S	8/17/2009	0.132	0.013		23.6			
PT 1.23 S	8/27/2009	0.045	<0.001		23.9			
PT 1.24 S	9/9/2009	0.07	0.004		24.1			
PT 1.25 S	10/13/2009	0.043	0.003		24.8			
Average		**0.060**	**0.004**		**23.9**			

9.5 Table A5. Putters Pond – North section data

North Putters Pond Nutrient Data

Sample ID	Sample Date	Total P mg/L	SRP mg/L	Total N mg/L	Cl mg/L	Chl-a ug/L	Phaeo-a ug/L	Secchi Depth ft
Epilimnion								
PT 2.03 N	6/11/2009	0.021	<0.001	1.55	17.7	1.6	1.6	4.5
PT 2.03 N	6/23/2009	0.018	<0.001	1.32	17.8	7.5	2.8	3.5
PT 2.03 N	7/13/2009	0.011	<0.001	0.849	17.9	2.7	0.9	7.5
PT 2.03 N	7/23/2009	0.01	<0.001	0.781	17.9	2.9	0.8	6.1
PT 2.03 N	8/17/2009	0.01	0.001	0.561	19.1	3.2	0.3	4.5
PT 2.03 N	8/27/2009	0.01	<0.001		19.3	2.7	1.1	8
PT 2.03 N	9/9/2009	0.011	<0.001	0.545	19.6	1.4	0.06	10
PT 2.03 N	10/13/2009	0.011	0.001	0.894	18.1	2.7	1.1	7.5
Average		**0.013**	**0.001**	**0.93**	**18.4**	**3.1**	**1.1**	**6.5**
Hypolimnion								
PT 2.75 N	6/11/2009	0.027	0.004		16.4			
PT 2.68 N	6/23/2009	0.013	<0.001		16.2			
PT 2.76 N	7/13/2009	0.022	0.003		17			
PT 2.60 N	7/23/2009	0.01	<0.001		16.6			
PT 2.70 N	8/17/2009	0.014	0.002		16.7			
PT 2.70 N	8/27/2009	0.018	0.004		16.3			
PT 2.70 N	9/9/2009	0.027	0.011		16.5			
PT 2.74 N	10/13/2009	0.038	0.021		16.1			
Average		**0.021**	**0.008**		**16.5**			

9.6 Table A6. Hammond Lake field water sampling data

Hammonds Lake Field Data

Sample ID	Sample Date	Temp C	pH	SpC	Salin	DO %Sat	DO mg/L	Turb Ntu
Epilimnion								
HA 2.03 W	6/11/09	21.69	9.06	0.511	0.25	105.8	9.09	37.2
HA 1.03 E	6/11/09	21.15	8.91	0.515	0.25	92.3	8.02	15.3
HA 1.03 E	6/23/09	18.05	9.03	0.516	0.25	104.8	9.76	45.8
HA 1.03 W	7/2/09	20.42	9.2	0.512	0.25	98.4	8.74	19.6
HA 1.03 W	7/13/09	21.3	9.2	0.52	0.25	97.5	8.46	36.2
HA 1.03 W	7/23/09	22.7	9	0.543	0.26	40.5	3.37	13.6
HA 1.03 W	8/4/09	23.72	9.06	0.533	0.26	27.3	2.26	16.4
HA 1.03 W	8/17/09	19.86	9.04	0.497	0.24	81.2	7.33	18.2
HA 1.03 W	8/27/09	20.36	8.93	0.528	0.25	84.1	7.46	20.3
HA 1.03 W	9/9/09	18.89	8.89	0.529	0.25	112.2	10.24	12.1
HA 1.03 W	9/21/09	18.08	8.8	0.519	0.25	88.9	8.4	17.7
HA 1.03 W	9/21/09	18.06	8.82	0.519	0.25	89.9	8.49	15.9
HA 1.03 W	10/1/09	14.34	8.87	0.531	0.25	88.6	9	21.7
HA 1.03 W	10/1/09	14.34	8.81	0.532	0.25	88.2	8.96	24.1
HA 1.03 W	10/13/09	9.42	8.99	0.53	0.25	106.1	11.78	34.1
HA 2.03 E	7/2/09	21.57	9.1	0.523	0.25	55	4.78	24.4
HA 2.03 E	7/13/09	21.69	9.33	0.517	0.25	110.4	9.54	55.6
HA 2.03 E	7/23/09	24.47	9.2	0.52	0.25	112.8	9.21	19
HA 2.03 E	8/4/09	25.18	9.29	0.524	0.25	96.8	7.8	17.1
HA 2.03 E	8/17/09	20.53	9.13	0.493	0.24	114.5	10.2	11.2
HA 2.03 E	8/27/09	19.88	8.94	0.532	0.26	73.5	6.64	16.4
HA 2.03 E	9/9/09	18.3	8.89	0.532	0.26	96.9	8.95	13.4
HA 2.03 E	9/9/09	18.31	8.89	0.532	0.26	96.8	8.94	13.3
HA 2.03 E	9/21/09	17.91	8.89	0.522	0.25	79.6	7.54	21.4
Average		**19.59**	**9.01**	**0.52**	**0.25**	**89.25**	**8.12**	**22.50**
Hypolimnion								
HA 1.09 E	6/11/09	20.46	8.68	0.524	0.25	27.2	2.39	4.5
HA 2.09 W	6/11/09	21.62	9.02	0.511	0.25	103.9	8.94	30
HA 1.09 E	6/23/09	17.67	9.01	0.513	0.25	95.6	8.95	15.9
HA 2.09 W	6/23/09	18.53	9.06	0.518	0.25	97.7	8.99	51.4
HA 1.08 W	7/2/09	18.49	9.08	0.53	0.25	51.7	4.77	9.7
HA 2.09 E	7/2/09	18.78	9.14	0.517	0.25	52.3	4.79	13.5
HA 1.08 W	7/13/09	21.13	9.15	0.521	0.25	80.6	7.04	24.3
HA 2.09 E	7/13/09	21.68	9.29	0.516	0.25	107.9	9.33	52.6
HA 1.08 W	7/23/09	21	8.76	0.547	0.26	2.1	0.18	15.8
HA 2.09 E	7/23/09	24.4	9.22	0.521	0.25	105.4	8.62	17
HA 2.09 E	7/23/09	24.37	9.2	0.522	0.25	109.9	8.99	17
HA 1.08 W	8/4/09	23.12	8.52	0.562	0.27	2.2	0.18	0
HA 1.08 W	8/4/09	23.09	8.56	0.558	0.27	1	0.09	0
HA 2.09 E	8/4/09	24.33	9.13	0.531	0.26	36.7	3	15
HA 1.08 W	8/17/09	19.31	8.88	0.505	0.24	1.8	0.17	19.5
HA 2.09 E	8/17/09	20.53	9.16	0.494	0.24	112.8	10.05	14.9

HA 1.08 W	8/27/09	19.82	8.52	0.546	0.26	3.4	0.31	32.3
HA 2.09 E	8/27/09	19.75	8.99	0.532	0.26	70	6.34	27.2
HA 1.08 W	9/9/09	18.13	8.78	0.535	0.26	69.3	6.42	17.5
HA 2.09 E	9/9/09	18.1	8.57	0.534	0.26	89.6	8.31	11.7
HA 1.08 W	9/21/09	18	8.82	0.511	0.25	90.1	8.52	17.2
HA 2.09 E	9/21/09	17.71	8.85	0.531	0.26	77.2	7.34	19
Average		**20.46**	**8.93**	**0.53**	**0.25**	**63.11**	**5.62**	**19.36**

9.7 Table A7. Putters Pond field water sampling data

Sample ID	Sample Date	Temp C	pH	SpC	Salin	DO %Sat	DO mg/L	Turb Ntu
North Putters Pond								
Epilimnion								
PT 2.03 N	6/11/09	22.2	8.6	0.55	0.26	108.9	9.2	5.0
PT 2.03 N	6/23/09	19.6	8.6	0.53	0.26	112	10.1	10.0
PT 2.03 N	7/13/09	22.5	8.8	0.51	0.25	112.7	9.6	0.0
PT 2.03 N	7/13/09	22.4	8.8	0.51	0.25	112.5	9.6	0.0
PT 2.03 N	7/23/09	24.3	8.8	0.50	0.24	121.2	9.9	0.0
PT 2.03 N	8/17/09	21.7	9.1	0.44	0.21	109.6	9.6	19.4
PT 2.03 N	8/27/09	21.4	9.0	0.46	0.22	110.9	9.7	0.0
PT 2.03 N	9/9/09	19.9	8.9	0.46	0.22	97.5	8.7	0.0
Average		**21.7**	**8.8**	**0.5**	**0.2**	**110.7**	**9.6**	**4.3**
Hyoplimnion								
PT 2.59 N	7/23/09	9.4	7.7	0.58	0.28	18.2	2.0	11.0
PT 2.59 N	8/17/09	9.9	7.6	0.54	0.26	4.8	0.5	39.3
PT 2.59 N	8/17/09	10.0	7.4	0.54	0.26	6	0.7	6.8
PT 2.69 N	6/23/09	8.7	7.7	0.58	0.28	37.7	4.3	13.7
PT 2.70 N	7/13/09	8.8	7.7	0.58	0.28	16.6	1.9	19.2
PT 2.70 N	8/27/09	9.4	6.6	0.56	0.27	12.4	1.5	22.6
PT 2.70 N	9/9/09	9.5	7.9	0.56	0.27	15.6	1.6	15.4
PT 2.72 N	6/11/09	9.3	7.8	0.58	0.28	42	4.7	22.1
Average		**9.4**	**7.5**	**0.6**	**0.3**	**19.2**	**2.1**	**18.8**
South Putters Pond								
Epilimnion								
PT 1.03 S	6/11/09	22.6	8.6	0.56	0.27	105.4	8.9	7.5
PT 1.03 S	6/23/09	19.1	8.3	0.57	0.28	87.2	8.0	40.2
PT 1.03 S	6/23/09	19.0	8.3	0.57	0.27	86.1	7.9	43.0
PT 1.03 S	7/13/09	21.7	8.5	0.57	0.28	98.8	8.5	32.4
PT 1.03 S	7/23/09	23.4	8.4	0.57	0.28	98.2	8.2	39.6
PT 1.03 S	8/17/09	20.6	8.5	0.53	0.25	98.6	8.8	22.7
PT 1.03 S	8/27/09	21.2	8.6	0.56	0.27	109.3	9.6	11.9
PT 1.03 S	9/9/09	19.1	8.3	0.55	0.26	87.2	7.9	17.3
PT 1.03 S	10/13/09	11.4	8.1	0.56	0.27	86.5	9.2	44.1
Average		**19.4**	**8.4**	**0.6**	**0.3**	**94.0**	**8.5**	**31.4**
Hypolimnion								
PT 1.20 S	6/11/09	16.2	7.8	0.58	0.28	9.7	0.9	30.1
PT 1.21 S	7/23/09	19.2	7.7	0.58	0.28	21.1	1.9	41.6
PT 1.21 S	8/17/09	16.9	7.4	0.55	0.26	4.3	0.4	30.2
PT 1.23 S	8/27/09	17.8	7.6	0.57	0.27	6.3	0.6	19.9
PT 1.23 S	8/27/09	18.4	7.7	0.56	0.27	26.1	2.4	18.7
PT 1.24 S	9/9/09	17.7	7.6	0.56	0.27	8.2	0.8	28.4
PT 1.25 S	6/23/09	13.3	7.7	0.59	0.28	6.3	0.7	61.9
PT 1.25 S	7/13/09	17.0	7.7	0.59	0.28	6.7	0.7	66.7
Average		**17.1**	**7.6**	**0.6**	**0.3**	**11.1**	**1.0**	**37.2**

9.8 Table A8.LIthology for wells drilled on northwest end of Hammond Lake.

MW-1

ft bgs	Lithology Formations logged as medium dense to very dense.
0 - 8.5	Fine to medium sand
8.5 - 13.5	Fine to medium sand w/ trace gravel, silt & occasional cobbles & boulders.
13.5 - 19	Fine to medium sand w/ silt & occasional cobbles.
19 - 34	Fine to coarse sand w/ gravel, trace silt & occasional cobbles.
34 - 40	Medium to coarse sand w/ gravel, trace silt and occasional cobbles.
40 - 87	Fine to medium sand w/ silt.
87 - 101	Fine to medium sand w/ gravel, silt & occasional cobbles and boulders.

MW-2

ft bgs	Lithology Formations below 9 ft logged as medium dense to very dense.
0 - 2	Silty fine sand (topsoil)
2 - 9	Silty fine sand (loose).
9 - 13	Fine to medium sand w/ silt.
13 - 23	Fine to coarse gravel with sand, trace silt, & occasional cobbles & boulders.
23 - 34.5	Fine to coarse sand w/ trace silt, & occasional boulders. (boulder 3-4 ft diameter, 31 - 34 ft depth)
34.5 - 60.5	Fine to medium sand w/ trace silt and occasional gravel, cobbles & boulders. (1/2 inch thick lens of brown silt approx. 56 ft.)
60.5 - 75.5	Fine to medium sand w/ gravel, trace silt, and occasional boulders.

MW-3

ft bgs	Lithology Formations logged as medium dense to dense.
0 - 14.5	Fine to coarse gravel w/ sand and trace silt.
14.5 - 36.5	Fine to coarse sand w/ gravel, trace silt, and occasional cobbles.
36.5 - 43.5	Coarse sand w/ gravel, trace silt, and occasional cobbles and boulders.
43.5 - 65	Fine to medium sand w/ cobbles, trace silt, and occasional gravel.
65 - 75	Fresh vesicular basalt.

Local Hydrogeology

General shallow lithology to a depth of about 100 ft consists mostly of variable energy flood/alluvial deposits of fine to coarse sand, gravel, Some silt & clay, and occasional cobbles and boulders. Within town, ground surface elevations range from approximately 620 to 650 ft. Ground surface elevations outside of town closer to basalt terraces are higher (over 700 ft). Static water levels (SWL) in local wells range from 5 to 45 ft measured below ground surface or from the tops of wells. Some SWL depend on the level of the Columbia River indicating a hydraulic connection between the river and local shallow groundwater.