A limnological assessment of the Best Hills Ranch Development lake with a focus on macrophyte growth and recommendations to reduce their abundance

Final Report prepared for:

Best Hills Ranch Development Homeowner’s Association, E. Best Ave, Coeur D’Alene, Idaho.

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Summary

The Best Hills Ranch Development lake was assessed by the University of Idaho FISH 415 Limnology class in the FALL 2009 semester. During the summer the homeowners contacted the university to explore possible options to remedy the continuing macrophyte problem in the lake. Our findings were that the macrophyte growth is dense (estimate of 6.3 tons dry mass), and contain a large mass of phosphorus (65.7 kg). Sediment accumulation in the 12 years since the lake was created has also been high. Estimates included 112.4 tons of sediment and 188 kg of phosphorus. We did not measure inflows, as this is intermittent and only active in spring with snowmelt. The fish community as only observed, but included many small fish (bluegill) that are probably negatively affecting the zooplankton community which was dominated by very small-bodied species.

After analyzing the data, and examining possible management strategies, we recommend a multi-faceted low-impact and low-cost approach. First we recommend that macrophytes be removed manually in a zebra-stripe type pattern, with alternate stripes harvested each year. Combined with this approach, the homeowners should consider the application of Aquashade to prevent algal blooms from the nutrients released when macrophytes are harvested. The homeowners should also consider installing a couple of aerators that can introduce air and mix the entire water column to prevent anoxic conditions at night. The surface pumps/fountains currently in use could still be used if they were desired for aesthetic purposes - but they do not appear to offer any functionality for circulating the water mass. The fish population should be adjusted to reduce the number of small planktivorous fish which seem to be negatively impacting the zooplankton population. Because homeowners currently use low height fencing to keep geese off lawn, and some lawns abut the lake edge, we recommend the homeowners collectively discuss alternative water edge landscaping to include a buffer strip (this does not have to be overly wide) planted with native plants to act as a runoff interceptor and goose deterrent at the same time. This will require some discussion to ensure that all homeowner’s needs and desires are met, and that plants, heights, and widths are consistent among all properties. Those with beaches but lawn further set back will require consideration as well. We did not assess inputs from lawns and they should be examined to determine if and what reductions of nutrient inputs can be gained from altered practices. All of these recommendations are relatively low cost approaches, but will take commitment, and will not offer a one-shot solution. Thus, residents should be patient. As well, we recommend that inflows be examined to obtain estimates of the impacts originating there, and explore possibilities of reducing inputs. To obtain more accurate estimates of the time-frame of the macrophyte removal, better estimates of sediment depth on the lake bottom should be obtained.
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Introduction

Waterfront properties provide recreational and aesthetic amenities for property owners, and also contribute to increase property value. Research suggests that homes abutting or in close proximity to water are more costly to purchase than homes away from water (Lansford and Jones 1995). Thus many developers of residential housing complexes aim to include some type of water feature in their plans. Often, storm water retention basins serve dual purposes of providing a permanent water feature but are also functional to filter and channel storm-generated runoff from the development. Other times, water features are incorporated as mitigation measures for wetland areas displaced due to the development itself.

It is the ‘free of floating surface algae’ and ‘clear water’ (i.e., not appearing green or murky) state that maintains property values and the aesthetic appeal for many waterfront owners (Correll 1998; 2005). However, because residential-type water features are typically shallow, and often surrounded by properties that have a significant amount of lawn, which all too often is fertilized and sprinkled to maintain lush growth and greenness, means that these water features are subjected to a variety of pressures which act in concert to degrade water quality (Caffrey and Monahan 1999). Thus, these water features typically require a high degree of maintenance to retain their recreational and aesthetic appeal.

It is well-known that urban activities can be major sources of macronutrients (nutrients that contribute > 0.1% of living biomass) and sediment to waterways (Carpenter et al. 1998, Donohue and Molinos 2009). Such activities also increase concentrations of total phosphorus (TP) (Moore et al. 2003) which is typically the limiting nutrient in freshwater ecosystems (Schindler 1977). Imbalances in ecosystems are manifested by loss of biotic diversity, (e.g., homogenization and domination of the biotic community by a single or low number of taxa - such as spread of cattails in littoral zone - or the dominance of small abundant fish such as bluegill). For small and shallow water bodies, urban pressures often contribute to a switch between alternative stable states (Scheffer 1998) - one in which a system has clear water but is dominated by large amounts of macrophytes; or one dominated by high turbidity (sediment or algal biomass - murky or green water) suspended in the water column with few macrophytes. Macrophytes stabilize bottom sediments via their roots; dampen wave action which reduces the resuspension of sediment and nutrients from the bottom; and remove nutrients from sediments by incorporating it into biomass. Thus macrophytes can limit or prevent the establishment of algal blooms in the water column due to lack of favorable conditions for such a bloom. Hence this state is stable. Conversely, in a turbid state, high amounts of sediment or algal biomass are suspended in the water column which prevent light from reaching the bottom and the establishment of macrophytes (due to light limitation). Thus, sediment is not anchored by roots and wave action contributes to resuspend sediment and nutrients. Nutrients are taken up by algae in the water column creating bloom conditions and further reduce the chance for
macrophyte establishment. This state is also stable. Shallow lakes can switch between these 'alternative' stable states (Scheffer 1998) and mechanisms controlling the switch are an intense area of research among limnologists.

Each of these alternative stable states has beneficial and detractive aspects from a recreational and aesthetic perspective. For example, beds of rooted macrophytes that reach the lake surface and form dense matts may impede recreational activities (Caffrey and Monahan 1999). However, clear water typically predominates. Macrophyte stands also provide nursery areas for young fish, thus they are vital in water bodies with a fishery. However, too dense, and predatory fish are unable to effectively prey on young fish allowing them to become very dense (Collingsworth and Kohler 2010), resulting in stunting of the predator population. High algal biomass typically has low aesthetic appeal with homeowners. It also reduces the effectiveness of sight feeders. However, populations of small invertebrate filter feeders can be dense, leading to high growth rates among fish populations (Nixdorf and Deneke 1997). Extremes of both conditions can have negative effects on biota through large fluctuations in concentrations of dissolved oxygen (high during the day and low or zero at night), killing fish (Caffrey 1992). Oxygen deficiencies in water near the sediment can result in internal phosphorous loading. This phenomenon occurs when ferric phosphate is reduced to ferrous phosphate which dissociates to form soluble forms of phosphate directly usable by algae (Wetzel 2001). Thus bloom conditions can provide positive feedbacks in terms of nutrient release from the sediments.

All lakes, from the time of their origin, are on a trajectory to solid land through the process of infilling. The rate of infilling depends on a variety of factors including basin morphometry, watershed characteristics, and land use. As a lake fills, its depth decreases and productivity typically increases - a process known as 'natural' eutrophication (Wetzel 2001). Human activities in a watershed often contribute to increase the rate of eutrophication and this is termed 'cultural' eutrophication. It is a problem worldwide (Wetzel 2001). The introduction of excess nutrients is most commonly characterized by increased primary production beyond that which could occur in an undisturbed system (Carpenter et al. 1985; McQueen et al. 1989; Moeller et al. 1997; Wetzel 2001). In freshwater systems, phosphorus is the nutrient most commonly associated with eutrophication. It can be introduced in a number of ways and forms. Sources of TP include, atmospheric precipitation (Wet and dry - e.g., dust), ground water, and land runoff carried via flowing water. A primary cause of cultural eutrophication is runoff from land that has had fertilizer added for lawn maintenance or agricultural use (Wetzel 2001).

The influx of sediment is also a key aspect of the infilling process and is one of the most widespread forms of aquatic pollution causing changes in lake transparency, oxygen concentration and heat budgets (Donohue and Molinos 2009). The type of sediment entering a water body as well as its composition (e.g., sand vs clay) are important in determining its overall effect because it determines what type and where plants will establish. For example, clay can support a higher biomass of macrophytes than sandy/coarse sediment (Xiao et al. 2007). In most
instances, high rates of input of sediment are correlated with high inputs of phosphate, because phosphate is a very ‘sticky’ molecule.

Problem statement

The Best Hills Ranch housing development in Coeur d’Alene, Idaho contains 18 houses that abut a lake created with the housing development in 1997. The housing development manages the lake through a lake committee elected by the community members. Despite efforts by the lake committee to maintain water clarity and reduce macrophytes, the lake continues to have cycles of nuisance blooms of algae and macrophytes throughout the summer. Over the past few (3-5) years, a macrophyte community dominated by charophytes has become well established in the lake (Figure 1) to the point that it has become a nuisance because it reaches the surface in summer and presents unsightly growths, and limits recreational opportunities such as boating and swimming. In addition, a foul smell is associated with the die-off of plants in late summer and early autumn, or when masses wash up on shore. The residents of the community feel that this detracts from the overall aesthetics of their lake, and have in the past managed the lake with the application of herbicides via contracting a consulting company. The University of Idaho was contacted in the summer of 2009 to explore the possibility of obtaining additional input and explore potential options other than the repeated application of herbicides. The Fall 2009 FISH 415 Limnology class decided to take this on as their term service-learning project.

Specific objectives included an overall assessment of the lake with a focus on the macrophyte problem and potential solutions. The class was split into different groups that would tackle specific sub-parts of the whole project. Specific objectives included: surveying the lake to establish a bathymetric map; examining water chemistry at a number of sites throughout the lake with respect to total phosphorus (TP), as well as examining the TP of the inflow from the groundwater well. The zooplankton community was also examined to determine the abundance and species present to assess if the community was capable of reducing algal biomass through grazing. The macrophyte community was examined in littoral and offshore areas to determine species, biomass, and TP. Sediment depth, and TP content were examined to establish how much sediment had accumulated in the lake since impoundment, and to estimate the reservoir of TP available to fuel potential future macrophyte growth. Finally, various remediation strategies were investigated to examine if, and to what extent each could be employed to address the macrophyte issue.
Methods and Materials

Study site
The 18 houses of the Best Hills Ranch development line the northern shore of a long (520 m) and narrow (30 m wide) lake with a surface area of 2.2 hectares and a maximum depth of 3.3 m. The houses are approximately 30m from the shore and have well maintained yards/lawns that in some cases abut the lake. The north side of the catchment beyond the development is predominantly urban and contains other residential areas. The south side of the lake catchment consists of a steep forested hillside that has very little development. The west end of the catchment is marked by the earthen dam constructed to create the residential lake when the development was created. Land use on the eastern side of the catchment is predominantly agricultural fields of row crops.

Intermittent runoff from forest and agricultural land supplies most of the water for the lake. When the stream flow ceases in the summer, the water level in the lake is maintained by groundwater pumped into the lake from a well owned by the homeowner’s association. The lake itself is entirely lined with a thick (2-3 mm) black plastic liner which is buried by surface sediment along the side from the shore/water interface to a depth of approximately 1.2 m( 4') extending 2.4 m (8') out from shore.

There is a well established macrophyte community in the lake dominated by charophytes, which consequently is a nuisance during the late summer when they reach the surface of the lake. Other macrophytes include curly-leaf pond weed and sparse sections of emergent cattails along the shorelines. Occasionally, algal blooms also occur in the water column.

Fish species in the lake include largemouth bass, *Micropterus salmoides*, and bluegill, *Lepomis macrochirus*, although others species might also be present.

Bathymetry
To determine the bathymetric map of the lake, we used a Lowrance LCX 25c GPS/Sonar unit to obtain latitude, longitude and lake depth measurements at 1 second intervals. We rowed the boat in a grid pattern to evenly cover the lake and obtain depth estimates at known locations. Depths that were too shallow for the sonar were measured with a leaded line and recorded. Data were transferred to a PC, processed and then entered into ArcGIS to create a bathymetric map of the lake. Contours at 0.5 m increments were drawn on the map. Lake, slope, and bottom area as well as lake volume were calculated via the 3D Analyst extension of ArcGIS.

Temperature, dissolved oxygen, and conductivity profiles
To determine the profiles of temperature, dissolved oxygen and conductivity in the lake, we used a YSI 85 multi-meter. The probe was lowered at 0.5 m intervals from the lake surface to the bottom at each site. On October 7, 2009 profiles were recorded at 1 site (Figure 1), while
on October 14, 2009 profiles were recorded at 3 sites (Figure 1). Data for each date were averaged and plotted in standard limnological fashion.

**Concentrations of total phosphorus and chlorophyll a in the water column**

To measure the concentration of Total phosphorus in the water column, water samples were collected with a 2 L Van Dorn water sampler from site 1 on October 7 and from 3 sites on October 14. Triplicate samples were collected at each site, and filled into 30 ml acid-washed test-tubes pre-filled with 0.3 g of potassium persulphate. Samples were returned to the laboratory and autoclaved for 20 minutes. After cooling they were stored in a refrigerator at 4 °C until analysis. Analysis followed the methods outlined in EPA and Standard Methods for the Examination of Water and Wastewater (APHA 1995). Briefly, mixed reagent containing ascorbic acid and molybdenum was added to each tube to complex (to blue) any phosphorus in the sample. Concentrations were determined with a spectrophotometer using basic colorimetric techniques and known TP standards. Means and standard errors were calculated for all samples.

To measure chlorophyll a concentrations, water samples were collected from surface and bottom samples at three sites on October 14 (Figure 1). Two liters of water were stored in opaque bottles for transport to the laboratory. Samples of known volume were filtered through a 0.45 glass fiber filter and frozen until analysis. Before analysis, filters were macerated and placed in 10 mL EtOH for 24 h to allow extraction of the pigment. Tubes containing the samples were then centrifuged and the supernatant analyzed on spectrophotometer at wavelengths of 750, 665 and 649 nm. Means and standard errors were calculated for all samples.

Contribution of well water to the total phosphorus concentration in the pond was calculated based on the assumption that the well operates for approximately 300-400 h during July and August at 75.7 l/min (20 g/min) (Chan personal communication). To calculate the mass of TP added, the rate was multiplied by the time of operation and the concentration in the inflow.

**Density of zooplankton**

To measure zooplankton density and composition, triplicate samples were taken from six pelagic locations (Figure 1) using a 64µm-mesh plankton net (0.12 m mouth diam.) hauled from just above the bottom to the lake surface. Haul depth was recorded for each sample and samples were preserved with formalin until analysis.

To estimate zooplankton density, sub-samples were taken from a known volume of sample from a graduated cylinder and placed in a petri dish for identification and enumeration with the aid of a dissecting microscope. Zooplankton density (organisms/L) was calculated using the equation:

\[
\text{organisms/L} = \frac{(\text{graduated cylinder V} \times \text{number of organisms counted})}{\text{V sub-sampled}}
\]

\[
\text{V of lake water sampled}
\]
For zooplankton composition, we pooled the different organisms identified into major taxonomic groups.

**Macrophyte density, biomass and total phosphorus content**

To measure macrophyte density and the total phosphorus (TP) in macrophytes, triplicate samples were collected from five littoral sites (Figure 1) using a ¼ m² quadrat. The quadrat was placed randomly at each site and submersed macrophytes from inside the area were physically removed, washed and bagged. To collect bottom macrophytes, we used a macrophyte grab sampler with an area of 0.2 m². The macrophyte sampler had closing jaws that removed macrophytes at the roots and collected all biomass in a bag. Samples were collected in triplicate at three sites (total of 9 samples - Figure 1). All macrophyte samples were returned to the laboratory where they oven dried at 50°C for 48 hours. Dry mass per unit area was then calculated.

To estimate total biomass of macrophytes in the lake, the mass of macrophytes per unit area in the littoral zone was multiplied by the area of the slope area (determined from the bathymetric map), while macrophyte biomass per unit area of the bottom was multiplied by the bottom area. The two estimates were added to arrive at a total biomass of macrophytes for the lake.

To analyze the TP content of macrophytes, a small sub-samples of dried macrophyte biomass was placed into individual test-tubes containing 0.3 g potassium persulfate and 20 ml of de-ionized water. Samples were then digested and process as for water TP described above.

To estimate the mass of TP contained in the macrophytes, the mass of TP per unit mass of macrophyte in each lake area (littoral and bottom) was multiplied by macrophyte biomass in each area and summed. (Note this study was completed in October when macrophytes were already starting to die - thus, maximum macrophyte biomass and therefore TP contained in their tissues is much greater. The estimates presented here should be considered conservative).

**Sediment water content, organic content, dry bulk density and areal total phosphorus content**

While attempting to sample bottom sediments, we discovered that the sediment depth in the middle of the lake was too shallow (2-3 cm of very flocculent material) to collect core samples. Instead, four core samples were taken from the edge of the lake. Two of the samples were taken on the shore of the lake containing the housing development (house shore) by the most westerly house (house 1) and the third house to the east (house 3). Two core samples were also taken on the shore of the lake abutting the hill (hill shore) across from house 1 and house 3 (Figure 1). A similar process was used to collect three cores from the eastern end of the lake the following week. Cores were spaced evenly from the middle of the lake to the end and taken.
along the south shore.

The core samples were sectioned at 2 cm intervals from the sediment-water interface to a depth of 8-12 cm using a sectioner similar to that describer by Glew (1988). A 5 cm$^3$ portion of each section was weighed and then dried at 50 °C for 24 h. After cooling, each sample was re-weighed and then ashed in a muffle furnace at 550 °C for 3.5 h to remove organic content. After cooling, samples were re-weighed to determine the mass of ash (inorganic material) that remained (Heiri et al 2001).

Organic content was calculated using the following equation:

$$\frac{\text{Dry Mass} - \text{Ash Mass}}{\text{Dry Mass}} \times 100$$

The percent water content was calculated using wet and dry sediment mass using:

$$\frac{\text{Wet Mass} - \text{Dry Mass}}{\text{Wet Mass}} \times 100$$

To determine the total phosphorus in the sediments, approximately 0.25 g of selected dried samples was removed and placed in a test-tube with 0.3 g of potassium persulphate and 20 ml of deionized water. TP analyses followed the methods outlined above for water TP.

Dry bulk density was calculated using equations and constants provided in Avnimelech et al 2001.

The sedimentation rate was calculated using the estimate of 2 cm of deposition in the bottom of the lake and dividing by the 12 years the lake has been in existence. Then a determination of the amount of phosphorus deposited per year was made using the average total phosphorus in the top 2 cm of the core samples using the following equation:

$$\frac{\text{Area of lake} \times \text{Sediment deposition} \times \text{Average TP}}{12 \text{ years}}$$

**Remediation Strategies**

**Removal of macrophytes**

We examined the effort and cost required to effectively managing the growth of charophytes in the Best Hills Ranch Development Lake. We estimated labor at $10/h for two laborers for two weeks per year to harvest macrophytes manually. Disposal costs were assumed to be zero if daily disposal (of dried or partially dried plant material) remained under 500 lbs to the Coeur D’Alene landfill. We estimated several different removal scenarios - one in which and attempt was made to harvest all macrophytes in from the lake, and one in which bands of macrophytes were harvested. The logic behind the latter strategy was to prevent the lake from
entering a permanently turbid state by removing all macrophytes and allowing wave action to resuspend bottom sediment.

**Buffer strips**

To examine the costs for modifying the nearshore (riparian area) to reduce the influx of unaltered runoff from adjacent properties, we estimated costs of plants listed on the Native Plants of Idaho Society web site. This was a very basic calculation, as any nearshore modification would require further consultation with landowners to discover what, if any, reduction in access to the lake front they were willing to tolerate, and how important lawn to the water’s edge was to them. As well, buffer effectiveness was difficult to determine, and would require further onsite research with a ‘demonstration’ plot.

**Addition of barley straw**

The addition of barley straw as an algacide was also investigated. Welch (1990), Pillinger et al. (1992) and Martin and Ridge (1999) have shown success of reducing the algal biomass with the addition of sunken bags of barley straw in small ponds. We used their estimates of mass of straw/unit area treated to examine the costs associated with implementing this treatment at the Best Hills Ranch Development lake. We only provide estimates for costs of materials, as we considered that labor to fill the bags could come from a high school service/volunteer group. Alternatively, a cost of laborers at $10/h would be a reasonable rate to consider.

**Aeration**

The construction of an aeration system would help to keep phosphorus at a manageable level because of the chemical redox reactions that occur with the addition of O$_2$ which bind the phosphorus in an insoluble and thus unavailable form. It must be cautioned that aeration is not always a perfect solution as it can unintentionally cause additional problems if not done correctly (class discussion). We examined the aerators offered by dripworks (http://www.dripworks usa.com/ev_store/ev_pondaer.php) as a possible installation.

**Draining and sediment removal**

We also examined the possibility of draining the entire lake, allowing accumulated sediment and macrophytes to dry out, sweeping out the entire basin using a walk-behind street sweeper, and then starting afresh. This would be an entire reset of the system, could mean a summer without water, but would then provide ‘like-new’ recreational and aesthetic opportunities once refilled. Rental of 3" water pumps as ~$430/pump/month, while a walk-behind sweeper was $195/wk (or $65/day). Labor to drain the pond was considered minimal, as it would only require someone starting up / adding fuel and shutting down the pumps; we assumed one of the homeowners could volunteer to take care of this. Possibly a local youth...
aquaculture or other volunteer group could be interested to assist with the sweeping and sediment removal work. We assumed that sediment would only be removed from the depth of 1.219m to the lake bottom because 0-4' or 0-1.219 m of depth is the depth to which the liner was originally buried when the lake was lined. Thus to avoid disturbing this layer, we considered sediment removal only below this depth. The lake area below 1.219 m is 6615.4 m². Sediment volume to be removed was multiplied by the dry bulk density to determine the mass of sediment that would be moved, or distributed to a disposal site. Because this is could be considered a dredging operation, disposal of the material could be on private land with a landowner willing to receive the material. Otherwise, disposal would need to be via landfill, for this a metal/toxic materials analysis would need to be completed. We did not factor in a cost for this analysis or cost of transport. If considered by the homeowners, we would suggest they contact a professional consultant for this purpose. The removed sediment could possibly be spread out on the field below the lake if the owner of that property agreed to this. This would eliminate large transportation cost and disposal fees.
Results

**Bathymetry**

The maximum depth was found to be 3.07 m (10') at a site approximately 34 m east of the earthen dam (Figure 2). Total lake surface was 14950 m² while surface of the lake bed was 15468.2 m² and the total volume was 16947 m³ (Table 1). The average lake depth was 1.1 m.

**Temperature, dissolved oxygen, and conductivity profiles**

Profiles of temperature, dissolved oxygen and conductivity showed that the lakes was isothermal at the time of sampling in October (Figure 3a). The average lake temperature cooled by approximately 4.5 °C between October 7 and 14th. A period of extremely cold weather that froze the surface of the pond occurred the weekend between the sampling periods. On October 14th, ice had to be broken at the surface on the eastern part of the pond to access the sampling sites. Dissolved oxygen was near maximum saturation on both sampling occasions and varied between 12 and 14 mg/l on October 7th and 14th, respectively (Figure 3b). Conductivity was approximately 110 μS/cm² on October 7th and 100 on October 17th (Figure 3c).

**Concentrations of total phosphorus and chlorophyll a in the water column**

The concentration of total phosphorus in the water column was constant between sampling dates, thus a mean concentration was calculated. It was 32.6 ± 1.9 μg/l (mean±SE) (Table 2). The range was high, and likely is the result of not removing plankton from water samples prior to analysis. Inflow of TP from the well was calculated at 17.7 to 23.6 g TP per year for an operational duration of 300 and 400 h, respectively. Here too the range was high, and these samples should be repeated to determine if this variability is real, or if sediment was entrained in several of the samples. At full pool, the mass of P in the water column was 0.552 kg (32.6 mg/m³ * 16947 m³ - total volume of lake Table 1).

The chlorophyll a concentration at the surface was 0.012 ± 0.011 µg/L while at the bottom it was 0.166 ± 0.047 µg/L (Table 2) indicating higher algal biomass at the bottom. The wide range of these values may have been to do the time of year that samples were collected, and the recent freezing of the lake.

**Loss of water due to evaporation and concentration of nutrients**

Due to evaporative losses, lake levels drop and concentrate remaining dissolved constituents, including nutrients. We used a lake level drop of 0.1 m (3") to examine this effect. The volume of water contained in the top 10 cm of the lake is 1466.3 m³, while the volume remaining below 0.1 cm was 15480.9 m³. Thus, dissolving the same mass of P from the entire lake 0.552 kg - see above) in a reduced volume would increase the concentration from 32.6 μg/l to 35.7 μg/l - a 9.5 % increase.
Density of zooplankton

Zooplankton taxa found in the lake included Cladocerans, Copepods, Ostracods, and Chaoborus (Table 3). Cladoceran densities ranged from 4.3 to 5.3 ind./L between the sampling dates (Table 3). This group was dominated by the genus Bosmina, a very small-bodied filter feeder. Copepods ranged from 3.1 to 3.6 ind./l while Ostracods were only found on October 14th at a density of 1.6 ind./l (Table 3). Chaoborus, or the phantom midge, a predatory larvae of a non-biting fly similar to a mosquito occurred at a density of 0.5 ind./l. It was surprising to find them in the water column, as in lakes with fish, they tend to be predominantly benthic during the day.

Macrophyte density, biomass and total phosphorus content

The dry mass of macrophytes varied from 289±37 g/m² in the littoral zone to 564±35 g/m² in the middle of the lake (Table 4). The mass of phosphorus associated with these plant densities was 2.6±0.13/m² for the littoral and 6.5±0.27 g/m² for the middle of the lake (Table 4).

Using the same measures as for the depth calculations above - considering the littoral area as that area of the lake that extends down to 1.219 m (4'), the dry mass of macrophytes in this area was 2.6 tons (8852.8 m² × 288.5 g/m²/1000000); while in the middle of the lake it was 3.7 tons (6615.4 × 564.4 g/m²/1000000). Thus in October the standing crop of pant matter in the lake totaled 6.3 tons (dry mass). This mass would be expected to be higher in summer when plant growth would be at its maximum.

In terms of phosphorus (following analogous calculations as above), the total P contained in the plant mass was 23.0 kg in the littoral zone and 42.7 kg in the middle of the lake. Again, this will likely be an underestimate given that plant growth was not at its maximum. The total amount of phosphorus contained in the macrophytes was 65.7 kg.

Sediment water content, organic content, dry bulk density and areal total phosphorus content

Because the lake was lined and the accumulation of sediment on the liner was relatively shallow (2 cm) cores were taken from the edge of the lake representing the material used to cover the liner. Thus we caution using these data to derive interpretations of sediment characteristics for the entire lake. For example, the cores had a high sand and clay content, which is not typical of the flocculent organic rich material found in the middle of the lake. Nevertheless, the water content in the cores varied from 60 to 80 % in surficial strata, decreasing to 30% at a depth of 5 to 7 cm (Figure 4a). The organic content was low, ranging from 8.5 to 11.5% in the 0-2 cm stratum and decreasing to approximately 5 % at a depth of 5 cm (Figure 4b). Dry bulk density was high and nearly constant at 4.5 to 6 g/cm³ (Figure 4c). The mass of phosphorus in the surficial strata was nearly identical across all sites at approximately 18.5 g/m² (Figure 4d), and increased with depth in core. Thus, if sediment accumulation in the middle of
the lake is greater than 2 cm, it is likely that P content increases with depth there as well.

Using the mass of phosphorus per unit area in the 0-2 cm stratum and multiplying by the bottom area of the lake (6615.4 m²) yielded a mass of 122.3 kg of phosphorus distributed over the bottom of the lake. Adding the mass of P in the sediment (122.3 kg) and macrophytes (65.7 kg) yielded a total of 188 kg of P that is potentially available for circulation (decomposition of macrophytes will add P to surficial sediments) in the lake. Dividing this mass by the time in existence of the lake (12 years) yielded an annual input of 15.7 kg of P.

The approximately 2 cm of deposition on the bottom indicates an accumulation of approximately 0.17 cm of sediment per year. Multiplying sediment depth (0.02 m) by the area (6615.4 m²) below 1.219 m (4') equates to a total volume of 132.3 m³ of accumulated sediment. Given the very flocculent nature of this sediment, a dry bulk density of < 1 (e.g., 0.85 g/cm³) can be assumed (not the 5 g/cm³ measured in the core samples from the sides of the lake) - such sediments typically range from 0.6-0.9 g/cm³ - meaning that approximately 112.4 tons of sediment (dry mass) have accumulated in the lake since it was dammed (or approximately 9.3 tons per yr). Dividing the mass of P in the sediment+macrophytes (188 kg) by the total sediment accumulated (112 461.8 kg) yielded a concentration of 1.08 g P/kg sediment (or in parts per million - ppm - 1087.4 mg P/kg sediment). Using these data, an influx of approximately 15.7 kg P per year can be calculated. Thus this would be the annual input that would need to be removed via macrophytes as well. Given the typical climatic conditions, we estimate that most of this input would occur during the early part of the year, so that harvesting of macrophytes would remove this part of the annual input.

**Remediation Strategy: Cost Analysis**

**Removal of macrophytes**

Given that the mass of phosphorus contained in all of the macrophytes is approximately 65.7 kg, while that in the top 2 cm of sediment is approximately 122.3 kg, (188 kg total) and annual input is 15.7 kg, harvesting all macrophytes from the lake per year could deplete the mass of P in the top 2 cm of sediment in approximately 4 yrs. If only approximately ½ the biomass of macrophytes is harvested, then depletion of the mass of P in the top 2 cm of sediment would not occur until year 11 (Table 5). (Note all of these calculations assume that rates would remain constant - some decrease in macrophyte growth can be expected, while not all of the P in the sediment will be available for macrophyte growth either).

We calculated that to harvest of macrophytes, the cost to homeowners would be on the order of $ 1600 per year (2 laborers * $10/laborer/hr * 40 hr/wk * 2 wks/yr). We did not assess any disposal costs, these would be in addition to the above labor rate, if incurred. Thus for a 4 yr removal strategy of removing all macrophytes from the lake, the cost would be $ 6400 + ancillary costs, such as truck rental, rakes, cost of gas = $7000. Under this scenario the per
homeowner cost would be approximately $390/yr. If only ½ of the biomass of macrophytes is removed, then 11 years would be required to remove the mass of P in the sediment, and costs would be $21120 - or approximately $ 22 000  (Accounting for 2 labor rate increases $2/hr in yr 5 and $2/hr in yr 8 + costs for gas, truck rental). The per homeowner cost under this scenario would be approximately $1230/yr.

**Buffer strips**

Buffer strips or set asides were considered, as this is a best management practice recommended to reduce the likelihood of nutrients applied to farm fields to enter adjacent waterways via runoff (Green and Haney 2005). The idea is that the buffer strip - a band of land with native vegetation that have a deep root system - intercepts, slows down and takes up nutrients before they are carried into the adjacent waterway. Given the application of lawn fertilizers (class observations) and the fact that lawns abut the lake, a buffer strip should aid in slowing the movement of fertilizer into the water. According to the USDA and NRCS, buffer strips can be effective in removing up to 50% of P in runoff. Several factors are important to buffer strip effectiveness. These include, width, the wider the better, and recommendations for minimum size start at 10 m (33’). Inclusion of native plants is also recommended, as these tend to have deep root systems that and are thus able to intercept groundwater flows to remove nutrients. Due to this deep root system, the are also not as prone to drought as non-native plants with shallow root systems that would require frequent watering. Thus reduction of watering could also help to slow the movement of soil associated fertilizers to the lake. Allowing plants in a buffer strip to reach a height of 2-2.5’ could also eliminated the need for the goose fence currently installed. Geese are unwilling to exit water onto land through high vegetation in which they are unable to determine the presence of potential predators.

We roughly estimated the cost for native plants for a small buffer strip along the home/lakeshore side at $2500-$3000, based on the cost of plants at local nurseries (Fall 2009). Cost would vary with species, number and size of plants selected. The establishment of a buffer strip would also require more consultation with homeowners to determine their willingness to have a buffer strip at the edge of their property. As well, we did not determine the contribution of lawn runoff to the overall nutrient budget of the lake. However, given that the P concentration of sediment is high, it is probable that runoff from applied fertilizer contributes to the P load in the lake.

Other options available to the homeowners include a course/partnership between the city of Coeur d'Alene Water Department and the Northern Idaho College Workforce Training Center. City residential customers who live in their home and who take the "Landscaping with Native Plants" class at NIC in Spring (March 11 and March 18, 2010) can receive a utility bill credit for the cost of the class and the workbook. More information is available at:
http://northidaho.augusoft.net/index.cfm?method=ClassListing.ClassListingDisplay
**Aeration**

The system we investigated could cost as little as $2000 and serve an area of up to 5 acres. The Best Hills Ranch Development lake is 3.69 acres, but occurs in a long narrow strip - thus two units may be required to adequately serve the entire lake. The units can be self-installed (http://www.dripworks usa.com/ev_store/ev_pondaer.php), and the system is supposedly quiet. It also has its own timer to allow programming so it can run at night when the lake likely experiences low oxygen concentrations. We caution that aeration will only present a patch, not an entire solution because of the external inputs of phosphorus to the Best Hills Ranch Development lake. Only coupled with a reduction in overall P will the lake remain clear and achieve the desired aesthetic function.

**Addition of barley straw**

The references we consulted recommended that 225 lbs of barley be used per acre of lake surface. With an area of 3.7 acres, the Best Hills Ranch Development lake would require in the vicinity of 833 lbs of straw. In fall 2009, the cost of ½ ton of barley straw in the Coeur D’Alene area was $22. Additional costs associated with this treatment would be mesh bags (similar to onion bags - 32 lbs/bag - 26 needed come in bundles of 100 for $96). The bags would need to be anchored, thus bricks would be required (24 bricks @ $3.50/brick = $84.00). Each bag would also need a float, so that the straw is kept off the bottom, and so that water could circulate through the bag (24 floats * $4/float = $96 http://www.tackletogo.com/cud6712styrb.html). Thus material costs for adding barley straw would be approximately $300. This does not include the labor to stuff the bags with straw or set and remove bags from the lake. We assumed that a volunteer group could be persuaded to help with this task.

**Draining and sediment removal**

We determined that two 3” intake water pumps from a rental shop would cost $400/pump/month (without hoses - CDA Rental All) and would drain the lake in 16-18 days if they ran 8 h per day. Given the relatively small depth of sediment accumulation observed at the bottom of the lake, the liner being black, we estimated that in July, this amount of sediment would dry in a matter of 1 wk. Total cost for the equipment would be $865.00 to $995.00 before taxes. Removal of 2 cm of sediment from an area of 6615.4 m² would equate to a total volume of 132.3 m³. Multiplying by an estimated dry bulk density of 0.85 g/cm³ yielded a mass of 112.5 tons. Adding the mass of macrophytes (6.3 tons) a total of 118 tons of material would need to be removed. This is not a task for the faint of heart - and this amount of material would likely require some sort of machinery to move it effectively into a truck for disposal. Unless a private landowner was found, disposal costs associated with this material would be included in the cost. We did not have the capacity to estimate this, or the type of machinery required to move the material. As well, our estimates are based on an average accumulation of 0.02 m based on under
water video footage of a relatively small area. If accumulations in other areas of the lake are
greater, the amount of material to be removed and costs would be accordingly increased. As
mentioned above - we did not consider any permitting issues either, or cost of analyses
associated with a permit.
Discussion / Recommendations

**Overall status of lake**

Overall the lake is shallow, maximum depth is only 3 m and the average depth is slightly over 1 m. Because of the earthen dam, the system is a terminal system, meaning that it receives and stores runoff from a large land area, without a high degree of flushing. During spring snowmelt, runoff can be high, and this sometimes exits over the earthen dam. However, because of the lake effect, and runoff that enters experiences a slowing of flow and a concomitant decrease in energy. Thus particles that may have been carried by currents are dropped in the lake. When constructed, the lake was entirely lined with a 2-3 mm impervious liner. Thus groundwater intrusions are likely low, as is the exit of water via groundwater from the system. Consequently all material flushed into the lake is captured in it. This has resulted in high accumulations of sediment and concentrations of phosphorus, which was the nutrient on which the class concentrated. Due to the constant addition of material, with little chance for escape, the lake currently (as measured in October) would be considered borderline meso-eutrophic. Based on water total phosphorus concentrations it would be classified as eutrophic. Many of the parameters we measured are likely to be underestimates given the time of year at which we sampled. Macrophyte growth, and this biomass are generally at a maximum near the beginning of summer, as are fish and algal populations. Based on our experience at the lake, and background data obtained during the summer, some intervention is needed to meet homeowner desires of a water body that contributes to the aesthetic value of their homes.

**Sediment and nutrient inputs**

Because the lake is a terminal system, efforts should be made to examine inputs of sediment and nutrients. The amount of material that has accumulated in the lake over the 12 years of its existence is large - approximately 9 tons of sediment and 10 kg of P per year. Any recommendations we make below are only band-aid solutions in the absence of serious consideration of inputs. Given the time of year the study was conducted, and the nature of this project, it was not possible to quantify the annual input of sediment or associated nutrients. However, it is likely large. Thus, attempting to rectify any in-lake problems should be considered in light of inputs - which are unknown at this time. Obtaining rough estimates of inputs is relatively simple and could be inexpensive. What is needed is a relationship between water depth in the stream channel and quantity of water discharged. Along with this, point estimates are needed of the amount of sediment and nutrient concentration. Once a relationship is established, constituent could be estimated from water depth alone. Because the Best Hills Ranch Development does not own property past the last house, or upstream of their lake, perhaps it would be possible to negotiate with the landowner to potentially construct a settling area, where water velocity is slowed, material allowed to settle out and cleaner water passed to the
lake. This would involved also negotiations with DEQ, and we were unable to determine if any wetland areas would be involved. However, armed with inflow data would allow for a stronger evaluation of the potential effectiveness of in-lake management decisions.

**Macrophytes**

Numerous investigations on macrophytes and their biological role in water bodies have shown they are important components of a healthy ecosystem. Investigations of charophyta have suggested they are pioneer colonizers and occupy recently disturbed water bodies (Wade 1990). Because of this, charophytes have been studied intensively. They have been shown to increase water quality and reduce turbidity in many aquatic systems (Blindow 1992; Blindow et al. 2002; Coops 2002). Likewise, management of aquatic systems often involves the use of charophyte species to restore water quality (Coops 2002). Other studies have shown that charophytes can effectively out-compete phytoplankton (algae) and periphyton (algae attached to rocks) for nutrients such as phosphorus, which subsequently limits the concentration of algal cells in the water and supports greater transparency (Kufel and Kufel 2002; van Donk and van de Bund 2002; Siong et al. 2006). Similarly, studies have also found that charophytes can suppress phytoplankton growth through a mechanism called allelopathy, which occurs when macrophytes excrete certain substances known as allelochemicals (van Donk and van de Bund 2002). However, more importantly, Hutchinson (1975) and Kufel and Kufel (2002) reported that charophyte beds can act as phosphorus sinks in aquatic systems by absorbing high levels from the sediment, keeping it bound up and unavailable for uptake by phytoplankton and other aquatic plants. Because sediment P concentrations are generally much higher than in surrounding water (Gabrielson et al. 1984, Smith and Adams 1986) found that macrophytes take up most of their phosphorus from the sediments. Our calculation of 2.62 g/m² P within the macrophytes was comparable to 2.8 g/m² reported for *Chara* spp. by Boyd (1967). The dry mass of approximately 289 g/m² fell within a range of biomasses according to the findings of Królikowska (1997), who found dry weights for several species of *Chara* to be between 43 g/m² and 384 g/m².

Although macrophytes are necessary for a healthy ecosystem, an overabundance of macrophytes can be problematic. For example, at night, plants cease photosynthesis and respire similar to other aerobic organisms - hence use oxygen. High density macrophyte beds in some shallow lakes or bays can use the entire mass of oxygen dissolved in the water making the water body unsuitable for fish, resulting in summer fish kills. In addition, the lack of oxygen can also change chemical reactions, leading to the introduction of nutrients such as P from the sediments. Extensive macrophyte growth can also limit the foraging success of large predators such as bass because small fish have such a highly structured environment in which to hide. Often times, predatory fish can not penetrate into high density macrophytes.

One approach to reduce macrophyte growth is to continue adding chemicals which have been shown to effectively control macrophytes (Gangstad, 1988; Westerdahl and Getsinger,
Although this has been the approach of the homeowners to this point, chemicals added in 2009 included 2.5 gallons DMA 4IVM, Renovate 3, Reward (1 gal), and Cutrine-Plus (1 gal). Of these chemical applied, only 1, Cutrine-Plus, has elemental copper which is known to be effective against Charophytes. None of the active ingredients in the other products are effective against charophytes (Holdren et al. 2001 - pg 280) which are the dominant macrophyte in the system. As well, according to the application label, the rate that Cutrine-Plus was applied, was too low to be effective against charophytes. For an average depth of 4’, the recommended application rate is 4.8 gal/acre. If this approach is continued, the homeowners should ensure that effective chemicals are applied at the appropriate dose. However, the removal of macrophytes via chemicals is short term, and repeated applications annually are required so costs would be high. Chemicals can also have many negative effects, especially the repeated application of elemental copper. Chen et al. (2004) found that some herbicides can cause negative effects in zooplankton and amphibian survival. The use of chemicals has also been found to release nutrients directly into the water column after killing the plants so there are often large phytoplankton blooms that can turn the water into an unsightly color (Hestand and Carter, 1978). We would recommend caution in continuing with this approach.

Our research suggests that by sequentially harvesting charophytes, phosphorous can be depleted from the system over time because as the macrophytes re-grow they will take up additional phosphorus from the sediments (Barko et al. 1991; Barko and James 1998; DeBusk et al. 2001; Cooke et al. 2005). We therefore recommend the manual removal of macrophytes from the lake using hand pulling with rakes. All biomass removed from the lake should be allowed to dry and then disposed of outside of the watershed so that material released during decomposition of plant remains does not re-enter the lake. Based on our calculations and consideration of the various strategies, we conclude that macrophyte removal is likely one of the most cost effective, reliable and accessible management strategies the homeowner’s can undertake. However, it is not without drawbacks.

Drawbacks of macrophyte harvest include the generation of turbidity during harvest, and potentially after harvest, commitment from the homeowners to remove macrophytes, and willingness to persist. Although removal of macrophytes will immediately reduce the biomass, regrowth will occur as long as the sediments contain sufficient nutrients to support macrophytes. Thus a commitment is needed to persist with this approach, and it will need to be repeated either in the same year, depending on growth conditions or at least in subsequent years. Based on our calculations, the commitment could be long (11 yrs). Because removal of macrophytes will expose the lake bed to potential disturbance by wave action, the lake could be forced into a turbid stable state (Scheffer 1998) which is also an undesirable state. Thus we recommend a modified approach to macrophyte removal - one in which macrophytes are harvested in bands perpendicular to the long axis of the lake. The width of bands could correspond to homeowner’s property lines so that waterfronts are cleared every other year. Alternatively, spacing could be
across half property lines, so that each homeowner has the benefit of clear water in front of their home over half of their property each year. By implementing such a strategy, wave action and consequently nutrient release from sediment would be reduced, or eliminated because in places where macrophytes were present they would prevent the large-scale movement of water. In addition, by having macrophytes present, any nutrients released during the removal process could be rapidly taken up by established plants rather than allow the formation of algal blooms. We would also recommend adding Aquashade to prevent the growth of algae. Homeowners would also need to be willing to have drying macrophytes along their shoreline or along the opposite side before they are removed from the site. This could result in some aesthetic (sight and odor) issues for some homeowners, and should be discussed in detail among the group).

Our assumptions with the time and effectiveness of this approach are as follows. We used the mass of macrophytes present during our October visits. This is likely an underestimate given the time of year. As well, some manual macrophyte removal had already occurred by homeowners. Thus, us it likely that the mass of P removed via macrophytes could be much higher than that calculated here. This would increase the rate at which P is depleted from the system. Another assumption we made was that the sediment accumulation in the bottom of the lake was a uniform 2 cm. This is unlikely, and is probably an underestimate. However, it was the best estimate we could obtain given the sampling time and equipment available. Because we failed to collect any material in the core samples along the length of the pond in the middle, we made this general assumption and based out calculations on it. An underestimate would have the consequence that the total amount of P reservoir is underestimated - this would increase the time of P depletion via macrophyte harvest. As well, our annual P input would be underestimated, which would also increase the time to depletion. Both of these would increase the needed commitment from homeowner’s for long-term macrophyte removal. It would also increase the cost of the project. To remedy this shortcoming, a detailed survey of sediment accumulation should be made. Given the flocculent nature of the sediment, it is unlikely that adequate measurements can be obtained with any sort of sampler. This means that manual survey techniques would need to be used. A diver would probably be the quickest way to obtain these measurements, or they could be collected from the surface via a camera mounted to a measuring pole on which sediment depth could be recorded. We would identify this sediment survey along with measures of plant biomass/unit area at height of growth as priority needs to fine tune calculations and estimates we present. We also assume that all P in sediment is available for macrophyte growth, and all P in macrophytes returns to the circulating pool. Both of these assumptions overestimate the availability of P to macrophytes. We were unable to locate any references that quantified the amount of P in lake sediments available to macrophytes. Similarly, part of annual plant growth contributes to the accumulation of sediment at the bottom of lakes, material that is buried over time and is ‘locked out’ of the system. Both of these estimates would reduce the time over which macrophytes need to be removed from the sediment.
Another remediation method would be to use biological controls to reduce macrophyte growth. Grass carp (*Ctenopharyngodon idella*) have been used in many lakes and ponds to control macrophyte growth. Grass carp are highly effective at eating *Chara* and once they have become established, the method is long lasting and requires minimal maintenance (Webb *et al.* 1993). The fish have an average lifespan of 10 years and can eat up to 40% of their body weight per day (Sutton and Vandiver 2000). They also found that the use of grass carp did not result in large phytoplankton blooms because the nutrients released by the carp were not readily available for uptake by phytoplankton. However, they found that the nutrients were available for more macrophyte growth (Hestand and Carter, 1978). Shireman *et al.* (1986) recommend stocking sterile triploid grass carp at a rate of 4 per acre. This equates to about 12 grass carp for the Best Hills Property Lake at a cost of approximately $200-$400 for the fish (Shireman *et al.*, 1986). Because grass carp are considered invasive and nonnative, a free permit would be required from the US Fish and Wildlife Service and stocked fish have to come from a certified producer so that they are ensured to be sterile. As well, were the lake to flood and allow grass carp to escape, downstream consequences could be severe. The downside of using this remediation method is that grass carp dig and uproot macrophytes causing very high turbidity levels (Hestand and Carter, 1978). This may not be aesthetically pleasing to the homeowners as this would be a persistent feature of the presence of grass carp. Given that clear water is one of the desired properties, we can not recommend the addition of grass carp.

Finally, as mentioned above, macrophytes are a necessary component of a healthy ecosystem. They serve as nursery areas for small fish, harbor invertebrates, and provide shade that keeps water cool during summer. In addition, they provide oxygen via photosynthesis. Thus, we would discourage the removal of all macrophytes from the lake in the course of macrophyte management.

**Loss of water due to evaporation**

Although P is brought in by the well, this is a relatively insignificant component compared to the mass stored in the sediment and macrophytes. However, as shown above, allowing the lake level to drop due to evaporation could significantly increase nutrient concentrations, thus we recommend that the homeowners maintain the lake level near the maximum pool as best as they can during the summer months.

**Zooplankton and fish community**

Zooplankton species present in the highest abundance were small-sized, indicating high predation pressure. It is well known, that large zooplankton are highly susceptible to predators and predators tend to select the largest-sized individuals first (Brooks and Dodson 1965). Thus, with a high density of fish that feed on zooplankton, what remains is a small-bodied community...
of zooplankton. This has implications for water clarity because, zooplankton are typically filter feeders and efficiency and ability to filter large volumes of water increase with zooplankton size. Thus, to maintain clear water, high densities of large-bodied zooplankton are desired (Carpenter et al. 1985). As a result, high densities of bluegill-type fish predators are not compatible with clear water. In terms of fish, many small fish were seen during a visit in summer, while in October relatively few fish were observed. The dense macrophyte beds present also provide ample hiding opportunities for small fish, such that piscivores, such as bass, are unlikely able to forage successfully and reduce their abundance. Therefore, it is likely that the fish community is dominated by many small fish that are stunted, and reduce the abundance of large zooplankton. Although a relatively high density of copepods was found, these are not consumed by fish at the same rate as cladocerans because of their rapid escape response (Kerfoot 1978). Their filtering efficiency is not as high as that of cladocerans either, and they display a high degree of omnivorous feeding.

Our recommendations in terms of the fish community would be to remove most of the small blue gill and planktivorous fish to promote the establishment of a community of large-bodied zooplankton that can effectively graze algae and assist in maintaining water clarity. Fish could be removed via gill nets, angling or traps. Rotenone could also be used, but this would kill all fish in the lake and requires a permit to apply. We recommend the homeowners check with IDFG for options and additional recommendations on how best to balance the fish community. Access to small fish for predators should increase once macrophytes are thinned.

**Aeration**

It is likely that the lake microstratifies during the summer time. The degree and extent of any stratification in summer should be investigated during summer as it can determine to what extend the lake circulates. This is important from a chemical reaction perspective near the sediment/water interface. During low or no oxygen periods, e.g., at night, nutrients could load into the water column form the sediment exacerbating the excessive nutrient concentrations (Jacoby et al. 1982). The aerator we recommend would inject air via a compressor at depth, allowing the entire water column to mix and be exposed to the air-water interface. This would be an improvement over the current system in place because it only circulates surficial water. If the lake is stratified, then lower layers are never aerated. Given the relative inexpensive equipment for the aerators, and the existence of power, we recommend that the homeowners consider installing two aerators to assist with other in-lake management strategies.

**Buffer strips to reduce the input of sediment and phosphorus into the lake**

Studies have shown that the application of a buffer strip can often be the best management practice to improve water quality (Dillaha et al.1988). Any type of vegetation abutting the edge of the water provides some level of benefit to the water body, but the most effective buffer strips
are typically planted with native vegetation. Buffer strips provide a number of services including the removal of nutrients and chemicals from run-off. For example, even in 1 m strips (Dorioz et al., 2006) reported removal of 60 to 80% nutrients. They also provide bank stabilization and can provide aesthetic value to properties. Based on a model buffer strip model around a New Jersey reservoir (Nieswand et al. 2007) recommended a width between 50 and 300'. Other recommended widths are between 5 and 10 meters (Dorioz et al., 2006). Obviously a buffer strip of this size is not feasible for the Best Hills Ranch Development, however, a narrow strip of shrubs, grasses and perennials may be sufficient as it has been shown that uptake of nutrients typically occurs in the first few meters (Vought et al., 1995). Combined with decreased fertilizer application in yards near the water, this may reduce run off and impact to the lake. Buffer strips cease to be effective once the soil and vegetation become saturated with phosphorous (Dorioz et al., 2006). To get around this issue, shrubs/grasses can be harvested or trimmed the and the cuttings removed. Compared to other management options, a buffer strip is quite affordable and requires low maintenance once established. As mentioned above, homeowners should thoroughly discuss this idea to ensure that desires and needs of each property owner are adequately met. To help with any potential planning here, services are available via the web from the Natural Resource Conservation Service.

We recommend that interested resident of the Best Hills Ranch Development take advantage of a class offered at the Northern Idaho College. The City of Coeur d'Alene Water Department has teamed up with the Northern Idaho College Workforce Training Center to provide a course for Coeur d’Alene residents titled, “Landscaping with Native Plants”. The class scheduled for March 11-18th, and homeowners that attend can receive a utility bill credit for the cost of the class and workbook. More information about the class can be found at the Northern Idaho College website.

**Removal of sediment from bottom of lake**

After evaluating the data associated with draining and cleaning out the pond, we feel that this should be considered as a viable option. However, as mentioned above, control of inputs would need to be ensured as this system ‘reset’ would be a large-scale undertaking, and the homeowners should ensure that it will last longer than 12 years - or the 5-7 years given the relatively long duration for which macrophyte problems have been present in the current system. The advantage of cleaning out the lake would be that sediment and nutrients that have accumulated to this point would be removed. If this could be implemented with a reduction in inputs, we would expect the lake to remain clear for a long time. Drawbacks to this approach is the lack of water in the system for up to a year. Given the lack of information on the inflow - it is unclear how long it would take for the system to refill entirely. A further issue is the amount of sediment that would need to be removed - shoveling 112.4 tons of dirt is no small task, nor is it’s disposal. At a volume of 132.3 m³ or 173 cubic yards and 5-10 cubic yards/truck load, a total
of 34 small dump truck loads need to be removed. A typical wheel barrow holds 3 cubic feet, thus removing the sediment manually would require in the vicinity of 1560 trips between the lake and the truck. If this undertaking is considered further, homeowners need to consider where trucks will enter and to what degree sediment will be removed manually versus machinery. If machinery is used, potential damage to and replacement of the liner must be factored into the cost.

**Suction dredging**

Another approach to removing the sediment would be via suction dredging and/or diver-operated dredging equipment (Wetzel, 2001). A suction dredger is a machine designed to remove sediments from the bottom of lakes. By removing the sediments, excess nutrients are also removed. The suction dredger vacuums up the sediment at specified layers without the need to drain the lake. Suction dredging technology becomes operationally and economically most effective when water areas are larger than several hectares and sediment volumes are above 10,000 m³ (Pokorny and Hauser, 2002). Supposedly the transport of sediment in pipes causes neither noise nor pollution. The removed sediments are then transported offsite and disposed of. In one case, 40,000 m³ of sediment was directly applied on an agriculture field (Pokorny and Hauser, 2002). This approach would require additional sediment analysis for other nutrients, heavy metals, and selected toxins before application. Alternatively, sediment can be dewatered on site using large geotubes. However, dried sediment would still need to be removed and the same obstacles as faced for the draining and cleaning in terms of hauling material away remain.

There are cases where suction dredging was effective and cases where the positive effects were only temporary. The trend seems to be correlated with whether there were plans that were executed to ensure that nutrients inflows were greatly reduced along with the in-lake dredging. Virtually all case studies of this restoration technique recommend using suction dredging only after an effective, holistic, long-term management plan has been put in place (Pokorny and Hauser, 2002; Madgwick, 2004).

However, suction dredging is probably not a practical option in the Best Hills Ranch Development lake. Both the lake area and volume to be removed is quite small from an operator perspective. An estimator from Air-Water-Soil Engineering, Inc stated that his company would not suction dredge small lakes such as this because it is not economical. The pricing for suction dredging projects are high - Dredge America has a minimum project price of $100,000, while ACC Hurlen Construction of Seattle, WA, the only local suction dredge service provider, would not consider the project because the lake and sediment loads are small. Another issue to consider is that suction dredges not only remove sediment, but also water which is used to assist in transporting the slurry through the pipes. Thus, the lake level may drop precipitously, and instead of dredging, the lake could be drained right off.
Conclusions

In conclusion, we recommend a multi-faceted low-impact and low-cost approach. First we recommend that macrophytes be removed manually in a zebra-stripe type pattern, with alternate stripes harvested each year. Combined with this approach, the homeowners should consider the application of Aquashade to prevent algal blooms from the nutrients released when macrophytes are harvested. The homeowners should also consider installing a couple of aerators that can introduce air and mix the entire water column to prevent anoxic conditions at night. The surface pumps/fountains currently in use could still be used if they were desired for aesthetic purposes - but they do not appear to offer any functionality for circulating the water mass. The fish population should be adjusted to reduce the number of small planktivorous fish which seem to be negatively impacting the zooplankton population. Because homeowners currently use low height fencing to keep geese off lawn, and some lawns abut the lake edge, we recommend the homeowners collectively discuss alternative water edge landscaping to include a buffer strip (this does not have to be overly wide) planted with native plants to act as a runoff interceptor and goose deterrent at the same time. This will require some discussion to ensure that all homeowner’s needs and desires are met, and that plants, heights, and widths are consistent among all properties. Those with beaches but lawn further set back will require consideration as well. We did not assess inputs from lawns and they should be examined to determine if and what reductions of nutrient inputs can be gained from altered practices. All of these recommendations are relatively low cost approaches, but will take commitment, and will not offer a one-shot solution. Thus, resident should be patient. As well, we recommend that inflows be examined to obtain estimates of the impacts originating there, and explore possibilities of reducing inputs. To obtain more accurate estimates of the time-frame of the macrophyte removal, better estimates of sediment depth on the lake bottom should be obtained.
Acknowledgments

We thank the Best Hills Ranch Development Homeowner’s association for suggesting this project and allowing us full access to the lake. As well we thank them for hosting the class after sampling trips and during the final presentations.

References


U.S. Environ. Prot. Agency, Madison, WI.


Table 1. Lake areas and volumes determined from the bathymetric evaluation of Best Hills Ranch Development Lake in Coeur D’Alene, Idaho. Note that area and volume below 1.219 m was used for calculation of sediment removal and littoral vs deep zone for macrophyte calculations because it is the depth to which the liner was originally buried (4’).

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>2D area (m²)</th>
<th>Surface Area (m²)</th>
<th>Area in stratum (m²)</th>
<th>Volume (m³)</th>
<th>Volume in stratum (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>14950</td>
<td>15468.2</td>
<td>16947.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>11876.7</td>
<td>12295.3</td>
<td>3172.9</td>
<td>10214.3</td>
<td>6732.9</td>
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<tr>
<td>1</td>
<td>8406.2</td>
<td>8707.6</td>
<td>3587.7</td>
<td>5119.9</td>
<td>5094.4</td>
</tr>
<tr>
<td>1.5</td>
<td>4218.3</td>
<td>4389.2</td>
<td>4318.4</td>
<td>2024.7</td>
<td>3095.2</td>
</tr>
<tr>
<td>2</td>
<td>1745.3</td>
<td>1819.6</td>
<td>2569.2</td>
<td>630.2</td>
<td>1394.5</td>
</tr>
<tr>
<td>2.5</td>
<td>488</td>
<td>505.3</td>
<td>1314.3</td>
<td>87.3</td>
<td>542.9</td>
</tr>
<tr>
<td>3.07</td>
<td>1.7</td>
<td>1.7</td>
<td>505.3</td>
<td>0.04</td>
<td>87</td>
</tr>
<tr>
<td>1.219 -3.07 m</td>
<td>6371.7</td>
<td>6615.4</td>
<td></td>
<td>3492.8</td>
<td></td>
</tr>
<tr>
<td>0-1.219 m</td>
<td></td>
<td></td>
<td>8852.8</td>
<td>13454.41</td>
<td></td>
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</tbody>
</table>
Table 2. Average concentrations of total phosphorus and chlorophyll $a$ in water of the Best Hills Ranch Development lake in October 2009. Means ± standard error, N - number of samples.

<table>
<thead>
<tr>
<th></th>
<th>Total Phosphorus (µg/L)</th>
<th>Chlorophyll a (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inflow</td>
<td>Water column</td>
</tr>
<tr>
<td>Mean</td>
<td>13.13 ± 3.69</td>
<td>32.63 ± 1.92</td>
</tr>
<tr>
<td>Range</td>
<td>2.00 - 25.71</td>
<td>15.83 - 82.50</td>
</tr>
<tr>
<td>N</td>
<td>8</td>
<td>54</td>
</tr>
</tbody>
</table>
Table 3. Zooplankton density (ind./l means ±standard error) in the Best Hills Ranch Development lake in October 2009.

<table>
<thead>
<tr>
<th>Taxon</th>
<th>40457 Mean ± N</th>
<th>40464 Mean ± N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cladocera1</td>
<td>4.3 ± 1.3</td>
<td>5.3 ± 1.3</td>
</tr>
<tr>
<td>Copepods2</td>
<td>3.1 ± 1.0</td>
<td>3.6 ± 1.1</td>
</tr>
<tr>
<td>Ostracoda</td>
<td>0.0 ± 0.0</td>
<td>1.6 ± 2.2</td>
</tr>
<tr>
<td>Chaoborus</td>
<td>0.5 ± 0.4</td>
<td>0.6 ± 2.6</td>
</tr>
</tbody>
</table>

1Includes *Bomina, Ceriodaphnia* spp., and *Daphnia* spp., but was predominantly *Bosmina*.

2Includes, Calanoids, cyclopoids, harpacticoids, and nauplii.
Table 4. Dry mass and total phosphorus (TP) content of macrophytes in the Best Hills Ranch Development lake collected from the littoral zone on 7 October, 2009, and from the center of the lake on 14 October, 2009. Means ± standard errors, N - sample size.

<table>
<thead>
<tr>
<th></th>
<th>October 7 Littoral</th>
<th></th>
<th>October 14 Middle</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Range</td>
<td>N</td>
<td>Mean</td>
<td>Range</td>
</tr>
<tr>
<td>Dry mass of macrophytes</td>
<td>288.53 ± 36.8</td>
<td>152-616</td>
<td>15</td>
<td>564.44 ± 34.7</td>
<td>210 - 1140</td>
</tr>
<tr>
<td>(g/m²)</td>
<td></td>
<td></td>
<td>15</td>
<td>564.44 ± 34.7</td>
<td>210 - 1140</td>
</tr>
<tr>
<td>Mass of TP/m² (g/m²)</td>
<td>2.62 ± 0.13</td>
<td>0.97 - 4.86</td>
<td>15</td>
<td>6.46 ± 0.27</td>
<td>1.7 - 11.9</td>
</tr>
<tr>
<td>Mass of TP/g of dry</td>
<td>0.01 ± &lt;0.01</td>
<td>0.0065 - 0.0124</td>
<td>15</td>
<td>0.01 ± &lt;0.01</td>
<td>0.0082 - 0.0151</td>
</tr>
<tr>
<td>macrophyte mass</td>
<td></td>
<td></td>
<td>15</td>
<td>564.44 ± 34.7</td>
<td>210 - 1140</td>
</tr>
</tbody>
</table>
Table 5. Annual depletion rates of P mass in top 2 cm of sediment in lake of Best Hills Ranch Development. Part 2 of table is for removal of only $\frac{1}{2}$ annual macrophyte biomass. See text for assumptions.

<table>
<thead>
<tr>
<th>Year of removal</th>
<th>Total mass of P at start of year (kg)</th>
<th>Annual input of P (kg)</th>
<th>Mass of P removed via macrophytes (kg)</th>
<th>Mass of P at end of year (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>188</td>
<td>15.7</td>
<td>65.7</td>
<td>138</td>
</tr>
<tr>
<td>2</td>
<td>138</td>
<td>15.7</td>
<td>65.7</td>
<td>88</td>
</tr>
<tr>
<td>3</td>
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<tr>
<td>4</td>
<td>38</td>
<td>15.7</td>
<td>65.7</td>
<td>-12</td>
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</tbody>
</table>

Removing only $\frac{1}{2}$ annual macrophyte biomass

<table>
<thead>
<tr>
<th>Year of removal</th>
<th>Total mass of P at start of year (kg)</th>
<th>Annual input of P (kg)</th>
<th>Mass of P removed via macrophytes (kg)</th>
<th>Mass of P at end of year (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>188</td>
<td>15.7</td>
<td>32.8</td>
<td>170.9</td>
</tr>
<tr>
<td>2</td>
<td>170.9</td>
<td>15.7</td>
<td>32.8</td>
<td>153.8</td>
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<td>3</td>
<td>153.8</td>
<td>15.7</td>
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<td>136.7</td>
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<td>119.6</td>
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<td>9</td>
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<td>15.7</td>
<td>32.8</td>
<td>34.1</td>
</tr>
<tr>
<td>10</td>
<td>34.1</td>
<td>15.7</td>
<td>32.8</td>
<td>17</td>
</tr>
<tr>
<td>11</td>
<td>17</td>
<td>15.7</td>
<td>32.8</td>
<td>-0.1</td>
</tr>
</tbody>
</table>
Figure Captions

**Figure 1.** Locations of sampling sites in the Best Hills Ranch Development lake. Samples were obtained on October 7th and 14th. White dots indicate profiles for temperature, dissolved oxygen and conductivity; Blue dots indicate sites at which water chemistry was samples; Green dots indicate sites for chlorophyll a analysis; Yellow dots indicate zooplankton sampling sites; Orange dots indicate sites at which macrophytes were samples; while pink dots indicate sediment coring sites.

**Figure 2.** Bathymetry of Best Hills Ranch Development lake.

**Figure 3.** Profiles of temperature (A), dissolved oxygen (B), and conductivity (C) recorded on October 7 and 14, 2009 in the Best Hills Ranch Development lake.

**Figure 4.** Profiles of water content (A), organic content (B), dry bulk density (C), and the mass of total phosphorus (TP) per square meter in cores collected from the Best Hills Ranch Development lake on October 7 and 14, 2009.
Figure 1.
Surveyed on October 07 & 14, 2009
University of Idaho
FISH 415 Limnology Class
Frank M. Wilhelm Instructor

Lowrance LCX-25c depth sounder
UTM NAD 1983 Datum

Depth Contours 0.5m
Figure 3.
- **Water content (%)**
  - Depth in core (cm): 0, 2, 4, 6, 8, 10, 12
  - October 7, 2009 and October 14, 2009

- **Organic content (%)**
  - Depth in core (cm): 0, 2, 4, 6, 8, 10, 12

- **Dry bulk density (g/cm³)**
  - Depth in core (cm): 0, 2, 4, 6, 8, 10

- **Mass of TP (g/m²)**
  - October 7, 2009 and October 14, 2009

**Figure 4.**