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Analysis of the Import, Export, and Bioavailability of Nitrogen and Phosphorus Within Pineview Reservoir

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ANALYSIS OF THE IMPORT, EXPORT, AND BIOAVAILABILITY OF NITROGEN AND PHOSPHORUS WITHIN PINEVIEW RESERVOIR, UTAH, USA

by

Brady Worwood

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ABSTRACT

Analysis of the Import, Export, and Bioavailability of Nitrogen and Phosphorus Within Pineview Reservoir

by

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Utah State University, 2011

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This study was conducted to provide new and useful data about Pineview Reservoir and its watershed, produce water and phosphorus (P) budgets for Pineview Reservoir, test the validity of conclusions made in the Pineview Reservoir Total Maximum Daily Loading (TMDL) document, and create estimates of nitrogen (N) loading to the reservoir from both surface and ground water sources. The production of the water and P budgets, as well as the N loading estimates, was accomplished by measuring flow, nitrate, ammonium, total phosphorus (TP), and soluble reactive phosphorus (SRP) that was entering and exiting the reservoir through surface water sources and the reservoir outlet over a period of approximately 2 years (2008 to 2010). Estimates of ground water contributions to the reservoir were also made using ground water P and N concentration data from a parallel study and ground water flow estimates from the literature. In order to test the validity of claims made in the TMDL, internal reservoir parameters such as temperature, dissolved oxygen, TP, orthophosphorus (OP), nitrate, ammonium and dissolved iron (Fe) were measured at the surface, thermocline, and hypolimnion of five sampling locations within the reservoir over the same sampling period. Chlorophyll A was also measured near the surface of the sites during each sampling event. Contrary to the conclusions made by the TMDL it was found that the internal cycling of nutrients, especially P, is occurring in Pineview Reservoir and that annually observed phytoplankton blooms can be attributed to the release of benthic nutrients. It was also found that there is a large store of sediment P that is currently or potentially could be made available for transfer into the water column. It was estimated that 14,800 kg of P was exported from the reservoir over the one-year sample period of 4/15/2009 to 4/14/2010. This large P release is due to the practice of exporting P rich hypolimnetic water throughout the summer irrigation season. It was shown that more P could be exported if outflows were increased during this period. P budgets indicated that P may not currently be building up within Pineview Reservoir, but given the limited amount of ground water data available for the Reservoir's watershed, further ground water flow and nutrient data are necessary to substantiate this claim. This study has helped to provide a clearer picture of the trophic status and internal P cycles of Pineview Reservoir. It has also helped to answer questions about the reservoir that have been overlooked in previous studies, such as the magnitude of internal P loading and the importance of Spring Creek and Geertsen Creek in the reservoir's water budget. This and other information gathered during this study could prove to be a useful benchmark for measuring the effectiveness of future efforts to improve water quality in the reservoir.

(149 pages)

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This study was conducted to provide new and useful data about Pineview Reservoir and its watershed, produce water and phosphorus budgets for Pineview Reservoir, test the validity of conclusions made in the Pineview Reservoir Total Maximum Daily Loading document and create estimates of nitrogen loading to the reservoir from both streams and ground water sources. The production of the water and phosphorus budgets, as well as the nitrogen loading estimates was accomplished by measuring stream flows going into the reservoir, and flows going out of the reservoir via the dam outlet, as well as the concentrations of nitrate, ammonium, total phosphorus, and soluble reactive phosphorus in those flows over a period of approximately 2 years (2008 to 2010). Estimates of ground water contributions to the reservoir were also made using ground water phosphorus and nitrogen concentration data from a parallel study and ground water flow estimates from previous studies. In order to test the validity of claims made in the Pineview Reservoir Total Maximum Daily Loading document, concentrations of temperature, dissolved oxygen, total phosphorus, orthophosphorus, nitrate, ammonium and dissolved iron were measured from water samples taken near the surface, middle and bottom of the reservoir at five sampling locations within the reservoir over the same sampling period. Chlorophyll A, which is a good indicator of the amount of algae present at any given time, was also measured near the surface of the reservoir sampling sites during each sampling event. Contrary to the conclusions made by the Total Maximum Daily Loading document, it was found that the internal cycling of nutrients, especially phosphorus, from the reservoir bottom sediments up into the reservoir water is occurring in Pineview Reservoir and that annually observed algal and cyanobacterial blooms can be attributed to the release of nutrients, especially phosphorus, from the bottom sediments up into the water column, where it can be utilized by algae and cyanobacteria. It was also found that there is a large store of phosphorus in the reservoir's bottom sediments that is currently or potentially could be made available for transfer into the water column. It was estimated that 14,800 kg of phosphorus were exported from the reservoir over the one year sample period of 4/15/2009 to 4/14/2010. This large phosphorus release is due to the practice of exporting phosphorus rich reservoir bottom water through the dam outlet, throughout the summer irrigation season when the largest amounts of phosphorus are leaving the bottom sediments due to a lack of oxygen in the bottom waters. It was shown that more phosphorus could be exported if outflows were increased during this period. Phosphorus budgets indicated that phosphorus may not currently be building up within Pineview Reservoir, but given the limited amount of ground water data available for the Reservoir's watershed, further ground water flow and nutrient data are necessary to substantiate this claim. This study has helped to provide a clearer picture of the current water quality status and internal phosphorus cycles of Pineview Reservoir. It has also helped to answer questions about the reservoir that have been overlooked in previous studies, such as the magnitude of internal phosphorus loading and the importance of Spring Creek and Geertsen Creek in the reservoir's water budget. This and other information gathered during this study could prove to be a useful benchmark for measuring the effectiveness of future efforts to improve water quality in the reservoir.

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Brady Worwood

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INTRODUCTION

With the rapidly increasing demand for clean water for municipal, agricultural, industrial and other uses it is becoming more and more important to care for and preserve existing water collection and storage systems. Due to increasing human activities such as agriculture, urban development, recreation, etc. occurring in and around the world's freshwater lakes, reservoirs and watersheds, greater and greater pollutant loads are making their way into water collection and storage systems.

Some of the most widespread pollutants of concern entering collection and storage systems are nutrients, principally nitrogen (N) and phosphorus (P). In most cases, as nutrients increase in a water body so does biological activity. The increase in biological activity within a water body due to the increase of nutrients is known as eutrophication (Hein 2006; Conley et al. 2009). In order to understand the reasons for the eutrophication of a water body, it is vital to create a clearer understanding of the nutrient dynamics (inputs, exports, availability and internal cycling) of the water body itself.

Eutrophication

In many freshwater systems throughout the world, the biomass of primary producers within a given lake or reservoir is limited by the concentration and bioavailability of nitrogen and phosphorus (Dodds 2002). As more of these nutrients become available within the photic zones of lakes and reservoirs, resident phytoplankton populations increase rapidly, often creating dense, problematic blooms of algae and cyanobacteria.

As nitrogen and phosphorus build up within a lake or reservoir from external sources they can force a shift in the trophic status of the water-body, changing it from a less productive system to a eutrophic one. One of the key symptoms of this change is a shift from blooms consisting predominately of algae to those made up of N_2 fixing cyanobacteria. Large blooms of cyanobacteria in a lake or reservoir can be particularly problematic as they can produce toxins, cause hypoxia, and disrupt food web structures. Their ability to fix N_2 from the atmosphere can also serve to eliminate nitrogen shortages and lead to a strictly P-limited system, ultimately providing fewer options for remediation of the affected water bodies (Conley et al. 2009). Although cyanobacterial blooms can serve to eliminate nitrogen shortages, this phenomenon is unlikely to occur in N-limited lakes and reservoirs of low to moderate fertility. In reservoirs of low to moderate fertility, N or P are equally likely to explain nutrient limitation for phytoplankton (Lewis and Wurtsbaugh 2008).

Reservoir Water Quality Management

Phytoplankton blooms associated with eutrophication can greatly hinder a lake's or reservoir's beneficial use capacities. Large blooms can lower nighttime levels of dissolved oxygen (DO) in the water column below acceptable levels for a given water body, they can cause taste and odor issues that can increase costs of municipal drinking-water production, and hinder surface water recreational activities.

Nutrients such as N and P, as well as other pollutants of concern in freshwater lakes and reservoirs, originate from one of two types of source classifications, point sources and non point sources. Point sources are sources of pollutants such as wastewater treatment facilities, factories or other singular entities where the waste stream can be easily identified and usually exits from a single point. Point sources are easy to identify and, with the proper technology, legislation rules and guidelines, such as those found in the Federal Water Pollution Control Act, relatively easy to regulate and control. Non point sources include agriculture, urban runoff, erosion, atmospheric deposition, and any other diffuse source that cannot be easily quantified or designated to a single point. Non point sources are the greatest contributors of N and P to freshwater lakes and reservoirs in the U.S. today (Carpenter et al. 1998). In a study performed by Gakstatter, Bartsch, and Callahan (1978), it was found that 72-82% of their sample of 255 eutrophic lakes and reservoirs in the eastern United States would require control of nonpoint P inputs to meet current water quality standards, even if all of the point sources contributing to the total loading of P to the systems was reduced to zero.

One such reservoir, where eutrophication is beginning to hinder water quality, despite a complete lack of point sources within the watershed, is Pineview Reservoir located in northern Utah, USA. The effects of eutrophication and P balance of Pineview Reservoir were the focus of this study.

TMDL Requirements and Process

A Total Maximum Daily Load (TMDL) can be defined as the maximum amount of any pollutant, contaminant or impairment that can enter a water body before that water body, ceases to provide its designated beneficial uses (Peterson and Bauder 2010). Water bodies that have been identified as impaired are placed on the state's 303D list (see Federal Water Pollution Control Act sec 303(d)(1)(A) and 33 USC sec1313) A TMDL must be prepared for each pollutant, contaminant or other impairment for listed water bodies. Within the state of Utah, A TMDL report has been or will be prepared for each individual water body or stream segment which has been identified as not meeting its designated beneficial uses. The report quantifies the acceptable total loads for each pollutant of concern, and allocates that load to different sources. When eutrophication is the primary concern, the pollutants of concern would likely be primary production limiting nutrients such as nitrogen and/or phosphorus. A strategy to reduce the impairments and monitor effectiveness of the implementation strategy is either part of the TMDL or is produced as a separate watershed implementation report (Peterson and Bauder 2010).

A TMDL report has been produced for Pineview Reservoir (Tetra Tech 2002). Pineview Reservoir was listed as being impaired for beneficial use designation 3A cold water aquatic life. It received this designation due to problems with DO, temperature and TP, the data and methods used to determine the reservoir's impairments can be found in the TMDL. Pineview was placed on Utah's list of impaired waters in 2000 (Tetra Tech 2002).

The data collection and analysis associated with the study described here provided information that was used to improve Pineview Reservoir's TMDL nutrient loading estimates and test assumptions made during the TMDL process, ultimately providing a clearer picture of actual stream and reservoir processes and dynamics.

Pineview Reservoir

Pineview Reservoir was created in 1937 as an impoundment of the upper reaches of the Ogden River. The reservoir itself is located within the Ogden Valley, with the vast majority of its watershed being located within the northernmost section of the Wasatch-Cache National Forest that surrounds the valley (Sadler and Roberts 1994).

After its initial creation in 1937 the reservoir had a maximum volume of 5448 hectare-meters (44,170 ac-ft) and a maximum depth of 18.6 m (Sadler and Roberts 1994). The elevation of the Pineview Reservoir's dam was increased in 1957 giving the reservoir a maximum storage capacity of 13,587 hectare-meters (110,150 ac-ft), a maximum surface area of 7102 hectares, and a maximum depth of 24.7 m (Tetra Tech 2002).

The major tributaries that feed into Pineview Reservoir include the South, Middle and North Forks of the Ogden River, Spring Creek and Geertsen Creek. Causey Reservoir is upstream of Pineview Reservoir on the South Fork of the Ogden River. Much of the flow in the South Fork of the Ogden River is water that has been discharged from Causey. The major irrigation diversion for the valley is on the South Fork between Causey and Pineview Reservoir. During the irrigation season (~May-October), the entire contents of the South Fork at the point of the diversion is rerouted into a series of canals and distributed around the valley for irrigation purposes.

Pineview Reservoir is a multi-use reservoir that provides water for both irrigation and municipal uses. Some of its other uses include recreational fishing, boating and

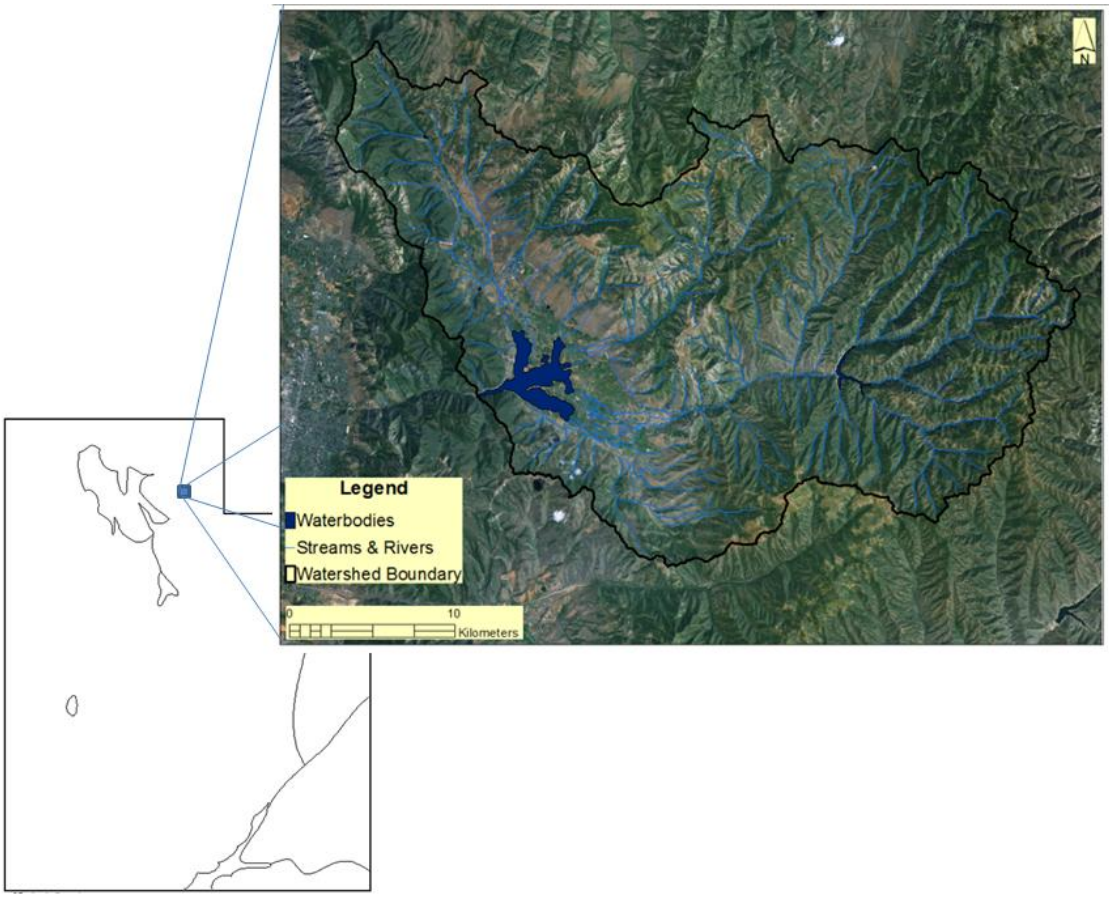

Figure 1. Pineview Reservoir and watershed.

water sports. Pineview is also a means of flood control for the community of Ogden, which is located approximately 7 miles downstream.

Throughout much of the year, Pineview Reservoir's water quality meets the criteria required by its designated beneficial uses. The reservoir is only moderately productive, and data collected in the present study shows that it falls loosely into the upper oligotrophic to lower mesotrophic ranges on the trophic state index (Hakanson and Victor 2001). However, water conditions show signs of eutrophication and general water quality degradation during the late summer to early fall of most years, when anoxic conditions occur in the hypolimnion and nuisance algal/cyanobacterial blooms arise following reservoir destratification. It is these anoxic conditions in the reservoir's hypolimnetic waters that ultimately lead to its being classified as impaired in its ability to function as a cold water fishery (State of Utah beneficial use designation Class 3A: Protected for cold water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain). This is due to the fact that the colder hypolimnetic waters in the reservoir do not meet the State of Utah's numeric criteria for a cold water fishery during the summer months due to low DO concentrations (Tetra Tech 2002).

HYPOTHESIS AND OBJECTIVES

The main objectives and hypotheses of this study are listed below. Objective A: determine the accuracy of the observations and recommendations that were made in the TMDL. Due to the extremely limited data used to produce the TMDL it is hypothesized that many of the observations and recommendations made in the TMDL may be based on insufficient information. It was recommended in the TMDL that monthly flow and nutrient data collection should be carried out in the reservoir's tributaries to verify its findings (Tetra Tech 2002).

Objective B: investigate reasons for annually observed blooms in the reservoir. It was hypothesized that annually observed phytoplankton blooms are caused by the internal cycling of the nutrients P and N from the benthic sediments into the water column.

Objective C: create a better understanding of sediment/water P cycles. It was hypothesized that significant amounts of bioavailable P is being released from sediments into the water column during times of anoxia in the reservoirs' hypolimnetic waters, and that iron plays a major role in the bioavailability of sediment P.

Objective D: better understand the reservoir ecosystem and microbiota as a means of understanding its trophic status, nutrient cycles and potential remediation techniques. It was hypothesized that the dominant species and total biovolume of reservoir phytoplankton communities readily change along with changing conditions in the reservoir. It was also hypothesized that by continually observing phytoplankton communities, a better understanding can be formed regarding reservoir trophic status, cycles and potential remediation techniques.

Objective E: create a mass balance of P in the reservoir, and create a better understanding of the sources of reservoir N and P. It was hypothesized that N and P entering the reservoir come from both surface and ground water sources and that atmospheric N fixation by cyanobacteria in the reservoir is one of the major sources of bioavailable N in the reservoir. It was also hypothesized that P is accumulating in the reservoir and that this accumulation is leading to the reservoir becoming more eutrophic.

Meeting these objectives helped to produce a better picture of the status of eutrophication within the reservoir, and the degree of intervention that may be required to best preserve the current water quality of this system.

LITERATURE REVIEW

Understanding Pineview Reservoir

In the process of meeting the objectives of this work it was imperative to obtain an understanding of the basic operational principals of reservoirs and their watersheds, including anthropogenic impacts and their relation to reservoir eutrophication and impairment. Some of the key ideas investigated in this literature review include, reservoir limnological processes, internal nutrient cycling and the nuisance blooms of algae and cyanobacteria that often accompany it, anthropogenic nutrient sources such as agriculture and wastewater, and a look at conclusions made during previous studies and the methods and information that was used to reach them. Researching these and other critical ideas helped to provide a basis of information that was critical to meeting the primary objectives of this study.

Dodds (2002) provides a wealth of information about lake and reservoir limnological principles, especially those applicable to eutrophication. Some of the major principles discussed in this book that were useful to this study were, thermal stratification of lakes and reservoirs, redox potential, nutrient forms and cycling in lakes and reservoirs and factors influencing freshwater biota and biodiversity.

Thornton, Kimmel, and Payne (1990) provided critical insights for understanding how limnological principals differ between different types of reservoirs and lakes. Lakes and reservoirs can be similar in many regards, such as similar phytoplankton communities, thermal stratification and nutrient limitation patterns. In spite of these similarities, Thornton, Kimmel, and Payne (1990) contend that lakes and reservoirs cannot be treated the same based on the fact that reservoirs are, on average, much newer limnological systems with newer accumulated sediments, that they have been designed and are managed to meet numerous beneficial uses such as irrigation, municipal water supply, hydroelectric power generation, recreation, etc. In order to meet all these uses, reservoir discharges are strictly controlled and are often set up to be taken from the reservoir's lower depths, while lake discharges are not controlled and come from their surface waters. Finally, lakes have been studied much more frequently than reservoirs, which have received very little study in past (Thornton, Kimmel, and Payne 1990).

Nutrient Sources

Nutrients can be introduced into water bodies from both point sources and non-point sources (Steinman, Chu, and Ogdahl 2009). In watersheds with no point sources, but significant urbanization or agriculture, the predominant sources of P loading into freshwater lakes and reservoirs are septic systems, urban and agricultural runoff, fertilizers, geologic P deposits and P rich surface soils within the watershed (Pettersson, Boström, and Jacobsen 1988). This phenomenon is especially applicable to reservoirs, due to the fact that reservoirs often have larger watersheds relative to their surface area than lakes and as a result, often experience higher natural loading rates than lakes (Havel and Rhodes 2009). Even in the absence of point sources, anthropogenic nutrient loading from agriculture and other land uses can significantly contribute to the eutrophication of a water body (Taranu and Gregory-Eaves 2008; Noll, Szatkowski, and Magee 2009). Agriculture is one of the most significant sources of nonpoint source nutrient loading to many impaired water bodies (USEPA 2003; Mishra, Kar, and Raghuwanshi 2009).

Fertilizers, manure, crop residues and erosion due to irrigation or animal activities are some of the ways that agriculture can contribute nutrients to ground water, streams and ultimately lakes and reservoirs (USEPA 2003).

In any reservoir, it is very important from a nutrient loading reduction standpoint to understand the fraction of nutrients entering the reservoir from natural versus anthropogenic sources. Knowing the sources of the P feeding into a lake or reservoir enables prioritization of pollution problems and their abatement measures within the watershed (Kelderman, Wei, and Maessen 2005). A primary goal of this study, however, was to produce a mass balance for P in the reservoir. Determining whether the P was from anthropogenic or natural sources was beyond the scope of this thesis. Parallel studies are currently identifying nutrient sources within the watershed and will produce some estimates as to what portion of the total nutrient load entering the reservoir may be accredited to human activities such as on-site wastewater treatment and agriculture.

Phosphorus Budget

It has been well established through many studies that P is, in many cases, the nutrient that limits primary production in freshwater lakes and reservoirs (Rast and Thornton 1996; Perkins and Underwood 2001; An 2003; Lewis et al. 2007; Buetel et al. 2008). Even in situations where P and N appear to be co-limiting, P is often the nutrient that is targeted for remediation purposes. This is due primarily to the fact that P has no global gas phase and can be more easily tracked and controlled within a system than N (Rast and Thornton 1996; An 2003).

A P mass balance for an impaired lake or reservoir is a very important tool that can be used to determine the rate of P accumulation or reduction, and potential sources of P that are contributing to the eutrophication of a water body (Forsberg 1988; An 2003; Kelderman, Wei, and Maessen 2005). Although it is true that the reduction of external P loads to a eutrophic lake or reservoir is an essential step if restoration is to be achieved (Cullen and Forsberg 1988), in producing a P budget it is critical to characterize both internal and external sources of P in order to effectively manage a lake or reservoir system (Nowlin, Evarts, and Vanni 2005).

Internal Cycling

In many lakes and reservoirs that experience seasonal stratification and anoxia in the hypolimnion, sediments can act as a source of P and other nutrients to the water column. This phenomenon is known as internal cycling (White, Noll, and Makarewicz 2008). Internal cycling occurs in lake and reservoir hypolimnia as oxygen is consumed by the decomposition of organic matter, producing anoxic conditions in the sediments and adjacent water column. In these low oxygen environments, elements such as iron (Fe) and manganese (Mn) undergo redox transformations, changing them from relatively immobile compounds to mobile metal ions and releasing any phosphate that may have been associated with Fe and or Mn oxyhydroxides (Davidson 1993; White, Noll, and Makarewicz 2008). The newly released phosphates then accumulate in the hypolimnion until a mixing event disperses them throughout the water column. Much of these phosphates reach the euphotic zone, or the portion of the water column where enough light is able to penetrate to allow for the growth of primary producers. If P is the limiting nutrient in that water body and growing conditions are good, a bloom of primary producers will shortly follow (James et al. 2000).

In many instances internal P loading can represent a significant contribution to the overall P entering a waterbody James, Barko, and Taylor (1991) found in their study of a north-temperate reservoir that during summer stratification, internal TP loading was 3 to 6 times greater than external loading. Ryding and Forsberg (1977) found that in lakes where point sources of nutrients have been eliminated or diverted, internal P loading contributed up to 4 times more TP to the water column annually than external sources. Given this information, it was essential to determine if internal cycling was occurring within Pineview Reservoir, and to what extent TP was being released into the water column.

A good way to estimate the pools of P within a lake or reservoir sediment that could become available to the water column under annually occurring standard conditions is through performing a sequential P extraction (Boström 1984). In a study by White, Noll, and Makarewicz (2008), a sequential P extraction showed that 25% of the sediment P measured in a bay of Lake Ontario was stored in a redox sensitive form. Depending on the depth of the P within the sediments and the diffusion rate across the sediment/water interface, up to a quarter of the sediment P had the potential of cycling back into the water column under anoxic conditions.

One of the major effects of increased nutrient loading due to internal cycling of P is a bloom of nuisance algae and cyanobacteria shortly following lake or reservoir mixing (James et al. 2000). The high algal and or cyanobacterial concentrations associated with bloom events can decrease water clarity, cause taste and odor issues for drinking water plants, and release potentially deadly cyanotoxins (Havel and Rhodes 2009).

In systems where internal cycling of P from benthic sediments to the water column is occurring, nuisance algal growth and bloom conditions can continue for many years after external P sources have been reduced or eliminated (Redshaw et al. 1988; Löfgren and Boström 1989; Rast and Thornton 1996; James et al. 2000; Lewis et al. 2007). This phenomenon is one that was and must continue to be considered for Pineview Reservoir. As measures are taken to reduce external P loading, annually observed blooms and anoxia in the hypolimnion are not likely to go away quickly unless measures are also taken to remove or permanently bind sediment P concentrations.

Management and Remediation Approaches

Because each lake and reservoir is different, development of optimal eutrophication management practices requires considering the ecosystem services provided by the specific water body, the cost of eutrophication control measures, and the potential response of the water body to reduced nutrient loading (Hein 2006). In the field of freshwater lake and reservoir eutrophication management and restoration, there are three general approaches that must be considered; 1) reducing external nutrient loads, 2) accelerating nutrient outflow and 3) locking sediment nutrients down so they no longer have the ability to recycle (Redshaw et al. 1990).

One of the major contributors of N and P to impaired water bodies are domestic sewage effluents. Cullen and Forsberg (1988) outlined some basic strategies for reducing nutrients entering water bodies from domestic wastewater. One of these strategies was to reduce the P content of sewage by reducing the P content of detergents, or using phosphate free detergents. This recommendation is one that is already being enforced in the state of Utah as detergents containing phosphates have been illegal for home use there since 2008 (Utah State Legislature 2008). This recent legislation could prove to be a great contributor to the reduction of P entering Pineview Reservoir as all of the individual septic wastewater treatment systems discharges in the valley have the potential of ending up in the shallow aquifer which drains into the reservoir (Peterson, Flint, and Holbrook 1990).

Some management practices that can serve to lessen agricultural nutrient loads to lakes and reservoirs include isolation of livestock and livestock waste facilities from surface water, conversion from flood to sprinkler irrigation to reduce return flows, use of proper fertilizer application rates, maintaining proper vegetative cover in stream riparian zones, and many others (USEPA 2003). Due to the large amount of land currently used for agricultural practices in the Ogden Valley, consideration should be given to these management practices as potential ways to decrease agricultural nutrient loads to Pineview Reservoir.

To counteract the effects of internal nutrient cycling, sediment nutrients (especially P) must be either transformed into stable compounds or removed from the system through methods such as flushing or sediment dredging. In the process of excluding nutrients (mainly P) from cycling between lake sediments and the water column there are several different methods and or compounds that are currently used.

One potentially affective approach that is to solve hypolimnetic oxygen deficits is the oxygenation of an otherwise anoxic hypolimnia through the bubbling of pure oxygen.

By using pure oxygen, which in its liquid form can be purchased economically in bulk, enormous amounts of DO can be introduced through the use of a relatively small amount of equipment (Beutel et al. 2007). Even a less than saturated oxygenated sediment-water interface of at least 2 mg/L DO can inhibit the release of phosphate, ammonia, Fe, and manganese. One of the best advantages of this method is that it does not disrupt the thermal stratification of the lake (Beutel et al. 2007) which is especially advantageous for Pineview Reservoir as the cold hypolimnetic waters must not only be oxygenated but remain cold in order to function according to its current designation as a cold water fishery.

Other methods of locking nutrients into lake sediments are through the use of chemicals such as aluminum sulfate (alum) or ferric sulfate (James, Barko, and Taylor 1991; Perkins and Underwood 2001). While both compounds have their benefits, the use of ferric sulfate is limited in that Fe bound P is redox sensitive and can easily be released under anoxic conditions (Davidson 1993; Perkins and Underwood 2001) associated with aluminum is immobile and can be considered permanently bound (Noll, Szatkowski, and Magee 2009).

Flushing and sediment dredging are the most commonly used methods of nutrient removal from impaired waters (Kelderman, Wei, and Maessen 2005). Flushing is accomplished by releasing large amounts of nutrient rich water, most likely from a bottom release, and replacing them with water that is relatively low in nutrients (Kelderman, Wei, and Maessen 2005) Dredging is the physical removal of benthic sediments through mechanical processes (Ryding 1981). Nutrient flushing is a method with great applicability to bottom draw reservoirs such as Pineview, as in many cases the amount and time of water release can easily be controlled, but the impacts of increased flow and nutrient loading on downstream ecosystems must also be considered before flushing can take place. Dredging on the other hand is extremely expensive and is generally considered to be one of the most radical methods of restoring impaired lakes and reservoirs (Ryding 1981).

Pineview Reservoir Specific Literature

There have been several studies conducted on Pineview Reservoir and its surrounding watershed over the life of the reservoir. Each of these studies contain important information about the Pineview Reservoir system, but they each have severe limitations in that they are based almost entirely on extremely limited data.

The Pineview TMDL

Few studies have been done on the water quality of Pineview reservoir, and the Pineview TMDL (Tetra Tech 2002) study had limited data from which to draw conclusions about the amount of water coming into the reservoir from surface water sources, ground water sources, and the concentrations of N and P associated with these flows. One estimate of nutrient loading to the reservoir due to surface water sources was detailed in the reservoir TMDL, where the Soil Water Assessment Tool (SWAT) model was used to estimate N and P loadings to the reservoir through surface waters based on digital elevation, land use, stream flow and meteorological data (Tetra Tech 2002).

There is currently only one continuously monitoring flow gauge in operation in the Ogden valley. This gauge has been in operation since 1921 and is located on the

South Fork of the Ogden River above the major diversion used to route water from the stream into a system of canals for irrigation use during the growing season. Since no other gauging stations on the major tributaries (North, South, and Middle forks of the Ogden River) have been in operation in the valley since 1974, flow estimates for the North and Middle Forks in the TMDL estimate were made based on current flow data from the South Fork, and historical similarities in the flows between the South Fork and the other two Forks when all three had operational gauging stations (Tetra Tech 2002). The flow contribution estimates produced by the TMDL model for the North and Middle Forks of the Ogden River, as well as other tributaries are difficult to verify without actual flow data. It is also plausible that changes in land use and irrigation water management practices over the 25- to 30-year period since stream flow records were kept had changed the flow correlations among the major tributaries.

Another limitation encountered in the modeling process was the scarcity of available nutrient data for tributaries entering the reservoir. The entirety of the available stream nutrient data available to support the model consisted of two sampling events per year during the years of 1992, 1994, 1996, 1998, and 2000. This limited data causes major concern as to the accuracy of the surface water nutrient loading results reported in the TMDL, where it was estimated that surface water sources were responsible for an average of 26,776 kg of dissolved nitrogen, 3,718 kg dissolved phosphorus, and 7,883 kg of TP entering the reservoir per year. These limitations were recognized by Tetra Tech (2002) and it was recommended in the Pineview Reservoir TMDL that the major tributaries should be sampled for flow and water quality on a monthly basis to confirm the validity of tributary loading estimates (Tetra Tech 2002).

In the absence of sediment nutrient release data when predicting the contributions of P from the reservoir's sediments, Tetra Tech (2002) made the assumption that the release rate of P from the sediment was approximately 5 mg/m^2/day, and that P release only occurred when DO levels fell below 0.2 mg/L. This DO assumption for sediment P release may be overly conservative as it was found by Marsden (1989), that at water column DO concentrations as high as 2 mg/L, a small surface layer of oxic sediment becomes anoxic, allowing the exchange of P across the sediment water interface. Due to the small number of days predicted by the model where DO would fall below 0.2 mg/L, it was assumed in the TMDL that internal P loadings in Pineview Reservoir were negligible (Tetra Tech 2002).

It is well documented that anaerobic conditions in the hypolimnion of lakes and reservoirs can lead to the release of bioavailable P from benthic sediments (Dodds 2002). One such instance, where bioavailable P releases from benthic sediments due to anoxic conditions in the hypolimnion were observed, was in Mona Lake Michigan during the summer of 2007 (Steinman, Chu, and Ogdahl 2009).

The Clean Lakes Study

Another important study documenting the water quality of Pineview Reservoir was the EPA funded Clean Lakes Study (Peterson, Flint, and Holbrook 1990). This study was conducted by the Weber Basin Water Quality Council in the late 1980s. Their primary goals were to provide information regarding water quality conditions in the reservoir, determine non-point nutrient sources and loadings to the reservoir, look at seasonal water quality conditions as they related to reservoir management for irrigation, determine the effects of ground water on reservoir water quality, and develop some guidelines for the protection and maintenance of water quality in the reservoir (Peterson, Flint, and Holbrook 1990).

The Clean Lakes study determined that the shallow, unconfined aquifer was the principal source of ground water to the reservoir, and that this aquifer was not, contaminated with nitrate but was extremely vulnerable to contamination (Peterson, Flint, and Holbrook 1990). To prevent ground water contamination from occurring, this study recommended several water management practices that it deemed to be reasonable water quality preserving alternatives. The primary alternatives it suggested included, building a public sewage treatment system for the valley, increasing the usage of pressurized irrigation to replace flood irrigation practices, and the construction of a centralized culinary water system for the valley (Peterson, Flint, and Holbrook 1990).

For this study, ground water, reservoir and stream data were collected throughout the irrigation season of 1988 and, based on these data; conclusions were drawn about the loading rates and possible sources of nutrients going into the reservoir. There were still several limitations in the applicability of the data set used for the Clean Lakes Study and, by extension, its conclusions. One limitation was that the study was limited to a single irrigation season (1988). This is especially limiting due to the fact that 1988 was a particularly dry year where the reservoir received slightly more than half (approximately 68,650 acre feet) of its annual average inflow (Peterson, Flint, and Holbrook 1990). Because of the low water levels, turnover occurred relatively early that year, increasing the duration of the fall algal bloom period. That scenario does work well as a possible worst case, but it was likely not indicative of average ambient conditions for the reservoir.

Another major oversight of the Clean Lakes Study was the exclusion of Spring Creek and Geertsen Creek from the total water and nutrient mass balance calculations, as they were likely significant sources of water and nutrients to the reservoir.

Ogden Valley Ground Water Hydrology

In the process of designing the present study, the effects of ground water on the reservoir's water and nutrient mass balances were taken into consideration. The most complete source of ground water information for the Ogden Valley is the 1994 report authored by Charles Avery for the U.S. Geological Survey (Avery 1994). Figure 2, from this report, is a diagram of the hydrologic geology of the Ogden Valley. Figure 3, is a map (Snyder and Lowe 1998) of the Ogden Valley that outlines the boundary between the confined and unconfined aquifer, where the unconfined aquifer (Layer 1) exists within the blue line.

In the reservoir related portion of his report, Avery focused only on the interactions and exchanges between Pineview Reservoir, and the confined aquifer, (LAYER 2, the principal aquifer) and potential contributions from LAYER 1 were ignored. It was assumed that the flow of ground water between Layer 2 and the reservoir was primarily up through the confining layer and the lakebed into the reservoir. Seepage rate estimates were made in July 1986, by pushing open ended barrels into reservoir

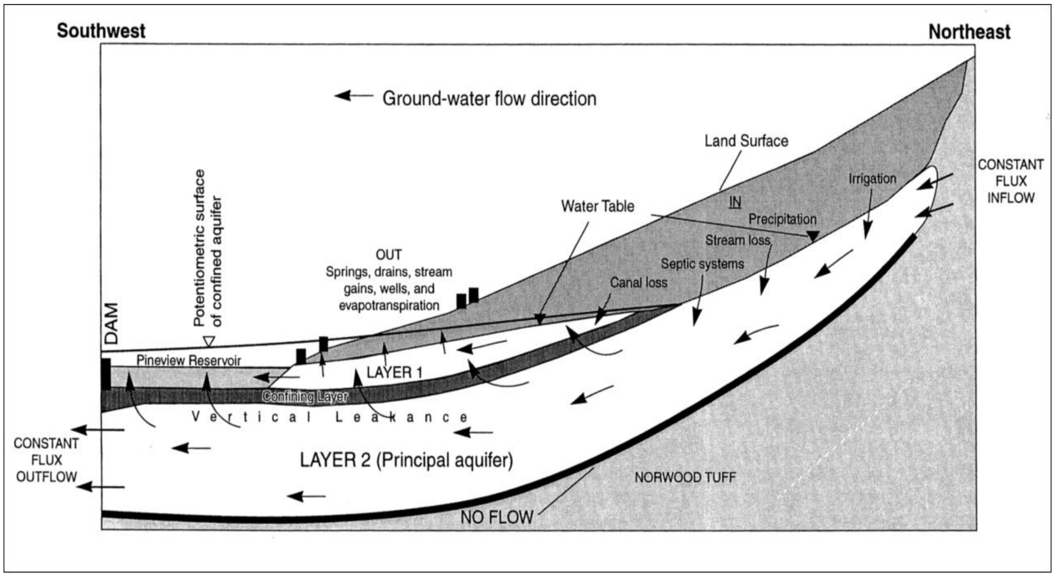

Figure 2. Ogden Valley ground-water flow schematic.

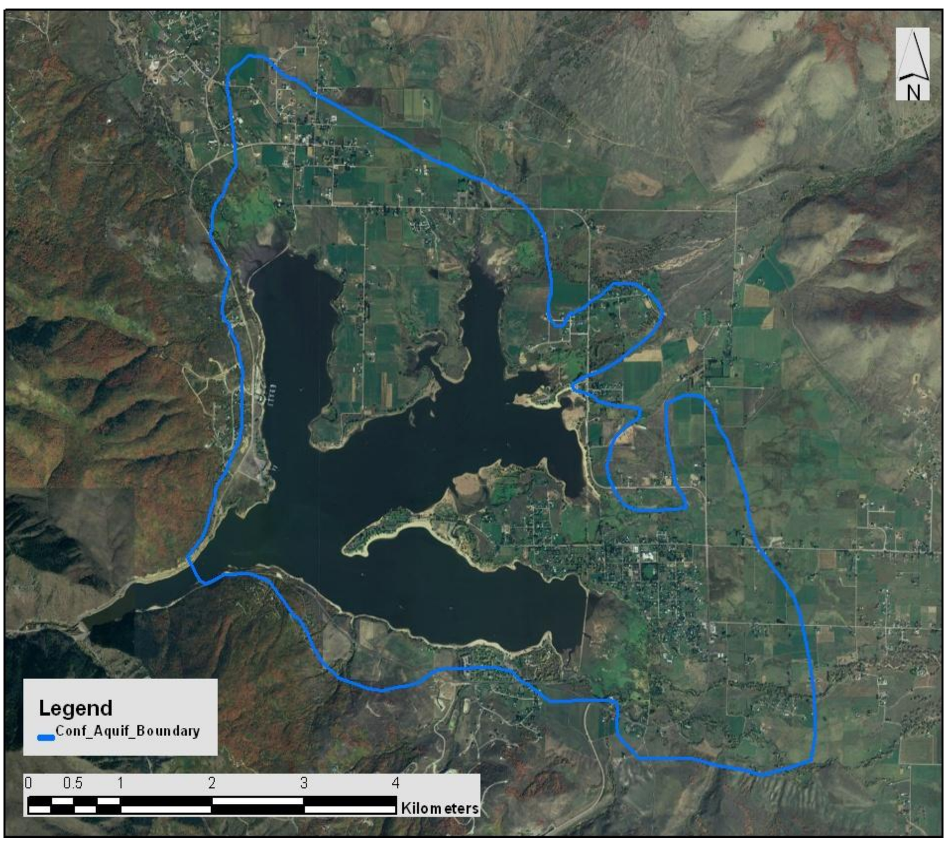

Figure 3. Boundary of the confined and unconfined aquifers (after Snyder and Lowe 1998).

sediments in each of the three arms (and main channel) of the reservoir, noting the time it took to fill each barrel, averaging the seepage rates to produce a reservoir wide estimate of the ground water seepage rate into the reservoir and multiplying the seepage rate by the total area of the reservoir. Winter estimates were also made by multiplying the same seepage rates over the smaller reservoir benthic area. Summer and winter estimates of ground water from Layer 2 going into the reservoir were 86.7 and 45.4 cubic feet per second (cfs), respectively. This equates to about 24 % of the total annual inflow to the reservoir (Avery 1994). This approach for calculating ground water inflows may not be accurate because the rate of reservoir water seeping into the barrels was unknown. Also, assuming that the seal was adequate to exclude all reservoir water, there is still no way to tell if the seepage rates measured are representative of the entire area of the reservoir, or whether they were contributed by the primary or secondary aquifer.

It was also assumed that some downward flow of water from the reservoir to the principal aquifer was likely to be occurring, especially around the area of the Ogden city well field, which is located between the middle and north arms of the reservoir. This flow pattern, however, is only likely to occur during times when water is being pumped from the aquifer and can only be roughly equivalent in magnitude to the amount of water removed which for Avery's 1985 study period was 13.8 cfs for the months of December through February, 15.9 cfs for the months of March through May, 14.6 cfs for the months of June through August and 11.0 cfs for the months of September through November (Avery 1994).

The Avery report also contains some limited nitrate concentration data collected from 30 wells around the valley that draw from the principal aquifer. Of these 30 wells only one was found to have nitrate concentrations in excess of the EPA drinking water maximum contaminant level of 10 mg NO_3-N/L. The average for the 30 wells was 1.2 mg NO_3-N/L, with a standard deviation of 2.1 mg NO_3-N/L (Avery 1994).

Additional studies were published in 1990 and 1998 by the Utah Geological Survey reporting at the potential impacts on ground water quality from increasing the density of septic tank soil absorption systems (Lowe and Miner 1990; Wallace and Lowe 1998). In both cases, researchers found average NO_3-N levels to be (< 2 mg NO_3-N/L)

One of the major problems with using the data set used by Avery (1994) to calculate the contributions of ground water to reservoir nutrient loading is that nutrient concentrations in the unconfined aquifer (LAYER 1 in Figure 2) were not measured and he could not differentiate between seepage coming from Layer 1 and Layer 2 based on his seepage measurement techniques (Avery 1994). The importance of understanding the contributions of nutrients from the shallow aquifer was emphasized in the Clean Lakes Study, which found that contamination of the shallow aquifer would be the single greatest threat to water quality degradation within the reservoir (Peterson, Flint, and Holbrook 1990).

Limnology of Bottom-Draw Reservoirs

There are several avenues currently available to slow an aquatic system's trophic progression. Two of the most common approaches involve finding ways to remove limiting nutrients from a system, or prevent them from ever entering (Thornton, Kimmel, and Payne 1990). For most systems, prevention is the only truly viable option.

Reservoirs are unique in that their releases can, to some extent, be controlled, giving the operators and stakeholders some ability to control nutrient removal from the system.

One of the primary limnological differences between the way that lakes and reservoirs operate has to do with the manner in which they discharge water. Natural lakes typically have no control on the magnitude of their discharge, and discharge usually occurs at the surface of the water body. Reservoirs are designed to regulate the magnitude and duration of water releases, and they often discharge from the subsurface waters (Thornton, Kimmel, and Payne 1990).

This release pattern suggests that surface-discharge lakes tend to trap nutrients and release heat, while bottom release reservoirs (such as Pineview) release nutrients and accumulate heat (Thornton, Kimmel, and Payne 1990). These trends can be very valuable in assessing possible routes of remediation for impaired reservoirs such as Pineview. Since Pineview Reservoir is classified as a cold water fishery, the ideal scenario would be one where both nutrients and heat could be released over time. Since this trend is unrealistic given the limnological principles of bottom draw reservoirs, it becomes increasingly import to have a better estimate of the amount of nutrients that are being flushed out of the system with the nutrient enriched hypolimnetic waters.

Such an estimate can be useful in understanding the reservoir's rate and timeframe of eutrophication, and any potential impacts of increased productivity (negative or positive) that might be expected in the future.

METHODOLOGY

A list of the analytical procedures used in the present project is provided in Table 1. Any specific modifications made to the referenced procedures are explained below.

Stream Inflows and Loadings

All stream flows for this study were estimated using the area-velocity method (Chapra 1997). Stream depths were measured using a top setting wading rod and stream velocities were measured using either a Swoffer Model 3000 velocimeter or a Swoffer model 2100 velocimeter. During times of high stream flows when streams were not wadeable, a Teledyne RD instruments StreamPro Acoustic Doppler Current Profiler

Table 1. Analytical method information and sources

Variable	Laboratory	Method	Source
Total Phosphorus (TP)	UWRL	SM 4500-PE	(APHA 1995)
Orthophosphate	WBWCD	EPA 300	(Pfaff 1993)
Nitrate + Nitrite	UWRL	EPA 353.2	(SEAL Analytical 2009)
Ammonia	WBWCD	EPA 300	(Pfaff 1993)
	USUAL	EPA 353.2 Rev. 2.0	(USEPA 1993b)
	UWRL	EPA 350.1 Rev. 2.0	(USEPA 1993a)
Nitrogen Fixation Rates	USUAL	EPA 350.1 Rev. 2.0	(USEPA 1993a)
	UWRL	Acetylene-Red.	(Flett, Hamilton, and Campbell 1975)
Chlorophyll and Other Pigments	UWRL	HPLC EPA 447.0	(Arar 1997)
Algae Counts	UWRL		(Wehr and Sheath 2003)
Sediment Phosphorus Sequential Extractions	UWRL	Seq. Extract.	(Psenner et al. 1988)
Reduced Iron Analysis	UWRL	Ferrozine	(Carter 1971)
Dissolved Iron Using Flame Atomic Absorption	WBWCD	SM 3111B	(APHA 1995)

UWRL = Utah Water Research Laboratory, WBWCD = Weber Basin Water Conservancy District

(ADCP) was used to measure discharge. Sampling sites were chosen on Geertsen Creek, Spring Creek, North Fork Ogden River, Middle Fork Ogden River, and both branches of the South Fork of the Ogden River (see Figure 4). Sampling locations within the streams were chosen based on proximity to a major road, stream channel uniformity and site accessibility. Flows for Spring Creek were calculated using the depth/flow relationship of an existing Parshall flume on the Spring Creek next to an old non-operational USGS gauging station. The flume calibration table was made using the ACA software package for the design and calibration of broad crested weirs and flumes (Merkley 2002). The calibration table for the Spring Creek Parshall flume can be found in the Appendix.

Field discharge measurements for the purposes of this work were made beginning on 5/9/2008 and ended on 6/29/2010, and were made on an approximately monthly basis, or up to bimonthly during the highest flow months of May through July, from most of the major streams (Ogden River South, Middle and North Forks, and Spring Creek) near where they enter the reservoir. The one exception to this was Geertsen Creek, which was only measured between the dates of 5/9/2008 and 4/13/2010 due to reservoir filling inundating all accessible measuring points on the creek during the latter half of the runoff season.

Because researchers were unable to take any flow measurements during the period of November 2008 to March of 2009, flow values recorded during December 2009 and February-March of 2010 were substituted into their respective days the year before, so that interpolated flow values would follow the expected trend of lower flows through the winter and a sudden flow increase in the spring as snow melt begins. Given the lack of available data to fill this gap and the consistency of baseline flows from year to year, (Tetra Tech 2002) this seemed the approach most representative of actual conditions. This process was only carried out on the three forks of the Ogden River, but not on Spring Creek and Geertsen Creek, as their flow patterns did not appear to be highly influenced by spring runoff patterns.

Flow and nutrient content for all of the major tributaries were measured during each sampling event throughout the duration of this study, as long as there was enough flow to produce an accurate estimate using the above mentioned measurement techniques. Stream water quality parameters such as DO concentration, specific conductance, temperature and pH were measured in-situ during each sampling period using a Troll 9500 probe system. Grab samples were, collected at each site, during each time of flow measurement, and were analyzed for TP, SRP, nitrate-N and ammonium-N. Field blanks were used during each stream sampling event for all of the different nutrients. Spikes were performed during the analysis of each nutrient sample set. The method detection limits were 4 µg/l for TP, 2 µg/l for SRP, 40 µg/l for nitrate-N and 35 µg/l for ammonium-N. Stream nutrient and flow contributions to the reservoir were then estimated by linearly interpolating between flow and nutrient data points using an arbitrarily chosen daily time step.

It was observed by Jones (2008) in her study of the Little Bear River in northern Utah that the method of interpolating N and P loads from monthly sampling events does not always produce accurate results. According to her findings, the probability of coming within 5 % of the reference load using monthly sampling at her sampling station near Mendon Utah which represents the lower, slower portions of the Little Bear River was between 0.21-0.31, while the probability of coming within 50% of the reference loads at the Mendon was very good (0.98-1.0) regardless of sampling frequency. At her sampling site in the faster flowing upper reaches of the Little Bear River near Paradise, it was found that in the probability of being within 50% of the reference load using monthly samples was between 0.52-0.89 (Jones 2008). Except during the runoff season (~ May-mid July) the streams entering Pineview Reservoir were found to be slow, comprised mostly of returned ground water and behaved more like the Mendon site than the Paradise site in the Jones (2008) study. It was still worth noting that there are limitations and significant potential for error using the monthly interpolation method for calculating N and P loads. Despite the fact that monthly sampling cannot account for storm and runoff events between sampling events, it still seemed an adequate approach for producing a first estimate of stream loadings to the reservoir given the data and resources available for this study. In order to produce more accurate flow and nutrient loading estimates for the streams entering Pineview Reservoir, parallel studies are currently collecting high frequency stream flow data for the North and South Forks of the Ogden River. This data can be used to check the validity of the estimates produced here and improve surface water flow and loading estimates to the reservoir.

Estimates of water entering the system due to direct precipitation on the reservoir's surface were made by multiplying the recorded rainfall (from the weather station located at the Pineview Reservoir dam keeper's house) during the sampling period by the known surface area of the reservoir. It was found by Burns in his 2004 study that the deposition of fixed atmospheric N in the nearby Rocky Mountains of Colorado and southern Wyoming ranged from 2 to 7 kg-N/Ha/yr (Burns 2004). By using these loading rates and Pineview Reservoir's surface area of approximately 1,127 Ha, somewhere between 2,300 and 7,900 kg of fixed N is being deposited into Pineview Reservoir each year from the atmosphere. Given the data gathered for this study, atmospheric deposition represents between 1 to 3 percent of the total fixed nitrogen entering the reservoir. Since this fraction is within the range of the total error of the total N loading estimates, the deposition of fixed atmospheric N entering the reservoir through direct precipitation were assumed to be negligible.

Ground Water Contribution Estimates

Since producing accurate estimates of ground water flows and associated nutrient loadings to the reservoir was beyond the scope of this study, these values were taken from the literature and parallel studies. The ground water flow estimates were taken from the Ground Water Hydrology of Ogden Valley Report (Avery 1994), and the nutrient concentrations of the ground water samples, were collected for a parallel study, from five monitoring wells around the reservoir (see Figure 4). This parallel study was being performed by Thomas Reuben through the Utah Water Research Laboratory. His study is also working on a more accurate estimate of the rate of ground water loading to the reservoir.

Unlike assumptions made in the Avery (1994) report, it was assumed that the majority of the ground water entering the reservoir passes through the valley's shallow, unconfined aquifer and not directly through the confined aquifer. This assumption was made because Avery's study did not distinguish between seepage to the reservoir from the confined or unconfined aquifer due to the measurement techniques used. The confined aquifer's confining layer is below the reservoir and serves as a natural boundary between the reservoir and aquifer waters while the unconfined aquifer runs freely into the reservoir above the confining layer. Because the available flow data was reported by Avery as a single bulk flow to the reservoir, it is impossible to determine the various contributions of the particular parts of the unconfined aquifer to the reservoir. All nutrient data to be used in calculating loading from ground water calculations were therefore averaged, and a single nutrient concentration for TP, SRP, nitrates and ammonium was applied to the entire aquifer. Although this approach only gives a first estimate for use in the reservoir's water and nutrient balance, Thomas Reuben's ground water studies are currently being performed to better define ground water loading to the reservoir.

Reservoir Outflows

Release flows from the reservoir were estimated by the Pineview Water Systems dam keeper on a daily basis. Samples of the hypolimnetic water exiting the reservoir were collected from the bottom waters of the site closet to the dam (site 380) on the reservoir, and also from a spigot on the penstock at the Bountiful Hydroelectric Plant at the base of the dam, when it was accessible. These samples were analyzed for all of the parameters mentioned above for the surface water samples.

Reservoir Evaporation Estimates

An evaporation rate estimate was taken from Hughes, Richardson and Frankiewicz (1974). The method used in their study was the Richardson method,

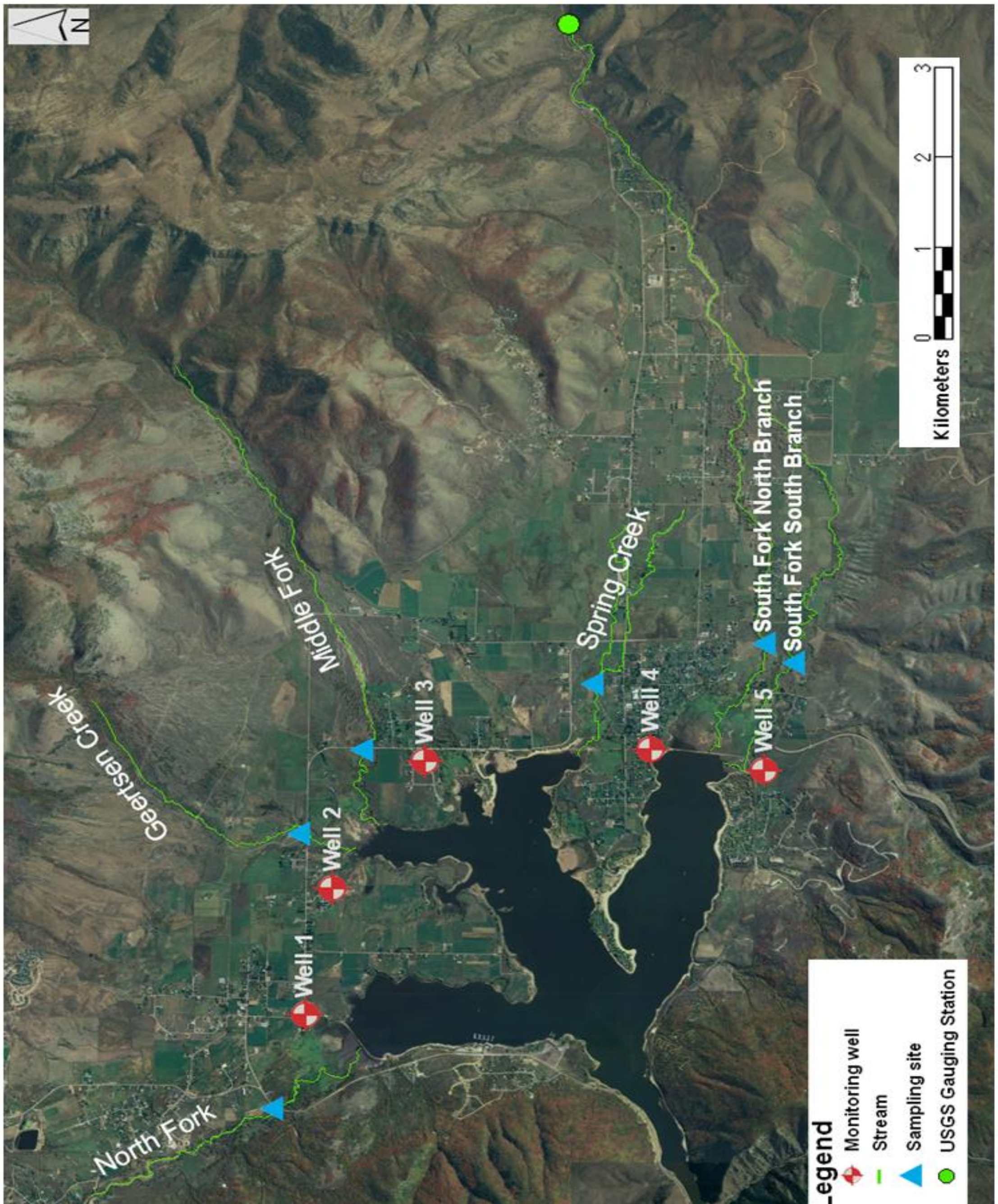

Figure 4. Streams and sampling locations.

which requires either measurement or estimation of the average water vapor pressure, relative humidity, mean wind speed and a classification of the site into one of the following categories. 1) Flat valley sites with pan wind less than 60 miles per day. 2) Flat valley sites with pan wind of 60 to 90 miles per day. 3) All canyon sites and valley sites with pan winds over 90 miles per day (Hughes, Richardson, and Franckiewicz 1974). Because the evaporation estimation methods used parameters (weather, wind, annual reservoir surface area patterns, etc.) that, on average, change very little over long periods of time, the losses due to evaporation that were calculated in 1974 are likely comparable to the reservoir's current evaporative losses.

Producing Estimated Values for Non-Detect Data

In order to estimate daily nutrient and flow values between data points using linear interpolation, some value between zero and the method detection limit (MDL) must be assigned to each data point with a value below the MDL (i.e., left censored data). Because assigning all of the censored points a single value such as zero, the MDL or some arbitrary value point between them would artificially skew the results, an imputation was used to assign these values based on the evident trends of the cumulative failure probability (CFP) values of the non-censored data graphed against their respective concentration or flow values.

In order to do this, non-censored flow and nutrient data sets were ranked and CFP values for each data point calculated (Lee 2008). The CFP values were then graphed against their respective data values and a curve fitted to the data set. The non-detect data points for each data set were then assigned a random ranking between one and the total number of censored data points, where no two points were assigned the same rank. CFP values were then calculated for the non-detect data points based on these rankings.

Imputed flows and concentrations were then calculated for the censored data points using these CFP values and the curves generated using the uncensored data.

In order to assess the validity of the statistical approach above, a bootstrap analysis was performed on a data set of ammonium concentrations containing 12 data points (five of which were below the MDL) gathered over a period of 11 months. For this exercise, theoretical NH_4 -N concentrations were calculated for each of the five censored data points using the techniques laid out above. Daily concentrations were then linearly interpolated between each of the data points over the time period. These daily concentration values were then multiplied by observed daily flow values to give an estimate of daily NH_4 –N loading to the system in kg NH_4 –N/day. The daily values were then summed over the entire sampling period yielding an estimate of total imported NH_4 –N in kg.

After programming these calculations in a spreadsheet, the assigned rankings of 1-5 were randomly assigned to each of the censored data points, and the ammonium loading recalculated for a total of 20 iterations. This test yielded a mean NH_4 –N loading of 6.43 kg, with a standard deviation of ± 0.01 kg, which represents a standard error of ± 0.17%.

This test showed that for the purpose of creating artificial values that pertain to this study’s censored data points, it made little difference how the censored data were ranked in relation to each other, and that they could be assigned randomly. In the case where there were not enough uncensored data points to establish a trend using the method detailed above, all data points below the MDL were assigned the value of half of the MDL.

Reservoir Water Parameters

In order to understand water quality dynamics, including DO concentrations, water temperatures, stratification, and N and P availability, reservoir water column profiles were measured using multiparameter sondes, and grab samples were collected on a monthly interval during the ice-free period at five sites representing the major reservoir areas (Figure 5). Samples were also taken through the ice on four separate occasions, 12/2/08, 1/27/09, 3/19/09, and 2/8/10. During these sampling events only sites 381 and 384 were sampled due to time restraints.

Each site was picked to represent a different area of the reservoir and to correspond with historical sampling locations. Site 380 represents what is happening near the dam, and what the water may be like that is exiting the reservoir through the dam outlet. Site 382 helps paint a picture of conditions in the south arm of the reservoir, which is fed primarily by the South Fork of the Ogden River. Site 383 best represents the middle arm of the reservoir, which is fed by the Middle Fork of the Ogden River and Geertsen Creek. Site 384 was chosen as a representation of conditions occurring in the north arm of the reservoir, which is fed primarily by the North Fork of the Ogden River. Lastly, site 381 was selected as a representation of the middle part of the reservoir. It also represents the confluence of the three branches of the reservoir.

Reservoir Profiling

Sondes

During each reservoir sampling event, the following water quality parameters were measured at approximately 4-foot (1.2 m) intervals throughout the entire depth of

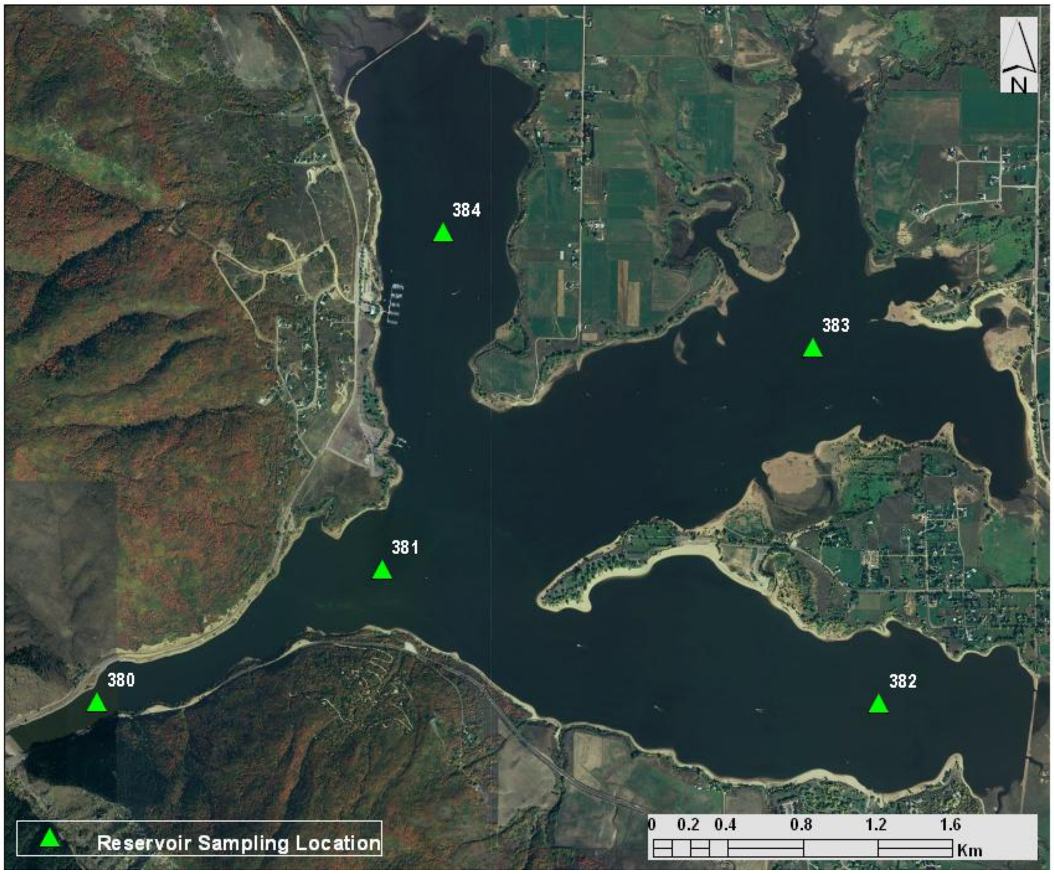

Figure 5. Pineview Reservoir sampling sites.

the water column at each site. An In-Situ Troll 9500 probe system or sonde was used to measure depth, DO concentration, specific conductance, pH, and temperature. Temperature data were used to determine reservoir stratification and the relative depth of the thermocline in relation to the water's surface.

<u>Continuous temperature monitoring</u>

A string of 10 HOBO Water Temp Pro V2 loggers with probes positioned at about 2.1 m of depth and every 1.5 m below that to a depth of approximately 17.4 m was attached to a buoy at the 381 site. These loggers were programmed to read temperatures throughout the water column at 4-hour intervals. This interval was chosen based on the data storage capacity of the loggers and the time between reservoir sampling events. The temperature loggers were only deployed from June-October as long as the US Forest Service buoys to which they were attached were deployed.

Grab sampling

Various grab samples were collected during each sampling event. Samples for TP, orthophosphate, nitrate + nitrite and ammonium, were collected from near the surface, bottom of the thermocline, and near the bottom of the water column at each site. Temperature data from reservoir profiling was conducted at each sampling site, during each sampling event and was used to determine the depth of the different thermal layers during times of stratification.

A 4.6 to 5.8 m (15 to 19 foot) deep integrated sample was also taken at each site using a 6.1 m (20 foot) long, 6.35 cm (2.5 inch) inside and 7.62 cm (3 inch) outside diameter, flexible sampling tube (Tygon G-44-4X) (Zohary and Ashton 1985). This sample was used to determine the predominant algal groups within the reservoir throughout the duration of the study. This integrated sample was more representative of the algal/cyanobacterial diversity of the reservoir than the surface samples. This is due to the fact that different phytoplankton inhabit different water depths within the reservoir based on their light requirements (Wehr and Sheath 2003).

Chlorophyll A and algal counts

Chlorophyll A was measured in reservoir surface and integrated samples using glass fiber filtration (Whatman, 934-AH, 47mm) to concentrate the phytoplankton.

Filters were then ground up and steeped in a 90% acetone and water solution. Samples were then filtered through 0.45µm nylon syringe filters before being analyzed for pigments using high performance liquid chromatography according to the method of Arar (1997). In order to achieve adequate peak separation, a modified solvent gradient was used (Table 2) where solvent A was a solution of 80% methanol and 20% 0.5 M ammonium acetate, solvent B was 90% acetonitrile and 10% water and solvent C was ethyl acetate. Chlorophyll analysis was only performed on samples taken near the surface and from the integrated samples collected using the large sampling tube at each site. Surface Chlorophyll A concentrations observed at each site were then plotted over time as a means of determining the reasons for annually observed trophic changes and the magnitude and duration of bloom periods in the reservoir.

Algae and cyanobacteria counts were also performed on the surface and integrated samples according to the methods of Lund, Kipling, and LeCren (1958). All samples that were counted were preserved and stained with Lugol's iodine solution and refrigerated in amber bottles until they were counted. For counting, 20 ml of sample was allowed to settle for 20 minutes in a circular, cover glass bottomed settling chamber, and algae were counted using an American Optical BIOSTAR inverted microscope at 200 X magnification. No less than 200 individual cells were counted for each sample. Algal counts were used to determine the predominant types of phytoplankton in the reservoir and how phytoplankton populations changed with changing reservoir conditions. Chlorophyll A and algae counts were also of importance to this study in order to determine the impacts of external and internal nutrient loading to the reservoir's ecology and rate of eutrophication.

Table 2. Modified HPLC solvent gradient

HPLC Solvent Gradient			
Time (min)	% A	% B	% C
0	100	0	0
2	0	100	0
12	0	70	30
22	0	22	78
24	0	100	0
25	100	0	0
32	100	0	0

During times when DO was below detection in the hypolimnion near the sediments, additional samples were taken to determine the concentrations of dissolved iron (~Fe^{2+}) present in the anoxic, hypolimnetic portion of the reservoir. These samples were filtered and acid preserved on site, and analyzed at the WBWCD.

Bathymetry

Determining internal loadings of nutrients within a reservoir requires good estimates of that reservoir's benthic area in order to determine the portion of the sediments likely to significantly contribute to nutrient release to the water column. Bathymetry data for Pineview Reservoir were limited, consisting of only of a single contour map created before the construction of the original dam in 1937. It was anticipated that these maps would not provide accurate information about the current condition of the reservoir because they did not account for the more than 70 years of sediment accumulation in the reservoir.

In order to update this information, the reservoir's bathymetry was mapped during the peak reservoir storage period of 2010 using a combination of sonar and global positioning system (GPS) equipment mounted on a small, motorized boat. Latitudinal and longitudinal coordinates were measured using a Trimble GeoXH gps with a Zephyr antenna. Depths were measured simultaneously using a Garmin GPSmap 530 sonar. The entire reservoir was mapped in this manner by first completing a reservoir outline and then filling it in by driving in cris-cross, zig-zag and other patterns until the entire area of the reservoir had been sufficiently mapped, meaning that the distance between lines of data never exceeded a distance of 100 m. Interpolation was performed between data points to create a three dimensional benthic reservoir surface map from which benthic areas and reservoir volumes could be derived.

This new bathymetry data were then used to produce better estimates of internal nutrient cycling, and an updated depth/capacity curve for the reservoir (Winkelaar 2010).

Reservoir Benthic Sediment Nutrients

Because internal nutrient cycling may be a significant factor contributing to the eutrophication of Pineview Reservoir, it was necessary to examine nutrient concentrations and release potential in the upper layers of the reservoir's benthic sediments. To do this, five sediment cores were collected by scuba divers from each of three separate locations within the reservoir. The sites selected for core sampling were sites 381, 383, and a new site, site 383-A, which is approximately halfway between sites

381 and 383. These sites were selected because they were considered the most representative of conditions throughout the anoxic portion of the reservoir.

Sampling of the sediments was performed on September 15, 2009, a time when the reservoir's hypolimnetic waters were anoxic. Sediment cores were taken using 30 cm (1 ft) lengths of 7 cm (2.75 in) inner diameter polycarbonate tubing with a wall thickness of 0.32 cm (1/8 in). The cores were contained within the tube under anoxic conditions using number 13 rubber stoppers and duct tape to hold them in the tubes. The cores were then taken back to the lab for extraction and analysis. Core were extracted in an anaerobic glove bag (`97% N_2, 3% H_2) to preserve the ambient redox status of the samples. In order to ensure that there was enough sediment from each site to complete all the necessary analyses, the top three centimeters of sediments from each of the cores collected at each individual site were removed in an anaerobic glove bag composited into a single container and mixed together. This produced a total of three integrated samples, one for each site.

Approximately 10 ml of the bulk sample was centrifuged at 5000 x gravity for 30 minutes and the pore water was analyzed for reduced Fe while still in the anaerobic glove bag using the ferrozine method (Carter 1971). The pore water was then removed from the glove bag, and analyzed for the same set of nutrients as the reservoir and stream water samples (Table 1).

Soluble reactive phosphorus concentrations in the pore water were used in conjunction with soluble reactive phosphorus concentrations measured at the time cores were collected in the hypolimnetic water column to determine an approximation of available P flux from the sediments to the water column due to diffusion in each of the major portions of the reservoir. In order to do this, the reservoir was broken into five parts (Figure 6), each containing one of the water column sampling locations, and representing a different portion of the reservoir. The mass flux of P due to pore water diffusion was calculated using Equation 1 below in conjunction with the approach of Chapra and Reckhow (1983).

$$J_s = -\emptyset D_s \frac{\partial C_{di}}{\partial Z} \quad (1)$$

Where C_{di} is the concentration of P in the pore water in µg P/L, ø is the porosity of the sediments (0.83), and D_s the whole sediment diffusion coefficient, was interpolated using a formation factor constant of 3. This formation factor was selected based on the silty clay texture (55% clay) of the reservoir's sediments and the range of 2.5 to 5.4 for clays from Chapra and Reckhow, where 5.4 represents pure clay and 2.5 a half-clay type

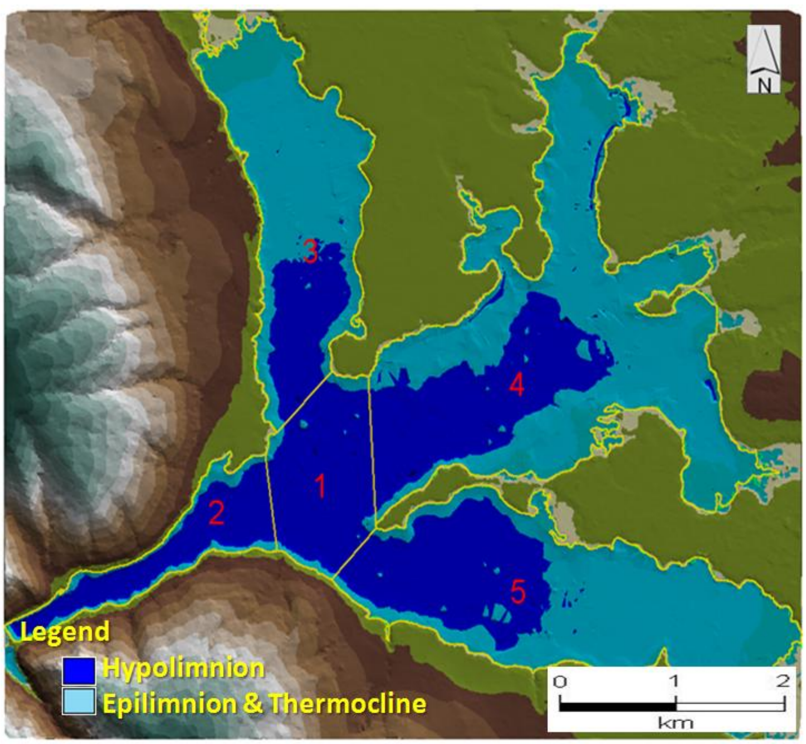

Figure 6. Reservoir delineation for P flux calculations.

sediment. ∂Z was arbitrarily chosen to be 1 cm, and the average annual time frame in which P would be able to move freely across the sediment/water interface was determined by finding the number of days in which DO levels of less than 2 mg/L were observed in the waters of the hypolimnion, because at DO levels above 2 mg/L there typically exists a layer of aerobic sediment that effectively blocks the majority of the transport of SRP from benthic sediments to the water column above (Marsden 1989).

This flux estimation was then used in conjunction with benthic areas derived from reservoir bathymetry data to produce an estimate of the amount of bioavailable P that is entered the water column from the sediments while there were anoxic conditions in the hypolimnion.

The TMDL assumed that a hypolimnetic DO concentration of 0.2 mg/L was required to facilitate the release of redox sensitive P from the reservoir sediments (Tetra Tech 2002). Hypolimnetic samples collected in the present study during periods of minimal DO had elevated concentrations of total and soluble reactive phosphorus. It was observed by Marsden (1989) that significant P release can occur from sediments with water column DO concentrations as high as 2 mg/L (Marsden 1989). A much longer period of P release from the reservoir's sediments was observed than was predicted by the TMDL.

After pore water removal, a small portion of the centrifuged solids from each sample site was subjected to the phosphorus extraction techniques of Psenner et al. (1988). This analysis provided a description of the fractions of phosphorus in the sediments that have the potential to diffuse out and become available to phytoplankton in the water column.

In order to determine the porosity of the sediments, the total water content of the centrifuged solids was determined through weighing a given amount of sediment before and after drying in an oven at 105^{o} C for a period of 24 hours. Since the sediment was saturated with water it was assumed that the total volume of water in the sediment would be equal to the volume of the sediment pore space. The porosity was then found by dividing the total sediment sample volume by the volume of the pore space ie, the water removed from the sample. A separate portion of the solids was also sent to the USU Analytical Laboratories for a soil texture analysis to determine the percent clay.

Weather Data

Precipitation data used for this analysis were taken from two monitoring stations in the Ogden Valley. One station was located near the dam of the reservoir and one at the monastery located in the lower reaches of the South Fork watershed. Precipitation numbers from these two weather stations were averaged on a daily basis, and the average values were used to estimate the total water contribution of rain and snowfall to the reservoir due to precipitation falling directly onto the reservoir itself, over the duration of the analysis period.

Producing Estimates for Below Detection Limit Data Points

Trends in flow and nutrient concentrations between data points were estimated based on calculated cumulative failure probabilities (CFP's) of known data points using the rank-data (R-D) distribution method (Lee 2008). This was accomplished by ranking the non-censored data points, and calculating a cumulative failure probability (a number between 1 and 0) for each known data point. Daily CFP values were then determined for days between observations through linear interpolation, and it is these CFP values that were used as the basis of interpolation for the daily flow and nutrient estimates between observations. This approach has been tested and proven to produce better flow estimates than direct linear interpolation between points in a given data set (Lee 2008).

Estimation of Nutrient Export from Dam Release

For the purposes of this study it was assumed that the only significant loss of bioavailable phosphorus from the reservoir is through reservoir release flows. This assumption was made based on the fact that P has no significant gas phase and in a reservoir system can either settle into the sediments or be physically exported with sediments, organic matter or water. Other pathways of P removal, such as fishing are difficult to quantify and most likely insignificant compared to the reservoir releases. Therefore they were not considered in this study.

Nutrient export due to reservoir release was estimated using the daily discharge measurements collected by the reservoir operator and nutrient data collected from the hypolimnion of sites 380 and 381, 380 because it is the closest to the dam outlet and 381 because it is the second closest and unlike site 380, was sampled through the ice during the winter months. Data from 381 was only used to fill in long gaps where site 380 was not sampled (October-April). Due to the difficulty in securing security clearance for each sampling event and the time it took to walk into the site, the discharge water at the hydro electric plant at the base of the dam was sampled on a very limited basis. Most of the sampling at the hydro electric plant occurred during the months of August and September when hypolimnetic P concentrations were at their highest. Daily nutrient concentrations between observations were estimated using the rank-data method explained in the N & P loading estimates section above.

Nitrogen Fixation

Cyanobacterial nitrogen fixation was measured on September 22, 2009 during or near the peak of the fall bloom period, when cyanobacterial concentrations were at their highest. Nitrogen fixation was measured using the acetylene reduction method of Flett, Hamilton, and Campbell (1975), where aliquots of reservoir water (or deionized water blanks) and acetylene gas were placed in 50 ml glass syringes with needles inserted into rubber stoppers to prevent gas escape and allowed to incubate floating in the reservoir at the mid lake (380), middle arm (383), and north arm (384) sites for a period of approximately 3 hours. Afterwards, air was drawn into the syringes. The syringes were then re-stoppered and shaken, allowing the air to equilibrate with the sample. The air was then drawn off and tested for the concentration of ethylene, the acetylene reduction byproduct using gas chromatography with flame ionization detection (Flett, Hamilton, and Campbell 1975). A one way analysis of variance along with a Tukey's HSD test was then performed on the data to see whether or not the samples were statistically different from the blanks.

RESULTS AND DISCUSSION

Water Budget

Surface water flows and loadings

Flow patterns in the major tributaries were found to follow closely a typical pattern in a snow melt driven watershed, with high flow during the spring runoff period followed by relatively small, constant flows throughout the rest of the year. Figures 7, 8 and 9 show the flows of the South Fork, Middle Fork and North Fork of the Ogden River, over the course of this study.

It can be seen in Figures 7-9 that 2008 showed the largest flows during spring runoff, 2009 showed the next greatest flows, followed by 2010. Of the three major tributaries the South Fork consistently produced the largest flows, with the North Fork showing the second largest followed by the Middle Fork with the smallest. It is also worth noting that in the 2009 spring runoff period, the North Fork produced flow rates with magnitudes similar to those produced by the South Fork. This observation may be related to year to year variations in water releases from Causey Reservoir whose outlet feeds into the South Fork of the Ogden River. The inconsistency of flow relationships between the three branches of the Ogden River is a good example of one of the limitations of the stream flow estimation procedure of estimating North and Middle Fork flows based on flows measured in the South Fork as was used in the TMDL study.

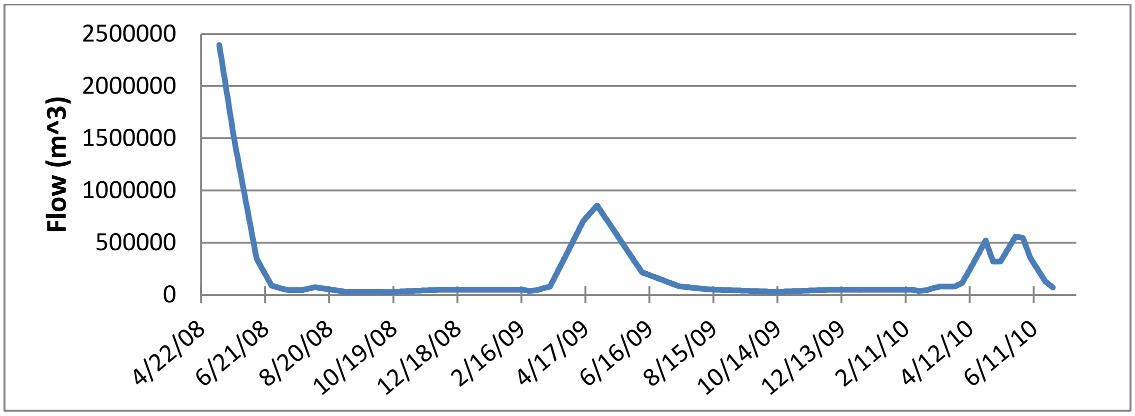

Figure 7. South Fork Ogden River flows.

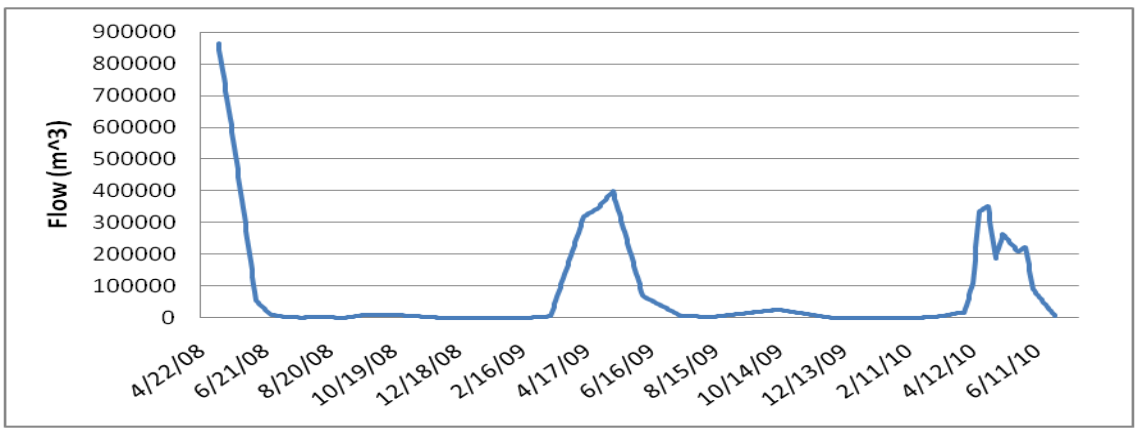

Figure 8. Middle Fork Ogden River flows.

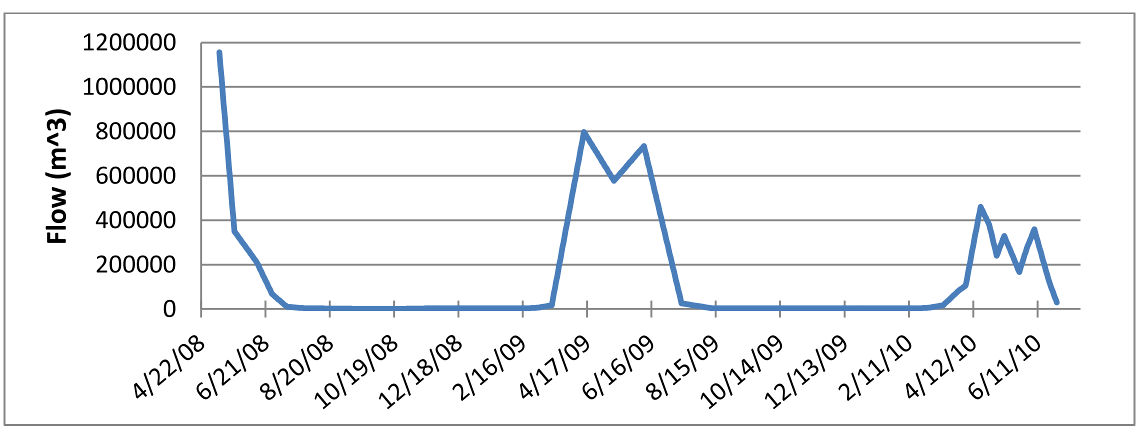

Figure 9. North Fork Ogden River flows.

Surface water sources contributed approximately 29,000 hectare-meters (HM) (235,000 acre-ft) of water to Pineview Reservoir during the sampling period from 5/9/2008 to 4/15/2010 about 17,000 HM (138,000 acre-ft) during 2009, and 15,000 HM (122,000 acre-ft) during the one year period from 4/15/09 to 4/15/10. The percentage of flow attributed to each of the monitored streams to the total over the entire time period (5/9/2008 to 4/15/2010), versus flow percentages used in the TMDL can be seen in Figure 10. Table 3 shows the breakdown of the individual stream N and P loads contributed to the reservoir between 4/15/09 and 4/15/10.

Total surface flow comparisons between surface flow estimates produced in the TMDL and the present study could not be made because, the total surface water flow estimates used by the TMDL for producing their nutrient loading estimates were not included in the TMDL document. It was also never made clear in the TMDL how exactly they used the South Fork USGS station data to derive their estimates of total surface flows entering the reservoir.

One of the reasons the TMDL predicted such a larger percentage of flow contribution from the South Fork may have to do with the fact that all of the data they used came from the USGS continuous monitoring station on the South Fork above the irrigation diversion (Station 10137500). During the irrigation season, the entire South Fork is diverted into a system of canals and used throughout the valley for agricultural purposes, such that all of the water reaching the reservoir from the South Fork during that time of the year can be attributed almost entirely to ground water return and agricultural return flows.

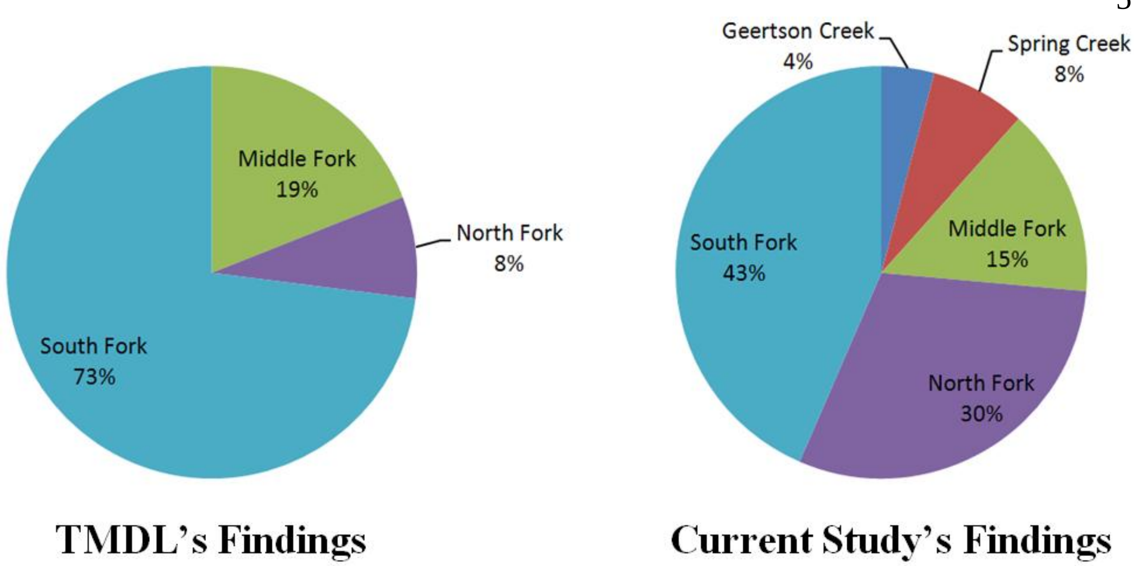

Figure 10. Current study vs TMDL surface water streams % contributions.

Table 3. Individual stream N and P contributions

	SF SB	SF NB	MF	NF	Geertsen	Spring Creek
Total P (kg)	1400	2000	500	3100	300	1000
% of total	17	24	6	37	4	12
SRP (kg)	500	200	200	500	100	200
% of total	29	12	12	29	6	12
Nitrate-N (kg)	8100	4800	800	28700	1500	6300
% of total	16	10	2	57	3	13
Ammonium-N (kg)	500	200	300	3000	0	200
% of total	12	5	7	71	0	5

This means that essentially all of the water measured in the South Fork at USGS gauging station 10137500 either enters branches of the South Fork more than 4.5 km downstream; enters other stream channels, including Spring Creek, Middle Fork, Geertsen Creek, and North Fork; enters the reservoir directly from ground water or it is consumed by evapotranspiration in agriculture and other ecosystems.

These results conflict with the reservoir inflow from surface water sources reported by the TMDL (Tetra Tech 2002) and the Ground-Water Hydrology of Ogden Valley Report (Avery 1994). In both cases, total surface water contributions to the reservoir were calculated using data from the South Fork of the Ogden river's USGS gauging station and estimated flow relationships between discontinued gauging stations located above irrigation diversions in each of the three forks of the Ogden River (Tetra Tech 2002). Also, due to the distance of these stations from the reservoir (in the case of the South Branch, several miles upstream) flow and nutrient contributions of the watershed between the gauging stations and reservoir were not properly accounted for.

The results of the placement of USGS gauging station 10137500 coupled with the South Fork diversion can be observed in Figure 11, which shows data produced by USGS gauging station 10137500 plotted against flow estimates for the south fork produced during this study. The interpolated discharge estimate in Figure 11 was made by linearly interpolating between flows measured for this study at the designated sampling sites on the north and south branches of the South Fork of the Ogden River (Figure 4).

Figure 11 shows great discrepancy between the flows measured at the USGS station and the flows produced for this study during the irrigation season when the South Fork is being diverted (~4/20/09 to 10/20/09). During the rest of the year, when the South Fork is allowed to flow freely, a strong correlation can be seen between the USGS flow estimates and the ones produced by this study.

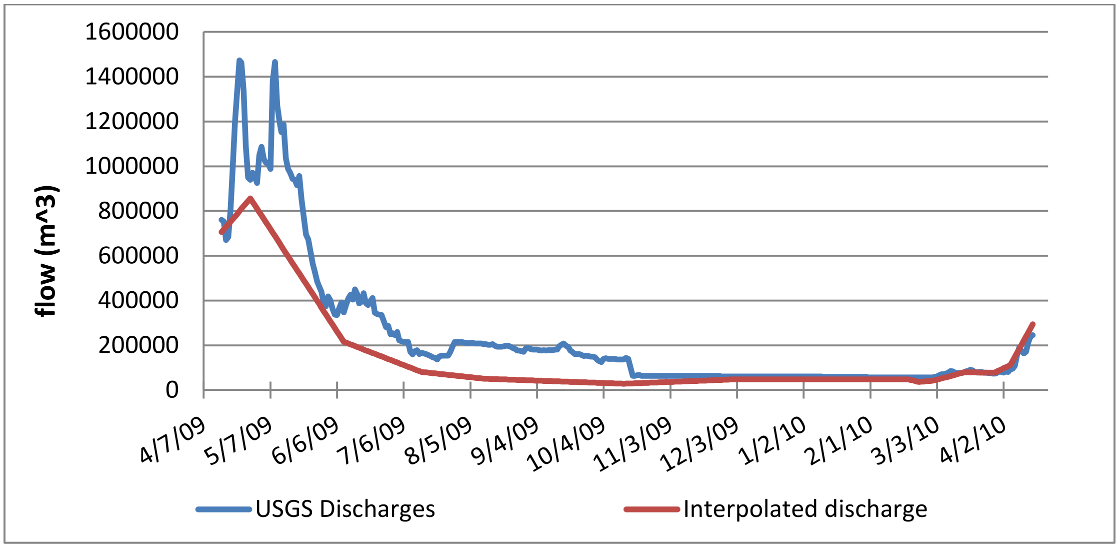

Figure 11. South Fork discharge USGS vs current study.

Another important finding is that the combined contributions of Geertsen and Spring Creek account for approximately 12% of the total surface water flows entering the reservoir. Failure to include these two streams in the water budget of all known previous studies was indeed a major oversight and may increase their margin of error for flows by more than 10%. To further substantiate the claim that the water and nutrient contributions of Spring Creek and Geertsen Creek to Pineview Reservoir were not insignificant, a breakdown of the % contributions N and P of each of the streams was made in Table 3. It can be seen in Table 3 that the combination of Spring Creek and Geertsen Creek accounted for as much as 16% of the TP and nitrate-N that entered Pineview Reservoir through surface water sources, over the one year sampling period.

Ground water inflow

Since no ground water flow measurements or calculations were made for this study, all ground water flows used in reservoir loading calculations were taken from the best available information, which was the work of Avery (1994). To date, Avery's work constitutes the best available seepage rates for ground water entering Pineview Reservoir, but is still limited in its number of observation points, inability to differentiate between seepage from the shallow unconfined and the confined aquifer, and its general lack of data. No measurements of ground water flow or nutrient concentrations were made in the TMDL study.

Nutrient concentrations in the shallow aquifer used in this study were taken from a concurrent study at the UWRL. For that study, five shallow wells were drilled into the valley's shallow aquifer around the reservoir, and total dissolved phosphorus (TDP, 0.45 µm filtered), OP and NO_3–N concentrations were measured over a period of several months.

Using the flow rates determined by Avery (1994), it was calculated that a volume of approximately 5940 HM (approx. 48,000 acre-ft) of ground water enter the reservoir per year. Despite the fact that this flow estimate is more than double the amount used by the TMDL (20,000 acre-ft), it still appears to be a similar estimate when compared to what Avery's seepage numbers yielded for the same time period (23,810 acre-ft) based on the fact that the TMDL estimate only considered the summer season (April – October) and not the entire calendar year (Tetra Tech 2002).

In order to check the validity of Avery's ground water loading estimate, a ground water loading estimate was calculated for the period of 4/15/2009 to 4/15/2010, using the data gathered for this study. For this estimate it was assumed that the daily ground water contributions to the reservoir can be defined as the sum of the daily change in reservoir volume and the daily reservoir discharge volume, minus the volume of the daily surface water load. Daily ground water estimates that were calculated and summed over the yearlong study period to produce a total annual ground water estimate of approximately 5,200 HM (42,000 acre-ft). The daily changes in reservoir volume were found using daily reservoir surface elevation data and the depth/capacity curve produced by Winkelaar in his 2010 bathymetry report of Pineview Reservoir. Evaporation and direct precipitation on the reservoir were not considered in this estimate as they were found to be approximately equivalent to each other.

Although this estimate was very similar to Avery's annual ground water loading estimate of 5,900 HM, it still contains a great potential for error. This is due to the fact that the error associated with the reservoir bathymetry, the surface water inflow and reservoir discharge measurements are all accumulated in this ground water calculation. Figure 12 shows a time series of the daily ground water flow estimates produced here, as well as the surface water, reservoir discharge and reservoir volume change data used to produce the estimate.

Along with the sources of error mentioned above, there is also a substantial potential error associated with the daily reservoir surface elevation measurements. Reservoir surface elevations are measured daily by the dam keeper. These measurements are done by visually determining the water level on a scale located near the reservoir spillway. There is error associated with these measurements due to the fact that accurate readings can be difficult when the water is choppy. At times when the reservoir is close to capacity, two centimeters of difference in reservoir elevation can represent a difference of 180 HM of reservoir volume. Whereas, when the reservoir is at its lowest levels, 2 cm of difference in surface elevation only accounts for a difference of about 9 HM total

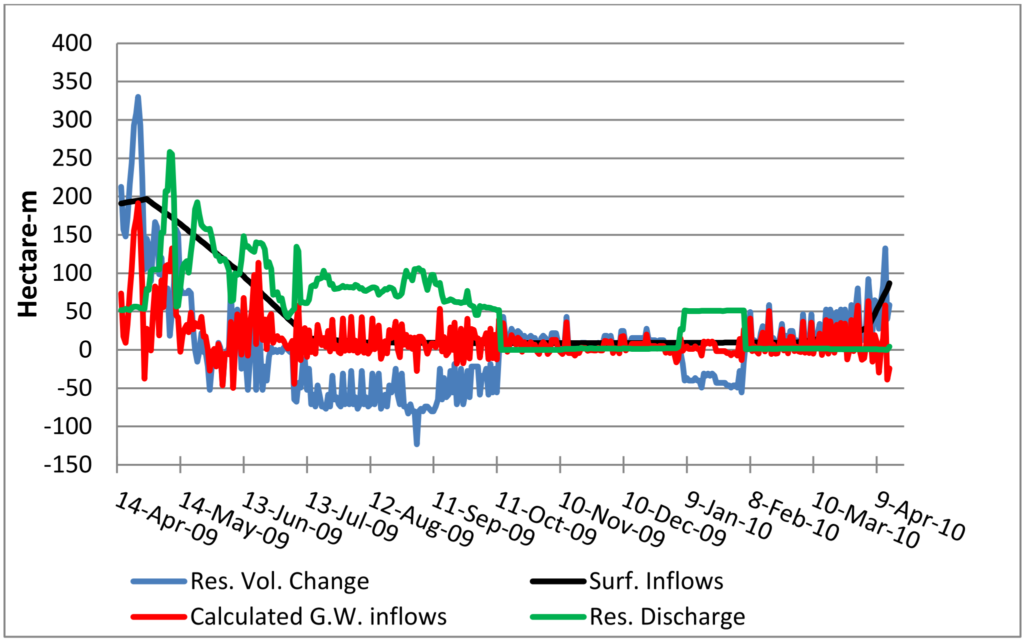

Figure 12. Time series of ground water inflow estimate components.

volume. This point is especially apparent in Figure 12, for the two data sets that are directly dependent on reservoir surface elevation for their calculation, the reservoir volume change and the ground water. These data sets show a daily fluctuation that is increased in magnitude when the reservoir is full or nearly so in March-July, and greatly decreased in magnitude when the reservoir levels are at their lowest in October-February. These small fluctuations are likely a representation of the error associated with the interpretation of the daily reservoir surface elevations. Despite the fact that the results of this water balance approach to calculating ground water loading to the reservoir were very similar to what was found by Avery (1994), there is too much potential error associated with it to have confidence in its accuracy.

Direct precipitation accumulations

Another avenue in which water enters the reservoir is through direct precipitation onto the water's surface. Using precipitation data gathered by the Pineview Water Systems dam keeper, it was estimated that approximately 866 HM (7,000 acre-ft) of water entered Pineview Reservoir over the study period of 4/15/09 to 4/15/10 through direct precipitation.

Evaporation losses

Evaporation losses for the calculations in this study were taken from Hughes, Richardson, and Franckiewicz (1974) and were assumed to be approximately 997 HM (8,079 acre-feet) per year.

Dam exports

For the period of 5/9/2008 to 4/15/2010, approximately 36,000 HM (291,857 acre-ft) of water was exported from the reservoir. During the entire calendar year of 2009, dam releases measured approximately 21,000 HM (170,250 acre-ft), and during the one year period from 4/15/2009 to 4/15/2010, about 19,000 HM (154,036 acre-ft) of water went through the dam.

Total water budget

The water budget estimated a net loss of 200 HM of water for the one year period from 4/15/2009 to 4/15/2010. This represents less than 1% of the total inflow and outflow for the reservoir. Although this water budget does come very close to a perfect balance between inflows and outflows over the sample period, it is difficult to confirm the accuracy of these results, due to the potential error associated with ground water inflows, surface water inflows, evaporation, direct precipitation and water export through the dam. By far, the contributor with the greatest potential for error in the total water budget of the reservoir is ground water, due to limited data available for the valley's shallow aquifer. The second largest potential for error can be attributed to surface flows followed by reservoir exports, evaporation, and direct precipitation, in that order.

Nutrient Budget

The nutrient balances for phosphorus and nitrogen considered nutrients entering the reservoir through several pathways, and nutrients exiting with the release of water from the dam. The pathways that were considered in this study for nutrients entering the reservoir are surface water sources (streams), ground water sources, and through the fixation of atmospheric nitrogen by cyanobacteria.

The nutrient budget for this study was evaluated over the one year period from 4/15/2009 to 4/15/2010. Due to unforeseen complications with lab analyses and the availability of sampling resources and manpower, this was the only period during the study in which all significant and applicable flows and nutrient concentrations of the various tributaries and outlets were recorded simultaneously.

Total P budget

Throughout the duration of this study, the TP loadings to the reservoir from surface water sources were measured and compared to estimates of TP leaving the reservoir through water discharges. For this study, all surface water inflow and reservoir release flow nutrient loadings were calculated using Equation 2.

$$Load = Q \times C \quad \text{in kg over time period} \tag{2}$$

Where Q, with units of m^3 per day, represents either measured or interpolated daily flows entering or exiting the reservoir, and C, with units of kg per m^3, represents either measured or interpolated concentrations of P in those flows. The calculated daily loads and exports were then summed over a year to produce an annual load value. Using the stream flow and nutrient data produced in this study, it was estimated that 8,000 kg of TP entered the reservoir through surface water sources over the one year period of 4/15/09 to 4/15/10.

Table 4 contains a total P budget for the reservoir, where a geometric mean as well as a positive and negative 95^{th} percentile was calculated for the ground water TP loads. This was done to show a potential range of ground water TP loading to the reservoir, due to the large amount of uncertainty in the ground water estimates.

Using the single season, ground water contribution estimates provided by Avery (1994), combined with the shallow aquifer nutrient data produced in parallel with this study, it was estimated that the shallow, unconfined aquifer in the Ogden Valley contributes anywhere from 2,000 to 6,700 kg of TP to Pineview Reservoir each year. It was also estimated that approximately 14,800 kg of TP are exported from the system each year through water releases at the dam. This means that based on the best available data, the reservoir could be importing up to 200 kg of P, or exporting up to 4,500 kg of P annually.

Table 4. Reservoir phosphorus budget for 4/15/09 to 4/15/2010

Reservoir Total P Budget	Total P (kg)
Surface Water Imports	8300
Ground Water Imports	
Negative 95th Percentile Estimate	2000
Geometric Mean Estimate	3700
Positive 95th Percentile Estimate	6700
Dam Exports	14800
Reservoir Accumulations	
Negative 95th Percentile Estimate	-4500
Geometric Mean Estimate	-2800
Positive 95th Percentile Estimate	200

Although these data suggest that a net reduction in P is occurring in Pineview Reservoir, biological conditions in the reservoir, such as the consistent annually observed anoxia in the hypolimnion and algal blooms following fall mixing events, suggest that an in-reservoir accumulation of P is more realistic. These TP findings are also an indication that additional information is needed regarding the quality and flow of the Ogden Valley's shallow uncontained aquifer before decisions can be made concerning the reduction of P in Pineview Reservoir.

Soluble reactive P

It was estimated that during the period between 4/15/09 and 4/15/2010, approximately 2,000 kg of soluble reactive phosphorus (SRP) entered Pineview Reservoir through surface water sources. It was also estimated that ground water contributed approximately 1,000 kg SRP using Avery's (1994) ground water flows. Over this same period it was also found that approximately 3,000 kg SRP was exported from the reservoir through the dam.

Dissolved mineral nitrogen

Contributions of dissolved nitrogen (nitrate + nitrite (NO_3+NO_2-N)) and ammonium (NH_4-N) to Pineview reservoir due to surface water sources over the sample period of 4/15/09 to 4/15/2010 were found to be approximately 49,000 kg. Using seepage rates from Avery (1994) and NO_3+NO_2-N and NH_4-N a geometric mean concentration calculated using concentrations measured from 5 shallow aquifer monitoring wells in the valley it was estimated that the shallow, unconfined aquifer contributed approximately 206,000 kg of dissolved nitrogen to the reservoir over the same one year sampling period. This means that the vast majority of the N entering the reservoir is in the form of nitrate and most of that nitrate is coming from the ground water. It was also calculated that approximately 46,000 kg dissolved nitrogen was exported from the reservoir through the discharge.

Nitrogen fixation

Nitrogen fixation was measured in Pinview Reservoir on September 22, 2009, close to the peak of the late summer bloom period. A one way analysis of variance along with a Tukey's HSD test was performed on the sample set (Berthouex and Brown 2002). The results of this experiment can be seen in Figure 13.

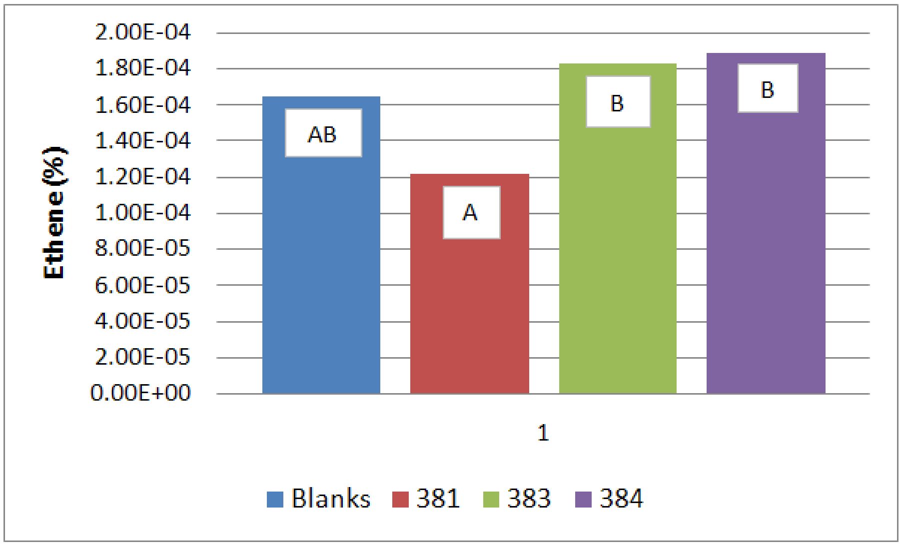

Figure 13. Ethene in the acetylene reduction assay.

As seen in Figure 13, the concentration of ethene measured at sites 381, 383, and 384 were found to be not significantly different than the blank, indicating that the experimental results were inconclusive in respect to both the validity of the method used and the occurrence of detectible amounts of nitrogen fixation occurring in the reservoir on September 22, 2009.

In order to determine the validity of the method used, cultures of *Anabaena spiroids* was acquired from the University of Texas and grown in COMBO medium (Kilham et al. 1988). After significant growth had been achieved, the original medium was decanted off, and replaced with a nitrogen free medium. The samples were then allowed to continue growing until significant heterocyst production was observed, at which time the cultures were subjected to the same acetylene reduction techniques used for the reservoir samples, and were allowed to incubate in a tub of approximately reservoir temperature water in sunlight for a three hour period (Flett, Hamilton, and Campbell 1975).

It was observed that the cyanobacterial cultures were indeed able to reduce acetylene to ethene, and that the nitrogen fixation process could be measured using the acetylene reduction method (Figure 14).

With the data produced by this experiment and the EPA method for determining detection limits, a method detection limit was estimated to be approximately 6.56 ppm ethene, using 3 degrees of freedom, based on triplicate samples and blanks (USEPA 2011). A maximum potential nitrogen fixation estimate of 7200 kg N per year was calculated by setting the concentration of ethene to the method detection limit, and assuming a 61 day period of bloom conditions (based on the period of significant cyanobacterial presence observed through algal counts) with an average of 14 hours of daylight per day, and half a meter of surface water depth available for the cyanobacteria

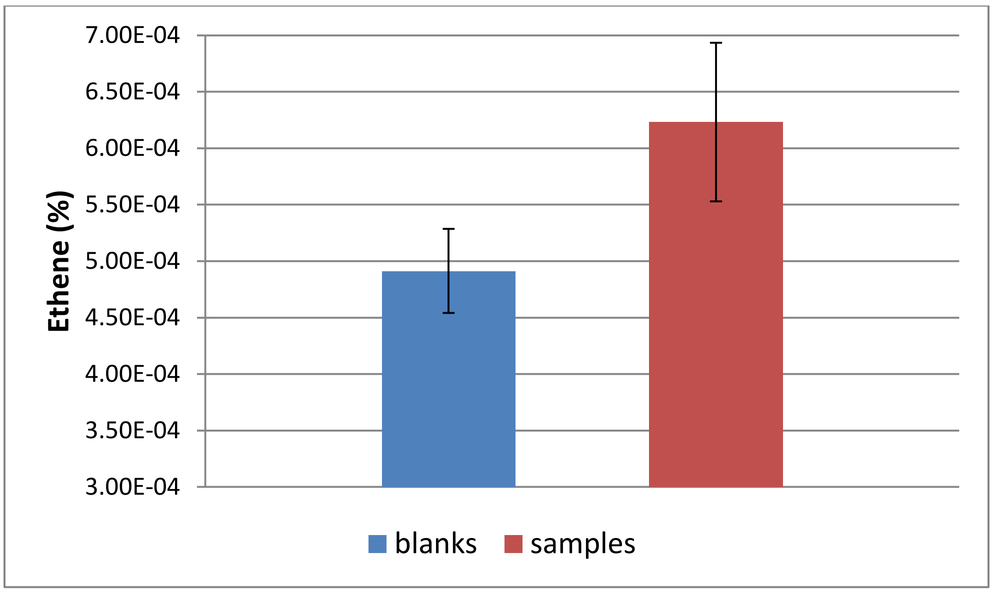

Figure 14. Acetylene reduction method positive control.

to grow in. This is less than 3% of the sum of nitrate-N and ammonium-N annual loads (Table 5) to the reservoir. Because this estimate represents an anticipated maximum rate and was derived using solely censored data, it was not included in the overall nutrient balance of the reservoir.

Nutrient accumulation breakdown

Table 5 includes measured and estimated inputs and outflows of soluble nutrients. Approximately equal loads of SRP entered and left the reservoir on an annual basis. In contrast, far more nitrate-N entered the reservoir than was exported through the dam. It is, however, impossible, given the available data, to complete a mass balance for N in Pineview Reservoir as there were no data available to qualify the amount of N that was lost from the system due to denitrification from anaerobic reservoir sediments and water. It is of note that findings in Table 5 rely heavily on the decidedly weak ground water component and are therefore subject to question. The results of a parallel ground water study should help to improve future estimates. Figure 15 represents the percent contributions of flow and nutrients to the reservoir from surface, ground water and direct precipitation. It is of note that for Figure 15, surface water sources were measured as TP, while ground water measurements were filtered and measured as total soluble phosphorus (TSP).

As seen in Figure 15, despite the fact that surface water sources are accountable for almost 70 % of the total water entering the reservoir, ground water sources may contribute 31% of the TP and 81% of the nitrate-N entering the reservoir, while contributing only 27% of the total flow entering the reservoir. This further substantiates the claims made by the TMDL and the Avery ground water studies that nutrients entering through the shallow aquifer represent the single greatest threat the water quality of Pineview Reservoir (Avery 1994; Tetra Tech 2002).

Table 5. Soluble nutrient breakdown for Pineview Reservoir (4/15/2009 to 4/15/2010)

Water and Nutrient Balance for Pineview Reservoir (4/15/09-4/15/10)					
	Water (HM)	Total P (Kg)	Soluble Reactive P (Kg)	Nitrate + Nitrite N (Kg)	Ammonium N (Kg)
Surface Water Imports	15000	8300	1700	50200	4200
Ground Water Imports	6000	3700	1300	205600	700
Direct Precipitation imports	900	-	-	-	-
Evaporation Losses	1000	-	-	-	-
Dam Exports	21000	14800	2600	46000	6200
Reservoir Accumulations	-100	-2800			
Percent Annual Retention (%)	-0.46	-23			

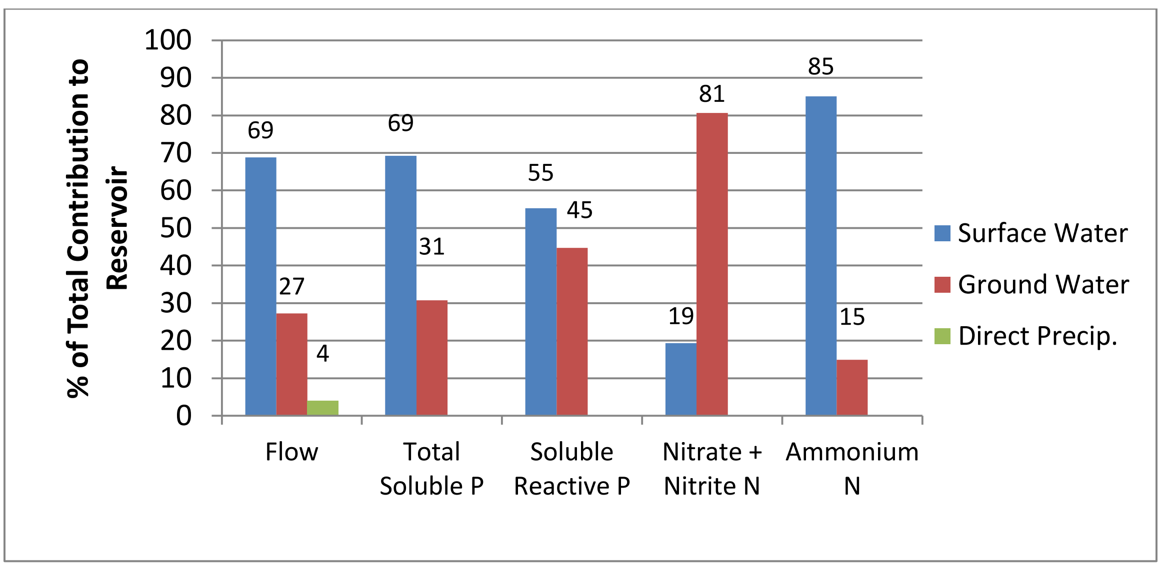

Figure 15. Surface water vs ground water loading contributions.

Internal Nutrient Dynamics

Bathymetry

Figure 16 is a map of the recently updated Pineview Reservoir bathymetry (Winkelaar 2010). Using the updated bathymetry for the reservoir it was found that the reservoir has a current maximum storage capacity of 13,236 Hectare-M (107,306 acre-ft). This is approximately 351 Hectare-M (2844 acre-ft) less than the maximum capacity

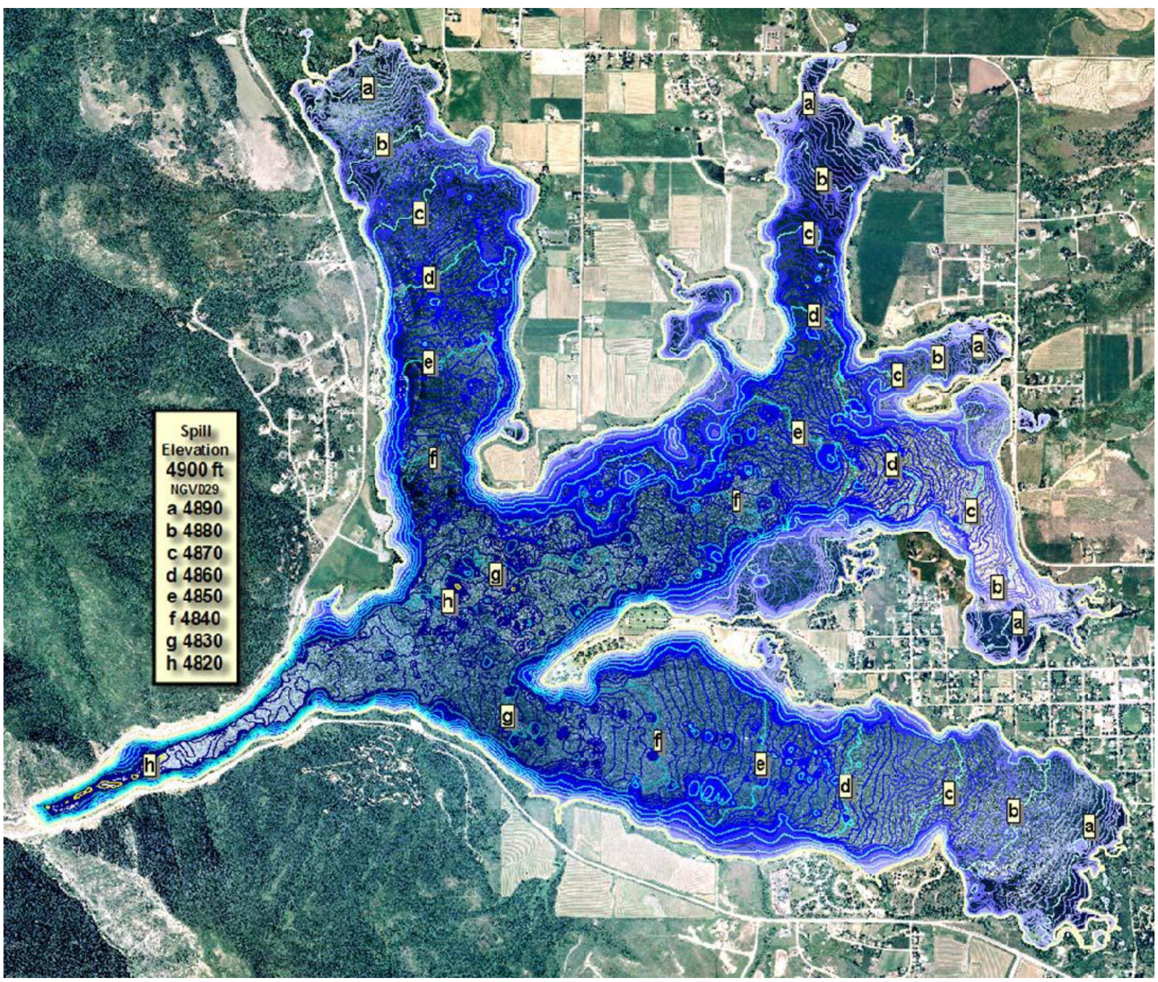

Figure 16. Pineview Reservoir bathymetry.

reported by the Army Corps of Engineers (1971) of 13587 Hectare-M (110,150 acre-ft). The updated bathymetry data indicate that Pineview Reservoir has lost approximately 2.6% of its maximum capacity over a period of 52 years (Winkelaar 2010).

Internal nutrient cycling

It was found over the course of this study that seasonal thermal stratification in Pineview Reservoir was occurring, and that the time duration of stratification and time of thermal destratification varied between the two seasons of observation. Figures 17 and 18 are a representation of the high frequency temperature data collected throughout the water column at site 381 during the summer stratification periods of 2008 and 2009, respectively.

Of the many differences in thermal stratification that can be observed between Figures 17 and 18, one of particular interest to this study is time and duration of the fall destratification event. It can be seen in that destratification (mixing) occurred much more quickly and uniformly in the 2008 season than it did in 2009. When viewed from the perspective of internal nutrient cycling, the date of fall mixing and the time it takes for the reservoir to mix completely can greatly impact the size of nutrient loads and the time period in which they may become available for uptake by primary producers.

One major purpose of this study was to establish if there is any correlation between anoxic hypolimnetic conditions and the release of nutrients from the Pineview Reservoir benthic sediments. It can be seen in Figures 19-23, that such a pattern did exist in this system.

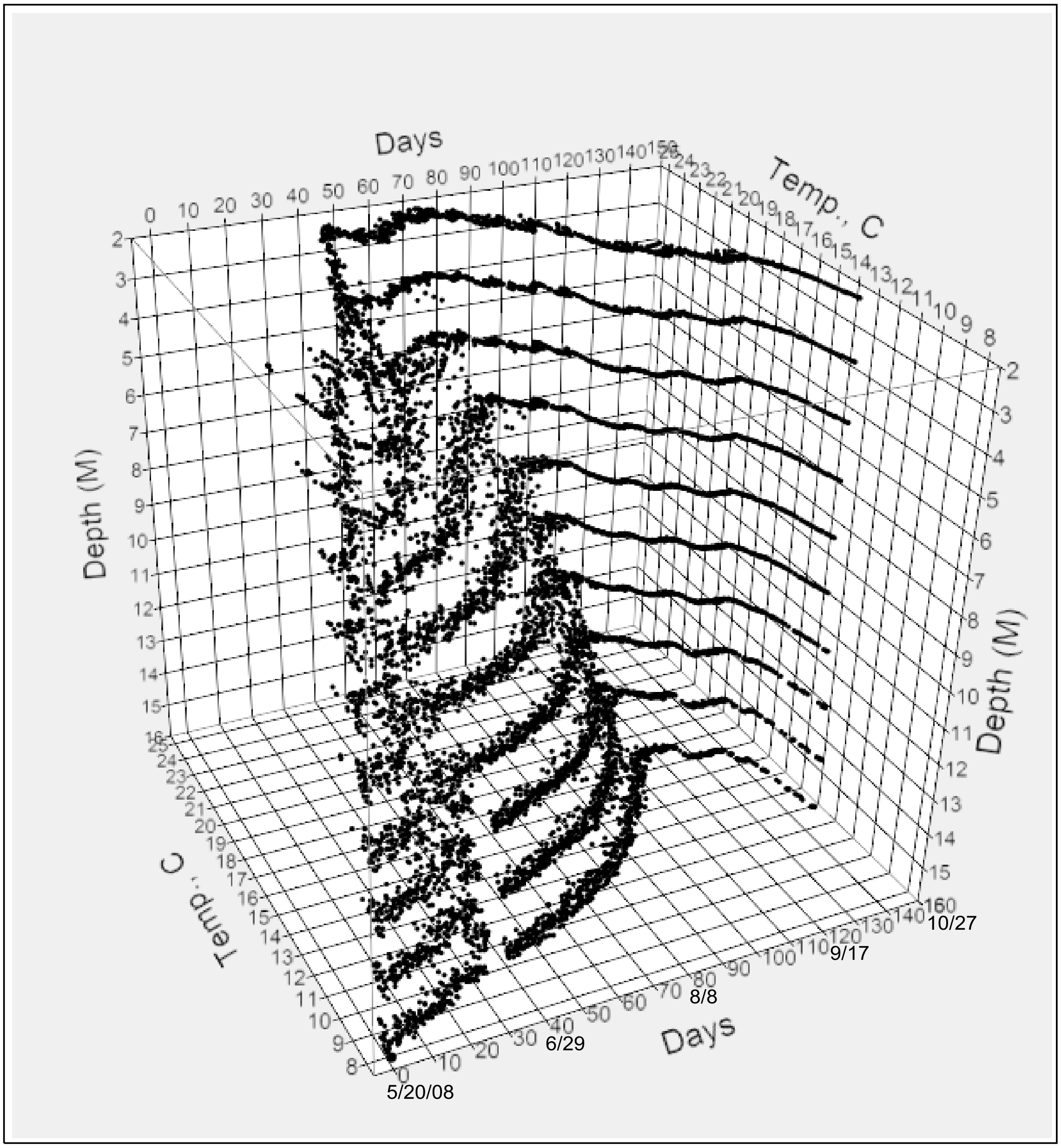

Figure 17. Temperature profile at Site 381 (5/20/08 to 10/27/08).

Figures 19-23 show the DO concentrations, and the levels of TP, NH_4-N, NO_3-N and dissolved Fe that were observed in the bottom portions of the water column at each

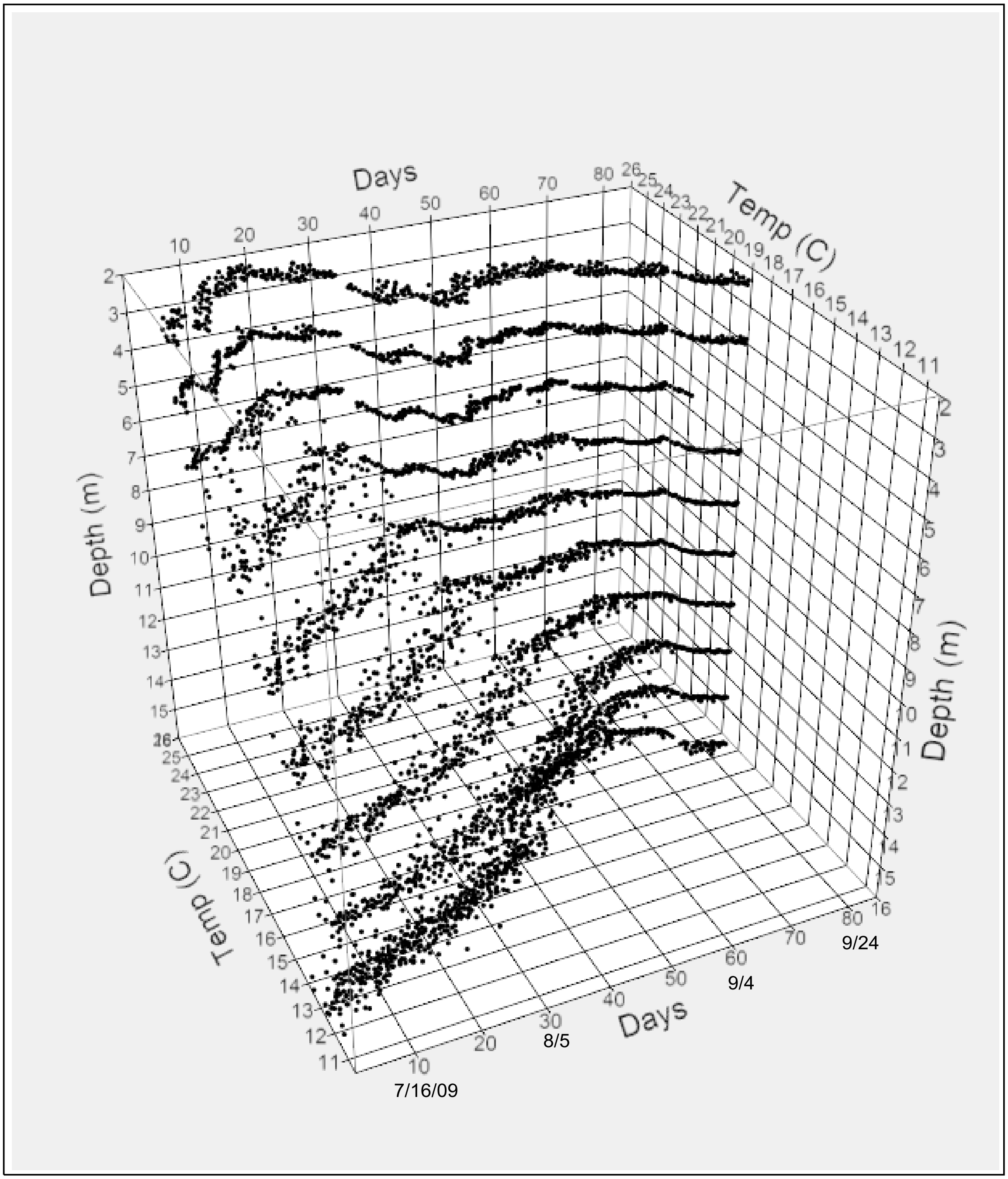

Figure 18. Temperature profile at Site 381 (7/6/09 to 9/29/09).

of the sampling sites. Hypolimnetic water temperatures just prior to turnover in early September were approximately 15° C and, at the 1,493 m elevation of the reservoir.

TP and to a lesser extent, NH_3-N increased in concentration during the time periods when DO deficits were at their highest. This trend suggests that these nutrients may indeed be cycling between the benthic sediments and the water column, and, with the exception of nitrate, are only able to go back into solution during reducing conditions. The 2.9 mg/L spike in dissolved Fe near the bottom of the hypolimnion at site 381 (Figure 20) during these periods also suggests that phosphorus is likely forming precipitates with Fe during oxic periods, and then re-dissolving into the water column as Fe^{3+} is reduced to Fe^{2+} . Similar behavior has been observed by White, Noll and Makarewicz in an embayment of Lake Ontario (2008).

One of the advantages of knowing when increased nutrient loads will be entering the water column from the sediments is the potential ability to control nutrient discharge

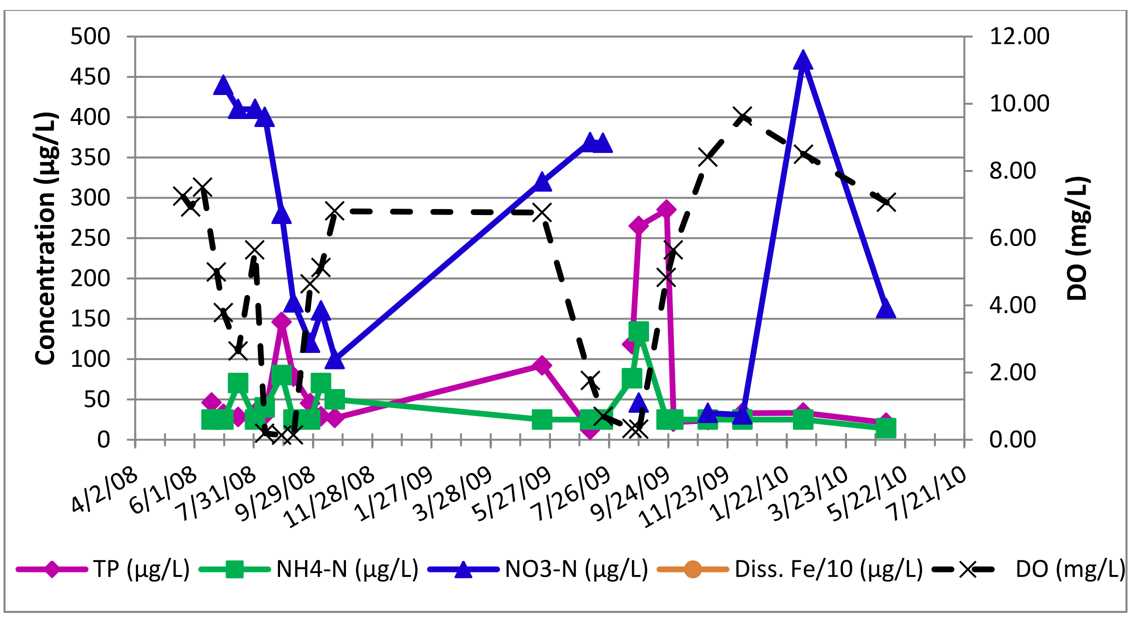

Figure 19. Dam Site 380 nutrients and DO over time.

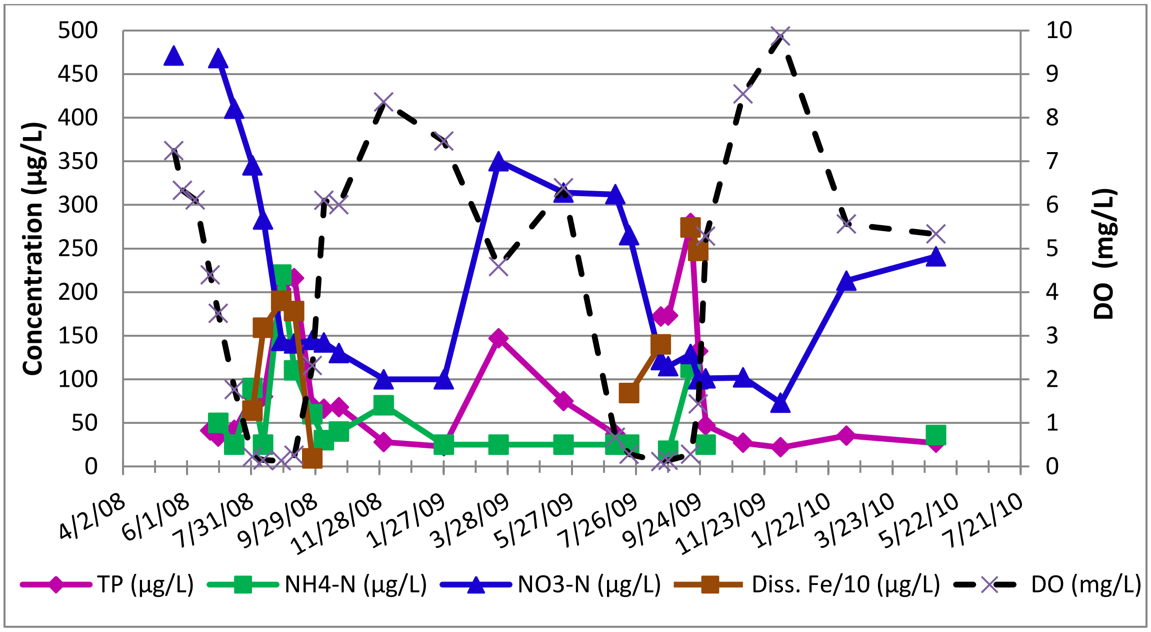

Figure 20. Mid Reservoir Site 381 nutrients and DO over time.

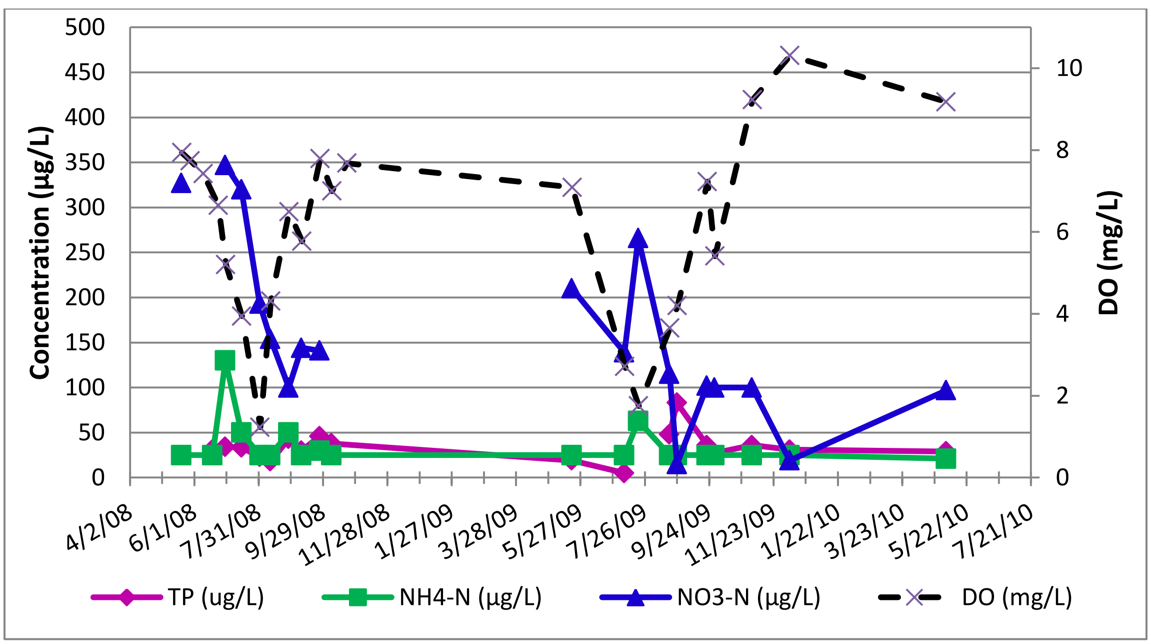

Figure 21. South Arm Site 382 nutrients and DO over time.

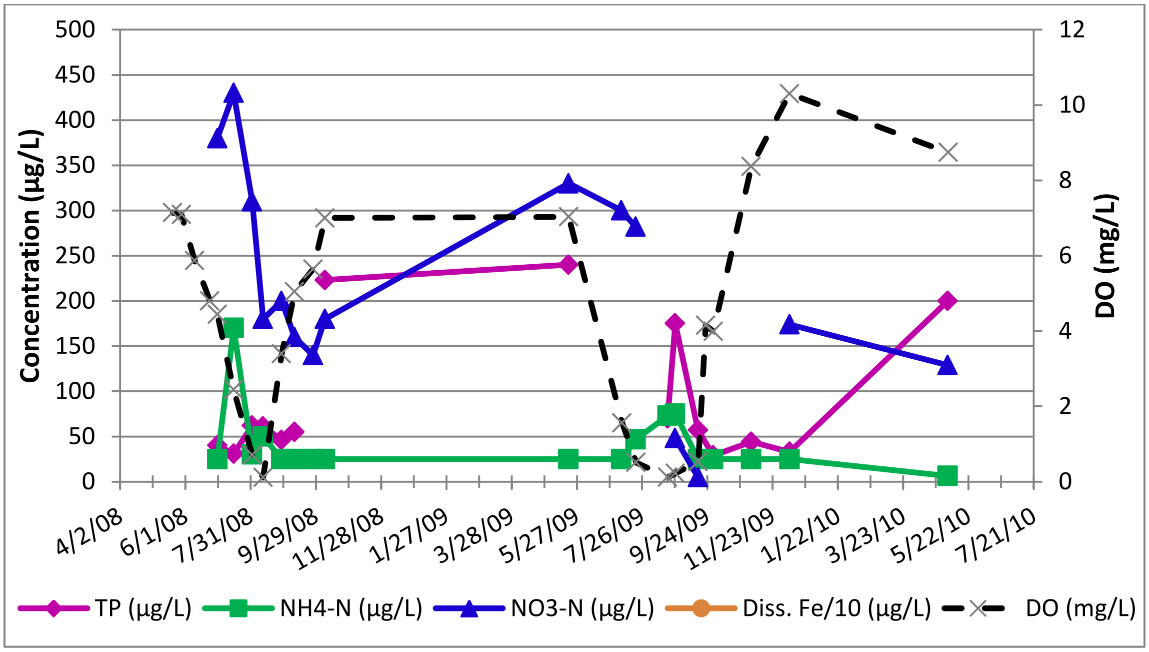

Figure 22. Middle Arm Site 383 nutrients and DO over time.

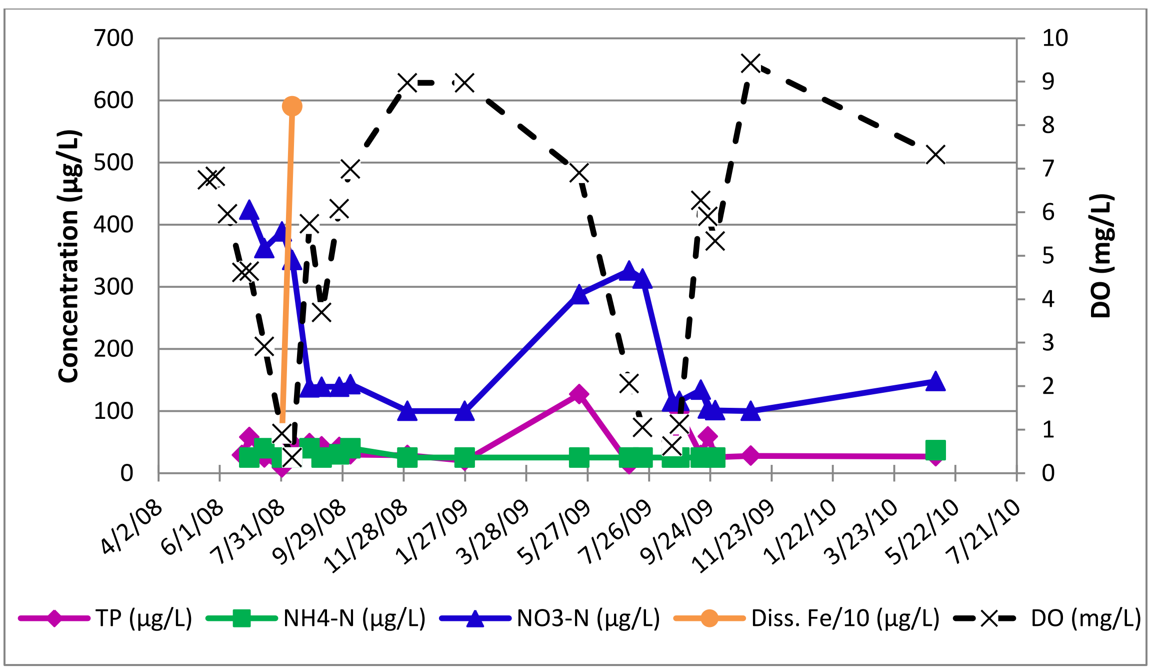

Figure 23. North Arm Site 384 nutrients and DO over time.

from the reservoir by increasing outflows during the seasons of increased N and P concentrations in the hypolimnetic waters. For Pineview, the time of year when hypolimnetic nutrient concentrations are the highest is the late summer. This time also coincides with the time of the year when downstream water demand for irrigation is very high. Figure 24 shows the patterns of hypolimnetic TP concentrations and reservoir releases that were measured over a period of approximately 26 months.

As seen in Figure 24, some of the highest discharges from the reservoir since 2008 occurred when some of the highest hypolimnetic P concentrations were observed. This serendipitous phenomenon is perhaps one indication as to why Pineview Reservoir has been able to maintain a slow progression towards eutrophication despite constantly increasing population and development within its watershed.

The information in Figure 24 also shows that although peak discharges appear to mirror peak P concentrations in 2008 and 2010, it can be seen that in the summer of 2009

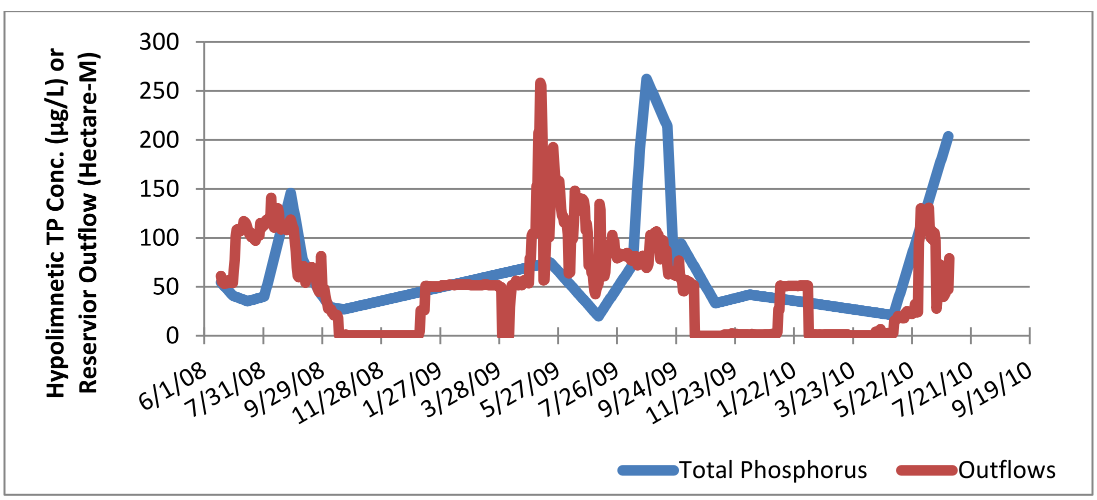

Figure 24. Hypolimnetic TP and reservoir outflows over time.

peak reservoir discharges preceded peak P concentrations by several months. Some of this may be due to the fact that the reservoir exceeded its capacity and spilled in 2009. Reservoir spillage was accounted for in this study and added to the discharge measurements.

Magnitude of sediment P releases

Using data gathered from the sediment pore water and hypolimnetic water column samples, a first estimate was made of the amount of bioavailable P entering the water column from the sediments during times of anoxia in the hypolimnion. The mass flux of bioavailable P due to pore water diffusion was found to be 463 mg SRP/m^2*y, calculated using Equation 1 (Chapra and Reckhow 1983). It was then determined using data gathered during the course of this study, that Pineview Reservoir experienced approximately 77 days in which DO concentrations in the hypolimnion, near the sediments, were low enough to allow the free transfer of SRP across the sediment/water interface (< 2 mg/l). These 77 days were between 7/7/09 and 9/22/09, when hypolimnetic DO concentrations were found to be 0.67 mg/l and 1.43 mg/l respectively. It was also found that the average elevation below which the sediment was exposed to <2.0 mg DO/L was 1,477 m (4,846 ft). Bathymetry data was then used to determine the benthic area of each of the five reservoir portions below 1477 m, or the area of the active P transfer interface. These areas were used in conjunction with the diffusive max flux rate to calculate the annual SRP loading to the water column from the sediments in each of the five reservoir sections (Table 6).

Using the pore water SRP concentrations from each of the three sediment sampling sites it was found that the annual TP loading from the benthic sediments within Pineview Reservoir is somewhere between 1,250 and 3,790 kg per year based on the standard deviation of the pore water TP concentrations between the three sites, with the mean being approximately 2,750. As seen in Table 6, 69% of the SRP load from the sediments is released from sediments within the middle trunk of the reservoir, which includes the Dam, Mid Lake, and Middle Arm sites. This is due to the fact that most of the deeper portions of the reservoir are located within these sections. Although the South arm has a large fraction of the surface area, it is relatively shallow and, for the most part, becomes de-stratified much earlier than the deeper portions of the reservoir. The North Arm is by far the smallest contributor, as it contains very few areas deep enough to support strong thermal stratification throughout the summer months.

The annual internal P load of 2,750 kg represents about one fourth of the TP that is brought into the reservoir through surface and ground water sources each year. Because the phosphorus is in forms readily available for uptake by phytoplankton and because it is delivered to the algal and cyanobacterial communities when temperatures

Table 6. Average annual benthic SRP releases

Average Soluble Reactive Phosphorus Loadings From Reservoir Benthic Sediments						
	1	2	3	4	5	Totals
	Mid Lake	Dam Site	North Arm	Middle Arm	South Arm	
Hypolimnetic Benthic Area (m^2)	820180	520470	270490	846810	721070	3179020
Annual H2PO4 Releases (kg)	380	240	130	390	330	1470
Annual HPO4 Releases (kg)	330	210	110	340	290	1280
Total Annual Benthic P Releases (kg)	710	450	240	730	620	2750
% of Total Benthic P Releases	26	16	9	27	23	100

are warm and light energy is still sufficient to produce near optimum growth conditions (late August to early September), it can serve to greatly stimulate the growth of phytoplankton causing bloom conditions within the reservoir.

Available sediment P

A sequential P extraction was performed on the collected benthic sediment samples. The results are in Table 7.

Table 7 shows the quantities of the different fractions of P in the Pineview reservoir benthic sediments at the time of sampling. The pore water fraction shows the amount of bioavailable P that had already made its way into the interstitial water of the sediment and was ready for diffusion into the water column. The $Ca(HCO_3)_2$ concentrations represent the portion of sediment P that could be made bioavailable through ion exchange. This fraction, in theory, would be readily available as more of the

Table 7. Sediment sequential P extractions

Extractable SRP in the Top 3 cm of Pineview's Benthic Sediments			
Extraction	Extractable SRP		
Solution	mg P/ kg dry sed.	Total kg P	% of total
Pore water	72	1919	9
$Ca(HCO_3)_2$	7	182	1
Buffered Dithionite §	92	2462	11
NaOH	303	8096	36
HCl	364	9743	43

§ per liter: 9.24g $NaHCO_3$, 1.92g $Na_2S_2O_4$

pore water P is diffused into the water column and the concentration gradient between sediment and pore water P increases. The dithionate bound portion represents P that is bound to metals, predominately Fe, this portion is also largely readily available for transfer to the water column, but only during times when there are reducing conditions (low DO) in the hypolimnion (Psenner et al. 1988). This means that during the time when the sediment samples were taken (Sept. 16, 2009), not including the SRP that was already present in the interstitial water of the sediments, there was over 2,000 kg of additional P that had the potential to become soluble and eventually diffuse into the water column, given the ambient hypolimnetic conditions at that time.

The fraction of P extracted with NaOH represents the P that is absorbed to metal oxides, and/or associated with organic materials (Psenner et al. 1988). Although this fraction does not have the potential to be as readily released as the other two fractions previously discussed, it still can be made available as organic compounds in the sediment decompose.

The last extraction step, HCl gives a representation of the carbonate bound P, that can be released under acidic conditions (Psenner et al. 1988). This portion is relatively inaccessible for release in Pineview Reservoir as the system is well buffered with carbonates and resistant to drastic changes in pH due to the highly carbonaceous geology of the reservoir's watershed (Spangler and Allen 1999).

Phytoplankton ecology

As mentioned above, during fall mixing, the now nutrient enriched hypolimnetic waters mix with the waters in the epilimnion and photic zone, allowing the bioavailable

N and P to reach the photosynthetic organisms in the photic zone, resulting in a bloom. This bloom phenomenon can be quantified in terms of surface water chlorophyll A concentrations shown in Figures 25-30. Chlorophyll A is generally well correlated with a phytoplankton biomass (Banse 1977).

The largest concentrations of chlorophyll A observed throughout the 2008 monitoring period come shortly after the fall mixing event, which was observed to have taken place around September 9th. Although chlorophyll concentrations in the Mid Lake, Middle Arm, Dam Site, and North Arm sites seemed to follow a similar pattern, chlorophyll A concentrations in the South Arm site peaked slightly earlier, especially in the 2008 season. This is most likely due to the relatively shallow depth of the south arm, and the drawdown of the hypolimnion, causing the south arm to become mixed at a much earlier date than the other two sites.

Figures 25, 26, 28, 29, and 30 also show that during the 2009 season, the spikes in chlorophyll A seemed to appear later in the year, have a longer duration, and for the South Arm and Mid Lake sites, a greater magnitude than those seen in 2008. It is unlikely that these bloom conditions were the result of nutrients imported from streams, as the volume of water entering the reservoir from the major tributaries is very small during the late summer to early fall months (Tetra Tech 2002). These observed increases in biovolume were likely the result of a longer season of anoxia in the hypolimnion and a prolonged period of mixing (see Figures 17 and 18). The combination of these conditions may have served to increase the amount of available nutrients from the sediments and lengthen the time of nutrient distribution throughout the water column.

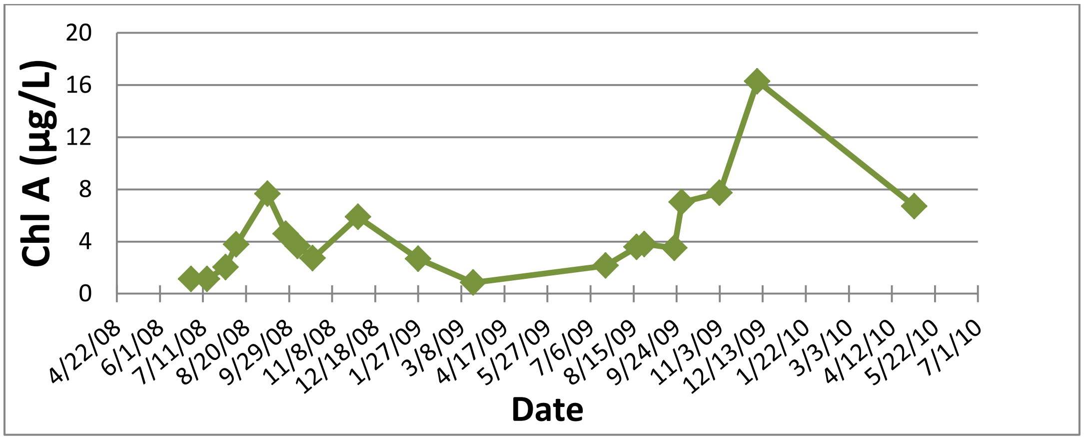

Figure 25. Mid Lake Site 381 chlorophyll A.

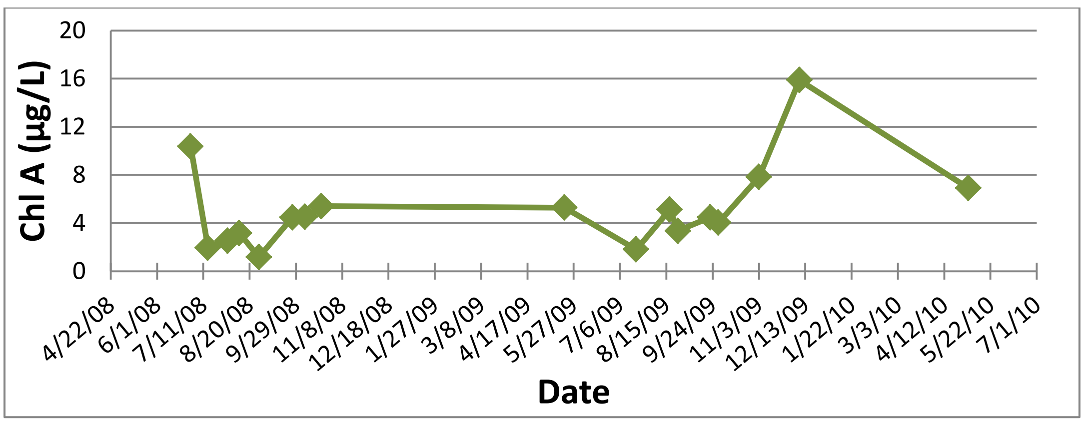

Figure 26. South Arm Site 382 chlorophyll A.

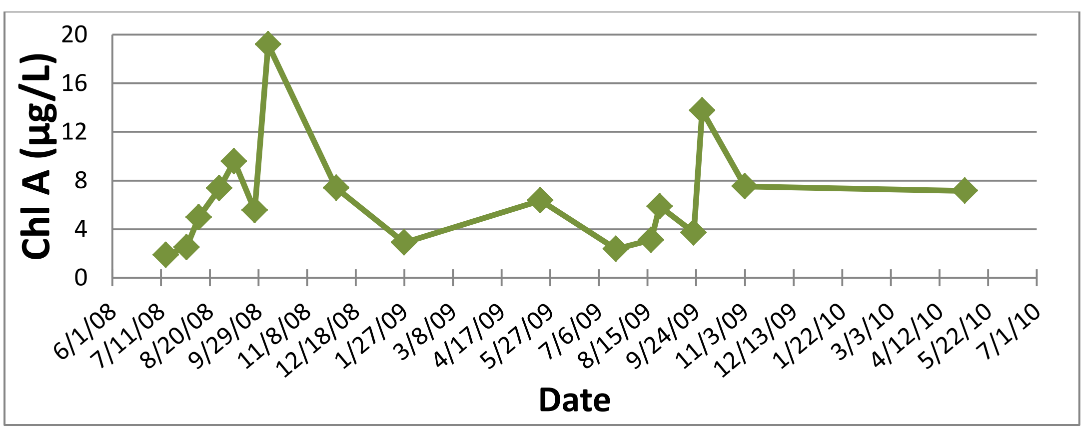

Figure 27. North Arm Site 384 chlorophyll A.

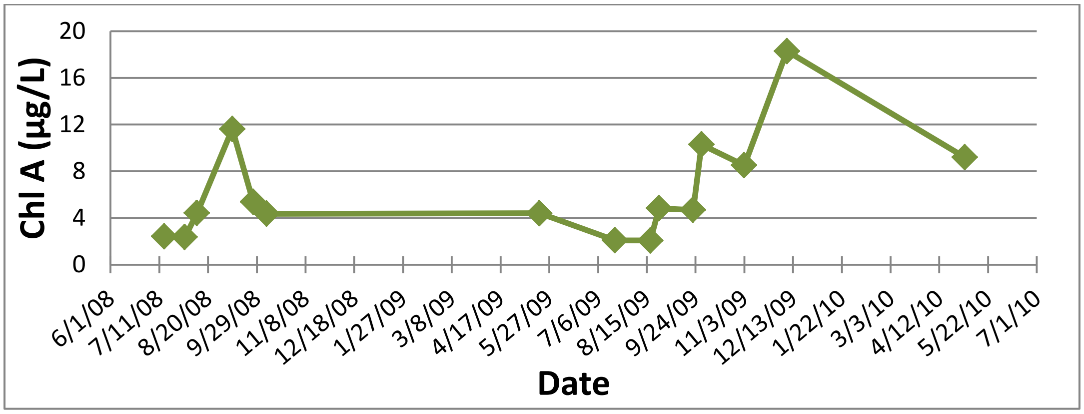

Figure 28. Middle Arm Site 383 chlorophyll A.

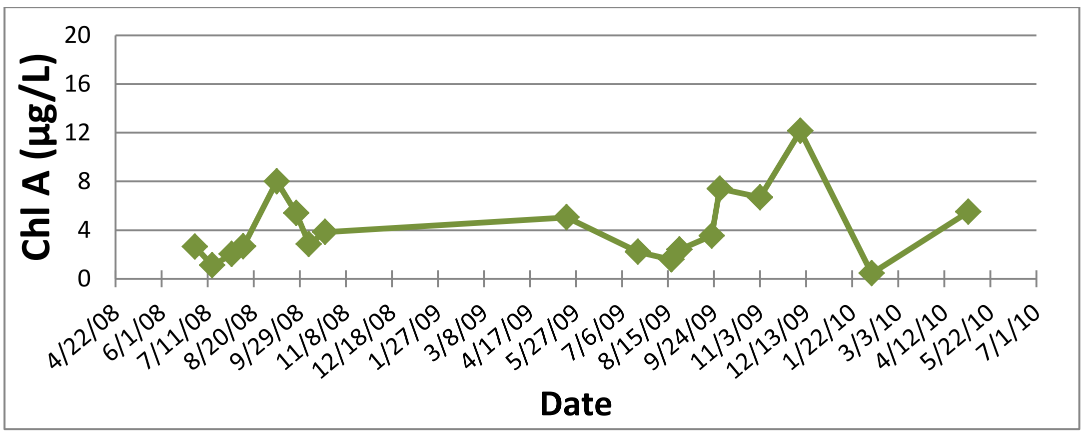

Figure 29. Dam Site 380 chlorophyll A.

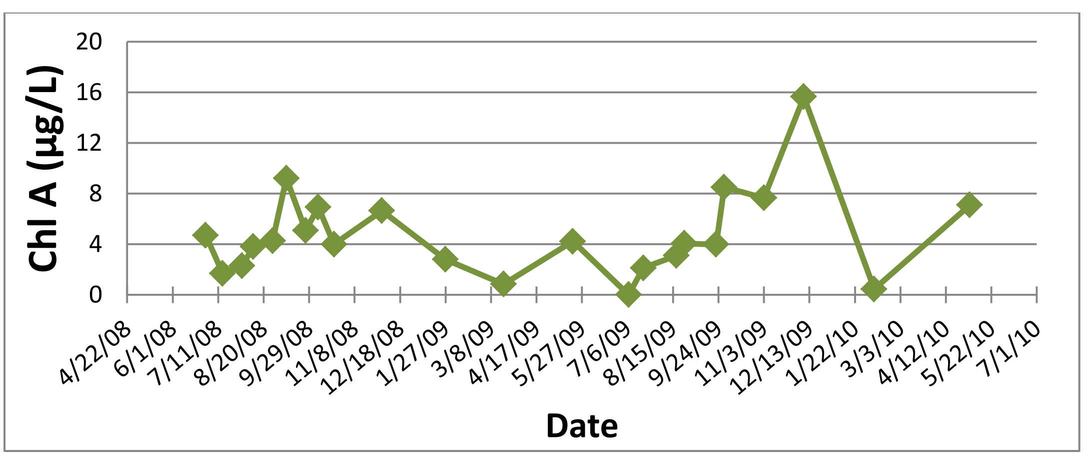

Figure 30. Average surface chlorophyll A.

One of the main questions asked by this study about these annual blooms was how the phytoplankton community in the reservoir changed before, during, and after bloom events. This information was especially useful to know for a number of reasons. One reason was to see if reservoir conditions during bloom periods tended to favor nitrogen fixing cyanobacteria. This is important information due to the abilities of cyanobacteria to produce cyanotoxins, and the taste and odor problems that can be associated with treating water that has large concentrations of cyanobacteria present. The relative abundance of these organisms can also help in determining which nutrient N or P is more limiting at any given time, as nitrogen fixers tend to thrive during times when P is available but N is in short supply (Zhang and Prepas 1995). Figures 31-33 show the contributions of different primary producers during average and bloom conditions as they were observed in Pineview Reservoir. These figures represent the average of what was observed at all five reservoir sites.

The algae that were the major contributors to the total algal biovolume were primarily diatoms, flagellates, dinoflagellates and green algae, with *Stephanodiscus*, *Mallomonas*, *Fragilaria*, and *Melosira* species dominating throughout most of the year. Two cyanobacterial genera, *Anabaena* and *Aphanizomenon* also made significant contributions to the overall biomass, but only during a short time after reservoir mixing events. These cyanobacteria are often organisms of concern as they may possess the ability to produce cyanotoxins and fix atmospheric nitrogen. By fixing nitrogen from the atmosphere, they create a source of nitrogen that is available for uptake by all surrounding plankton, potentially speeding the process of eutrophication within the system if phosphorus is available (Carpenter 2008).

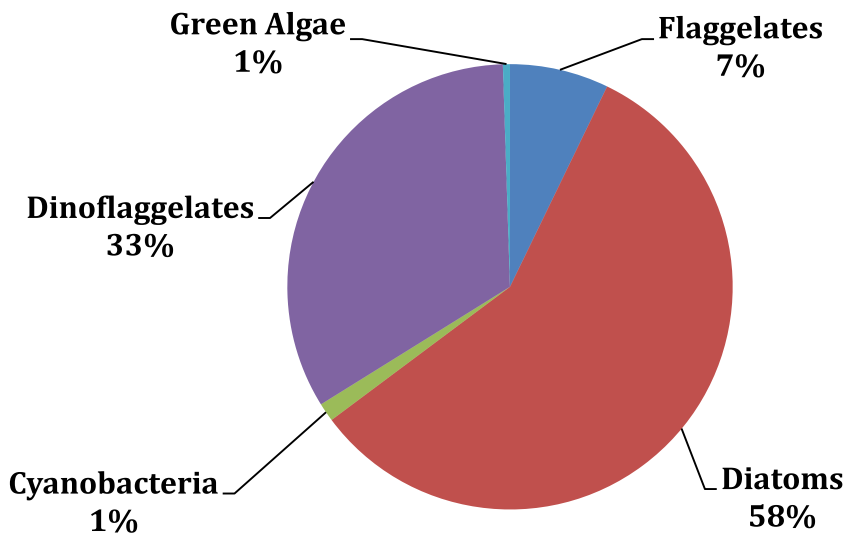

Figure 31. Percentage of total biovolume of primary producers during average reservoir conditions (6/2008-10/2010).

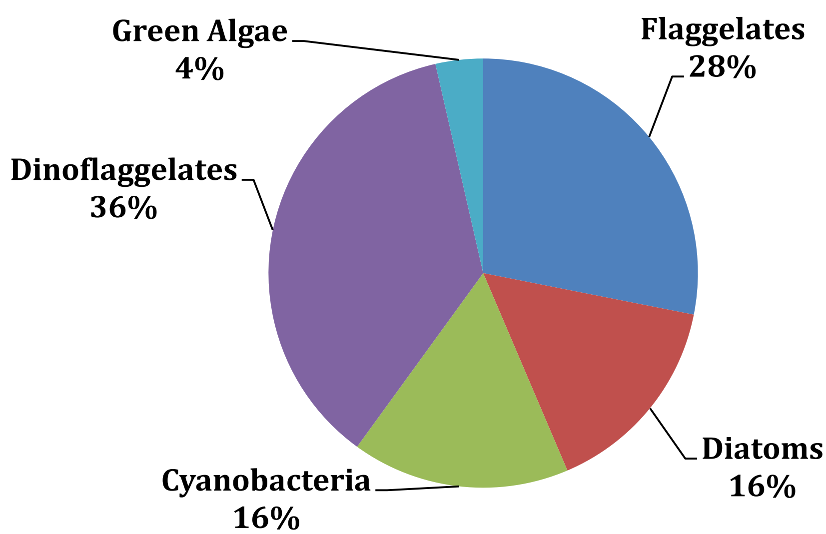

Figure 32. Percentage of total biovolume of primary producers during pre-bloom reservoir conditions (7/20/09).

During the peak of the bloom periods of 2008 and 2009, thin mats of cyanobacteria were visible on the surface of the water at different locations on the

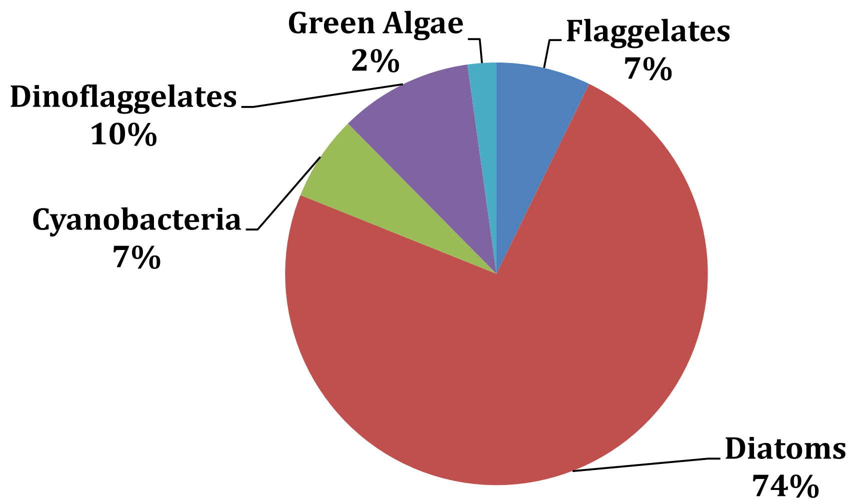

Figure 33. Percentage of total biovolume of primary producers during bloom conditions (9/22/09).

reservoir. This is due to the fact that many cyanobacteria, such as *Anabaena* and *Aphanizomenon* can create vacuoles enabling them to float. Since surface phytoplankton samples were consistently taken from approximately 10 cm below the actual water surface, during the two weeks in September of 2008 and 2009 when floating phytoplankton mats were observed, the full magnitude of cyanobacterial blooms may not have been completely manifested.

It can be seen in Figure 31 that diatoms and dinoflagellates made up the bulk of the algal biomass in the reservoir through most of the year. Even during bloom conditions cyanobacteria were never observed to exceed 16 % of the total biomass of primary producers. The almost year round dominance of diatoms in this system is a good indication that for most of the year the system is still not highly productive, as these types of algae generally seem to thrive in fairly low nutrient environments (Wehr and Sheath 2003). This dominance also suggests that nitrogen is not a limiting nutrient for much of the year, as one would expect to see a greater proportion of N-fixing cyanobacteria if nitrogen were indeed the primary limiting nutrient.

As a means of checking the co-limiting status of N and P that was stated in this study and the TMDL, some N/P ratios were calculated using N and P measurements from the surface waters at site 381. Using the N/P ratios from this study and the Redfield Ratio, some estimation of N or P limitation in Pineview Reservoir can be made. The Redfield Ratio suggests the need for a molar ratio of 106:16:1 of carbon, N and P respectively for the balanced, continual growth of phytoplankton (Redfield 1934). Assuming that bioavailable carbon is present in excess, (which is likely the case in a bicarbonate, carbonate buffered system such as Pineview) a 16:1 molar ratio of N to P is needed to ensure optimal growth. This means that any ratio >16 would indicate P limited system, while any ratio < 16 would be limited by N. The calculated N/P ratios can be seen in Table 8.

Based on the Redfield ratio, both N and P were limiting phytoplankton growth during different times of the sampling period. These findings match those of the TMDL which stated that phytoplankton growth in Pineview Reservoir was limited by both N and P (Tetra Tech 2002).

One thing that is apparent from the above figures and data is that although some form of a bloom in the late summer through fall can be expected each year and that the magnitude, duration and biota of these blooms can vary greatly from year to year. These factors are also likely related to the length of the anoxic period in the hypolimnion and the volume of hypolimnetic water in the reservoir prior to the fall mixing event.

Table 8. N/P Ratios

Date	NO_3-N	NH_4-N	TMN§	SRP	N/P
	(mmol/l)				
8/28/08	1.82		1.82	2.11	1
9/9/08	1.82		1.82	0.34	5
9/26/08	1.68		1.68	0.43	4
10/21/08	4.76	0.84	5.60	0.37	15
8/25/09	0.72	0.18	0.90	0.19	5
9/15/09	0.28	16.87	17.15	0.31	55
9/29/09	3.65		3.65	0.22	17
11/3/09	0.48		0.48	0.19	3
12/8/09	36.61		36.61	0.62	59
2/8/10	1.04		1.04	0.43	2
5/3/10	1.56	0.20	1.76	0.56	3

§ TMN = Total Mineral Nitrogen

CONCLUSIONS

It was hypothesized that many of the observations and recommendations made by the TMDL may have been based on insufficient information. This was indeed the case for several of the TMDL's findings. One major oversight that was discovered was the exclusion of Geertsen and Spring Creeks from the surface water flow and nutrient budgets, as these creeks were found to be responsible for up to 10% of the total surface water flow and 16 % of the total surface water N and P loads.

Another major oversight was the method used to predict flows in the North and Middle Forks of the Ogden River based on Flows measured by the South Fork USGS gauging station (10137500), due to the fact that the USGS gauging station is located up stream of a major irrigation diversion which artificially alters flow patterns in the South Fork between the months of May and October. It is therefore recommended that the flows of Geertsen and Spring Creeks be considered in any future water balance, and that greater consideration be taken as to the location of sampling points so that no diversions exist between the monitoring point and the reservoir. This approach would provide a clearer picture of actual flow and nutrient loadings to the reservoir.

Additionally, the TMDL assumed that internal P cycling within the reservoir was negligible. This too was found to be false as large increases in hypolimnetic P concentrations were observed both years of this study during times of anoxia in the hypolimnion (late summer).

It was also hypothesized that the internal cycling of N and P was the cause of the annually observed phytoplankton blooms in the reservoir and that Fe played a major role in the nutrient cycle. This was also found to be the case as increased P, reduced Fe and ammonium concentrations were observed in the hypolimnion prior to fall mixing. Increased Chlorophyll A concentrations were observed during and after reservoir mixing. This pattern indicates that nutrients, especially P, are coming out of the sediments into the water column, and that these nutrients are the driving force behind Pineview Reservoir's annually observed phytoplankton blooms. Increased concentrations of reduced Fe suggest that P and Fe are forming precipitates that are accumulating within the sediments. It is these precipitates that are being dissolved under anoxic conditions, producing reduced Fe and bioavailable P. Through sequential P extractions of reservoir sediments it was found that there is a large pool of P within the sediments that is currently available or could potentially be made available for transfer into the water column.

Another hypothesis was that the total biovolume and dominant species of phytoplankton communities in the reservoir would readily change along with changing conditions in the reservoir and that continued observation of phytoplankton communities would produce a better understanding of the reservoir's cycles, trophic status, and potential remediation techniques. This was indeed the case as increases in cyanobacteria were observed during and following the fall mixing events of 2008 and 2009, and the dominant phytoplankton species shifted during that time from diatoms to flagellates. Eutrophic conditions, based on Chlorophyll A concentrations, were observed in Pineview Reservoir during the months of September-October 2009, and September-December 2010. These findings showed that Pineview Reservoir trophic status only falls into the eutrophic range for a short period of each year during and after the fall mixing and that the magnitude, duration and biota of the phytoplankton community during that time can vary greatly from year to year.

Finally, it was hypothesized that N and P was entering the reservoir from both surface and ground water sources, that fixation of atmospheric N by cyanobacteria was a major source of bioavailable N in the reservoir and that P was accumulating in the reservoir, which was leading to increased primary production and trophic status. It was found that both surface and ground water sources were contributing significant fluxes of N and P to the reservoir. Cyanobacterial N fixation rates, however, were found to be below detectable limits. It was therefore concluded that atmospheric N contributions from N fixation by cyanobacteria were relatively low and that more sensitive procedures were needed to confidently measure it.

The P balance for Pineview Reservoir showed that P may not be building up within the reservoir, but due to the limited data available, especially data regarding ground water flow into the reservoir and P loads associated with those flows, it is difficult to say with confidence whether or not this is actually the case. A study of the area's ground water flows and nutrient concentrations is currently being conducted by the UWRL and will hopefully help to provide a clearer picture of actual ground water contributions to the reservoir. It was also found that large amounts of P were being exported from the reservoir, especially during the summer months when P from the benthic sediments is circulated back into the hypolimnetic water due to anaerobic conditions. By paying closer attention to conditions in the hypolimnion during periods of reservoir stratification and increasing reservoir discharges at the opportune times, greater amounts of nutrients can be exported from the reservoir helping to offset nutrient accumulations. Although application of this technique might be limited due to water rights issues, water availability, and down-stream impacts, it is definitely something that merits further investigation as it has the potential to produce great results with minimal effort as the infrastructure needed to carry it out already exists.

During this study, Pineview Reservoir was not suitable for supporting cold water fish species but, was a quality warm water fishery and recreational use water body. It was not highly eutrophic for most of the year and was meeting nearly all of its designated beneficial uses. The information gathered for this and other parallel studies is a useful tool for understanding the dynamics of Pineview Reservoir and its watershed, by providing a greater understanding of the greatest threats to the reservoir, and the best management practices to neutralize them.

ENGINEERING SIGNIFICANCE

One of the major applications of this study is to provide a more complete picture of the current trophic status of Pineview Reservoir. This study has helped to create a database of useful information about the reservoir, such as chlorophyll concentrations, algal types and diversity, temperature profiles and trends, updated bathymetry and depth capacity curves and nutrient dynamics. All of this information is vital in ascertaining Pineview's current state and rate of eutrophication.

This report and the data used to make it could potentially be of great value in the planning, zoning and design of any future systems designed to help prevent nutrients from entering the reservoir. These systems could include, but are not limited to, centralized sewage treatment systems with nutrient removal capacity, pressurized sprinkler irrigation systems etc.

This study also helped to identify oversights in previous studies, especially in the area of stream flow monitoring, and determining actual surface water loads that are reaching the reservoir through the three forks of the Ogden River and other significant tributaries not previously considered by said studies. This information will encourage future studies to reconsider data collection points, the inclusion of Geertsen Creek and Spring Creek in reservoir water and nutrient budgets, and more accurately use data collected by the Ogden Valley's lone operational USGS gauging station above the irrigation diversion on the South Fork of the Ogden River.

It was also confirmed that shallow ground water entering Pineview Reservoir is likely one of the most significant contributors of nutrients to the reservoir. This information further emphasizes the need to gather more data about the Ogden Valley's shallow aquifer system, in order to better estimate the actual loading of nutrients to the reservoir due to ground water, and the likely sources of these nutrients whether they be natural or anthropogenic. Having this information will be invaluable in determining the potential effectiveness of water quality improvement projects that are being considered for the valley, such as a centralized wastewater treatment system with nutrient removal capability and expanded pressurized sprinkler irrigation.

All of the information gathered during this study will also provide a useful benchmark with which to measure the effectiveness of any future water quality improving measures that may be taken.

PROPOSED FUTURE WORK

One of the most important pieces of information that will be necessary in the future to provide a more holistic picture of the nutrient flow and balance of the Pineview Reservoir system is more data regarding flows and nutrient concentrations within Ogden Valley's shallow aquifer. A study is currently being undertaken to determine this information by Thomas Ruben at the Utah Water Research Laboratory at Utah State University. This study is using a series of shallow monitoring wells placed strategically around the reservoir to look at shallow ground water levels, flow patterns and nutrient concentrations among other things to produce a viable estimate of nutrient loadings to Pineview Reservoir from the Ogden Valley's shallow aquifer system.

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APPENDIX

Table A-1. Chlorophyll A concentrations (µg/L)

	380		381		382		383		384	
	Surf.	Int.	Surf.	Int.	Surf.	Int.	Surf.	Int.	Surf.	Int.
6/30/2008	2.77	-	0.60	-	10.55	-	0.6	-	0.6	-
7/15/2008	1.80	-	1.80	-	1.80	-	1.80	-	1.80	-
8/1/2008	1.80	-	2.68	-	1.80	-	1.80	-	1.80	-
8/11/2008	1.80	-	1.60	1.78	1.80	1.80	1.80	-	1.75	-
8/28/2008	1.40	1.40	1.40	-	0.80	0.00	0.00	3.16	1.80	1.30
9/9/2008	0.00	1.35	7.74	1.50	0.00	1.40	1.90	1.50	1.55	1.45
9/26/2008	1.80	1.40	4.50	1.80	1.20	1.00	1.45	1.55	1.80	1.25
10/7/2008	1.15	1.05	0.90	2.94	1.20	1.10	1.80	1.35	0.45	1.10
10/21/2008	1.80	1.55	1.40	4.50	5.80	0.00	0.00	0.00	0.00	0.00
12/2/2008	-	-	1.50	1.50	-	-	-	-	1.20	-
1/27/2009	-	-	1.80	-	-	-	-	-	1.80	-
3/19/2009	-	-	2.00	-	-	-	-	-	-	-
5/19/2009	1.40	1.40	1.40	1.60	1.80	1.80	1.60	1.80	6.25	1.70
7/7/2009	-	2.04	-	2.70	-	3.02	-	2.91	-	3.01
7/20/2009	2.29	2.74	2.11	2.54	1.90	2.87	2.19	3.60	2.37	3.56
8/18/2009	3.17	3.19	3.64	3.81	5.36	6.36	2.08	9.09	3.17	0.00
8/25/2009	2.37	2.51	3.97	2.50	3.39	4.33	4.86	5.81	5.97	9.89
9/22/2009	3.64	4.22	3.53	0.00	4.48	5.78	4.79	6.63	3.67	7.24
9/29/2009	7.59	9.34	7.01	9.22	4.07	7.80	10.10	8.98	14.34	10.27
11/3/2009	6.56	6.89	7.77	8.42	7.87	11.16	8.63	14.02	7.81	12.27
12/8/2009	12.14	-	16.29	-	15.88	-	18.30	-	-	-
2/8/2010	0.90	-	-	-	-	-	-	-	-	-
5/3/2010	5.50	5.27	6.71	7.06	6.91	8.52	9.19	9.19	7.16	6.48

Surf. = Surface
Int. = Integrated

Table A-2. Algae biovolume estimates from surface samples (mm^3 algae/m^3)

	Flagellates	Diatoms	Cyanobacteria	Dinoflaggelates	Green Algae	Totals
6/30/2008	12541	1047	0	82	14	13684
7/15/2008	2228	610	0	302	6	3146
7/29/2008	3274	2557	370	247	105	6554
8/11/2008	5936	3044	1562	1079	208	11829
8/28/2008	3432	1828	1099	65203	0	71562
9/9/2008	130	250492	1261	136724	77	388684
9/26/2008	1338	14036	723	2227	3	18327
10/7/2008	1370	6406	54	1586	0	9416
10/21/2008	264	5117	391	412	352	6537
12/2/2008	123	9473	0	0	0	9596
1/27/2009	44	1927	0	0	1	1973
3/19/2009	111	140	0	74	1	327
5/19/2009	176	1208	0	149	3	1536
7/20/2009	1467	808	857	1902	187	5221
8/18/2009	1692	6145	899	3909	302	12947
8/25/2009	405	1984	120	8719	283	11511
9/22/2009	1705	17411	1537	2407	519	23579
9/29/2009	2214	35118	313	11439	540	49623
11/3/2009	12830	37696	270	297	1058	52151
12/8/2009	63	14598	198	1486	0	16345

Table A-3. Hypolimnetic nutrient and DO data for Pineview Reservoir Site 380

Date	TP (µg/L)	SRP (µg/L)	NH4-N (µg/L)	NO3-N (µg/L)	DO (mg/L)	Iron (µg/L)
5/20/2008		7			7.24	
5/28/2008		7			6.92	
6/9/2008		6			7.51	
6/18/08	46		n/d			
6/23/08		5			4.99	
6/30/08	32	4	n/d	440	3.78	
7/15/08	28	2	70	410	2.63	
8/1/08	33	1	n/d	410	5.64	
8/11/08	30	0	40	400	0.19	727
8/28/08	146	3	80	280	0.13	2923
9/9/08	78	5	n/d	170	0.14	1306
9/26/08	45	6	n/d	120	4.63	6580
10/7/08	29	7	70	160	5.12	
10/21/08	27		50	100	6.8	
5/19/09	92	7	n/d	320	6.76	
7/7/09	12	2	n/d	369	1.76	
7/20/09		1	n/d	368	0.69	
8/18/09	118	0	76		0.33	
8/25/09	265	0	134	46	0.31	
9/22/09	285	4	n/d		4.82	
9/29/09	22	4	n/d		5.64	
11/3/09	24	8	n/d	33	8.4	
12/8/09	33	10	n/d	31	9.62	
2/8/10	33		n/d	471	8.49	
5/3/10	21	9	14	163	7.06	

Iron = dissolved iron

Table A-4. Hypolimnetic nutrient and DO data for Pineview Reservoir Site 381

Date	TP (µg/L)	SRP (µg/L)	NH4-N (µg/L)	NO3-N (µg/L)	DO (mg/L)	Iron (µg/L)
5/20/08				471	7.24	
6/18/08	41					
6/30/08	34		50	468	3.51	
7/15/08	42	15	25	410	1.76	
8/1/08	80		90	345	0.22	640
8/11/08	80		25	283	0.15	1590
8/28/08	203	11	220	144	0.13	1900
9/9/08	216	15	110	141	0.26	1780
9/26/08	69	16	60	145	2.31	90
10/7/08	66	14	30	142	6.10	
10/21/08	68	15	40	130	6.00	
12/2/08	28		70	100	8.36	
1/27/09	23		n/d	100	7.46	
3/19/09	147		n/d	350	4.58	
5/19/09	75		n/d	314	6.39	
7/7/09	37		n/d	312	0.67	
7/20/09			n/d	265	0.28	840
8/18/09	172			122	0.11	1400
8/25/09	173	16	18	115	0.14	
9/15/09	279	17	113	129	0.28	2740
9/22/09	132	13		100	1.43	2470
9/29/09	47	8	25	101	5.28	
11/3/09	27	6		102	8.54	
12/8/09	22	18		73	9.87	
2/8/10	35.4	15		213	5.56	
5/3/10	27	16	36	241	5.33	

Iron = dissolved iron

Table A-5. Hypolimnetic nutrient and DO data for Pineview Reservoir Site 382

Date	TP (µg/L)	SRP (µg/L)	NH4-N (µg/L)	NO3-N (µg/L)	DO (mg/L)	Iron (µg/L)
5/20/08		10	n/d	327	7.94	
6/18/08	31		n/d		6.65	
6/30/08	34	10	130	347	5.20	
7/15/08	34	10	50	320	3.94	
8/1/08	23	13	25	193	1.23	1121
8/11/08	18	10	25	154	4.31	209
8/28/08	43	10	50	100	6.49	388
9/9/08	30	11	n/d	144	5.77	280
9/26/08	46	13	30	141	7.79	524
10/7/08	38	16	n/d		7.00	
5/19/09	19	10	25	210	7.09	
7/7/09	5		25	139	2.71	
7/20/09			63	266	1.75	
8/18/09	48		25	115	3.65	
8/25/09	83	10	25	15	4.20	
9/22/09	36	10	25	102	7.23	
9/29/09	27	10	25	100	5.41	
11/3/09	36	10	n/d	100	9.23	
12/8/09	31	20	n/d	19	10.31	
5/3/10	29	49	21	97	9.18	

Iron = dissolved iron

Table A-6. Hypolimnetic nutrient and DO data for Pineview Reservoir Site 383

Date	TP (µg/L)	SRP (µg/L)	NH4-N (µg/L)	NO3-N (µg/L)	DO (mg/L)	Iron (µg/L)
5/20/2008		10			7.14	
5/28/2008					7.09	
6/9/2008					5.87	
6/23/2008					4.80	
6/30/08	40	10	n/d	380	4.44	
7/15/08	31	10	170	430	2.44	
8/1/08	62	10	30	310	0.71	698
8/11/08	61	17	50	180	0.11	1030
8/28/08	46	10	n/d	200	3.39	514
9/9/08	55	12	n/d	160	5.04	588
9/26/08		12	n/d	140	5.64	759
10/7/08	223	14	n/d	180	7.00	
5/19/09	240	10	n/d	330	7.03	
7/7/09			n/d	300	1.56	
7/20/09			46.8	282	0.51	
8/18/09	70		72.9		0.12	
8/25/09	175	18	75.3	48.2	0.22	
9/15/09	57	21	n/d	5	0.53	32
9/22/09					4.15	
9/29/09	29	10	n/d		3.99	
11/3/09	44	10	n/d		8.37	
12/8/09	33	18	n/d	174	10.3	
5/3/10	200	13	6.4	129	8.74	

Iron = dissolved iron

Table A-7. Hypolimnetic nutrient and DO data for Pineview Reservoir Site 384

Date	TP (µg/L)	SRP (µg/L)	NH4-N (µg/L)	NO3-N (µg/L)	DO (mg/L)	Iron (µg/L)
6/18/08	29				4.61	
6/30/08	58	10	n/d	424	4.64	
7/15/08	25	10	40	362	2.91	
8/1/08	9	10	n/d	389	0.91	994
8/11/08	48	10	n/d	343	0.36	1315
8/28/08	48	11	40	138	5.73	982
9/9/08	43	11	n/d	139	3.69	494
9/26/08	42	12	30	139	6.08	562
10/7/08	30	12	40	143	6.99	
12/2/08	29		n/d	100	8.97	
1/27/09	20		n/d	100	8.97	
5/19/09	127	10	n/d	288	6.90	
7/7/09	14		n/d	326	2.06	
7/20/09			n/d	313	1.05	
8/18/09	26		n/d	115	0.62	
8/25/09	98	10	n/d	116	1.12	
9/15/09	29	12	n/d	134	6.27	
9/22/09	59	10		104	5.90	
9/29/09	26	10	n/d	101	5.33	
11/3/09	28	10		100	9.42	
5/3/10	27	23	37	148	7.32	

Iron = dissolved iron

Table A-8. Nitrogen fixation (measurements represent the % of acetylene in each sample or blank that was reduced to ethene during incubation in the reservoir)

sample (site)	Ethene (%)
blank	1.67E-04
blank	1.67E-04
blank	1.60E-04
381	1.42E-04
381	1.01E-04
383	2.05E-04
383	1.94E-04
383	1.58E-04
383	1.76E-04
384	1.66E-04
384	1.96E-04
384	1.94E-04
384	2.00E-04

Table A-9. Nitrogen fixation method check (measurements represent the % of acetylene in each control sample containing anabaena or blank that was reduced to ethene during incubation outdoors near the UWRL)

Sample	**Ethene**
	(%)
blank	5.32E-04
blank	4.83E-04
blank	4.59E-04
Control	7.22E-04
Control	5.99E-04
Control	5.87E-04
Control	6.99E-04
Control	5.48E-04
Control	5.84E-04

Table A-10. Sediment/water fractionation and porosity of benthic sediment samples

Sample	water in sediment	Dry sediment	particle density	porosity
(site)	(g)	(g)	(g/cm^3)	(Φ)
383	7.3042	3.0921	2.66	0.78
383-A	6.2042	2.1218	2.66	0.84
381	5.3805	1.5036	2.66	0.87

Table A-11. Pore and hypolimnetic water SRP concentrations used to calculate P Flux rates from the sediments, measured on 9/15/2009

	Pore water SRP	Hypo. SRP	Bkgrnd. SRP	Cor. Hypo. SRP
	(μg P/L)	(μg P/L)	(μg P/L)	(μg P/L)
383	2658	210	100	110
383-A	2218	170	100	70
381	889	170	100	70
average	1922	183	100	83

Hypo. = hypolimnetic
Bkgrnd. = background water column
Cor. Hypo. = Corrected hypolimnetic

Table A-12. Pineview benthic sediment soil texture analysis

site	Sand	Silt	Clay	Texture
	----------------%------------------			
381	1	42	57	Silty Clay
383-A	0	47	53	Silty Clay
383	0	69	31	Silty Clay Loam

Table A-13. Geertsen Creek flow and nutrient data

Date	flow m^3/Day	µg TP/L	µg SRP/L	mg NH4-N/L	mg NO3-N/L
5/9/08	35165				
5/23/08	36405				
6/13/08	927				
8/7/08	13285				
9/5/08	12380				
9/19/08	13402				
10/16/08	7296				
4/7/09		67.0		n/d	0.18
4/15/09	57739	104.0	13.0	n/d	0.12
4/28/09	43304	36.0	n/d	n/d	0.12
5/12/09		12.0	n/d	n/d	0.12
6/9/09	1084	40.0		n/d	0.23
10/13/09	3587		11.0	n/d	0.78
3/29/10	18349	107.6	13.0	n/d	
4/13/10	32148	132.6	9.8	n/d	0.33

Table A-14. Spring Creek flow and nutrient data

Date	flow m^3/Day	µg TP/L	µg SRP/L	mg NH4-N/L	mg NO3-N/L
5/9/08	24906				
5/23/08	37482				
6/13/08	47782				
6/27/08	31561				
7/11/08	20674	16.8			
7/25/08	20380	21.6			
8/7/08	35377				
9/5/08	33176				
9/19/08	44175				
10/16/08	23154				
4/7/09		50.0		n/d	0.39
4/15/09	32931	84.0	19.0	n/d	0.32
4/28/09	34252	98.0	17.0	0.026	0.34
5/12/09		79.0	15.0	n/d	1.34
6/9/09	44136			n/d	0.69
7/14/09	34521	25.0	12.0	n/d	0.71
8/11/09	36530	36.0			
10/13/09	25689		13.0	n/d	0.41
3/15/10	30081	168.6	20.0	0.065	0.37
3/29/10	15267	45.6	11.0	n/d	0.55
4/5/10	40271	255.6	21.0	n/d	0.38
4/13/10	35500	158.6	17.0	n/d	0.30
4/19/10	25004	57.6	12.0	n/d	0.29
4/27/10	28356	630.4	7.0		0.00
5/4/10	16661	39.0	10.0	n/d	0.36
5/11/10	23389	124.0		n/d	0.36
5/25/10	29212	75.0	12.0	n/d	0.21
6/1/10	42252	71.0	12.0	n/d	0.17
6/8/10	31854	49.0	11.0	n/d	0.16
6/22/10	38338	49.0	49.0	n/d	0.16
6/29/10	30974	106.0	16.0	n/d	0.05

Table A-15. South branch of the South Fork Ogden River flow and nutrient data

Date	flow m^3/Day	µg TP/L	µg SRP/L	mg NH4-N/L	mg NO3-N/L
5/9/08	1039795				
5/23/08	604304				
6/10/08			n/d		
6/13/08	168814				
6/23/08			n/d		
6/27/08	53091				
7/8/08			15.0		
7/11/08	25738	22.0			
7/21/08			n/d		
7/25/08	21775	22.0			
8/5/08			15.0		
8/7/08	36283	22.0			
8/19/08			16.0		
9/2/08			31.0		
9/5/08	13750	33.0			
9/16/08			28.0		
9/19/08	15399	29.0			
9/30/08			27.0		
10/13/08			28.0		
10/16/08	20615	27.0			
2/10/09	34228				
2/18/09	36258				
2/23/09	25420				
3/2/09	29775				
3/15/09	52552				
4/7/09		106.0		n/d	0.26
4/15/09	408089	88.0	12.0	n/d	0.18
4/28/09	489315	57.0	13.0	n/d	0.24
5/12/09		37.0	11.0	n/d	0.18
6/9/09	114877			n/d	0.35
7/14/09	53732	24.0	29.0	n/d	0.27
8/11/09	33024				
10/13/09	22122		19.0	n/d	0.14
12/1/09	34228				
1/25/10		17.4	1.0	0.1901	0.47
2/10/10	34228	23.4	6.0	n/d	0.28

Date	flow m^3/Day	µg TP/L	µg SRP/L	mg NH4-N/L	mg NO3-N/L
2/18/10	36258				
2/23/10	25420	19.4	8.0	n/d	0.20
3/2/10	29775	22.4	6.0	n/d	0.18
3/15/10	52552	28.6	11.0	0.0243	0.22
3/29/10	50008	18.6	11.0	n/d	0.42
4/5/10	75306	48.6	15.0		0.28
4/13/10	163480	99.6	19.8	n/d	0.38
4/19/10	217378	62.6	10.7	n/d	0.15
4/27/10	302152	57.6	8.3		0.00
5/4/10	184716	26.0	7.4	n/d	0.09
5/11/10	191298	34.0		n/d	0.06
5/25/10	307583	33.0	10.1	n/d	0.14
6/1/10	304917	32.0	7.4	n/d	0.17
6/8/10	190246	23.0	6.0	n/d	0.25
6/22/10	83257	23.0	2.9	n/d	0.28
6/29/10	50302	17.0	7.9	n/d	0.35

Table A-16. North branch of the South Fork Ogden River flow and nutrient data

Date	flow m^3/Day	µg TP/L	µg SRP/L	mg NH4-N/L	mg NO3-N/L
5/9/08	1355819				
5/23/08	883214				
6/13/08	177181				
6/27/08	33763				
7/11/08	21016	33.0			
7/25/08	21775				
8/7/08	36283				
9/5/08	13750				
9/19/08	15399				
10/16/08	6501				
12/1/08	13334				
2/10/09	13334				
2/23/09	10716				
3/2/09	13603				
3/15/09	26399				
4/15/09	297993	48.0	6.0	n/d	0.20
4/28/09	366986	44.0	11.0	n/d	0.20
5/12/09		262.0	10.0	n/d	0.19
6/9/09	101036	50.0		n/d	0.28
7/14/09	27042		13.0	n/d	0.32
8/11/09	17735	18.0			
10/13/09	6060		14.0	n/d	0.21
12/1/09	13334				
1/25/10		16.4	8.0	0.217	0.35
2/10/10	13334	19.4	10.0	n/d	0.19
2/23/10	10716	17.4	8.0	n/d	0.15
3/2/10	13603	28.4	10.0	n/d	0.16
3/15/10	26399	32.6	14.8	n/d	0.24
3/29/10	28209	16.6	9.3	n/d	0.40
4/5/10	36503	16.6	8.8	n/d	0.21
4/13/10	93582	33.6	6.0	n/d	0.17
4/19/10	150073	36.6	4.0	n/d	0.11
4/27/10	217721	37.6	5.0		0.00
5/4/10	132971	21.0	3.1	n/d	0.07
5/11/10	127785	19.0		n/d	0.05
5/25/10	249698	21.0	5.1	n/d	0.13

Date	flow m^3/Day	µg TP/L	µg SRP/L	mg NH4-N/L	mg NO3-N/L
6/1/10	240719	21.0	3.8	n/d	0.11
6/8/10	162086	17.0	2.4	n/d	0.17
6/22/10	44601	17.0	3.3	n/d	1.88
6/29/10	20233	10.0	3.3	n/d	0.16

Table A-17. Middle Fork Ogden River flow and nutrient data

Date	flow m^3/Day	µg TP/L	µg SRP/L	mg NH4-N/L	mg NO3-N/L
5/9/08	865109				
5/23/08	562712				
6/10/08			6.0		
6/13/08	55293				
6/23/08			6.4		
6/27/08	9321				
7/8/08			6.7		
7/11/08	2814	22.0			
7/21/08			7.1		
7/25/08	700	22.0			
8/5/08			10.0		
8/7/08	1730				
8/19/08			12.0		
9/2/08			12.0		
9/5/08	568	6.0			
9/16/08			12.0		
9/19/08	7555	8.0			
9/30/08		8.0	15.0		
10/13/08			13.0		
10/16/08	10207	6.0			
12/1/08	563				
2/23/09	563				
3/2/09	1713				
3/15/09	5064				
4/7/09		19.0		n/d	0.003
4/15/09	319523	80.0	5.0		
4/28/09	344967	29.0	10.0	n/d	0.110
5/12/09	398792	6.0	10.0	0.028	0.003
6/9/09	69030	16.0		n/d	0.020
7/14/09	7129	14.0	8.0	n/d	0.003
8/11/09	2317	11.0			
10/13/09	25841		6.0	n/d	0.048
12/1/09	563				
1/25/10		20.4	4.3	0.211	0.169
2/23/10	563	10.4	4.3	0.456	0.027
3/2/10	1713	8.4	3.3	0.011	0.048

Date	flow m^3/Day	µg TP/L	µg SRP/L	mg NH4-N/L	mg NO3-N/L
3/15/10	5064	16.6	5.2	0.018	0.077
3/29/10	14826	14.6	3.6	n/d	0.153
4/5/10	15340	12.6	3.1	n/d	0.003
4/13/10	108310	46.6	5.0	n/d	0.007
4/19/10	335230	51.6	6.9	n/d	0.065
4/27/10	352600	38.6	5.5		0.003
5/4/10	187065	27.0	4.0	n/d	0.011
5/11/10	264211	21.0		n/d	0.003
5/25/10	208915	23.0	4.7	n/d	0.003
6/1/10	222566	21.0	2.9	n/d	0.011
6/8/10	89942	21.0	2.9	n/d	0.018
6/22/10	32199	21.0	2.9	n/d	0.009
6/29/10	5722	11.0	5.1	n/d	0.037

Table A-18. North Fork Ogden River flow and nutrient data

Date	flow m^3/Day	µg TP/L	mg SRP/L	mg NH4-N/L	mg NO3-N/L
5/9/08	1156007				
5/23/08	349860				
6/10/08			10.0		
6/13/08	209745				
6/23/08			6.2		
6/27/08	67599				
7/8/08			6.6		
7/11/08	10300	122.0			
7/21/08			7.0		
7/25/08	4282	122.0			
8/5/08			10.0		
8/7/08	3156	41.0			
8/19/08			10.0		
9/2/08			11.0		
9/5/08	1492	7.0			
9/16/08			12.0		
9/19/08	878	12.0			
9/30/08		7.0	14.0		
10/13/08			12.0		
10/16/08	46	14.0			
12/1/08	3939				
2/23/09	3939				
3/2/09	6043				
3/15/09	16881				
4/7/09		21.0		n/d	0.88
4/14/09	797584	347.0		n/d	0.63
4/15/09			8.0		
4/28/09	687488	32.0	10.0	n/d	0.60
5/12/09	577392		10.0	n/d	0.43
6/9/09	733973	25.0		0.1529	0.41
7/14/09	25557	10.0	9.0	n/d	0.54
8/11/09	3741	37.0			
10/13/09	2765		6.0	n/d	0.43
12/1/09	3939				
1/25/10			4.3	0.2071	1.04
2/23/10	3939	11.4	4.3	n/d	0.81

Date	flow m^3/Day	µg TP/L	mg SRP/L	mg NH4-N/L	mg NO3-N/L
3/2/10	6043	11.4	3.3	n/d	0.88
3/15/10	16881	12.6	3.3	n/d	0.60
3/29/10	80688	16.6	2.1	n/d	1.31
4/5/10	105521	14.6	2.1	n/d	0.98
4/13/10	311131	71.6	6.4	n/d	0.72
4/19/10	460176	58.6	6.4	n/d	0.55
4/27/10	378608	42.6	6.9		n/d
5/4/10	239414	21.0	3.6	n/d	0.52
5/11/10	329616	41.0		n/d	0.43
5/25/10	166753	31.0	6.0	n/d	0.35
6/1/10	272506	35.0	7.0	n/d	0.30
6/8/10	358819	33.0	3.8	n/d	0.26
6/22/10	120686	33.0	2.9	n/d	0.35
6/29/10	29112	12.0	4.7	0.0467	0.30

Table A-19. Precipitation measured by weather station near Pineview Dam

Date	Precip. (cm)	Date	Precip. (cm)	Date	Precip. (cm)
4/15/2009	2.2098	5/20/2009	0.127	6/24/2009	0
4/16/2009	1.143	5/21/2009	0.0127	6/25/2009	0
4/17/2009	0.0762	5/22/2009	0	6/26/2009	0.127
4/18/2009	0	5/23/2009	0	6/27/2009	0.508
4/19/2009	0	5/24/2009	0.0762	6/28/2009	0
4/20/2009	0	5/25/2009	0.3048	6/29/2009	0
4/21/2009	0	5/26/2009	0.127	6/30/2009	0
4/22/2009	0	5/27/2009	0.0508	7/1/2009	0.0127
4/23/2009	0	5/28/2009	0	7/2/2009	0.2032
4/24/2009	0	5/29/2009	0	7/3/2009	0.8128
4/25/2009	1.0922	5/30/2009	0	7/4/2009	0
4/26/2009	0.0762	5/31/2009	0.254	7/5/2009	0
4/27/2009	0	6/1/2009	0.0254	7/6/2009	0
4/28/2009	0	6/2/2009	1.4732	7/7/2009	0
4/29/2009	0.254	6/3/2009	0.762	7/8/2009	0
4/30/2009	0	6/4/2009	0	7/9/2009	0
5/1/2009	0.3048	6/5/2009	0	7/10/2009	0
5/2/2009	0.8636	6/6/2009	0.4318	7/11/2009	0
5/3/2009	1.9304	6/7/2009	0.7874	7/12/2009	0
5/4/2009	0.9144	6/8/2009	2.5146	7/13/2009	0.0254
5/5/2009	0.0762	6/9/2009	0.4318	7/14/2009	0
5/6/2009	0.0254	6/10/2009	0.5842	7/15/2009	0
5/7/2009	0	6/11/2009	2.3114	7/16/2009	0
5/8/2009	0	6/12/2009	0.508	7/17/2009	0
5/9/2009	0	6/13/2009	0.254	7/18/2009	0
5/10/2009	0	6/14/2009	0.6604	7/19/2009	0
5/11/2009	0	6/15/2009	0.0762	7/20/2009	0.0254
5/12/2009	0	6/16/2009	0	7/21/2009	0
5/13/2009	0	6/17/2009	0.0254	7/22/2009	0
5/14/2009	0	6/18/2009	1.6002	7/23/2009	0
5/15/2009	0.2032	6/19/2009	1.8288	7/24/2009	0
5/16/2009	0	6/20/2009	0	7/25/2009	0.0254
5/17/2009	0	6/21/2009	1.3208	7/26/2009	0
5/18/2009	0	6/22/2009	0.381	7/27/2009	0
5/19/2009	0	6/23/2009	0	7/28/2009	0

Date	Precip. (cm)	Date	Precip. (cm)	Date	Precip. (cm)
7/29/2009	0	9/3/2009	0	10/9/2009	0
7/30/2009	0	9/4/2009	0	10/10/2009	0
7/31/2009	0	9/5/2009	0	10/11/2009	0.1524
8/1/2009	0	9/6/2009	0	10/12/2009	0
8/2/2009	0	9/7/2009	0	10/13/2009	0.4318
8/3/2009	0	9/8/2009	0	10/14/2009	1.4732
8/4/2009	0	9/9/2009	0	10/15/2009	0.2286
8/5/2009	0	9/10/2009	0	10/16/2009	0
8/6/2009	0.0254	9/11/2009	0	10/17/2009	0
8/7/2009	0	9/12/2009	0	10/18/2009	0
8/8/2009	0	9/13/2009	0	10/19/2009	0.0127
8/9/2009	0	9/14/2009	0.0508	10/20/2009	2.032
8/10/2009	0	9/15/2009	0.8636	10/21/2009	0.1016
8/11/2009	0	9/16/2009	0	10/22/2009	0
8/12/2009	0	9/17/2009	0	10/23/2009	0
8/13/2009	0	9/18/2009	0	10/24/2009	0.2794
8/14/2009	0	9/19/2009	0	10/25/2009	0.0127
8/15/2009	0.762	9/20/2009	0.254	10/26/2009	0
8/16/2009	0	9/21/2009	0	10/27/2009	0.4572
8/17/2009	0	9/22/2009	0	10/28/2009	0.5334
8/18/2009	0	9/23/2009	0	10/29/2009	0.0508
8/19/2009	0	9/24/2009	0	10/30/2009	0.1016
8/20/2009	0	9/25/2009	0	10/31/2009	0.0254
8/21/2009	0	9/26/2009	0	11/1/2009	0
8/22/2009	0	9/27/2009	0	11/2/2009	0
8/23/2009	0.0762	9/28/2009	0	11/3/2009	0
8/24/2009	1.905	9/29/2009	0	11/4/2009	0
8/25/2009	0	9/30/2009	0	11/5/2009	0
8/26/2009	0	10/1/2009	1.8034	11/6/2009	0
8/27/2009	0	10/2/2009	0	11/7/2009	0
8/28/2009	0	10/3/2009	0	11/8/2009	0
8/29/2009	0	10/4/2009	0.127	11/9/2009	0
8/30/2009	0	10/5/2009	2.7178	11/10/2009	0
8/31/2009	0	10/6/2009	0.381	11/11/2009	0
9/1/2009	0	10/7/2009	0	11/12/2009	0
9/2/2009	0	10/8/2009	0	11/13/2009	0

Date	precip. (cm)	Date	precip. (cm)	Date	Precip (cm)
11/14/2009	0.0508	12/20/2009	0	1/25/2010	0
11/15/2009	0.508	12/21/2009	0	1/26/2010	0.0127
11/16/2009	0	12/22/2009	0	1/27/2010	0.1778
11/17/2009	0	12/23/2009	0.127	1/28/2010	0
11/18/2009	0	12/24/2009	0.0254	1/29/2010	0
11/19/2009	0	12/25/2009	0	1/30/2010	0
11/20/2009	0	12/26/2009	0	1/31/2010	0.5588
11/21/2009	0	12/27/2009	0	2/1/2010	0.4572
11/22/2009	0	12/28/2009	0	2/2/2010	0
11/23/2009	0.6604	12/29/2009	0	2/3/2010	0
11/24/2009	0	12/30/2009	0.4572	2/4/2010	0.0127
11/25/2009	0	12/31/2009	0.6604	2/5/2010	0
11/26/2009	0	1/1/2010	0.381	2/6/2010	0.9652
11/27/2009	0	1/2/2010	0.0762	2/7/2010	0
11/28/2009	0	1/3/2010	0	2/8/2010	0
11/29/2009	0	1/4/2010	0	2/9/2010	0
11/30/2009	0	1/5/2010	0	2/10/2010	0
12/1/2009	0	1/6/2010	0	2/11/2010	0.5842
12/2/2009	0	1/7/2010	0	2/12/2010	0.381
12/3/2009	0	1/8/2010	0	2/13/2010	0.4064
12/4/2009	0	1/9/2010	0	2/14/2010	0.254
12/5/2009	0	1/10/2010	0	2/15/2010	0.3048
12/6/2009	0.1524	1/11/2010	0	2/16/2010	0.2794
12/7/2009	0.1778	1/12/2010	0	2/17/2010	0.0508
12/8/2009	0.381	1/13/2010	0	2/18/2010	0.0127
12/9/2009	0.2032	1/14/2010	0	2/19/2010	0
12/10/2009	0.0762	1/15/2010	0	2/20/2010	0.0127
12/11/2009	0	1/16/2010	0	2/21/2010	0
12/12/2009	0.2794	1/17/2010	0	2/22/2010	0
12/13/2009	2.6416	1/18/2010	0.0127	2/23/2010	0
12/14/2009	2.3368	1/19/2010	1.524	2/24/2010	0
12/15/2009	0	1/20/2010	0.7112	2/25/2010	0.9144
12/16/2009	0	1/21/2010	0.9144	2/26/2010	0
12/17/2009	0.0508	1/22/2010	0.3048	2/27/2010	0
12/18/2009	0	1/23/2010	1.2446	2/28/2010	0
12/19/2009	0	1/24/2010	0.762	3/1/2010	0

Date	precip. (cm)	Date	precip. (cm)	Date	Precip (cm)
3/2/2010	0	3/19/2010	0	4/5/2010	0.8636
3/3/2010	0	3/20/2010	0.0762	4/6/2010	3.556
3/4/2010	0.2286	3/21/2010	0	4/7/2010	0
3/5/2010	0.6858	3/22/2010	0	4/8/2010	0
3/6/2010	0	3/23/2010	0.3302	4/9/2010	0.0508
3/7/2010	0	3/24/2010	0	4/10/2010	0
3/8/2010	0.127	3/25/2010	0	4/11/2010	0
3/9/2010	0	3/26/2010	0	4/12/2010	0
3/10/2010	0.0254	3/27/2010	0.4318	4/13/2010	2.1082
3/11/2010	0	3/28/2010	0	4/14/2010	0.2032
3/12/2010	0	3/29/2010	0	4/15/2010	0
3/13/2010	0	3/30/2010	0		
3/14/2010	0.0508	3/31/2010	0.3048		
3/15/2010	0	4/1/2010	0.9144		
3/16/2010	0	4/2/2010	0.1524		
3/17/2010	0	4/3/2010	1.2954		
3/18/2010	0	4/4/2010	0.0254		

precip. = precipitation

Table A-20. Spring Creek Parshall flume calibration table

Depth (m)	Flow (cms)	Depth (m)	Flow (cms)	Depth (m)	Flow (cms)
0.0152	0.0075	0.1189	0.2009	0.2225	0.5476
0.0183	0.0101	0.1219	0.2092	0.2256	0.5597
0.0213	0.0129	0.1250	0.2176	0.2286	0.5719
0.0244	0.0159	0.1280	0.2261	0.2317	0.5841
0.0274	0.0192	0.1311	0.2348	0.2347	0.5965
0.0305	0.0228	0.1341	0.2436	0.2377	0.6089
0.0335	0.0265	0.1372	0.2525	0.2408	0.6214
0.0366	0.0305	0.1402	0.2616	0.2438	0.6341
0.0396	0.0346	0.1433	0.2707	0.2469	0.6468
0.0427	0.0390	0.1463	0.2800	0.2499	0.6596
0.0457	0.0436	0.1494	0.2894	0.2530	0.6726
0.0488	0.0483	0.1524	0.2989	0.2560	0.6856
0.0518	0.0532	0.1554	0.3085	0.2591	0.6987
0.0549	0.0583	0.1585	0.3183	0.2621	0.7119
0.0579	0.0636	0.1615	0.3281	0.2652	0.7251
0.0610	0.0690	0.1646	0.3381	0.2682	0.7385
0.0640	0.0746	0.1676	0.3482	0.2713	0.7520
0.0671	0.0804	0.1707	0.3583	0.2743	0.7656
0.0701	0.0863	0.1737	0.3686	0.2774	0.7792
0.0732	0.0924	0.1768	0.3790	0.2804	0.7930
0.0762	0.0986	0.1798	0.3896	0.2835	0.8068
0.0792	0.1050	0.1829	0.4002	0.2865	0.8207
0.0823	0.1115	0.1859	0.4109	0.2896	0.8348
0.0853	0.1182	0.1890	0.4217	0.2926	0.8489
0.0884	0.1250	0.1920	0.4327	0.2957	0.8630
0.0914	0.1320	0.1951	0.4437	0.2987	0.8773
0.0945	0.1391	0.1981	0.4548	0.3018	0.8917
0.0975	0.1464	0.2012	0.4661	0.3048	0.9061
0.1006	0.1538	0.2042	0.4774	0.3079	0.9207
0.1036	0.1613	0.2073	0.4889	0.3109	0.9353
0.1067	0.1689	0.2103	0.5004	0.3139	0.9500
0.1097	0.1767	0.2134	0.5121	0.3170	0.9648
0.1128	0.1846	0.2164	0.5239	0.3200	0.9797
0.1158	0.1927	0.2195	0.5357	0.3231	0.9947

Depth (m)	Flow (cms)	Depth (m)	Flow (cms)	Depth (m)	Flow (cms)
0.3261	1.0098	0.4298	1.5702	0.5334	2.2185
0.3292	1.0249	0.4328	1.5880	0.5365	2.2388
0.3322	1.0401	0.4359	1.6060	0.5395	2.2592
0.3353	1.0554	0.4389	1.6240	0.5426	2.2796
0.3383	1.0708	0.4420	1.6420	0.5456	2.3002
0.3414	1.0863	0.4450	1.6602	0.5486	2.3208
0.3444	1.1018	0.4481	1.6784	0.5517	2.3414
0.3475	1.1175	0.4511	1.6967	0.5547	2.3622
0.3505	1.1332	0.4542	1.7151	0.5578	2.3829
0.3536	1.1490	0.4572	1.7336	0.5608	2.4038
0.3566	1.1649	0.4603	1.7521	0.5639	2.4248
0.3597	1.1809	0.4633	1.7707	0.5669	2.4458
0.3627	1.1969	0.4663	1.7894	0.5700	2.4669
0.3658	1.2131	0.4694	1.8081	0.5730	2.4880
0.3688	1.2293	0.4724	1.8269	0.5761	2.5092
0.3719	1.2456	0.4755	1.8458	0.5791	2.5305
0.3749	1.2619	0.4785	1.8648	0.5822	2.5518
0.3780	1.2784	0.4816	1.8839	0.5852	2.5732
0.3810	1.2950	0.4846	1.9029	0.5883	2.5947
0.3841	1.3116	0.4877	1.9221	0.5913	2.6163
0.3871	1.3283	0.4907	1.9414	0.5944	2.6379
0.3901	1.3450	0.4938	1.9607	0.5974	2.6595
0.3932	1.3619	0.4968	1.9801	0.6005	2.6813
0.3962	1.3788	0.4999	1.9996	0.6035	2.7031
0.3993	1.3958	0.5029	2.0192	0.6066	2.7250
0.4023	1.4129	0.5060	2.0388	0.6096	2.7469
0.4054	1.4301	0.5090	2.0585	0.6127	2.7689
0.4084	1.4473	0.5121	2.0782	0.6157	2.7910
0.4115	1.4646	0.5151	2.0981	0.6188	2.8131
0.4145	1.4820	0.5182	2.1179	0.6218	2.8353
0.4176	1.4995	0.5212	2.1379	0.6248	2.8576
0.4206	1.5170	0.5243	2.1579	0.6279	2.8799
0.4237	1.5347	0.5273	2.1780	0.6309	2.9023
0.4267	1.5524	0.5304	2.1982	0.6340	2.9248

Depth (m)	Flow (cms)	Depth (m)	Flow (cms)	Depth (m)	Flow (cms)
0.6370	2.9473	0.6828	3.2930	0.7285	3.6528
0.6401	2.9699	0.6858	3.3166	0.7315	3.6773
0.6431	2.9926	0.6889	3.3402	0.7346	3.7019
0.6462	3.0153	0.6919	3.3638	0.7376	3.7265
0.6492	3.0381	0.6950	3.3876	0.7407	3.7512
0.6523	3.0610	0.6980	3.4114	0.7437	3.7759
0.6553	3.0839	0.7010	3.4353	0.7468	3.8007
0.6584	3.1069	0.7041	3.4592	0.7498	3.8255
0.6614	3.1299	0.7071	3.4832	0.7529	3.8504
0.6645	3.1530	0.7102	3.5072	0.7559	3.8754
0.6675	3.1762	0.7132	3.5313	0.7590	3.9004
0.6706	3.1994	0.7163	3.5555	0.7620	3.9255
0.6736	3.2227	0.7193	3.5798	0.7651	3.9507
0.6767	3.2461	0.7224	3.6041	0.7681	3.9759
0.6797	3.2695	0.7254	3.6284		

Depth = upstream depth
Flow = flow rate
cms = cubic meters per second

Table A-21. Ground water nutrient concentrations

Site	Date	NO3-N (mg N/L)	TDP (µg P/L)	SRP (µg P/L)	Iron (mg Fe/L)
Well 1	02/22/10	3.7	6.4	2.3	
	03/02/10	3.6	12	2.3	3.3
	04/05/10	2.5	7.6	2.1	4.6
	04/19/10	8.4	45	BDL	0.43
	05/04/10	4.5			0.13
	05/25/10				0.23
	06/08/10		16	8	
	06/22/10		14	7	
	07/20/10			6	
Well 2	02/22/10	2.2	16.8	3.3	
	03/02/10	2.4		3.3	BDL
	04/05/10	2.8	110	2.6	0.02
	04/19/10	2.9	7.6	2.1	0.01
	05/04/10	2.6			0.10
	05/25/10		52		0.02
	06/08/10		86	3	
	06/22/10		25	2.9	
	07/20/10			2.4	
Well 3	02/22/10	3.0	6.4	BDL	
	03/02/10	2.8	15	5.3	BDL
	04/05/10	2.7	23	22	0.28
	04/19/10	2.7	25	BDL	
	05/04/10	2.4			BDL
	05/25/10		6		0.01
	06/08/10		5	2	
	06/22/10		24	2.9	
	07/20/10			14.7	

Site	Date	NO3-N (mg N/L)	TDP (µg P/L)	SRP (µg P/L)	Iron (mg Fe/L)
Well 4	02/22/10	4.4	188	190	
	03/02/10	4.6	226	218	BDL
	04/05/10	4.8	993	205	BDL
	04/19/10	5.0	267	225	0.01
	05/04/10	4.3			BDL
	05/25/10		275		0.00
	06/08/10		479	257	
	06/22/10		420	221.2	
	07/20/10			214.8	
Well 5	02/22/10	3.1	459	101	
	03/02/10	3.5	314	231	0.01
	04/05/10	3.5	327	304	BDL
	04/19/10	3.9	305		
	05/04/10	3.5			0.01
	05/25/10		331		0.02
	06/08/10		315	348	
	06/22/10		340	322.1	
	07/20/10			335.7	

TDP = total dissolved phosphorus
Iron = dissolved iron

Table A-22. Reservoir water and nutrient export data

	flow m^3/Day	µg TP/L	µg SRP/L	mg NH4-N /L	mg NO3-N/L
5/20/08	519296		n/d		
6/18/08	610574	54.4			
6/30/08	539032	41.0	n/d	n/d	0.440
7/8/08	1073129		22.0		
7/15/08	1096565	35.3	n/d	0.070	0.410
7/21/08	996653		n/d		
8/1/08	1128636	40.1	n/d	n/d	0.410
8/11/08	1106433		n/d	0.040	0.400
8/19/08	1094098		15.0		
8/28/08	1186610	146.0		0.220	0.280
9/2/08	859737		20.0		
9/9/08	710486	78.0	12.0	0.080	0.170
9/16/08	683349		13.0		
9/26/08	448987	45.0	17.0	n/d	0.120
9/30/08	469957		13.0		
10/7/08	272599	29.0	15.0	0.070	0.160
10/13/08	215859		15.0		
10/21/08	4934	27.0	12.0	0.050	n/d
12/2/08	7401			0.070	n/d
1/27/09	504494			n/d	n/d
5/19/09	1271720	75.0	n/d	n/d	0.320
7/7/09	536565	20.0		n/d	0.369
7/20/09	939913			n/d	0.368
8/11/09	784494	72.9			
8/18/09	763525	190.9			0.045
8/25/09	693217	262.4	22.0	0.135	0.046
9/15/09	715419	214.2			n/d
9/22/09	620441	67.2	9.0		n/d
9/29/09	574803	94.2	9.0	n/d	n/d
11/3/09	0	33.2	7.0		n/d
12/8/09	12335	42.0	21.0		n/d
2/8/10	12335	33.4	15.0	n/d	0.472
5/3/10	27137	21.0	16.0	n/d	0.163
6/29/10	791895	207.0	9.2	n/d	0.218