CURRENT PERFORMANCE OF A PASSIVE WETLANDS TREATING ACID MINE DRAINAGE FROM UNDERGROUND MINE SEALS AT MORAINE STATE PARK, BUTLER COUNTY, PENNSYLVANIA

A THESIS

Submitted to the Faculty of the School of Graduate Studies and Research

Of California University of Pennsylvania in partial

Fulfillment of the requirements for the degree of

Master of Science

By
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Research Advisor, Dr. Kyle Fredrick

California, Pennsylvania
2008

CALIFORNIA UNIVERSITY OF PENNSYLVANIA
CALIFORNIA, PA

THESIS APPROVAL

Earth Sciences

We hereby approve the Thesis of

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ABSTRACT

Coal mining was conducted in the area of Moraine State Park prior to establishment of the park and associated Lake Arthur. Sixty-nine underground mine entries were sealed during the 1960s and early 1970s along the proposed shore of Lake Arthur. Not all seals were successful and some were leaking acid mine drainage (AMD) and depositing iron hydroxides. A passive wetlands treatment system was constructed in 1996 to treat the AMD from one of these leaking seals. The design life of the system was estimated as twelve years. Six monitoring locations were established, water samples collected, analyzed for AMD parameters, and precipitate thickness measured to determine if the ponds continue to function properly twelve years later. This research determined the wetlands treatment system continues to ameliorate the AMD discharge, determined that the ponds do not need to be cleaned out at this time, recommends a monitoring and maintenance schedule.

Acknowledgements:

I would like to acknowledge all those who have helped me with this project, but I am sure I am leaving some people out. Thank you to Dr. Robert Vargo, who got this whole thing started (in my Mind). I wish I could have taken more classes from him. My current advisor Dr. Kyle Fredrick and all my advisors and professors at California University of Pennsylvania. Mr. John Foreman, for providing me with several files, mapping, and for the reclamation plan that helped to make the area surrounding Lake Arthur suitable for a state park and a lake that is not just an AMD treatment pond. The park area is a wonderful resource for work and play and I was able to explore portions of the park that not many people have visited. Most park visitors are not even aware that the area had a mining history. Jeremy Rekich and staff at the Moraine State Park Office and Davis Hollow Marina, especially Wink who saved me some travel time. Members of the Slippery Rock Watershed Coalition, especially Margaret Dunn, Cliff Denholm, and Wil Taylor. Members of the Lake Arthur Sailing Club for being interested in the study I was doing during the sailing season. Department of Environmental Protection Laboratory. North County Brewing in Slippery Rock for liquid sustenance and rehydration after long days outstanding in the field. My wife (Patty) and children (Paul and Jill) who supported me and have missed me while I was outstanding in the field, I think.

Table of Contents

Introduction

Moraine State Park is a 16,725-acre green space surrounding Lake Arthur located to the east of the Interstate 79 interchange with State Route 422 in Butler County, Pennsylvania (Figure 1). The geologic history of the area includes the formation of predecessor glacial lakes, their draining, and the erosive processes that formed the gorge that is now part of McConnell's Mill State Park, located to the west of Moraine State Park (Figure 2). The bedrock in the area of Moraine State Park is sedimentary layers of sandstone, siltstone, shale, limestone and coal. The stratigraphy consists of the Pennsylvanian aged Conemaugh and Allegheny Formations with a thin veneer of unconsolidated Pleistocene and recent sediments (Shepps et al., 1959 and Fleeger et al. 2003). The general stratigraphic sequence is shown in Figure 3.

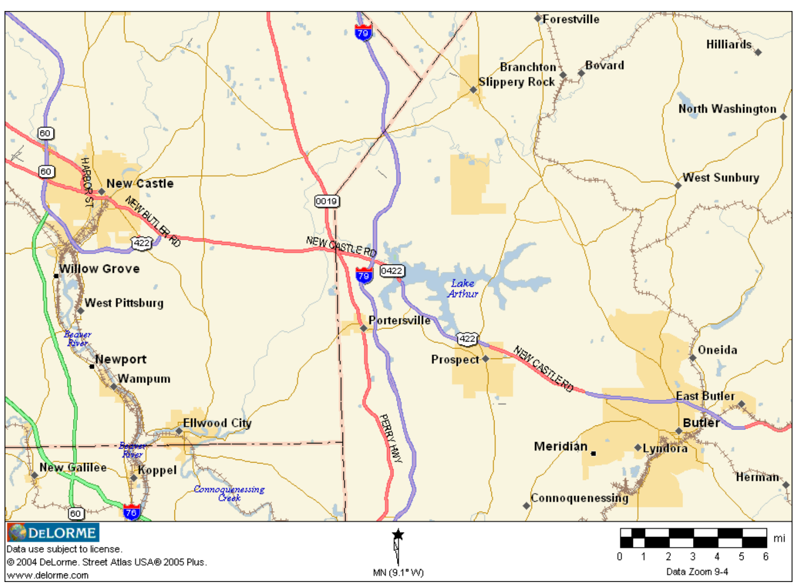


Figure 1 - Location Map (From: DeLorme Street Atlas USA ® 2005 Plus, 2004)

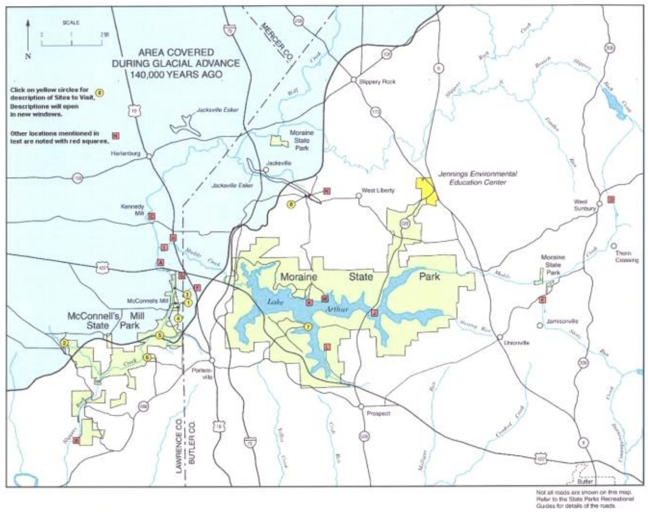


Figure - 2 Moraine State Park and McConnells Mill Location Map (From Fleeger, et al, 2003)

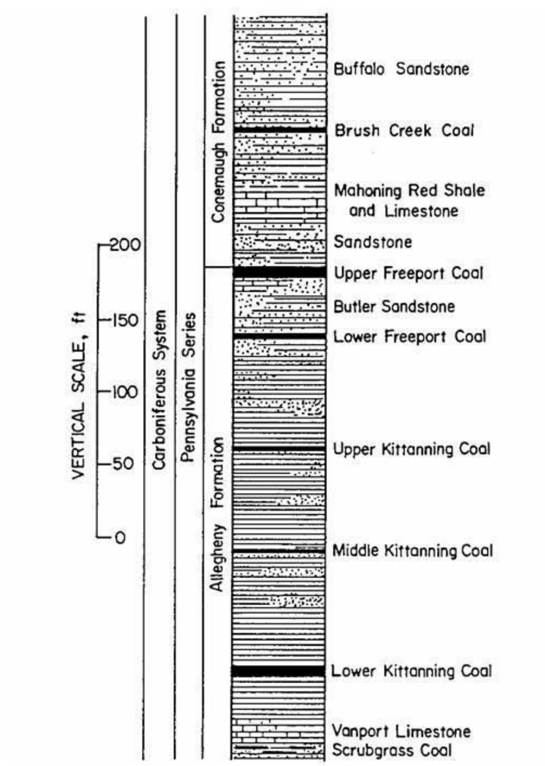


Figure 3 – Generalized Stratigraphic Column for Moraine State Park Area (Maksimovic and Maynard, 1983)

The bedrock is weathered and soils cover most of the park area with some areas covered with Pleistocene glacial deposits of Wisconsin Age. Evidence of several continental glacial advances have been noted and described in the area of Moraine State Park. These ground and end moraine deposits are how the park was named. “Glaciers moved into northwestern Butler County at least twice during Pleistocene time and deposited a heterogeneous mixture of clay, silt, sand and boulders, called till” (Poth, 1973). The depositional records of first and second glacial advances have been eroded. The third ice advance occurred approximately 140,000 years ago (Fleeger, et al. 2003). Frank W. Preston (1950) performed the initial mapping of glacial lakes in the area. Preston described the largest and earliest one, Lake Arthur. During one of the glacial advances, glacial Lake Arthur was “reduced in size and split into two lakes called Lake Edmund and Lake Watts” (Shepps, et al. 1959) and a third smaller lake, Lake Prouty, was formed to the southwest (Fleeger et al. 2003) (Figure 4).

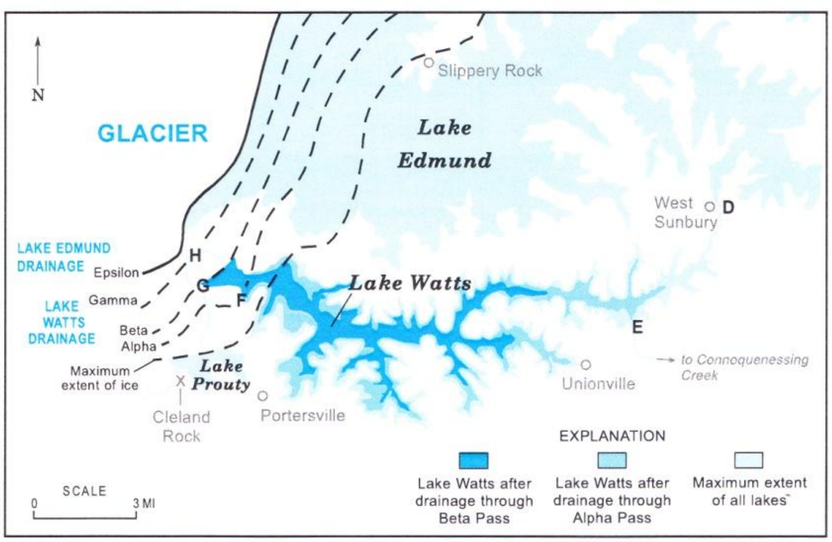


Figure 4 (From: Fleeger et al, 2003)

As stated by Alley (2000), “More commonly, the meltwaters will pond along the edge of the ice” and this is what happened in the area of glacial Lake Arthur. Glacial Lake Edmund formed to the north in the Slippery Rock Creek valley, glacial Lake Watts formed in the Muddy Creek valley, and the smaller Lake Prouty formed near Cleland Rock (Fleeger et al. 2003). All of these lakes formed along the edge of glacial ice. Ice dam failure and subsequent release of floodwaters is how Slippery Rock gorge was formed. Lake water flooded the area catastrophically to erode the gorge several times. Approximately 23,000 years ago, lakes were dammed behind the most recent continental glaciation (Fleeger et al. 2003). The lakes either broke through these ice barricades several times or flowed around the front of the glacial ice after it melted. The gorge of McConnells Mill State Park was eroded by successive releases of water from glacial lakes in the past.

These state parks are used by local and regional residents for a variety of recreational activities. There are 60 miles of trails for hiking, biking, horseback riding, and in the winter months, cross country skiing and snowmobile riding. The park receives about 1.2 million visitors each year. The 3,225 acre Lake Arthur is utilized by water enthusiasts for swimming, fishing, kayaking, rowing, canoeing, windsurfing and sailing. Ten boat launches around the lake allow access for all of these boating opportunities (DCNR, 2008)

The major tributary drainages that contribute water to Lake Arthur include Bear Run, Swamp Run, Big Run, Shannon Run, and Muddy Creek along with approximately 75 unnamed intermittent streams (U. S. Geological Survey 7.5

Minute Topographic Quadrangle Maps - Mount Chestnut, Portersville, and Prospect Quadrangles). Water exits the lake over the dam spillway via Muddy Run located on the west side of the lake. Muddy Creek has a USGS flow monitoring station at this downstream location that provides real-time flow data (USGS, 2008).

Background

The region has a long history of coal mining including surface and underground mines with their associated mine spoil and coal refuse piles. Many of the input streams had been affected by AMD from historical coal mining (Maksimovic and Maynard; 1983 and Foreman et al, 1972). During the early to mid 1900s, many of these historical coal mines and associated facilities were left unreclaimed and abandoned.

The Middle Kittanning coal was mined both prior to and after World War I along the north side of Muddy Creek where the coal seam outcrops. During this time period, it was standard mining practice to develop underground coal mines in the up-dip direction. This facilitated the transport of coal out of the mine and gravity drainage of water. This practice allowed the water encountered by the mine workings to drain from the mine entries as AMD. Underground mining operations were practically non-existent after the 1930's. From 1940 to 1966, surface mines were active in the future park area on several coal seams. Most of the up-dip or upslope mining operations were located along the north shore of the proposed Lake Arthur. During the time of planning for the construction of the park, only one underground mine in the area (Salzano-Ross Mine shown on Figure 5) was in operation (Foreman, 1968). Four coal seams were mined in the area of the park: Middle Kittanning, Upper Kittanning, Lower Freeport and Upper Freeport (Figure 4).

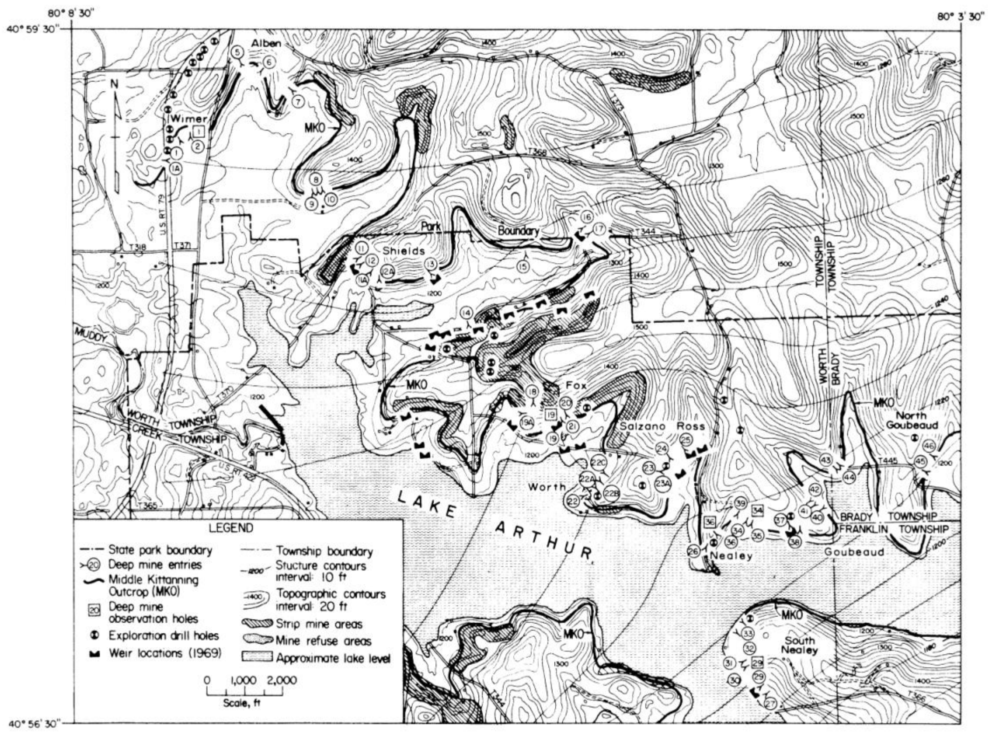


Figure 5 – Mined Areas Western Portion of Moraine State Park (From: Maksimovich and Maynard, 1983)

The Brush Creek and both Freeport Coal seams were mined in the area, however only surface mining techniques were utilized when these seams were mined. The largest amount of coal removed within the proposed park area was by a number of underground and surface mines that removed coal from the Middle Kittanning seam. This coal seam is laterally persistent and averages approximately 36 inches in thickness (Foreman, 1968). At the climax of mining, coal was being loaded onto the rail cars of the Western Allegheny Railroad that ran the entire length of Muddy Creek within the present park area (Foreman, 1968). The Middle Kittanning coal has high sulfur content “up to 3.8 pct.” (Maksimovic and Maynard, 1983) and therefore spoils and coal mine refuse leaches large amounts of AMD.

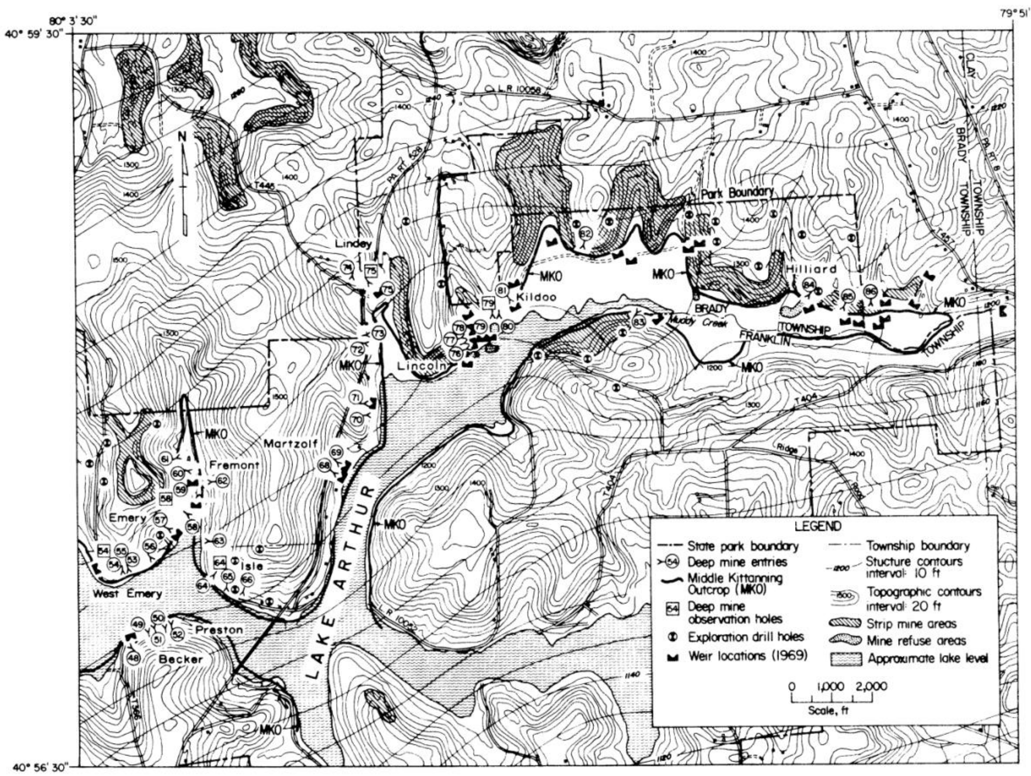


Figure 6 – Mined Areas Eastern Portion of Moraine State Park (From: Maksimovich and Maynard, 1983)

Acid mine drainage forms as a result of exposing pyrite bearing materials to water and oxygen which begins the weathering process. Pyrite is the mineral that is mainly responsible for AMD. It contains iron and sulfur that can react with water and oxygen to generate acid. The acid can dissolve minerals and metals in rock including iron, aluminum, and manganese. Once mobilized, the water containing metals and acidity can have a deleterious effect on the environment by disrupting or eliminating entire stream ecosystems (Taylor, et al, 2003).

Coal and coal mining waste contains the mineral pyrite (FeS_2). In the presence of oxygen and water, pyrite weathers as expressed in equation 1.

$$2FeS_2(s) + 7O_2(aqu) + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+ \quad (1)$$

The weathering process produces sulfate (SO_4^{2-}), dissolved ferrous iron (Fe^{2+}), and acidity represented by the hydrogen ions (H^+). If additional oxygen is available ferrous iron (Fe^{2+}) can be further oxidized to Fe^{3+} (ferric iron).

$$2Fe^{2+} + ½O_2 + 2H^+ \rightarrow 2Fe^{3+} + H_2O \quad (2)$$

Additional amounts of acidity can be produced when ferric iron precipitates as iron oxyhydroxide forming yellow boy or ochre. The precipitate is the reddish-yellow or orange stain on the bottom of many streams in the coal fields and the material that collects in the bottom of treatment ponds. Equation 3 shows the iron oxyhydroxide precipitation reaction.

$$2Fe^{3+} + 6H_2O \leftrightarrow 2Fe(OH)_3(s) + 6H^+ \quad (3)$$

This reaction can attain equilibrium, therefore the equation is written as both a forward and reverse reaction (Rose and Cravotta, 1998). Additional acidity can be generated when ferric iron reacts with pyrite to form ferrous iron as shown in equation 4.

$$14Fe^{3+} + 2FeS_2(s) + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (4)$$

The ferrous iron in equation 4 could either be oxidized and carry on the reactions shown in equations 2, 3, and 4 or remain in solution.

When iron precipitates, as in equation 3, hydrogen ions are released into solution. One method of removal of iron from solution is to increase the alkalinity with bicarbonate ions (Younger et al., 2002). Some water has natural alkalinity from the dissolution of limestone rock units. According to Hedin et al, (1994), net alkaline water contains at least 1.8 mg/l alkalinity for each 1mg/l of dissolved iron. Water is considered to be net alkaline if the ratio of alkalinity to acidity is positive (Hedin et al, 1994). Water with a lower ratio is considered net acidic because the oxidation and hydrolysis reactions release hydrogen ions, the pH is lowered, and acidity correspondingly increases. Younger et al (2002), state that "Mine waters that contain an excess of alkalinity are referred to as net alkaline. A fundamental aspect of the efficient passive treatment of mine drainage is the recognition of net alkaline conditions when they exist naturally, and the passive creation of net alkaline conditions when they do not exist". Passive wetlands treatment systems are designed to emulate natural amelioration processes in wetlands. The passive technique and process is not a construct the system and walk away solution. Passive wetlands treatment systems use inherent chemical and complimentary biological processes that occur in natural wetlands to affect positive changes in water quality (Taylor, et al, 2003). When water flowing through a passive wetlands treatment system has an iron concentration decrease and a corresponding pH decrease, the water can be classified as net acidic. When water flowing through an aerobic passive wetlands treatment system has an iron concentration decrease and a corresponding pH increase, the water can be classified as net alkaline.

When calcium carbonate dissolves from limestone it can increase the pH of water by combining with hydrogen ions and adds alkalinity with bicarbonate ions. These reactions are expressed in equations 5 and 6.

$$CaCO_3 + 2H^+ \leftrightarrow Ca^{+2} + H_2O + CO_2 \qquad (5)$$

$$CaCO_3 + H_2CO_3 \leftrightarrow Ca^{+2} + 2HCO_3 \qquad (6)$$

Under aerobic conditions, iron can form oxyhydroxides (FeOOH) or hydroxides ($Fe(OH)_3$) (Costello, 2003). The removal of iron from solution occurs in three steps: 1) ferrous iron oxidation (equation 7), 2) ferric iron hydrolysis (equation 8), and 3) sedimentation of ferric oxyhydroxide solids (equation 9).

$$2Fe^{2+} + ½O_2 + 2H^+ \rightarrow 2Fe^{3+} + H_2O \qquad (7)$$

$$Fe^{3+} + 3H_2O \leftrightarrow FeOOH(sus) + 3H^+ \qquad (8)$$

$$FeOOH(sus) \leftrightarrow FeOOH(sed) \qquad (9)$$

Where “sus” indicates a suspended solid and “sed” indicates a sediment (settled) solid (Younger et al, 2002). This process can be entirely chemical or receive a microbial assist, depending on the pH, as various bacteria can act as catalysts to the reaction. The chemical process is most active between ph of 6 to 7; whereas the biological process is more dominant at lower pH. At pH values greater than 4, the rate of ferric iron hydrolysis is fast and therefore formation of suspended precipitate solids is fast. At pH value less than 3, the of the hydrolysis reaction rate appears to be very slow and solutions can maintain their ferric iron content despite over saturation of numerous ferric (oxy)hydroxide and oxide minerals. The rate of the iron removal is dependent on the pH, iron concentration and the amount of dissolved oxygen. As pH decreases, iron removal is limited by the oxidation step (Younger et al, 2002).

Manganese oxidizes and hydrolyzes according to equation 10.

$$4Mn^{2+} + 0.25O_2 + 6H_2O \rightarrow 4MnOOH + 8H^+ \quad (10)$$

The precipitates of MnOOH or MnO_2 appear as black particles. Certain bacteria can influence manganese oxidation and removal. The pH of water has to be greater than 6 for bacteria to efficiently catalyze Mn^{2+} oxidation. The removal of manganese from solution requires the water be at a pH greater than 6 and most, if not all, of the iron must have previously been removed from solution. The manganese oxide precipitation is autocatalytic and once some manganese has precipitated, then the rate of precipitation can increase (Watzlaf et al., 2004, Hedin et al, 1994).

Four main processes remove ferric hydroxide from water.

1. Settlement of ferric hydroxide flocculate from suspension in ponds.
2. Physical filtering of colloidal ferric hydroxide from water by plants roots and stalks, fibrous materials placed in the wetlands, or other non-vegetative filtering materials, such as gravel.
3. Batty described iron plaque formation on the root structures of plants, such as *Typha latifolia* and *Phragmites australis,* which seep out oxygen

that causes the dissolved ferrous iron to precipitate as a ferric hydroxide covering on the roots (as cited in Younger et al, 2002).

4. Jarvis and Younger describe surface catalyzed oxidation of ferrous iron (SCOOFI) as a three stage process where dissolved Fe^{2+} is adsorbed to existing ferric hydroxide (as cited in Younger et al, 2002). Then the ferric hydroxide surface is the site of a catalytic reaction for the oxidation of the adsorbed ferrous iron to ferric iron as shown in equation 7. The ferric iron hydrolyses as shown in equation 8 which forms a layer of new ferric hydroxide that then perpetuates the cycle (Younger et al, 2002).

Costello (2003) describes some of the same processes, like filtering of suspended precipitate, and other processes that can remove metals in wetland treatment systems. These include uptake and incorporation of materials in roots and leaves of plants, adsorption on algal material, decaying plant matter, or inorganic soils material, or removal of material in either the aerobic or anaerobic zone by bacterial activity.

Many processes in a passive wetland treatment system can affect the stability of alkalinity and acidity in the treated water. According to Younger et al (2002), the most important is sulfate reduction by bacteria. Sulfate reducing bacteria can remove metals from solution by reducing sulfate to sulfide which reacts with dissolved metals that then precipitate out of solution (Costello, 2003). In order for this reaction to occur, the conditions have to be anaerobic, or without oxidizing compounds like oxygen, Fe^{3+}, or Mn^{4+}. Conditions like this are present in wetlands treatment systems that have a substrate material of compost or other organic material (Watzlaf, et al, 2004). In equation 11, the CH_2O in the reaction represents a carbon source.

Sulfate in AMD can be removed by organic material in anaerobic conditions through bacterial sulfate reduction. The sulfate-reducing bacteria oxidize the organic compound and utilize sulfate as an electron acceptor. This reaction releases hydrogen sulfide and bicarbonate as shown in equation 11.

$$2CH_2O + SO_4^{2-} \rightarrow H_2S + 2HCO_3^- \quad (11)$$

The "sulfate-reducing bacteria utilize acetate produced by the hydrolysis of lingo-cellulose materials", (Younger, et al 2002). The requirements for the sulfate-reducing bacteria to both survive and thrive include circum-neutral pH, anoxic conditions, no Fe^{3+}, and a minimum of 100 mg/l of sulfate in the water. If the sulfate-reducing bacteria are active (i.e. alive and thriving), then the alkalinity produced by the reaction in equation 11 can assist with the functioning of the wetlands treatment. According to Manahan (1990), "the bacteria *Desulfovibrio* can reduce sulfate ion to H_2S". The hydrogen sulfide product can react with dissolved metals to form metal sulfide precipitates (Costello, 2003) as shown in equation 12.

$$H_2S + M^{+2} \rightarrow MS + 2H^+ \quad (12)$$

The AMD discharges from the underground mines, and surface runoff from several unreclaimed surface mines and refuse piles, could have contributed poor quality water to the 3,225-acre Lake Arthur (Foreman, 1968). However, during the late 1960s and early 1970s, a surface mine reclamation and underground mine sealing program ameliorated many of the AMD generation sites. Prior to the development of Moraine State Park, abandoned surface mines and coal refuse piles were reclaimed using various pollution abatement measures. From 1969 to 1971, numerous deep mine entries were sealed to assist in water quality improvement and filling of Lake Arthur (Foreman and McLean, 1972). Some of the old coal mining roads from the past mining operations became park roads and trails.

A variety of wildlife now inhabits the park setting and recreational hunting of deer, turkey, and geese is allowed in approved areas. Lake Arthur currently supports numerous fish species including bass, walleye, crappie, catfish, bluegill, perch, musky, and other baitfish.

During 1979 and 1980, a study was performed by the United States Department of the Interior, Bureau of Mines personnel (Maksimovic and Maynard; 1983) to assess the long-term effectiveness of the deep mine sealing. The study by Maksimovic and Maynard identified original weir locations at previous mine entries, evaluated the condition of the entry area, measured water flow from the sealed areas, recorded water levels in the mine pools behind the seals, collected water samples for laboratory analysis, and compared their data to data collected both prior to and after the initial sealing of the mines in 1969-1971. They found that the total acid loading was reduced and was less variable. The total mean and minimum iron loading increased and the maximum iron load decreased. The variability of the iron loading was reduced. “Overall, mine sealing improved the water quality in the park's Lake Arthur" (Maksimovic and Maynard; 1983) Maksimovic and Maynard noted that,

> "Deep mine seals installed in the Kildoo Mine area were found to be ineffective, and in the mid-1970's the Pennsylvania Department of Environmental Resources designed a new mine pollution abatement project. In 1979, exploratory borings indicated waterflow through a pervious shale zone located under the coal seam. During subsequent reclamation of the strip mine area, a subsurface drainage system was installed and the area regraded and resealed. Postconstruction monitoring data are not available for this project."

Project Scope

The research presented in this paper includes an examination of precipitation, flow rates and water quality at six monitoring points: three at a passive wetland treatment system, an untreated AMD discharge, and two at control stream points not affected by mine drainage. The passive wetlands treatment system and the untreated discharge (MDJ-1) are located in close proximity to both the Lincoln Mine and the Kildoo Mine area (Figure 6). These locations were monitored to (1) determine how the flow rate is affected by precipitation, (2) measure water quality changes from the wet through the dry season, (3) record seasonal fluctuations in water quality, and (4) assess performance of the passive treatment system. Recent and historical precipitation data presented in this study are tabulated and analyzed to determine if precipitation amounts increase or decrease flow from the wetlands treatment system. Any changes to the amount of precipitation and therefore AMD flow from the passive wetlands treatment system could have a detrimental impact on Lake Arthur, the park wildlife, and recreational opportunities for the users of Moraine State Park.

Methods

This study is a review of the passive wetlands treatment system that was designed and constructed during 1995-96 to treat an AMD discharge emanating from sealed mine entries of either the Lincoln Mine and/or Kildoo Mine (Middle Kittanning coal seam) (Foreman, 1968). The design life of the passive wetlands treatment system was approximately twelve (12) years (Moraine State Park Office files). After this period, it was believed the iron oxyhydroxide precipitate in the settling and cattail treatment ponds would need to be removed. A maintenance plan was considered but one was not implemented (Rekich, personal communication, 11/16/2008). The operation and maintenance of the wetlands is the responsibility of Moraine State Park. In order to determine the current performance of the passive wetland treatment system, precipitation data was tabulated, field measurements were made, water samples were collected for laboratory analysis, and precipitate thickness was measured in Pond 1 of the passive wetlands treatment system (Figure 18 and Figure 23). The precipitate thickness measurements were collected to determine how much volume remained in the pond, whether the pond needed to be cleaned, and to estimate how much time remained before cleaning was required.

Precipitation data was compared to discharge values to determine if precipitation has an effect on the wetlands treatment system. Flow rates of the untreated AMD discharge and the control stream were compared to precipitation and the flow rate from the treatment pond system. Precipitation in the region is measured at several recording stations. Three regional stations, between 7 and 12 miles from the park, have been recording data since the late 1940s, which is prior to the beginning of initial AMD flow monitoring for the original mine reclamation projects completed in the 1960s and 1970s. A meteorology weather station is located at the Moraine State Park South Shore Office (Figure 5). Park Rangers record the daily total precipitation, maximum and minimum temperature, plus wind speed and direction. The park staff measure lake water temperature a few times each month. The climatological data are maintained at the Moraine State Park South Shore Office. This station was utilized for January 2007 through September 2008 precipitation and temperature measurements for this study. The weather station is located approximately 4.5 miles from both the passive wetlands treatment system and the untreated AMD discharge, and 2.3 miles from the control stream (Mount Chestnut, Portersville, and Prospect USGS Topographic Quadrangle Maps). Precipitation data from 2007 through September 2008 recorded at the park office are included in Appendix 1, Table 1.

Figure 7 – Weather Station at Moraine State Park Office

Initial site reconnaissance was conducted with Mr. Jeremy Rekich, Assistant Park Manager from Moraine State Park. The ponds in the passive wetland treatment system were reviewed, along with several other potential monitoring locations in the area. The incoming AMD discharge location(s) for the passive wetlands treatment system could not be located. A Pennsylvania Department of Conservation and Natural Resources (DCNR) Collectors Permit needed to be approved prior to establishing the monitoring locations and sampling the sites. The initial flow readings at the wetland treatment ponds and an untreated AMD discharge were measured using a 1 inch portable Baski® flume (Figure 8). Based on these readings, it was determined that 90º triangular (V-notch) weirs would be sufficient to monitor flow from Pond 1, Pond 3, and the untreated AMD discharge (MDJ-1) (Figures 9, 10, and 11).

Figure 8 – 1 inch Portable Baski® Flume

These weirs were constructed from ¾ inch lumber. The weir for Pond 3 was installed against pre-existing 2 inch by 10 inch pressure treated lumber that had been installed during the original pond construction as a flow regulating device.

Another flow regulating board was later uncovered when vegetation was removed from the Pond 1 outlet area. At the time of initial site reconnaissance, these original design boards were not visible as vegetation had overgrown the outlet areas of both Pond 1 and Pond 3.

Figure 9 - 90º Triangular (V-notch) Weir at Pond 1 Outlet (MSP-1)

The outflow pipe for Pond 2 was measured and a 90º "street bend" of appropriate size was purchased to attach to the outlet pipe (Figure 12). Flow was directed into a graduated bucket and the standard bucket and stop watch method used to measure the flow rate from Pond 2 (Trimmer, 1994). This 90º pipe was attached each time a flow measurement was made and then removed.

Figure 10 – Pond 3 Outlet (MSP-3)

Figure 11 – Untreated Mine Drainage Discharge (MDJ-1)

Figure 12 – Pond 2 Outlet (MSP-2)

Water quality screening of potential monitoring locations was done using a HACH iron test kit (Model IR-18B) to field test for iron concentration to determine whether these sites were affected by AMD. When testing with the HACH kit, Pond 1 in the passive wetland treatment system showed greater than 10 mg/l, 1.6 mg/l for Pond 2, and 1.6 mg/l for the Pond 3. An untreated AMD discharge, located approximately 800 feet northeast of the passive wetlands treatment system, had a field screening iron concentration of 4.0 mg/l. This AMD discharge flows via a stream channel and natural wetlands, approximately 174 feet, before entering Lake Arthur. This stream was screened using the HACH test kit and at the point where it enters Lake Arthur, the iron measured 1.6 mg/l. Therefore, the majority of the iron had precipitated out of solution by the time the flow reached the lake. There was no iron hydroxide staining on either the stream substrate where it enters the lake or in the lake. No iron was detected in numerous HACH tests performed in the control stream (Davis Hollow). Based on these field screening measurements, this stream near the Davis Hollow Marina is not affected by mine drainage. Several other potential monitoring locations were checked for iron and none proved to have elevated iron and the flow rates did not appear to be high enough to flow throughout the proposed monitoring period.

The initial flow readings at the Davis Hollow control stream were measured using an 8 inch portable Baski® flume. Based on these flow measurements, the appropriate size of the rectangular weir was estimated. Rectangular weirs with a three foot width were constructed from 2 inch by 12 inch, eight foot long pressure treated lumber. Reconnaissance was performed for the control stream to determine appropriate locations to install three-foot rectangular weirs, one upstream and one downstream (Figure 13 and 14).

Figure 13 – Davis Hollow Control Stream Upstream (DHM-1)

Figure 14 – Davis Hollow Control Stream Downstream (DHM-2)

It was believed that if the flow rates diminished significantly at the control stream monitoring locations, and measurements could not be made at the 3 foot wide weirs, then either the 8 inch or the 1 inch portable Baski® flume (Figure 12) could be used to collect flow measurements.

Figure 15 – Baski® Flume Measurement near DHM-2

The discharge locations from Pond 1, Pond 2, and Pond 3 were determined to be the best monitoring locations at the wetlands treatment system. The monitoring location for the untreated AMD discharge location was selected based on the distance to Lake Arthur, the best location to direct several separated flows to one point, and the weir location remaining discreet and unobtrusive in order to avoid vandalism and protect the park setting. The control stream monitoring locations were selected based on ease of access, no apparent mining impacts, the ability to use the portable flumes if flow reduced, and proximity to the Davis Hollow Marina. Table 2 is a listing of sample locations selected for the monitoring program:

Table 2 – Monitoring Points

Mon. Pt.	Location	Description	Figure No.
MSP-1	Pond 1 outlet	Primary settling pond	9, 19, 23
MSP-2	Pond 2 outlet	Secondary cattail pond	12, 20, 22
MSP-3	Pond 3 outlet	Polishing pond prior to entering Lake Arthur	10, 21
MDJ-1	Mine Drainage	Collection of untreated AMD	11
DHM-1	Control Stream	Davis Hollow upstream location	13
DHM-2	Control Stream	Davis Hollow downstream location	14, 15

Field measurements of pH, flow, and water temperature were recorded from March through September of 2008 at the six monitoring locations. These monitoring locations are shown in Appendix 2 (Figures 16 and 17). Flow measurements were recorded both before and after precipitation events to determine if precipitation increases flow from the treatment ponds, untreated AMD discharge, and/or the control stream.

A diagram of the passive treatment pond system layout is shown on Figure 18.

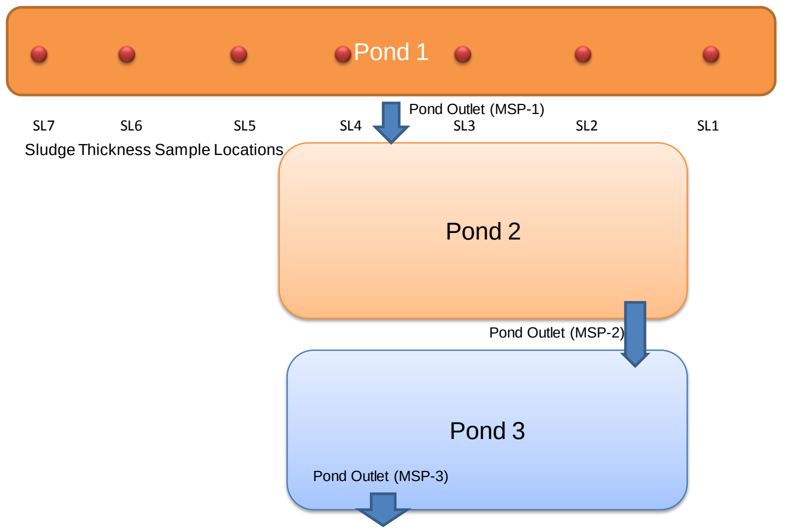


Figure 18 – Diagram of Pond Layout and Sample Locations
(North is to the right side of diagram)

Pond 1 measures approximately 185 feet by 14 feet (Figure 19) and is the primary settling pond in the system. Pond 2 measures approximately 100 feet by 45 feet and a monoculture of cattails (*Typha latifolia*) has become well established in this shallow pond (Figure 20). A photo of the original pond construction, located at an information display adjacent to the wetlands, indicates the placement of compost and straw bales in Pond 2 to increase the flow distance and therefore the detention time of water. Pond 3 measures approximately 100 feet by 40 feet and has emergent vegetation during the summer months (Figure 21). The adjacent untreated AMD discharge (MDJ-1) is located proximal to Burton Road (Figure 16) where it emerges from a sphagnum moss covered area, approximately 174 feet from where the flow enters Lake Arthur. This discharge location is located proximal to where the Kildoo Mine is shown on Figure 6. The control stream (Davis Hollow) is located proximal to the

Davis Hollow Marina and was sampled because it was determined by field screening to not be affected by mining. Water quality samples were collected from all monitoring locations on a monthly basis from March through August of 2008. Water quality analyses consisted of standard AMD parameters of pH, iron, manganese, aluminum, sulfate, acidity, alkalinity, and total suspended solids.

Figure 19 – Pond 1

Figure 20 – Pond 2 Cattails

Figure 21 – Pond 3 with Emergent Vegetation

Field Data Sampling Events

At each visit to the study area, field measurements for flow, temperature, and pH, were collected and recorded along with qualitative observations at the monitoring locations. The field measurements record data between the monthly laboratory sample events.

Figure 22 – Thermometer at MSP-2 for scale (note iron oxide staining)

Temperature was measured with a FISHERbrand® thermometer (Figure 19) and readings were made to the closest degree. Readings of pH were measured using a pHTestr 1, hand held pH meter, manufactured by Oakton® Instruments. This device was calibrated according to the manufacturers' recommendation. Flow depths were measured with a Lufkin Rugged Red End (No. 1066), six-foot collapsible rule. Tables of field data are included in Appendix 2 (Tables 3 through 8).

Laboratory Water Quality Sample Events

Water samples were collected monthly from March through August of 2008 for laboratory analysis of water quality parameters. The downstream location within the wetland treatment system was sampled first so that succeeding samples would not affect the downstream sample results (i.e. MSP-3 was sampled first, then MSP-2, and finally MSP-1). The untreated AMD discharge (MDJ-1) location was collected. Davis Hollow stream sample location DHM-2 was sampled first and then the upstream sample DHM-1 was collected. Two Nalgene® HDPE sample bottles were filled at each monitoring location; one 500 ml bottle for general analysis and one 125 ml bottle for metals analysis. The 125 ml samples were fixed with nitric acid as a preservative to a pH less than 2 and all samples were packed in ice and shipped to the Department of Environmental Protection (DEP) Laboratory in Harrisburg, Pennsylvania. Laboratory Data is included in Appendix 2 (Table 9).

Precipitate Thickness Measurements

Precipitate thickness was measured in Pond 1 to assist with the assessment of life expectancy or volume remaining for precipitate retention. This assessment is needed for recommendation of when and if the pond needs to be cleaned out and refurbished. A total of seven (7) iron hydroxide precipitate thickness measurements were made on October 4, 2008. Precipitate depth in Pond 1 was measured by extending a six foot graduated ruler attached to a ¾ inch wooden dowel rod, taped perpendicular to the end of an extendable aluminum pole (Figure 23).

Figure 23 – Precipitate Thickness Measurement Device

The depth of the water was measured when the dowel rod first encountered the top of the precipitate. The wooden dowel rod/ruler assembly was then pressed into the precipitate to resistance with hand pressure and the measurement was recorded. Next, the aluminum extension pole was struck with a standard round-pointed shovel five times to drive the dowel to refusal at the bottom of the pond, and then a measurement was recorded. This procedure was repeated at seven locations along the length of Pond 1 (Figure 18). The thickness of precipitate was calculated and a cross section of the pond was constructed (Figure 21). A table of precipitate thickness measurements is included in Appendix 2 (Table 10). Since the original design depth of the pond is unknown, the depth of the pond was estimated as five feet deep. Therefore, only an approximation of the amount the pond has filled since construction could be determined. In order to calculate the potential life expectancy of the treatment pond, the average precipitate thickness of 12 inches was compared to the remaining pond depth and projections were made to determine how much longer the ponds could continue to retain precipitate. An unsuccessful attempt was made to identify and describe any layering in the precipitate. A three foot long, 1 inch diameter clear plastic soil sample tube, was pushed into the bottom of the pond. The tube was then tapped five times with a shovel in an attempt to set a plug of precipitate in the bottom of the sample tube. The tube was carefully withdrawn from the bottom of the pond. However, each time the tube was withdrawn, no precipitate sample was retained in the tube.

Analysis

Four general types of data were analyzed for this project: (1) climate data (Figures 24-26); (2) field measurements of pH, temperature, and flow; (3) laboratory sample analysis; (4) precipitate depth/thickness measurements. All of data are included graphically in Appendix 2

Climatic Data

The daily precipitation measurements recorded at the Moraine State Park South Shore Office weather station are shown in Figure 24. Figure 25 shows the monthly precipitation totals for the period from January 2007 through September 2008. Figure 26 shows the departure from normal of the monthly precipitation data. In addition to the weather monitoring station at the South Shore Park Office, precipitation data is available at three NOAA weather monitoring stations in the region. These three locations are between 7 and 12 miles from Moraine State Park. Precipitation amounts, lake level and temperature are measured by the park rangers and tabulated. Copies of this data was provided and compared to the regional monitoring locations. The precipitation amounts for the three regional stations and the Moraine State Park data coincide. Unfortunately, the month of October 2007 is not available for the Moraine State Park station. Comparisons of daily precipitation data to flow data are shown in Figures 27 through 29. Monitoring point water temperature is compared to ambient air temperature maximums and minimums in Figure 30. Air temperature increased throughout the monitoring period. Water temperatures at the monitoring locations increased as air temperature increased. Temperature of the treatment pond water increased as it flowed through the system.

Field Data Measurements

Flow data for the wetlands treatment ponds and MDJ-1 is shown in Figure 31. A comparison was made between upstream (DHM-1) and downstream (DHM-2) flow measurements for the control stream (Figure 32).

Laboratory Water Quality Data

A comparison was made between upstream (DHM-1) and downstream (DHM-2) laboratory water quality data of the control stream. Most of the parameters were below detection limits. Therefore, only pH and alkalinity vs. acidity were graphed for comparison (Figures 33 and 34). A limited amount of historical water quality data was obtained from the Moraine State Park office. Several agencies were contacted to request any additional data they might have regarding the construction and design of the treatment system. Several samples had been collected; however, the descriptions of the sample locations did not lend themselves to location in the field. Attempts to locate someone with knowledge of the original location of the samples were not successful. One set of samples from the completed wetland treatment system was collected on August 28, 1996 after construction. Laboratory data from this sample and the 2008 sample events is included in Appendix 1 (Table 9).

Water quality for the wetlands treatment ponds is depicted in two ways. The first is water quality trends over time and the second is trends through the wetlands treatment system. Figure 35 shows the pH data for the treatment ponds over time compared to the untreated discharge at MDJ-1. Figure 36 shows the data as the water flows through the treatment pond system. Figure 37 is a graph of the iron data for the treatment pond system over time. Figure 38 is a graph of the iron data as the water flows through the treatment pond system. Figure 39 is a graph of the field pH data for all monitoring locations. Figure 40 is a graph of the iron data compared to the pH data over time. Figure 41 is a graph of the manganese data over time. Figure 42 is a graph of the manganese data as the water flows through the treatment system. Figure 43 is a graph of the sulfate data over time. Figure 44 is a graph of the sulfate data as the water flows through the treatment system.

Iron Hydroxide Precipitate Thickness

Iron hydroxide precipitate thicknesses are presented in Appendix 1 (Table 10). The precipitate thickness was variable along the length of Pond 1. The average of the seven measurements was approximately 12 inches. A cross section through the pond is depicted in Figure 45.

Discussion

The graph of daily precipitation measured at the Moraine State Park Station show there were higher precipitation events in 2007 and generally lower and more frequent precipitation in 2008 (Figure 24). The graph of monthly precipitation (Figure 25) shows a general decrease in monthly precipitation amounts from January 2007 through September of 2008. Figure 26, the departure from normal graph, shows 3 months below average in 2007 and precipitation amounts were lower than average for April, May, July, August and September of 2008. Several graphs (Figures 27, 28, and 29) show that as precipitation decreased there was a corresponding decrease in flow especially during the months of below average precipitation near the end of the study period. There is a corresponding reduction in flow through the treatment ponds during the monitoring period. Water temperatures increased through the monitoring period and mimicked the ambient air temperature readings (Figure 30). The groundwater discharge temperatures, measured at MDJ-1 and Pond 1, remained fairly constant with only a slight increase (8 degrees F at MDJ-1) during the summer. The water in the wetlands treatment system warmed as it flowed through the ponds by a few degrees (8 to 10 degrees F). A comparison of treatment pond flow to MDJ-1 flow is shown in Figure 31. The treatment ponds had more flow than MDJ-1 and MDJ-1 had the least amount of flow variability. Flow in the control stream decreased through the monitoring period and there was no flow during late August in the Davis Hollow stream channel and pools were no longer present during early September (Figure 32). The flow amount was slightly higher at the downstream location (DHM-2) compared to the upstream monitoring location (DHM-1). By the end of September 2008, flow was beginning to return to Davis Hollow. Control stream pH increased through the monitoring period and the downstream pH was consistently higher than the upstream location (Figure 33). Figure 34 compared the alkalinity to acidity of the control stream monitoring locations and alkalinity increased with a corresponding decrease in acidity through the monitoring period. Metals concentrations were generally below detection limits which confirmed that this control stream is not affected by AMD.

The passive treatment system pH compared to the untreated discharge at MDJ-1 shows that the untreated discharge pH is slightly higher than the treatment system pH (Figure 35). The pH of MSP-2 decrease significantly during the monitoring period and the pH of the water decreased as it flowed through the system (Figure 36). Based on the analytical laboratory results the treatment ponds are net acidic. Aluminum concentrations were below detection limits and are not an issue at the passive treatment system. Figure 37 and Figure 38 show that iron concentrations are lowered from Pond 1 to the discharge of water at Pond 3. Iron is precipitating out of solution in Pond 1 and Pond 2. The discharge limit for iron from treatment ponds in Pennsylvania is 7 mg/l and the treatment ponds are meeting this standard. Figure 38 shows that there has been a water quality improvement since the ponds were constructed in 1996. However, the discharge in 1996 did not meet the 7 mg/l discharge limit for iron for treatment systems. Manganese concentrations were constant through the monitoring period (Figure 41). The concentration of manganese at the untreated discharge (MDJ-1) was consistently less than at the wetlands treatment system. During the spring months of March, April, and May there was a slight decrease in concentration as the water flowed through the wetlands treatment system (Figure 42). During the months of June, July, and August analysis showed a slight increase in manganese concentration. A similar increase in concentration was recorded in the data from August of 1996. Manganese concentrations are slightly lower than when the ponds were initially constructed. However, manganese is not being removed in large quantities. The discharge limit for manganese from treatment ponds in Pennsylvania is 5 mg/l and the treatment ponds are meeting this standard. Figure 42 shows that there has been a water quality improvement since the ponds were constructed in 1996. However, the discharge in 1996 met the 5 mg/l discharge limit for manganese. Sulfate concentration at MDJ-1 increased through the monitoring period and the treatment ponds showed a fluctuation with an increase for the June sample. Sulfate concentrations decreased as the water flowed through the wetlands treatment system similar to the samples collected in 1996. However, the concentration of sulfate is lower than when the ponds were initially constructed (Figure 44). As a qualitative indicator, the "rotten egg" smell of Pond 3 demonstrates that the reaction described in equation 12 is present and ongoing. The requirements for sulfate reducing bacteria appear to be met and these processes appear to be occurring, based on the decrease in sulfate concentration through the wetlands treatment system. The single historical sample (August 28, 1996) from the wetlands treatment system matches this same trend. This is apparent in the graphs of sulfate concentration (Figure 43 and Figure 44). During the summer months, the pH of the final effluent from the system lowers. Iron is removed from the water as it moves through the system. Sulfate concentrations are lowered slightly as the water flows through the system. The compost and organic materials growing in Pond 2 and Pond 3 contribute to the amelioration.

As of this date, the cleaning out of the ponds has not been necessary because the iron precipitate is accumulating in the treatment system and not in Lake Arthur. Precipitate depth measurements (Figure 45) show that the thickness decreases from northern to the southern portion of the pond (20 inches to 8 inches respectively) with an average thickness of about 12 inches. This equates to an accumulation rate of 1 inch a year. With between 30 and 40 inches of pond depth remaining, the precipitate could be retained in Pond 1 for another 25 to 30 years before the pond would need to be cleaned and the precipitate removed.

Conclusions

At the beginning of the monitoring period, in March 2008, there was still an accumulation of snow on the ground. The elevated flow readings at the control stream monitoring points clearly showed the spring thaw (Figure 28). Precipitation is typically higher in the spring and decreases through the summer and fall season. Treatment pond flow decreased through the monitoring period which corresponds to the recorded decrease in precipitation.

Based on the initial visual examination of the passive wetlands treatment system, the system appeared to be functioning properly. There was no accumulation of iron precipitate in Lake Arthur at the outlet from Pond 3. However, no measurements of water quality had been collected to determine if the treatment system was functioning properly and to determine if the water quality had improved since the system was installed. The only samples collected were shortly after the construction of the treatment system (August 28, 1996) and no samples had been collected since that time. Moraine State Park Staff had not measured iron concentrations from the treatment system and did not know if the system was continuing to functioning properly. This is the philosophy of construct the system and it will passively treat the water with no other involvement needed. Minimal maintenance was done on the ponds over the twelve years since construction. After 12 years, the assumption was that the ponds would need to be cleaned and maintained. Someone needed to collect water samples to determine whether the system was functioning properly and determine whether the ponds needed to be cleaned out. This study determined that the passive wetlands treatment system is treating the AMD discharge adequately with no major impacts to the lake and Pond 1 can continue to collect and contain additional precipitate volume for many years.

Dissolved iron is precipitating out of solution in Pond 1 and Pond 2. The hydrolysis reaction from the precipitation of iron hydroxide in Pond 2 increases the hydrogen ion concentration and therefore the pH is lower at the outlet to Pond 2 (MSP-2). A pH increase is shown for Pond 3 for most months. This could be due to the removal of sulfate and a corresponding slight increase in alkalinity. The data show that the passive wetlands treatment system is functioning properly. The passive wetlands treatment ponds lower the iron concentration as the water flows through the system. All measurements at the discharge to Lake Arthur are below Pennsylvania water quality discharge limits for treatment systems.

Hedin et al (1994) and Watzlaf et al (2004) describe the most common maintenance concerns for passive wetlands treatment ponds is embankment and outlet stability. In addition, they describe pests (muskrats, beavers, and other burrowing creatures) causing instability of embankments, blocking outlet structures and uprooting emergent vegetation causing water level fluctuations. Muskrat(s) have been active in Pond 3 and at monitoring point MSP-3 during the time of this investigation (Figure 46). Vegetative material was piled against the flow monitoring weir, blocking the flow, and raising the pond water level. This vegetation was removed several times (Figure 47). This affected the Pond 3 water level and therefore the flow rate measurements for MSP-3. Elevated flow readings were measured but were not included on the graphs of flow data.

Figure 46 – Muskrat blockage of Pond 3 outlet (MSP-3 weir covered; rock hammer for scale)

It was anticipated that the treatment pond flow rate would be steady with slight seasonal fluctuations and increased flow corresponding to precipitation events. This did occur through the monitoring period. The treatment pond system shows a general trend of decreased flow through the monitoring period.

Figure 47 – (Field assistant, Paul Winter, shown removing blockage from outflow pond.)

The decrease in flow may be due to the uptake of water and evapotranspiration processes of the wetland vegetation. The water quality was expected to improve as it flowed through the passive wetlands treatment system. The control stream was expected to have consistently better water quality and that flow rates would vary seasonally with higher flows in the spring and lower discharge in the summer. It was unanticipated that the pH of the control stream would increase over time and that there would be a difference between the upstream and downstream pH measurements.

Water quality did improve as the water flowed through the passive wetlands treatment system. Iron, manganese, and sulfate all had lower concentrations by the time treated water flowed out of the final pond. Although the manganese concentration was reduced less than 1 mg/l, the discharge still meets Pennsylvania discharge requirements of less than 5 mg/l. It was unexpected and interesting that the acidity increased (with a corresponding lowering of the pH) as the metals precipitated out of solution. The hydrolysis reaction is evident in Figures 38 and 40. As iron is removed the pH of the water in Pond 2 is lowered.

Water quality for MDJ-1 (the untreated AMD discharge) changed throughout the monitoring period. The quality of the untreated AMD discharge was expected to remain consistent with some improvement during and immediately after precipitation events due to dilution. The quality changes, however, could not be linked to the flow conditions as flow remained fairly constant through the monitoring period. Sulfate concentration increased throughout the monitoring period. This could be due to less rainfall available for groundwater recharge and shallower groundwater being used in evapotranspiration processes. While the manganese concentration was lowest at MDJ-1, compared to the wetland treatment system, the concentration increased through the monitoring period. This could be due to the lack of dilution caused by a reduction of groundwater recharge.

The wetlands treatment ponds showed a slight lowering of sulfate through the treatment system. Through the monitoring period, sulfate concentrations lowered from high in the spring (295.9 mg/l) to fluctuating in the summer and an upward trend is apparently occurring in the fall (Figure 43). This could be due to reduced precipitation, reduction of groundwater recharge due to increased evapotraspiration and precipitation, or changes in the conditions needed for sulfate removal (equation 11) such as circum-neutral pH, anoxic conditions, no Fe^{3+}, and a minimum of 100 mg/l of sulfate in the water. Manganese concentrations decreased slightly through the wetlands treatment system for most dates of monitoring. The initial samples collected in 1996 showed an increase of manganese through the system (Figure 42). The July 14, 2008 samples indicated an increase in manganese concentration through the system. Iron concentration was lowered as the water flowed through the treatment system. By the time water flowed into Lake Arthur, the treatment system had removed enough iron that the water would meet Pennsylvania discharge limits (7 mg/l). In general, the overall water quality has improved since the treatment system was installed. All parameters are lower than they were after the system was initially installed in 1996 (Figures 38, 42, and 44).

One of the limiting factors for passive wetlands treatment systems is the accumulation of precipitate which reduces the retention time of the water being treated. By using the average measured precipitate thickness present in Pond 1 (approximately 12 inches), over the twelve year life of the pond, this yields an accumulation rate of about one inch per year. With a current remaining pond depth estimated at 36 inches, there should be sufficient volume in Pond 1 for approximately 25 to 30 years of precipitate retention remaining.

Recommendations

This study analyzed the passive wetlands treatment performance. As part of the study, three concerns were addressed as recommendations: 1) whether the initial settling pond required cleaning 2) suggested monitoring and maintenance plan 3) recommend the best timing for the pond precipitate cleaning to be performed.

It appears that there is sufficient capacity in Pond 1 for many more years of precipitate retention. Ponds in the wetlands treatment system should be monitored on a yearly basis for standard AMD parameters. A standard HACH test for iron would be sufficient. There are several small shrubs and trees growing on the pond embankments. These trees and shrubs should be removed from the embankments and the larger dead trees on the northern side of the ponds should be removed. The outlet structures of the ponds should be checked and cleaned of vegetation material on at least an annual basis. After the vegetation is removed from the pond outlets, a few wheelbarrow loads of limestone cobbles could be added to the outlet structures of Pond 1 and Pond 3 to increase aeration and add alkalinity. When the ponds do need to be cleaned out, this procedure should be performed during the dry/low flow season of the year (August/September). (Note: These recommendations will be forwarded to the staff at Moraine State Park)

Further Study

Many researchers are studying the microbial-facilitated chemical processes that occur in wetlands treatment systems. These processes and additional research could be conducted at this passive wetlands treatment system and others in the area (Margaret Dunn, personal communication, 9/25/2008).

Currently, funding is not in place for the removal of the iron precipitate from both Pond 1 and Pond 2. Funding sources should be planned and an account established for future maintenance costs associated with the wetlands.

Alternative methods of precipitate removal could be researched to determine what method of removal would be best suited and what would cause the least amount of disturbance to the area around the wetland treatment system.

Precipitate samples could be collected prior to pond cleaning, and forwarded to companies that currently process iron hydroxide precipitate, to determine if there is a viable use for the recovered materials. These materials could also be used for educational activities at the park. After precipitate removal, water samples could be collected to determine if the removal of the precipitate improved the quality of the effluent water from the treatment system and/or how quickly the treatment system returned to normal operating conditions.

Bibliography

Alley, R. B.; (2000) The Two Mile Time Machine: Ice Cores, Abrupt Climate Change, and Our Future; Princeton University Press, Princeton New Jersey.

Costello, C.; (2003) Acid Mine Drainage: Innovative Treatment Technologies; United States Environmental Protection Agency, Office of Solid Waste and Emergency Response Technology Innovation Office, Washington, D.C.; Paper by a National Network of Environmental Studies Grantee, Unpublished.

DeLorme Street Atlas USA® 2005 Plus, 2004.

Dunn, Margaret; (2008); Personal Communication; Slippery Rock Watershed Coalition and Stream Restoration Incorporated, Cranberry, Pennsylvania.

Fleeger, G. M., Bushnell, K. O., and Watson, D. W., (2003) Moraine and McConnells Mill State Parks, Butler and Lawrence Counties—Glacial Lakes and Drainage Changes; Pennsylvania Geological Survey, 4th ser., Park Guide 4, 12 p.

Foreman, J. W. and McLean, D. C.; (1972) Evaluation of Pollution Abatement Procedures Moraine State Park, Butler County, Pennsylvania; Gwin, Dobson & Foreman, Inc. Consulting Engineers, Altoona, Pa. for United States Department of the Interior Federal Water Pollution Control Administration Project #14010 DSC & Commonwealth of Pennsylvania Department of Mines and Mineral Industries CR-85,. Includes Progress Reports from 1968, 1969, 1971.

Foreman, J. W.; (1968) Report of Mine Drainage Project MD-8A, Moraine State Park Watershed Area, Butler County, Pennsylvania; Gwin Engineers, Inc. Consulting Engineers, Altoona, Pa. for Commonwealth of Pennsylvania Department of Mines and Mineral Industries.

Hedin, R. S.; Narin, R. W.; and Kleinman, R. L. P.; (1994) Passive Treatment of Coal Mine Drainage; United States Department of the Interior, Bureau of Mines; Information Circular IC9389.

Maksimovic, S. D., Maynard, B. R.; (1983) Long-Term Effectiveness of Deep Mine Sealing at Moraine State P, Butler County, Pa.; United States Department of the Interior, Bureau of Mines; Report of Investigations 8767.

Manahan, S. E.; (1990) Environmental Chemistry; 4th Edition, Lewis Publishers, Inc.; originally published by W. Grant Press, Boston, 1984.

National Climatic Data Center, NOAA Precipitation Data; Monthly total precipitation and departure from normal (Received November 5 and 12, 2007) for

Stations Butler 2 SW, Slippery Rock 1SSW, and New Castle 1N. [Available online at http://ncdc.noaa.gov].

Pennsylvania Department of Conservation and Natural Resources: <http://www.dcnr.state.pa.us/stateparks/parks/moraine.aspx>.

Pennsylvania Department of Conservation and Natural Resources DCNR (2008) PAMAP Program Bureau of Topographic and Geologic Survey (Figures 16 and 17).

Poth, C.W.; (1973) Summary Ground-Water Resources of Butler County, Pennsylvania; United States Geological Survey; Water-Resources Division, in Cooperation with the Pennsylvania Geological Survey; Water Resource Report 36.

Rekich, Jeremy D.; Personal Communication, Assistant Park Manager, Bureau of State Parks, Moraine State Park and McConnells Mill State Park, Portersville, Pennsylvania.

Rose, A. W., and Cravotta III, C. A. (1998), Geochemistry of Coal Mine Drainage. P.1.1-1.22. *In* Brady, K.B., Smith, M. B., and Schuek, J. (ed.); Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania. 5600-BK-DEP2256. Pennsylvania Department of Environmental Protection, Harrisburg, Pennsylvania.

Shepps, V.C., White, G. W., Droste, J. B., and Sitler, R. F.; (1959) Glacial Geology of Northwestern Pennsylvania; Commonwealth of Pennsylvania, Department of Internal Affairs, Topographic and Geologic Survey, Bulletin G 32.

Singer, P. C. and Stumm, W. (1970) Acid Mine Drainage: the rate limiting step, Science, 167, 1121-1123.

Taylor, W., Dunn, M., and Busler, S. (2003) Accepting the Challenge – A Primer About the History, Cause, and Solutions to Abandoned Mine Drainage, Third Edition; A Slippery Rock Watershed Coalition Publication, Stream Restoration, Incorporated.

Trimmer, W. L., (1994) Estimating Water Flow Rates, EC 1369 Oregon State University Extension Service.

United States Department of the Interior Geological Survey 7.5 Minute Series Topographic Quadrangle Maps: Mount Chestnut Quadrangle, 1964; Photo revised 1993. Portersville Quadrangle, 1961; Photo revised 1979. Prospect Quadrangle, 1961; Photo revised 1970.

USGS, 2008 <http://waterdata.usgs.gov/nwis/uv?03106300>.

Watzlaf, G. R., Schroeder, K.T., Kleinman, R. L. P., Kairies, C. L., and Narin, R. W.; (2004) The Passive Treatment of Coal Mine Drainage; United States Department of Energy, National Energy Technology Laboratory 2004/1202.

Younger, P. L., Banwart, S. A., and Hedin, R. S.; (2002) Mine Water - Hydrology, Pollution, Remediation; Kluwer Academic Publishers, Dordrecht, Netherlands.

Appendix 1

Table 1 – Precipitation Data

Tables 3 through 8 – Field Data

Table 9 – Laboratory Data

Table 10 – Precipitate Thickness

Table 1

MSP Weather Information 2007-2008

Date	Precip. (in.)	Date	Precip. (in.)	Date	Precip. (in.)	Date	Precip. (in.)	Date	Precip. (in.)	Date	Precip. (in.)
1/1/2007	0.45	2/1/2007	0.00	3/1/2007	0.01	4/1/2007	0.00	5/1/2007	0.03	6/1/2007	0.02
1/2/2007	0.40	2/2/2007	0.02	3/2/2007	0.84	4/2/2007	0.54	5/2/2007	0.14	6/2/2007	0.00
1/3/2007	0.00	2/3/2007	0.01	3/3/2007	0.00	4/3/2007	0.00	5/3/2007	0.00	6/3/2007	0.58
1/4/2007	0.00	2/4/2007	0.01	3/4/2007	0.01	4/4/2007	0.13	5/4/2007	0.00	6/4/2007	0.12
1/5/2007	0.57	2/5/2007	0.01	3/5/2007	0.01	4/5/2007	0.03	5/5/2007	0.00	6/5/2007	0.45
1/6/2007	0.55	2/6/2007	0.01	3/6/2007	0.01	4/6/2007	0.12	5/6/2007	0.00	6/6/2007	0.06
1/7/2007	0.10	2/7/2007	0.15	3/7/2007	0.17	4/7/2007	0.03	5/7/2007	0.00	6/7/2007	0.00
1/8/2007	0.05	2/8/2007	0.01	3/8/2007	0.00	4/8/2007	0.01	5/8/2007	0.00	6/8/2007	0.00
1/9/2007	1.47	2/9/2007	0.00	3/9/2007	0.00	4/9/2007	0.14	5/9/2007	0.00	6/9/2007	1.08
1/10/2007	0.05	2/10/2007	0.00	3/10/2007	0.25	4/10/2007	0.01	5/10/2007	0.00	6/10/2007	0.00
1/11/2007	0.00	2/11/2007	0.00	3/11/2007	0.00	4/11/2007	0.00	5/11/2007	0.00	6/11/2007	0.00
1/12/2007	0.10	2/12/2007	0.01	3/12/2007	0.07	4/12/2007	0.62	5/12/2007	0.00	6/12/2007	0.00
1/13/2007	0.70	2/13/2007	0.06	3/13/2007	0.00	4/13/2007	0.15	5/13/2007	0.00	6/13/2007	0.00
1/14/2007	0.30	2/14/2007	0.50	3/14/2007	0.05	4/14/2007	0.01	5/14/2007	0.00	6/14/2007	0.03
1/15/2007	0.79	2/15/2007	0.00	3/15/2007	1.27	4/15/2007	0.51	5/15/2007	0.00	6/15/2007	0.00
1/16/2007	0.55	2/16/2007	0.00	3/16/2007	0.44	4/16/2007	0.03	5/16/2007	0.09	6/16/2007	0.00
1/17/2007	0.06	2/17/2007	0.01	3/17/2007	0.05	4/17/2007	0.24	5/17/2007	0.35	6/17/2007	0.00
1/18/2007	0.00	2/18/2007	0.01	3/18/2007	0.01	4/18/2007	0.01	5/18/2007	0.01	6/18/2007	0.00
1/19/2007	0.09	2/19/2007	0.00	3/19/2007	0.00	4/19/2007	0.00	5/19/2007	0.02	6/19/2007	0.02
1/20/2007	0.07	2/20/2007	0.09	3/20/2007	0.50	4/20/2007	0.00	5/20/2007	0.17	6/20/2007	1.01
1/21/2007	0.01	2/21/2007	0.16	3/21/2007	0.05	4/21/2007	0.00	5/21/2007	0.00	6/21/2007	0.00
1/22/2007	0.06	2/22/2007	0.03	3/22/2007	0.25	4/22/2007	0.00	5/22/2007	0.00	6/22/2007	0.26
1/23/2007	0.04	2/23/2007	0.07	3/23/2007	0.30	4/23/2007	0.00	5/23/2007	0.00	6/23/2007	0.00
1/24/2007	0.01	2/24/2007	0.00	3/24/2007	0.60	4/24/2007	0.00	5/24/2007	0.00	6/24/2007	0.00
1/25/2007	0.15	2/25/2007	0.01	3/25/2007	0.01	4/25/2007	0.00	5/25/2007	0.02	6/25/2007	0.00
1/26/2007	0.01	2/26/2007	0.26	3/26/2007	0.00	4/26/2007	0.75	5/26/2007	0.07	6/26/2007	0.00
1/27/2007	0.07	2/27/2007	0.01	3/27/2007	0.00	4/27/2007	0.22	5/27/2007	0.02	6/27/2007	0.00
1/28/2007	0.05	2/28/2007	0.01	3/28/2007	0.00	4/28/2007	0.15	5/28/2007	0.17	6/28/2007	1.53
1/29/2007	0.04			3/29/2007	0.00	4/29/2007	0.03	5/29/2007	0.00	6/29/2007	0.20
1/30/2007	0.09			3/30/2007	0.00	4/30/2007	0.00	5/30/2007	0.00	6/30/2007	0.00
1/31/2007	0.19			3/31/2007	0.00			5/31/2007	0.00		

Table 1 (cont)

Date	Precip. (in.)	Date	Precip. (in.)	Date	Precip. (in.)	Date	Precip. (in.)	Date	Precip. (in.)	Date	Precip. (in.)
7/1/2007	0.00	8/1/2007	0.00	9/1/2007	0.00	10/1/2007		11/1/2007	0.03	12/1/2007	0.00
7/2/2007	0.00	8/2/2007	0.00	9/2/2007	0.00	10/2/2007		11/2/2007	0.00	12/2/2007	0.02
7/3/2007	0.00	8/3/2007	0.00	9/3/2007	0.00	10/3/2007		11/3/2007	0.00	12/3/2007	0.66
7/4/2007	0.00	8/4/2007	0.00	9/4/2007	0.00	10/4/2007		11/4/2007	0.00	12/4/2007	0.20
7/5/2007	0.02	8/5/2007	0.00	9/5/2007	0.00	10/5/2007		11/5/2007	0.00	12/5/2007	0.10
7/6/2007	0.12	8/6/2007	0.97	9/6/2007	0.00	10/6/2007		11/6/2007	0.29	12/6/2007	0.25
7/7/2007	0.00	8/7/2007	0.03	9/7/2007	0.00	10/7/2007		11/7/2007	0.23	12/7/2007	0.15
7/8/2007	0.00	8/8/2007	1.65	9/8/2007	0.51	10/8/2007		11/8/2007	0.00	12/8/2007	0.22
7/9/2007	0.00	8/9/2007	0.42	9/9/2007	0.26	10/9/2007		11/9/2007	0.01	12/9/2007	0.01
7/10/2007	0.00	8/10/2007	1.72	9/10/2007	0.00	10/10/2007		11/10/2007	0.01	12/10/2007	0.85
7/11/2007	0.00	8/11/2007	0.01	9/11/2007	0.02	10/11/2007		11/11/2007	0.00	12/11/2007	0.00
7/12/2007	0.18	8/12/2007	0.00	9/12/2007	0.00	10/12/2007		11/12/2007	0.44	12/12/2007	0.62
7/13/2007	0.00	8/13/2007	0.00	9/13/2007	0.00	10/13/2007		11/13/2007	0.55	12/13/2007	0.75
7/14/2007	0.00	8/14/2007	0.00	9/14/2007	0.00	10/14/2007		11/14/2007	0.08	12/14/2007	0.25
7/15/2007	0.00	8/15/2007	0.00	9/15/2007	0.41	10/15/2007		11/15/2007	0.18	12/15/2007	1.12
7/16/2007	0.00	8/16/2007	0.01	9/16/2007	0.00	10/16/2007		11/16/2007	0.12	12/16/2007	0.70
7/17/2007	0.00	8/17/2007	0.00	9/17/2007	0.00	10/17/2007		11/17/2007	0.03	12/17/2007	0.12
7/18/2007	0.08	8/18/2007	0.00	9/18/2007	0.00	10/18/2007		11/18/2007	0.25	12/18/2007	0.00
7/19/2007	0.09	8/19/2007	0.01	9/19/2007	0.00	10/19/2007		11/19/2007	0.02	12/19/2007	0.01
7/20/2007	0.54	8/20/2007	1.01	9/20/2007	0.00	10/20/2007		11/20/2007	0.01	12/20/2007	0.00
7/21/2007	0.00	8/21/2007	2.36	9/21/2007	0.00	10/21/2007		11/21/2007	0.00	12/21/2007	0.00
7/22/2007	0.00	8/22/2007	0.06	9/22/2007	0.00	10/22/2007		11/22/2007	0.55	12/22/2007	0.00
7/23/2007	0.00	8/23/2007	0.06	9/23/2007	0.00	10/23/2007		11/23/2007	0.20	12/23/2007	0.80
7/24/2007	0.00	8/24/2007	0.00	9/24/2007	0.00	10/24/2007		11/24/2007	0.06	12/24/2007	0.15
7/25/2007	0.33	8/25/2007	0.85	9/25/2007	0.00	10/25/2007		11/25/2007	0.00	12/25/2007	0.00
7/26/2007	0.01	8/26/2007	0.00	9/26/2007	0.00	10/26/2007		11/26/2007	0.47	12/26/2007	0.00
7/27/2007	0.88	8/27/2007	0.00	9/27/2007	0.04	10/27/2007		11/27/2007	0.95	12/27/2007	0.78
7/28/2007	0.26	8/28/2007	0.00	9/28/2007	2.50	10/28/2007		11/28/2007	0.00	12/28/2007	0.01
7/29/2007	0.05	8/29/2007	0.00	9/29/2007	0.00	10/29/2007		11/29/2007	0.00	12/29/2007	0.22
7/30/2007	0.00	8/30/2007	0.00	9/30/2007	0.00	10/30/2007		11/30/2007	0.00	12/30/2007	0.00
7/31/2007	0.00	8/31/2007	0.00			10/31/2007				12/31/2007	0.01

Table 1 (cont)

Date	Precip. (in.)	Date	Precip. (in.)	Date	Precip. (in.)	Date	Precip. (in.)	Date	Precip. (in.)	Date	Precip. (in.)
1/1/2008	0.10	2/1/2008	0.50	3/1/2008	0.01	4/1/2008	0.18	5/1/2008	0.01	6/1/2008	0
1/2/2008	0.17	2/2/2008	0.51	3/2/2008	0.02	4/2/2008	0.00	5/2/2008	0	6/2/2008	0
1/3/2008	0.04	2/3/2008	0.00	3/3/2008	0.00	4/3/2008	0.00	5/3/2008	0.02	6/3/2008	0
1/4/2008	0.00	2/4/2008	0.01	3/4/2008	0.68	4/4/2008	0.16	5/4/2008	0.35	6/4/2008	0.37
1/5/2008	0.00	2/5/2008	1.25	3/5/2008	0.56	4/5/2008	0.30	5/5/2008	0	6/5/2008	0.23
1/6/2008	0.20	2/6/2008	0.53	3/6/2008	0.00	4/6/2008	0.00	5/6/2008	0	6/6/2008	1
1/7/2008	0.01	2/7/2008	0.19	3/7/2008	0.03	4/7/2008	0.00	5/7/2008	0	6/7/2008	0
1/8/2008	0.00	2/8/2008	0.08	3/8/2008	0.50	4/8/2008	0.00	5/8/2008	0.45	6/8/2008	0
1/9/2008	0.16	2/9/2008	0.01	3/9/2008	0.25	4/9/2008	0.00	5/9/2008	0.01	6/9/2008	0
1/10/2008	0.00	2/10/2008	0.10	3/10/2008	0.01	4/10/2008	0.00	5/10/2008	0.26	6/10/2008	0.01
1/11/2008	0.94	2/11/2008	0.02	3/11/2008	0.00	4/11/2008	0.16	5/11/2008	0	6/11/2008	0.1
1/12/2008	0.01	2/12/2008	0.25	3/12/2008	0.06	4/12/2008	0.42	5/12/2008	0.46	6/12/2008	0
1/13/2008	0.00	2/13/2008	0.51	3/13/2008	0.00	4/13/2008	0.22	5/13/2008	0.01	6/13/2008	0
1/14/2008	0.30	2/14/2008	0.00	3/14/2008	0.25	4/14/2008	0.20	5/14/2008	0	6/14/2008	0.62
1/15/2008	0.02	2/15/2008	0.10	3/15/2008	0.53	4/15/2008	0.00	5/15/2008	0.08	6/15/2008	0.51
1/16/2008	0.08	2/16/2008	0.00	3/16/2008	0.01	4/16/2008	0.00	5/16/2008	0.4	6/16/2008	0.07
1/17/2008	0.00	2/17/2008	0.02	3/17/2008	0.35	4/17/2008	0.00	5/17/2008	0.03	6/17/2008	0.01
1/18/2008	0.13	2/18/2008	0.15	3/18/2008	0.02	4/18/2008	0.00	5/18/2008	0.35	6/18/2008	0.05
1/19/2008	0.00	2/19/2008	0.05	3/19/2008	0.25	4/19/2008	0.00	5/19/2008	0.1	6/19/2008	0
1/20/2008	0.00	2/20/2008	0.00	3/20/2008	1.05	4/20/2008	0.39	5/20/2008	0	6/20/2008	0
1/21/2008	0.00	2/21/2008	0.01	3/21/2008	0.00	4/21/2008	0.06	5/21/2008	0.01	6/21/2008	0
1/22/2008	0.00	2/22/2008	0.25	3/22/2008	0.02	4/22/2008	0.00	5/22/2008	0.04	6/22/2008	0.54
1/23/2008	0.11	2/23/2008	0.25	3/23/2008	0.03	4/23/2008	0.00	5/23/2008	0	6/23/2008	0.01
1/24/2008	0.04	2/24/2008	0.01	3/24/2008	0.00	4/24/2008	0.01	5/24/2008	0	6/24/2008	0.11
1/25/2008	0.00	2/25/2008	0.00	3/25/2008	1.63	4/25/2008	0.00	5/25/2008	0	6/25/2008	0
1/26/2008	0.01	2/26/2008	0.21	3/26/2008	0.00	4/26/2008	0.01	5/26/2008	0	6/26/2008	0.9
1/27/2008	0.02	2/27/2008	0.30	3/27/2008	0.00	4/27/2008	0.00	5/27/2008	0.01	6/27/2008	0.2
1/28/2008	0.01	2/28/2008	0.05	3/28/2008	0.85	4/28/2008	0.75	5/28/2008	0	6/28/2008	0.88
1/29/2008	0.18	2/29/2008	0.48	3/29/2008	0.01	4/29/2008	0.22	5/29/2008	0	6/29/2008	0.09
1/30/2008	0.00			3/30/2008	0.00	4/30/2008	0.00	5/30/2008	0	6/30/2008	0.44
1/31/2008	0.00			3/31/2008	0.40			5/31/2008	0.12		

Table 1 (cont)

Date	Precip. (in.)	Date	Precip. (in.)	Date	Precip. (in.)
7/1/2008	0.09	8/1/2008	0	9/1/2008	0
7/2/2008	0	8/2/2008	0.7	9/2/2008	0
7/3/2008	0.04	8/3/2008	0	9/3/2008	0
7/4/2008	0.2	8/4/2008	0	9/4/2008	0
7/5/2008	0	8/5/2008	0.02	9/5/2008	0
7/6/2008	0	8/6/2008	0.15	9/6/2008	0
7/7/2008	0	8/7/2008	0.08	9/7/2008	0
7/8/2008	0	8/8/2008	0.5	9/8/2008	0
7/9/2008	0.12	8/9/2008	0.06	9/9/2008	0.45
7/10/2008	0.03	8/10/2008	0.23	9/10/2008	0.08
7/11/2008	0	8/11/2008	0.14	9/11/2008	0
7/12/2008	0.25	8/12/2008	0	9/12/2008	0.66
7/13/2008	0.22	8/13/2008	0	9/13/2008	0.63
7/14/2008	0.47	8/14/2008	0	9/14/2008	0.39
7/15/2008	0	8/15/2008	0	9/15/2008	0
7/16/2008	0	8/16/2008	0	9/16/2008	0
7/17/2008	0	8/17/2008	0	9/17/2008	0
7/18/2008	0	8/18/2008	0	9/18/2008	0
7/19/2008	0	8/19/2008	0	9/19/2008	0
7/20/2008	0.25	8/20/2008	0	9/20/2008	0
7/21/2008	0.15	8/21/2008	0	9/21/2008	0
7/22/2008	0.25	8/22/2008	0	9/22/2008	0
7/23/2008	0.4	8/23/2008	0	9/23/2008	0
7/24/2008	0	8/24/2008	0	9/24/2008	0
7/25/2008	0.2	8/25/2008	0.01	9/25/2008	0
7/26/2008	0	8/26/2008	0	9/26/2008	0
7/27/2008	0.2	8/27/2008	0	9/27/2008	0.04
7/28/2008	0	8/28/2008	0.67	9/28/2008	0.03
7/29/2008	0	8/29/2008	0.07	9/29/2008	0
7/30/2008	0	8/30/2008	0.02	9/30/2008	0.03
7/31/2008	0	8/31/2008	0		

Table 3

Location MSP-1 Pond-1outlet

Date	Flow (gpm)	Temp. (F)	pH	Fe (Hach Kit)	Comments:
3/13/2008	21.6	50		>10	Flow measured using Baski Flume.
3/17/2008	30.8	50	4.52		pH meter may be low on batteries
4/4/2008		54	5.0		no weir set up yet.
4/12/2008		55	5.7		no weir set up yet.
4/19/2008		61	5.1		no weir set up yet.
4/21/2008	21.7	57	5.6		Installed weir at pond overflow.
5/4/2008	21.7	56			batteries low on pH meter.
5/10/2008	16.7	60			
5/16/2008	16.7	58	5.7		
5/19/2008	21.7	56	5.8		
5/23/2008	21.7	65	5.9		
5/25/2008	16.7	63	5.7		
5/30/2008	16.7	60	5.8		
6/7/2008	16.7	63	5.8		
6/13/2008	16.7	62	5.8		
6/16/2008	16.7	62	5.6		
7/7/2008	8.89	64	5.6		
7/11/2008	8.89	65	5.6		
7/14/2008	8.89	59	5.6		
7/19/2008	8.89	60	5.8		
8/9/2008	6.05	59	5.8		
8/15/2008	248	57	5.8		
8/17/2008	8.89	56	5.9		
8/18/2008	12.4	58	5.7		
8/31/2008	8.89	59	5.9		
9/7/2008	8.89	56	5.8		
9/11/2008	8.89	60	5.7		
9/13/2008	12.4	58	5.8		
9/20/2008	8.89	56	5.9		

Table 4

Location MSP-2 Pond-2 outlet

Date	Flow (gpm)	Temp. (F)	pH	Fe (Hach Kit)	Comments:
3/13/2008		50		1.6	Flow from outlet of pond 2 6.75 inch OD PVC pipe.
3/17/2008		48	4.9		pH meter may be low on batteries
4/4/2008		52	5.6		
4/12/2008		55	5.3		no flow measurement; need a 90 degree pipe.
4/19/2008	26.6	62	5.2		
4/21/2008	30	58	5.2		
5/4/2008	30	56			batteries low on pH meter.
5/10/2008	26.6	60			
5/16/2008	26.6	57	5.0		
5/19/2008	24	58	5.1		
5/23/2008	26.6	67	5.0		
5/25/2008	24	66	4.9		
5/30/2008	24	62	4.9		
6/7/2008	24	65	4.7		
6/13/2008	21.8	65	4.4		Pipe outlet submerged about 1".
6/16/2008	20	64	4.4		
7/7/2008	14.1	66	4.2		
7/11/2008	12	69	4.1		
7/14/2008	12.6	64	4.3		
7/19/2008	12	66	4.1		
8/9/2008	8	62	4.1		
8/15/2008	120	58	5.8		
8/17/2008	16	60	4.3		
8/18/2008	16	60	4.2		
8/31/2008	13.33	63	4.2		
9/7/2008	14.1	59	4.3		
9/11/2008	13.33	60	4.3		
9/13/2008	21.8	60	4.3		
9/20/2008	12.6	59	4.5		

Table 5

Location MSP-3 Pond-3 outlet

Date	Flow (gpm)	Temp. (F)	pH	Fe (Hach Kit)	Comments:
3/13/2008	21.7	51		1.6	
3/17/2008	41.8	42	5.06		pH meter may be low on batteries
3/20/2008	50.3	51			
3/29/2008	27.5	51			
4/4/2008	34.2	50	5.6		
4/12/2008	27.5	58	5.5		
4/19/2008	21.7	64	5.3		
4/21/2008	21.7	60	5.4		
5/4/2008	156	56			Possible rodent blockage; cleaned out & measured.
5/10/2008	21.7	61			batteries low on pH meter.
5/16/2008	21.7	59	5.3		
5/19/2008	21.7	56	5.4		
5/23/2008	21.7	67	5.3		
5/25/2008	21.7	68	4.9		
5/30/2008	16.7	62	5.3		
6/7/2008	50.3	68	5.2		vegetation blockage of weir; therefore flow higher.
6/13/2008	123	68	5.4		vegetation blockage of weir; therefore flow higher.
6/16/2008	193	67	5.6		Muskrat blocked weir with vegetation
7/7/2008	193	69	5.3		Muskrat blocked weir with vegetation
7/11/2008	108	74	5.1		Muskrat blocked weir with vegetation
7/14/2008	156	67	5.7		Muskrat blocked weir with vegetation
7/19/2008	81.7	70	5.1		Muskrat blocked weir with vegetation
8/9/2008	139	67	5.3		Muskrat blocked weir with vegetation
8/15/2008	193	65	4.3		Muskrat blocked weir with vegetation
8/17/2008	81.7	62	4.1		Muskrat blocked weir with vegetation
8/18/2008	34.2	63	4.6		Muskrat blocked weir with vegetation
8/31/2008	156	64	4.2		Muskrat blocked weir with vegetation
9/7/2008	94.2	62	4.1		Muskrat blocked weir with vegetation
9/11/2008	59.7	62	4.2		Muskrat blocked weir with vegetation
9/13/2008	12.4	63	4.1		No blockage
9/20/2008	8.89	62	4.7		No blockage

Table 6

Location MDJ-1 Untreated AMD Discharge

Date	Flow (gpm)	Temp. (F)	pH	Fe (Hach Kit)	Comments:
3/13/2008	8.9	52		4	
3/17/2008	12.4	52	4.52		pH meter may be low on batteries
3/20/2008	8.89	52			
3/29/2008	12.4	52			
4/4/2008	8.89	52	5.5		
4/12/2008	8.89	54	5.7		
4/19/2008	6.05	53	5.6		
4/21/2008	6.05	53	5.1		
5/4/2008	6.05	54			batteries low on pH meter.
5/10/2008	8.89	54			
5/16/2008	8.89	53	5.5		
5/19/2008	8.89	54	5.6		
5/23/2008	6.05	65	5.6		
5/25/2008	6.05	57	5.6		
5/30/2008	6.05	61	5.6		Repair/redirect some flow uphill through MDJ-1.
6/7/2008	8.89	60	5.6		
6/13/2008	8.89	59	5.5		
6/16/2008	8.89	57	5.6		
7/7/2008	6.05	58	5.5		
7/11/2008	6.05	60	5.5		
7/14/2008	8.89	56	5.6		
7/19/2008	8.89	57	5.4		
8/9/2008	6.05	56	5.5		
8/15/2008	6.05	58	5.4		
8/17/2008	6.05	56	5.4		
8/18/2008	6.05	58	5.6		
8/31/2008	6.05	58	5.4		
9/7/2008	6.05	58	5.4		
9/11/2008	6.05	57	5.4		
9/13/2008	6.05	57	5.6		
9/20/2008	6.05	57	5.5		

Table 7

Location MSPDHM-1

Date	Flow (gpm)	Temp. (F)	pH	Fe (Hach Kit)	Comments:
3/13/2008	233.0	42		0	Measure flow with 8" Baski flume.
3/17/2008	624.0	40	3.4		pH meter may be low on batteries
3/20/2008	1990.0	46			Weir full plus 3/4 inches across 8 feet; est. of flow.
3/29/2008	422.0	46			
4/4/2008	302.0	47	6.2		
4/12/2008	248.0	52	6.7		
4/19/2008	107.5	60	7.1		
4/21/2008	150.4	54	5.6		
5/4/2008	248.0	55			pH meter needs new batteries.
5/10/2008	197.0	57			batteries low on pH meter.
5/16/2008	197.0	54	5.8		
5/19/2008	197.0	52	6.9		
5/23/2008	65.0	62	6.7		
5/25/2008	40.0	64	7.2		
5/30/2008	24.5	59	7.5		flume measurement of flow
6/7/2008	23.0	64	7.6		
6/13/2008	17.6	66	7.5		
6/16/2008	17.6	63	7.4		
7/7/2008	13.0	65	6.5		
7/11/2008	10.9	66	6.5		
7/14/2008	14.4	64	7.1		
7/19/2008	13.0	67	6.6		
8/9/2008	9.9	62	6.7		
8/15/2008	9.0	62	6.4		
8/17/2008	9.0	62	6.3		
8/18/2008	9.0	63	6.5		
8/31/2008	0.0	64	6.5		Temp and pH measured in pool
9/7/2008	0.0	nm	nm		No flow or pool
9/11/2008	0.0	nm	nm		
9/13/2008	45.0	64	6.5		
9/20/2008	2.0	62	6.3		

Table 8

Location MSPDHM-2

Date	Flow (gpm)	Temp. (F)	pH	Fe (Hach Kit)	Comments:
4/4/2008		50	6.3	0	No flow measurement device installed.
4/12/2008		53	6.7		No flow measurement device installed.
4/19/2008	150.4	62	7.3		New 3 foot rectangular weir installed.
4/21/2008	197	53	7.5		
5/4/2008	302				batteries low on pH meter.
5/10/2008	197	58			
5/16/2008	248	54	6.2		
5/19/2008	197	52	6.9		
5/23/2008	107.5	61	6.7		
5/25/2008	65	64	7.2		
5/30/2008	63.2	60	7.5		flow measured with flume.
6/7/2008	70.6	60	7.4		flow measured with flume.
6/13/2008	29.2	66	7.8		
6/16/2008	26.0	64	7.8		
7/7/2008	13.0	66	6.8		
7/11/2008	9.92	68	6.8		
7/14/2008	29.2	63	7.4		
7/19/2008	13.0	67	6.6		
8/9/2008	6.1	59	5.8		
8/15/2008	9.0	62	6.4		
8/17/2008	9.0	62	6.3		
8/18/2008	9.0	63	6.2		
8/31/2008	0.0	64	6.8		Temp and pH measured in pool
9/7/2008	0.0				No flow or pool
9/11/2008	0.0				No flow or pool
9/13/2008	78.3	64	6.5		
9/20/2008	3.8	66	6.4		

Table 9

MSP-1 First Settling Pond MSP-1

Date	pH	Iron (total)	Manganese	Sulfate	Aluminum	Alkalinity	Acidity	Flow (gpm)	TSS	Collected by:
8/28/1996	5.7	35.2	2.71	331.3	0.584	32	86		18	DEP - Tim Gillen
3/17/2008	6.1	22.858	2.753	295.9	<0.5	35.8	18	30.8	16	jaw
4/21/2008	5.5	21.162	2.662	282.9	<0.5	13	15	21.7	20	jaw
5/19/2008	5.9	21.671	2.555	260.0	<0.5	32.5	21.4	21.7	6	jaw
6/16/2008	5.8	19.939	2.560	274.2	<0.5	32.2	28.4	16.7	6	jaw
7/14/2008	5.8	18.824	2.368	248.6	<0.5	25.4	21	8.89	<5	jaw
8/18/2008	5.8	32.586	2.630	283.8	<0.5	32.2	25	12.4	10	jaw

MSP-2 Second Treatment Pond discharge MSP-2

Date	pH	Iron (total)	Manganese	Sulfate	Aluminum	Alkalinity	Acidity	Flow (gpm)	TSS	Collected by:
8/28/1996	5.5	25.8	2.76	312.8	<0.5	24	60		24	DEP - Tim Gillen
3/17/2008	5.9	3.437	2.437	292.8	<0.5	12.6	12.6		<3	jaw
4/21/2008	6.0	0.713	2.479	272.1	<0.5	8.0	12.4	30	4	jaw
5/19/2008	5.2	0.682	2.525	253.6	<0.5	8.8	17.2	24	<5	jaw
6/16/2008	4.5	0.785	2.700	269.5	<0.5	6.6	26.8	20	<5	jaw
7/14/2008	4.3	2.004	2.378	251.6	<0.5	5.2	12.6	12.6	<5	jaw
8/18/2008	4.2	2.026	2.532	277.7	<0.5	4.4	8	15.99	<5	jaw

MSP-3 Final Treatment Pond from wetlands MSP-3

Date	pH	Iron (total)	Manganese	Sulfate	Aluminum	Alkalinity	Acidity	Flow (gpm)	TSS	Collected by:
8/28/1996	4.4	16.9	2.82	292.2	<0.5	6.4	54		48	DEP - Tim Gillen
3/17/2008	5.8	2.078	2.437	290.5	<0.5	11.4	12	30.8	<3	jaw
4/21/2008	6.2	0.527	2.458	260.2	<0.5	9.8	8.8	21.7	4	jaw
5/19/2008	5.6	0.762	2.436	240.2	<0.5	10.6	12.2	21.7	<5	jaw
6/16/2008	5.6	2.372	2.582	248.9	<0.5	11.2	14.6	193	<5	jaw
7/14/2008	5.8	4.908	2.471	242.9	<0.5	13.8	7.6	156	<5	jaw
8/18/2008	4.5	2.085	2.601	269.6	<0.5	6.6	4.4	34.2	8	jaw
								Blocked by muskrat		

Table 9 (cont)

Untreated Mine Drainage East of Treatment Ponds MDJ-1

Date	pH	Iron (total)	Manganese	Sulfate	Aluminum	Alkalinity	Acidity	Flow (gpm)	TSS	Collected by:
3/17/2008	6.0	4.184	1.223	190.6	<0.5	23	5.4	12.4	<3	jaw
4/21/2008	6.4	2.828	1.062	204.8	<0.5	15	2	6.05	4	jaw
5/19/2008	5.8	3.312	1.226	228.2	<0.5	18.2	9.2	8.89	<5	jaw
6/16/2008	5.8	2.469	1.413	246.5	<0.5	17.0	1.8	8.89	<5	jaw
7/14/2008	5.8	2.842	1.342	250.9	<0.5	17.8	6.8	8.89	<5	jaw
8/18/2008	5.8	3.984	1.675	277.2	<0.5	19	1	6.05	<5	jaw

Davis Hollow Marina Control Stream - Upstream Monitoring point DHM-1

Date	pH	Iron (total)	Manganese	Sulfate	Aluminum	Alkalinity	Acidity	Flow (gpm)	TSS	Collected by:
3/17/2008	6.0	<0.3	0.063	<20.0	<0.5	8	9.4	624		jaw
4/21/2008	6.3	<0.3	<0.05	25.8	<0.5	8.8	3	150.4	<3	jaw
5/19/2008	6.6	<0.3	<0.05	25.0	<0.5	10.4	10.4	197	<5	jaw
6/16/2008	6.9	<0.3	<0.05	<20.0	<0.5	16.8	8.4	17.6	<5	jaw
7/14/2008	7.0	<0.3	<0.05	23.6	<0.5	16.6	-6.6	14.1	<5	jaw
8/18/2008	7.1	<0.3	<0.05	<20.0	<0.5	17.4	-10.8	9.0	<5	jaw

Davis Hollow Marina Control Stream - Downstream Monitoring Point DHM-2

Date	pH	Iron (total)	Manganese	Sulfate	Aluminum	Alkalinity	Acidity	Flow (gpm)	TSS	Collected by:
4/21/2008	6.4	<0.3	<0.05	24.5	<0.5	10	4.2	197	<3	jaw
5/19/2008	6.7	<0.3	<0.05	30.1	<0.5	11.6	10.6	197	<5	jaw
6/16/2008	7.0	<0.3	0.059	25.8	<0.5	18.4	7.8	26	<5	jaw
7/14/2008	7.2	<0.3	0.065	<20.0	<0.5	18.6	-5.2	29.2	<5	jaw
8/18/2008	7.2	0.91	0.057	<20.0	<0.5	19.8	-10.6	3.8	<5	jaw

Table 10

Precipitate Thickness Measurements Pond 1			
Measurement point	Distance	Thickness (inches)	Pond Depth (approx.)
SL-1	20	20	60
SL-2	45	15.5	60
SL-3	75	15.5	60
SL-4	100	8	60
SL-5	125	12	60
SL-6	150	9	60
SL-7	180	8	60

Appendix 2

Monitoring Point Location Maps

Figure 16 and Figure 17

Data Graphs

Figures 22 through 43

Figure 16 - Barkley Road Passive Wetlands Treatment System Monitoring Locations North ↑

From: PAMAP Program Bureau of Topographic and Geologic Survey Pennsylvania Department of Conservation and Natural Resources (2007)

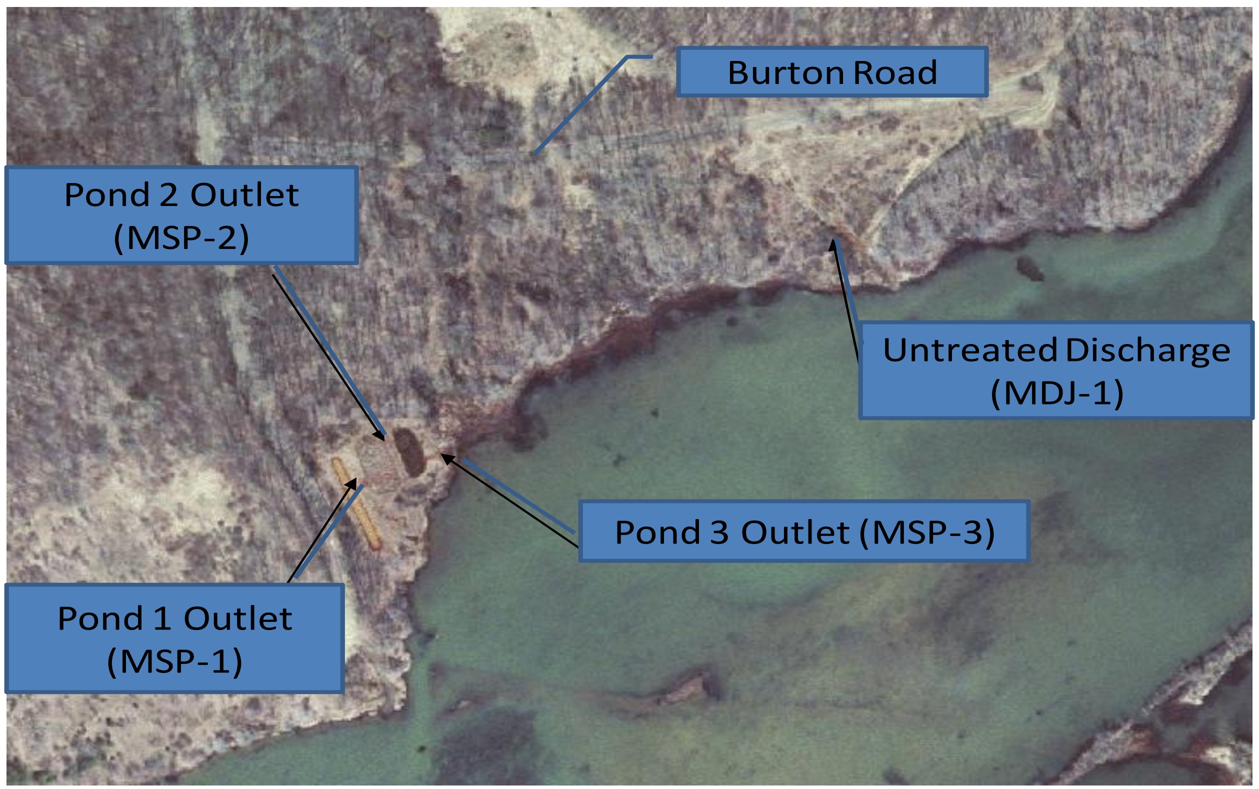
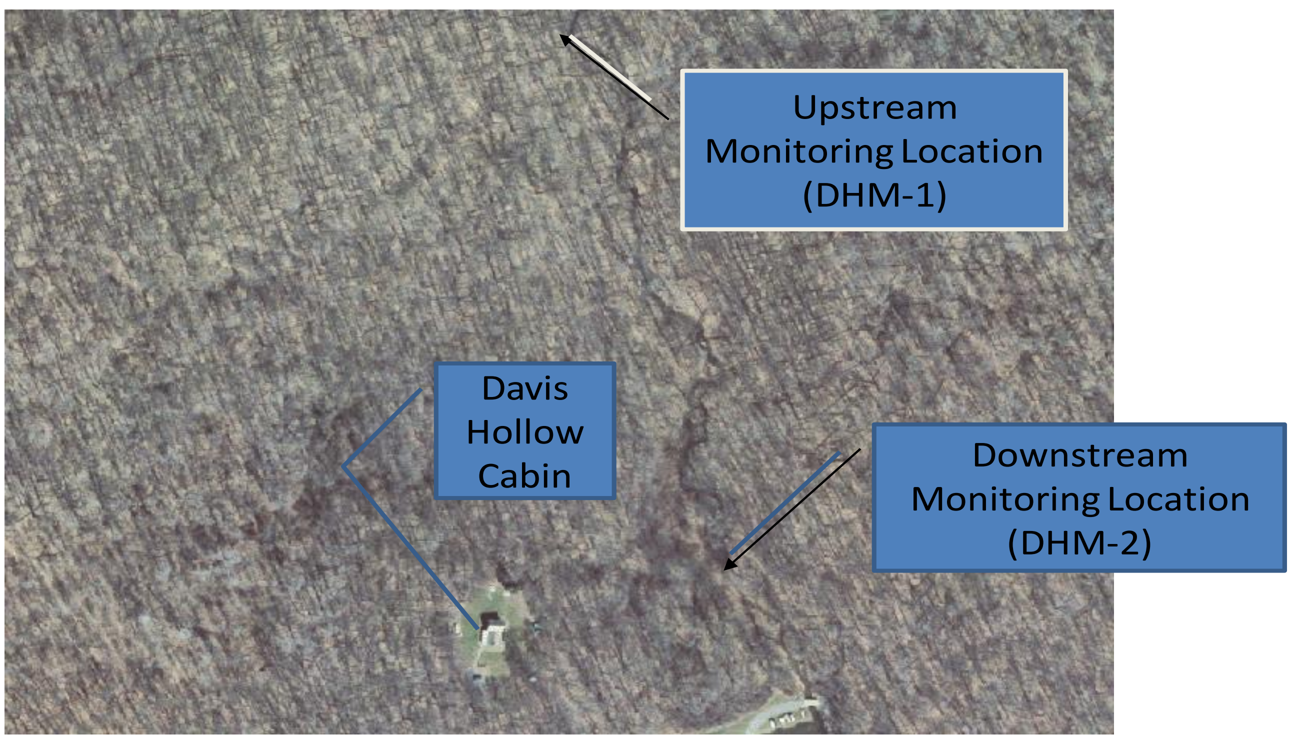


Figure 17 - Davis Hollow Monitoring Point Locations

North ↑

From: PAMAP Program Bureau of Topographic and Geologic Survey Pennsylvania Department of Conservation and Natural Resources (2007)



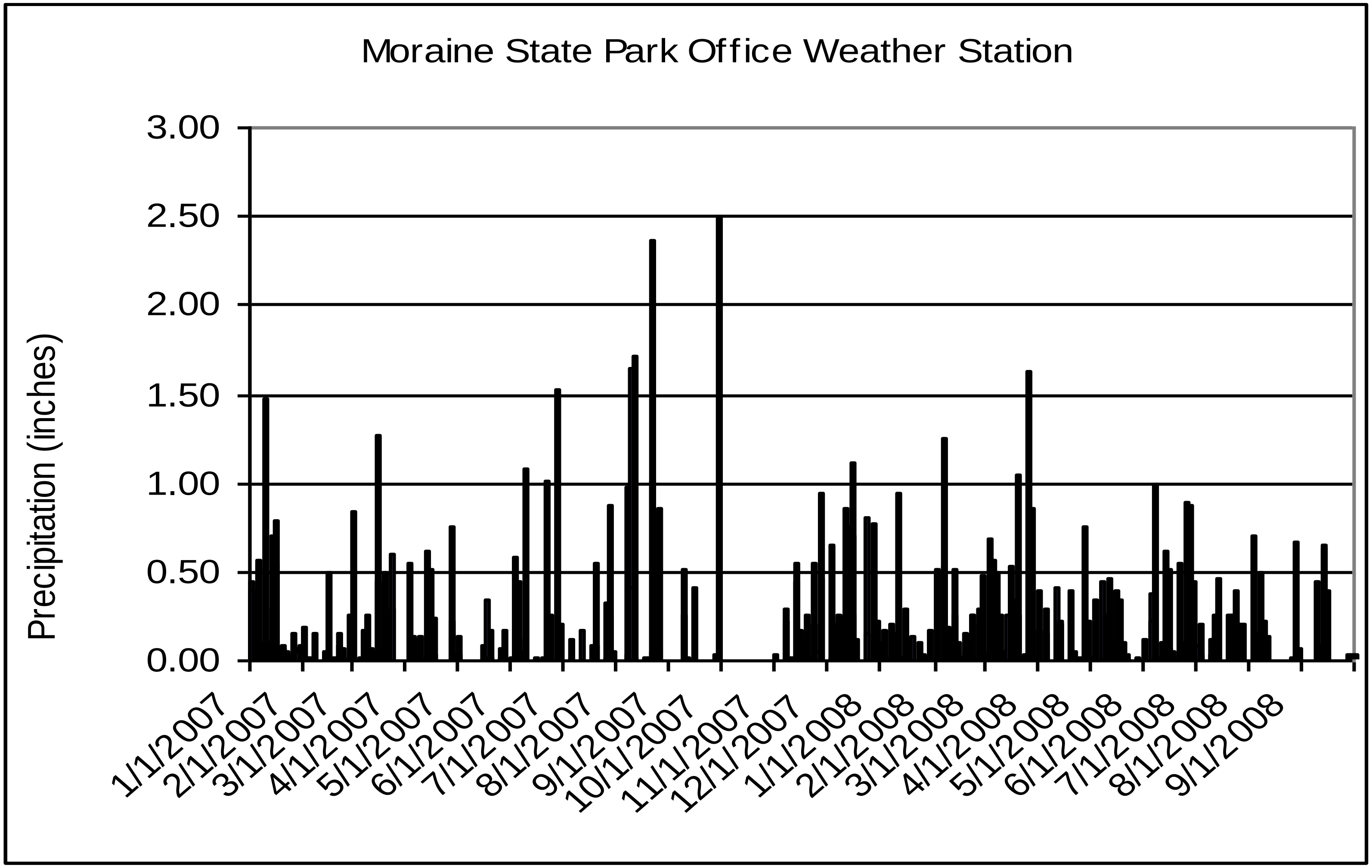
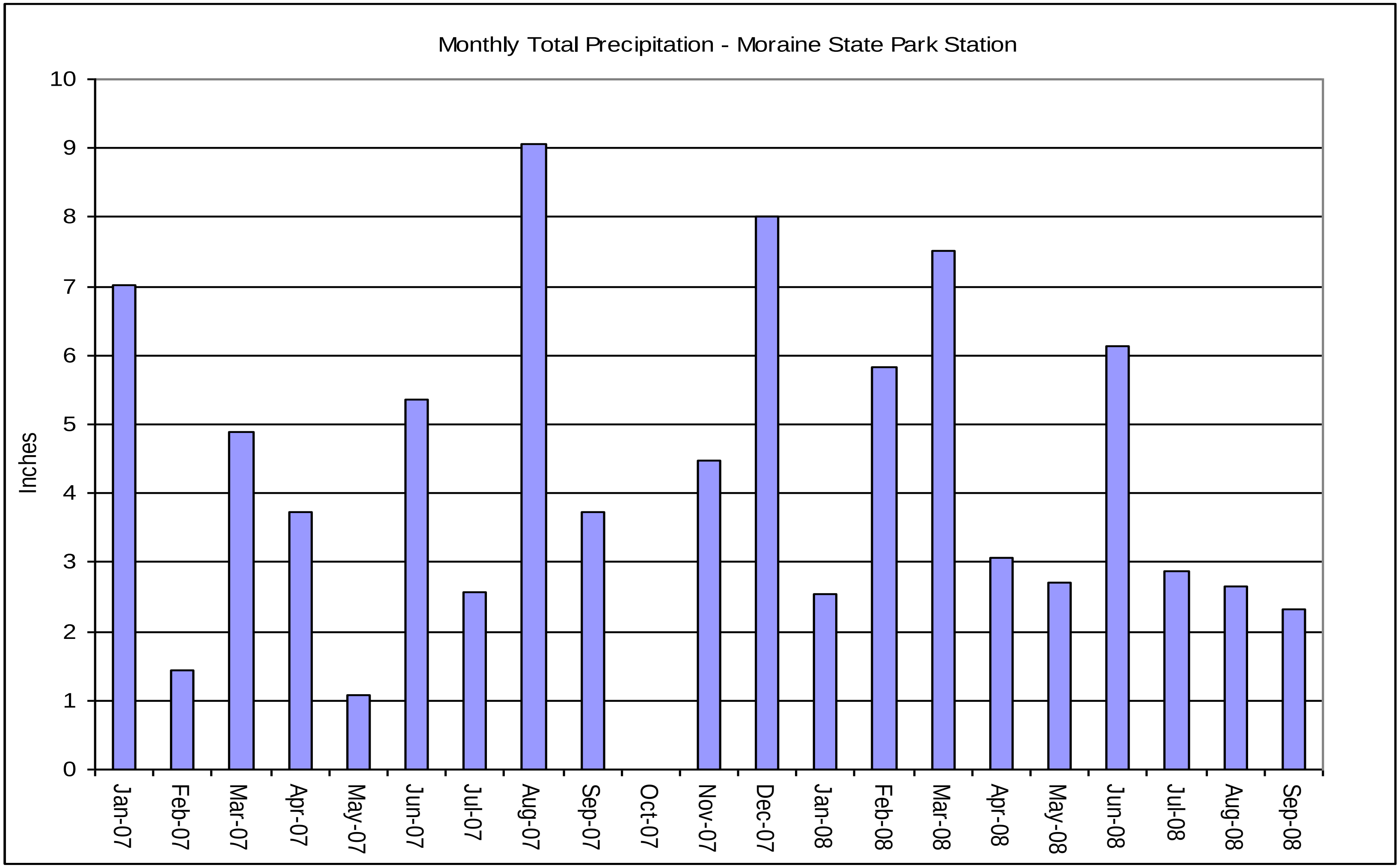
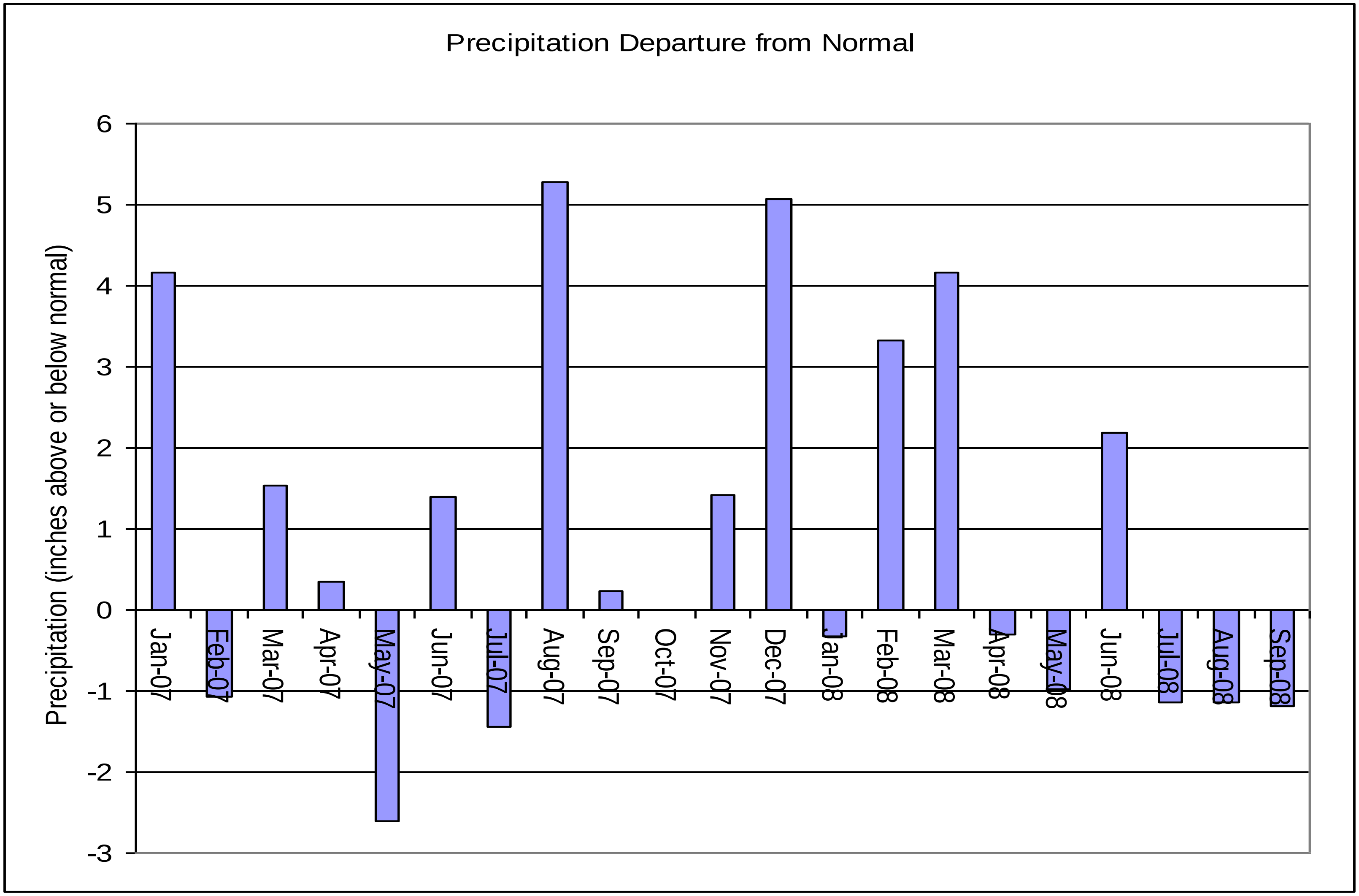

Moraine State Park Office Weather Station
Precipitation (inches)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1/1/2007
2/1/2007
3/1/2007
4/1/2007
5/1/2007
6/1/2007
7/1/2007
8/1/2007
9/1/2007
10/1/2007
11/1/2007
12/1/2007
1/1/2008
2/1/2008
3/1/2008
4/1/2008
5/1/2008
6/1/2008
7/1/2008
8/1/2008
9/1/2008

Figure 24



Monthly Total Precipitation - Moraine State Park Station
Inches
0
1
2
3
4
5
6
7
8
9
10
Jan-07
Feb-07
Mar-07
Apr-07
May-07
Jun-07
Jul-07
Aug-07
Sep-07
Oct-07
Nov-07
Dec-07
Jan-08
Feb-08
Mar-08
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08

Figure 25



Precipitation Departure from Normal
Precipitation (inches above or below normal)
6
5
4
3
2
1
0
-1
-2
-3
Jan-07
Feb-07
Mar-07
Apr-07
May-07
Jun-07
Jul-07
Aug-07
Sep-07
Oct-07
Nov-07
Dec-07
Jan-08
Feb-08
Mar-08
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08

Figure 26

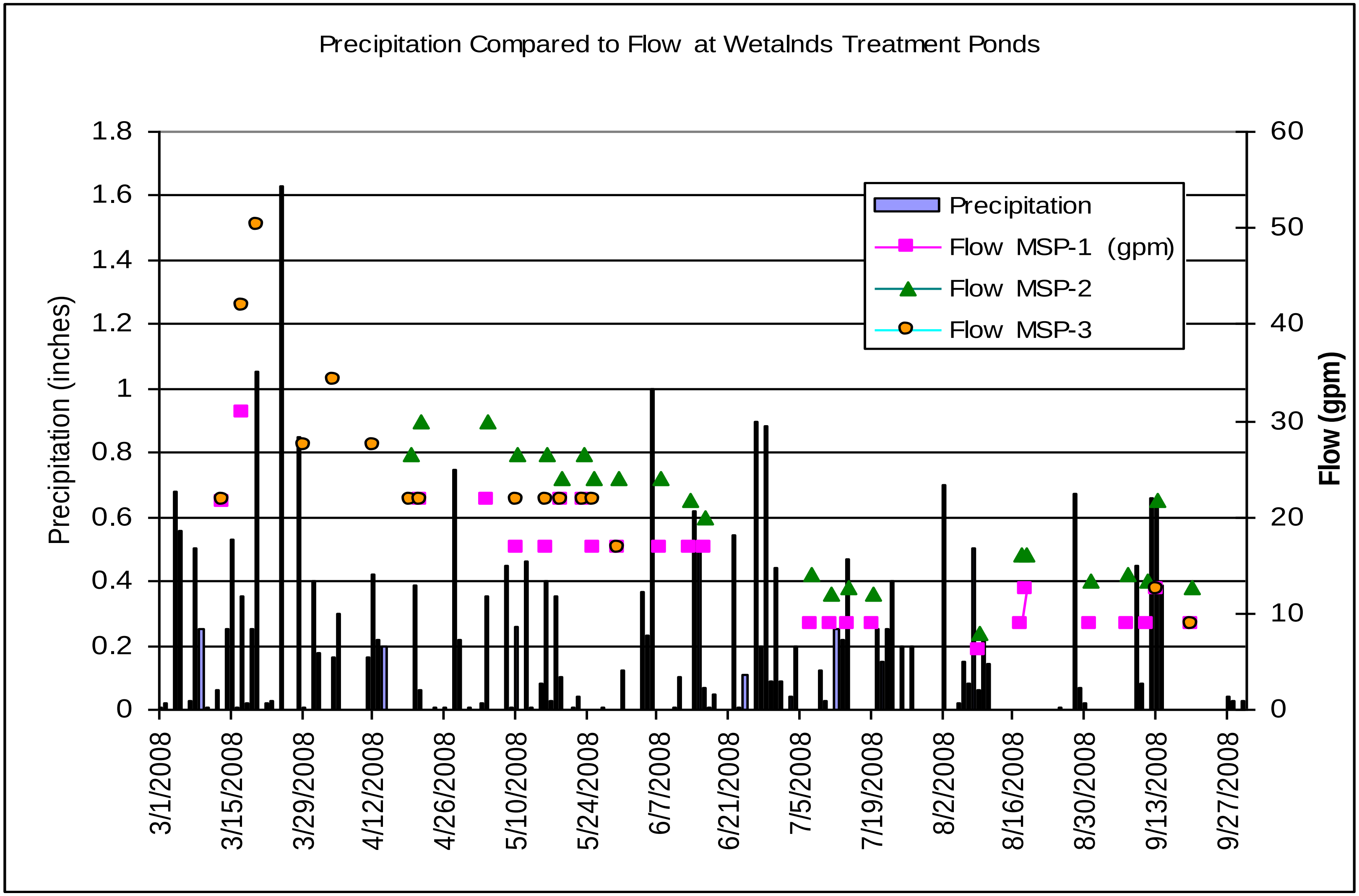
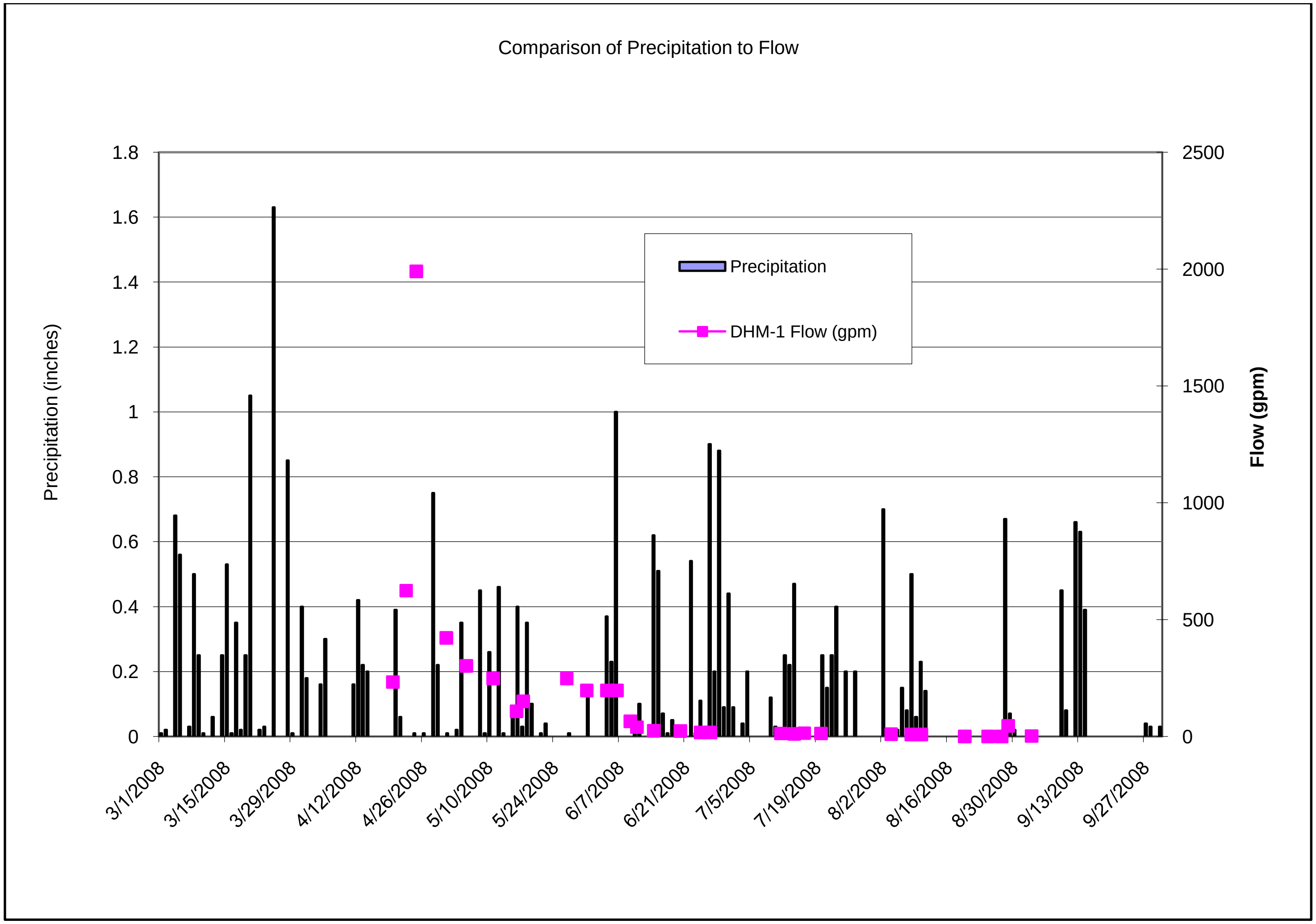
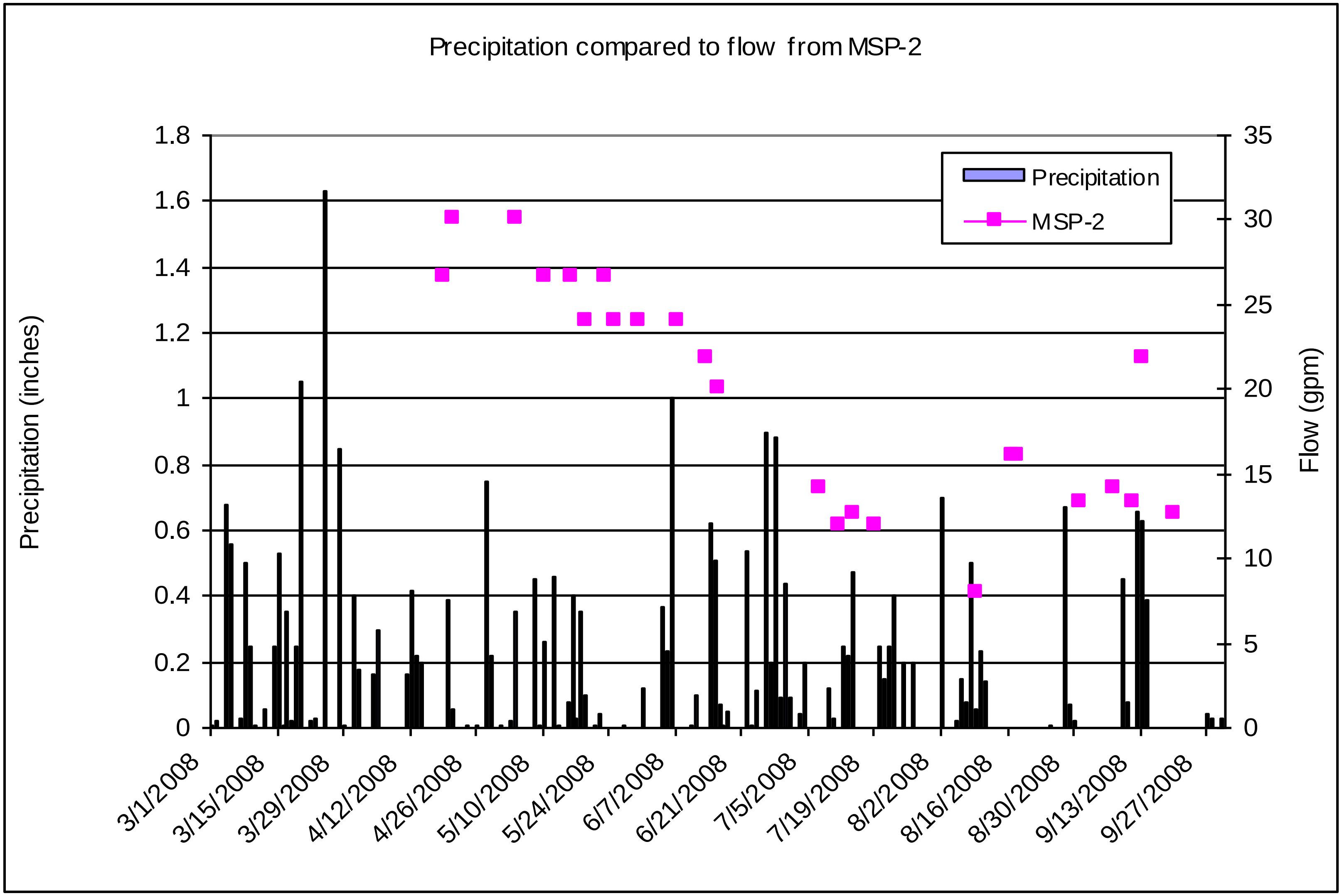

Precipitation Compared to Flow at Wetalnds Treatment Ponds
Precipitation (inches)
Flow (gpm)
Precipitation
Flow MSP-1 (gpm)
Flow MSP-2
Flow MSP-3
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
60
50
40
30
20
10
0
3/1/2008
3/15/2008
3/29/2008
4/12/2008
4/26/2008
5/10/2008
5/24/2008
6/7/2008
6/21/2008
7/5/2008
7/19/2008
8/2/2008
8/16/2008
8/30/2008
9/13/2008
9/27/2008

Figure 27



Comparison of Precipitation to Flow
Precipitation (inches)
Flow (gpm)
Precipitation
DHM-1 Flow (gpm)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2500
2000
1500
1000
500
0
3/1/2008
3/15/2008
3/29/2008
4/12/2008
4/26/2008
5/10/2008
5/24/2008
6/7/2008
6/21/2008
7/5/2008
7/19/2008
8/2/2008
8/16/2008
8/30/2008
9/13/2008
9/27/2008

Figure 28



Precipitation compared to flow from MSP-2
Precipitation (inches)
Flow (gpm)
Precipitation
MSP-2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
35
30
25
20
15
10
5
0
3/1/2008
3/15/2008
3/29/2008
4/12/2008
4/26/2008
5/10/2008
5/24/2008
6/7/2008
6/21/2008
7/5/2008
7/19/2008
8/2/2008
8/16/2008
8/30/2008
9/13/2008
9/27/2008

Figure 29

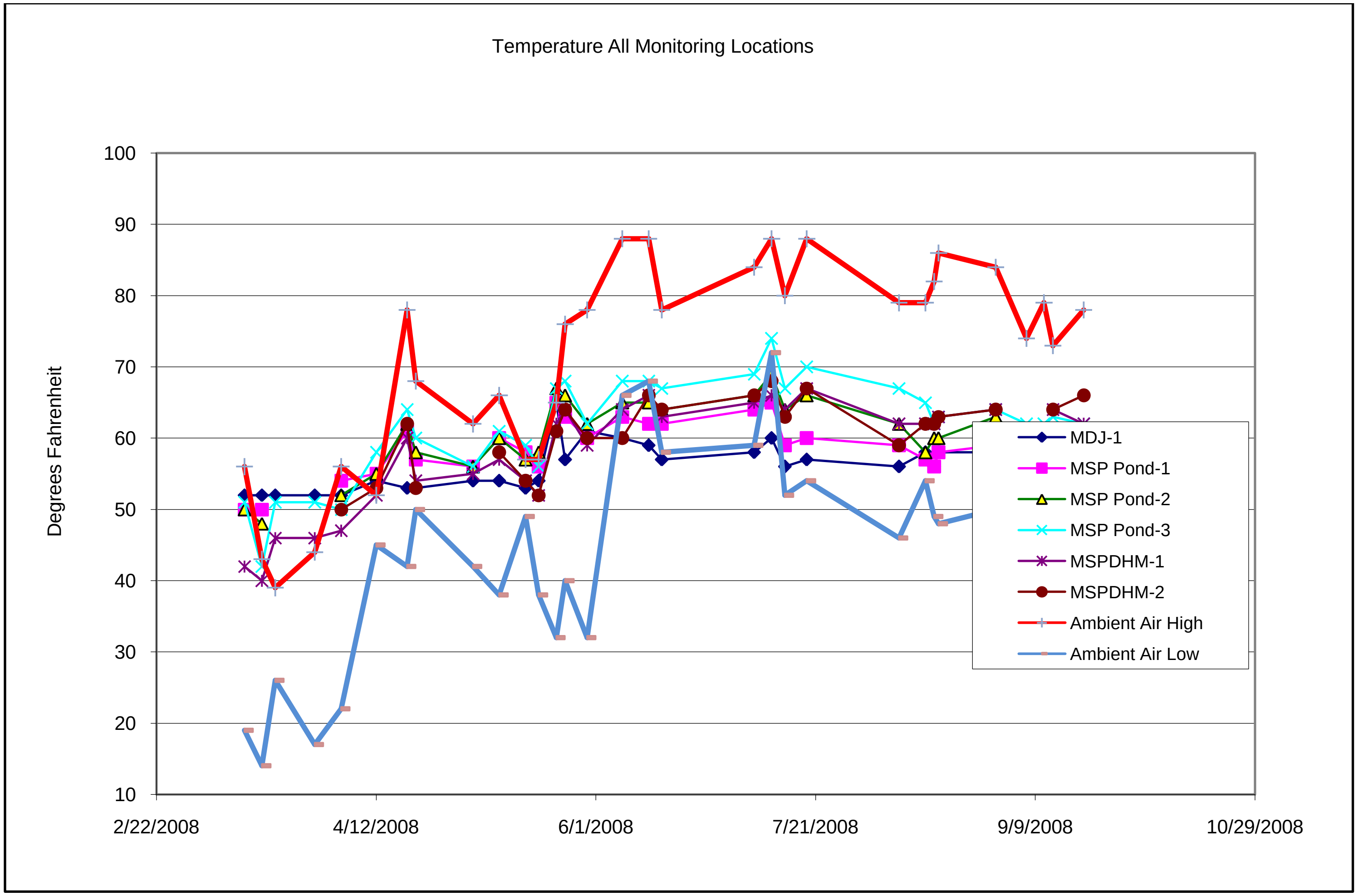
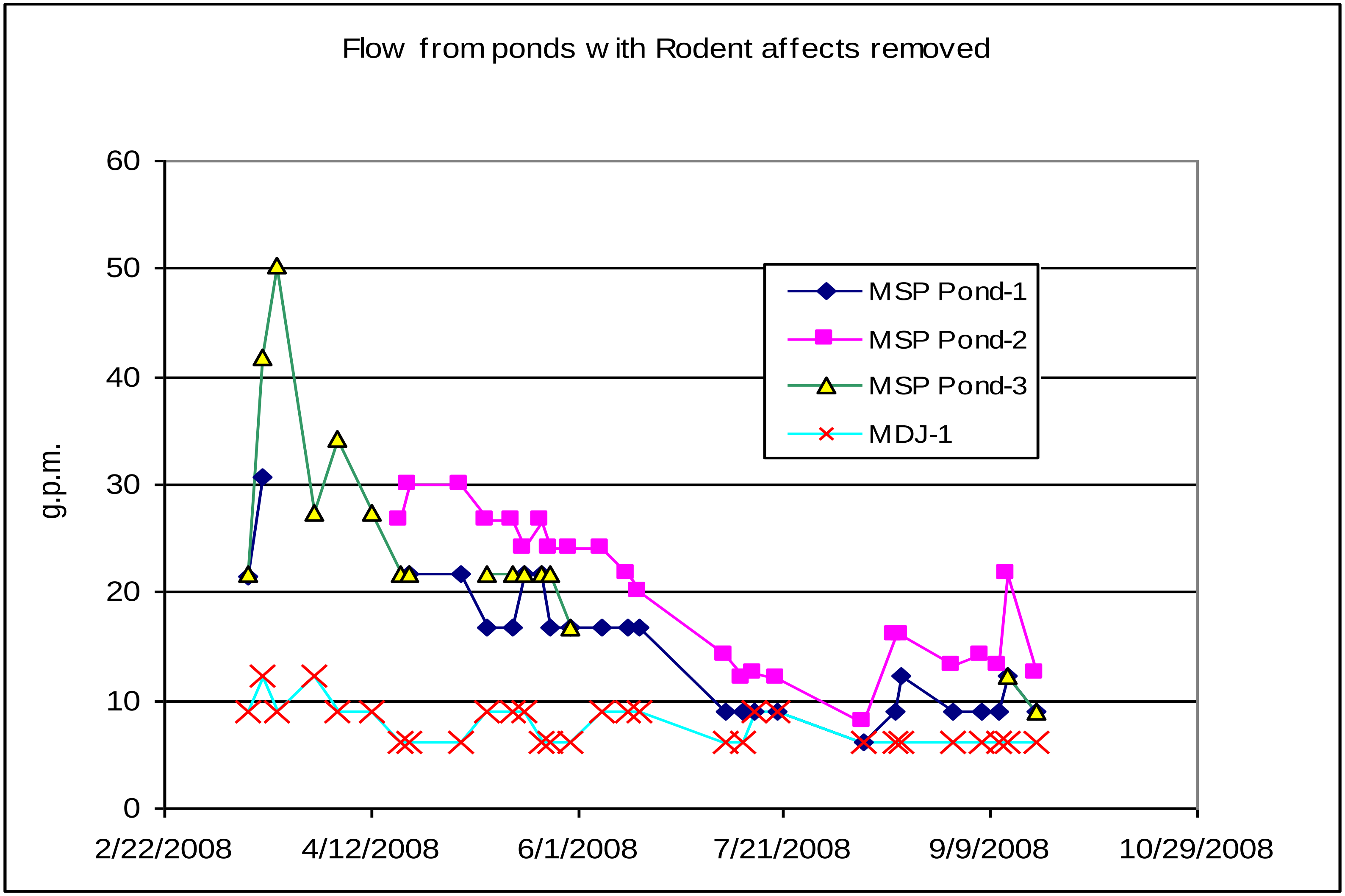

Temperature All Monitoring Locations
Degrees Fahrenheit
100
90
80
70
60
50
40
30
20
10
2/22/2008
4/12/2008
6/1/2008
7/21/2008
9/9/2008
10/29/2008
MDJ-1
MSP Pond-1
MSP Pond-2
MSP Pond-3
MSPDHM-1
MSPDHM-2
Ambient Air High
Ambient Air Low

Figure 30


Flow from ponds with Rodent affects removed
g.p.m.
60
50
40
30
20
10
0
2/22/2008
4/12/2008
6/1/2008
7/21/2008
9/9/2008
10/29/2008
MSP Pond-1
MSP Pond-2
MSP Pond-3
MDJ-1
Figure 31

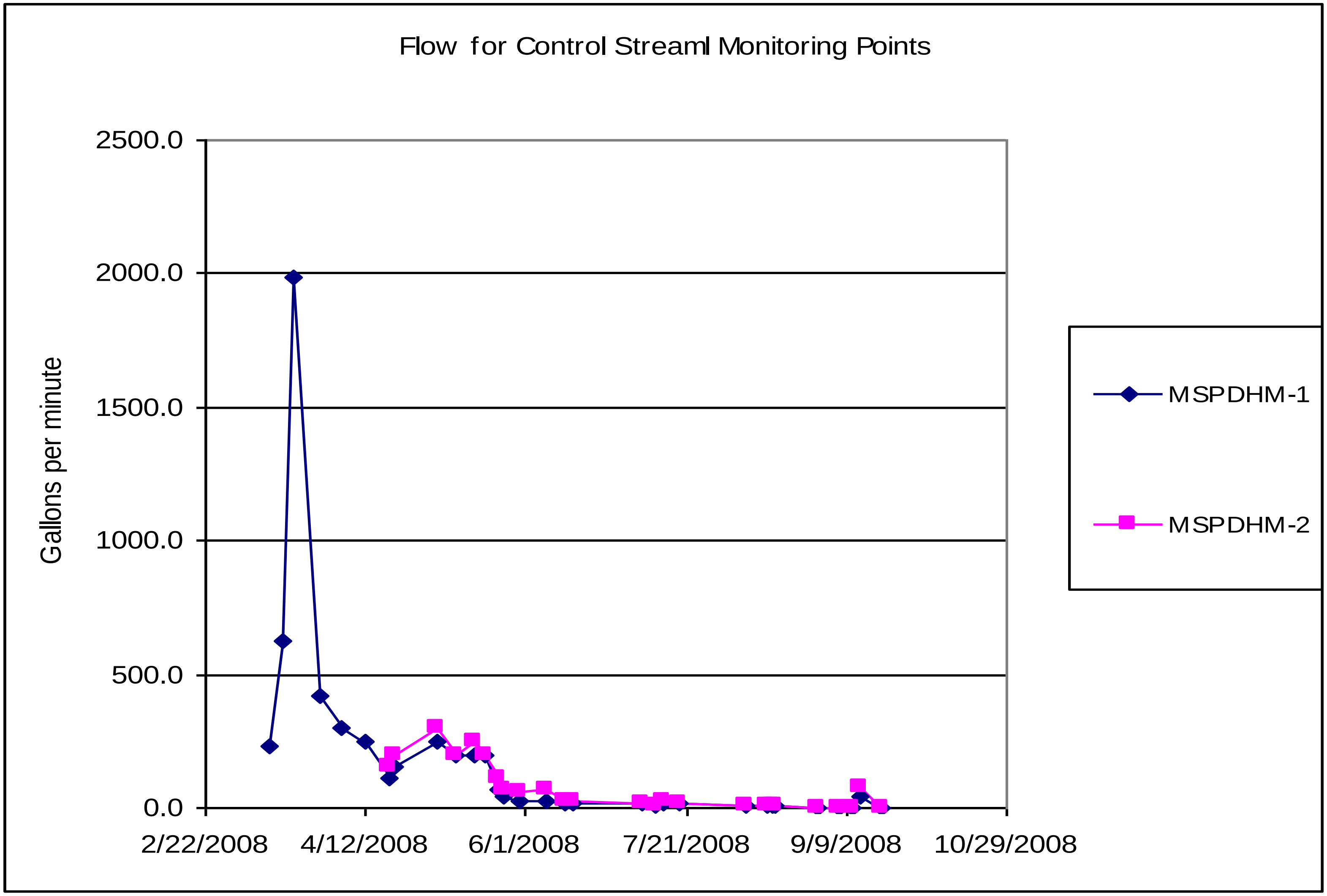

Flow for Control Streaml Monitoring Points
Gallons per minute
2500.0
2000.0
1500.0
1000.0
500.0
0.0
2/22/2008
4/12/2008
6/1/2008
7/21/2008
9/9/2008
10/29/2008
MSPDHM-1
MSPDHM-2

Figure 32

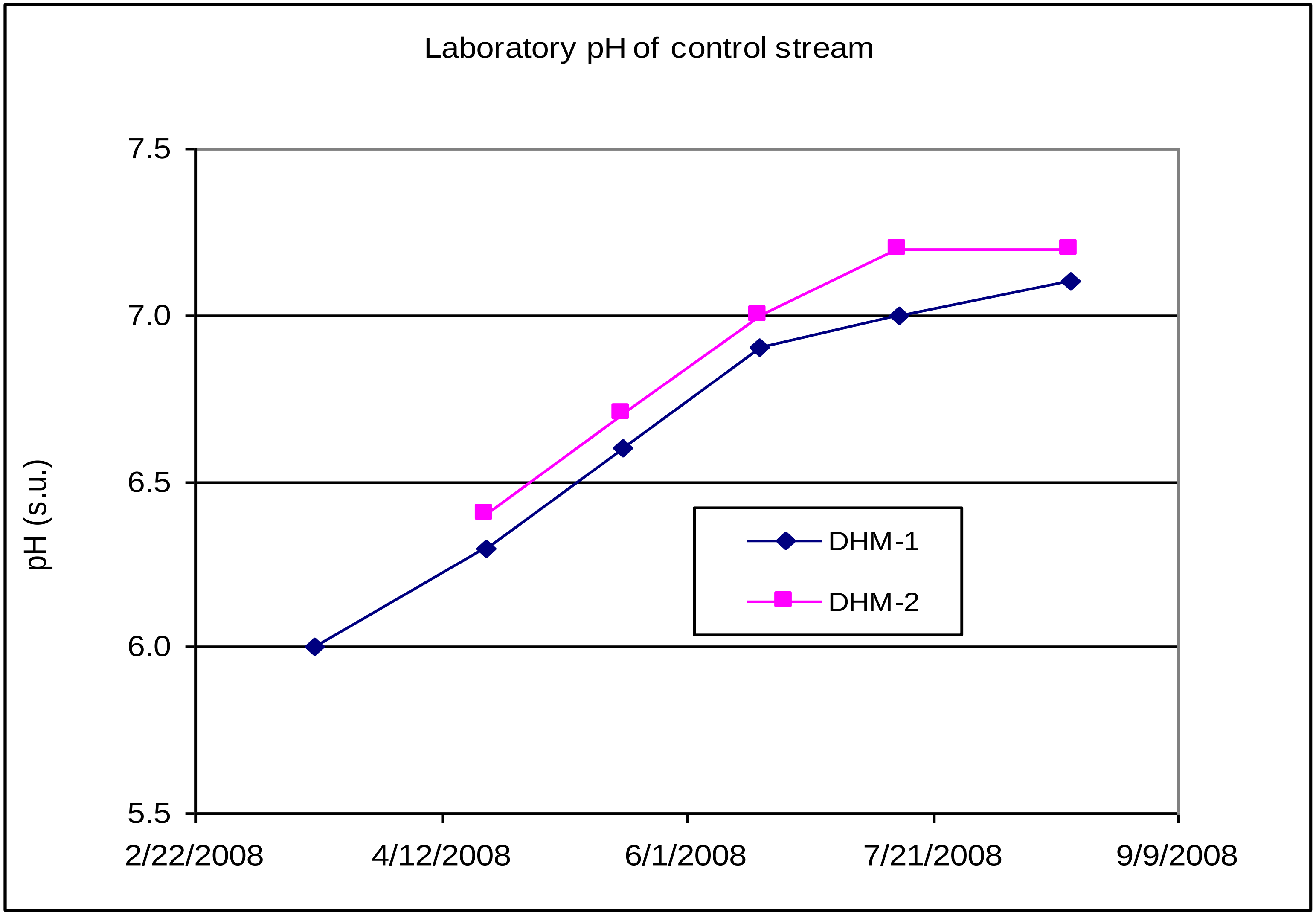


Figure 33 – Graph of pH of Control Stream

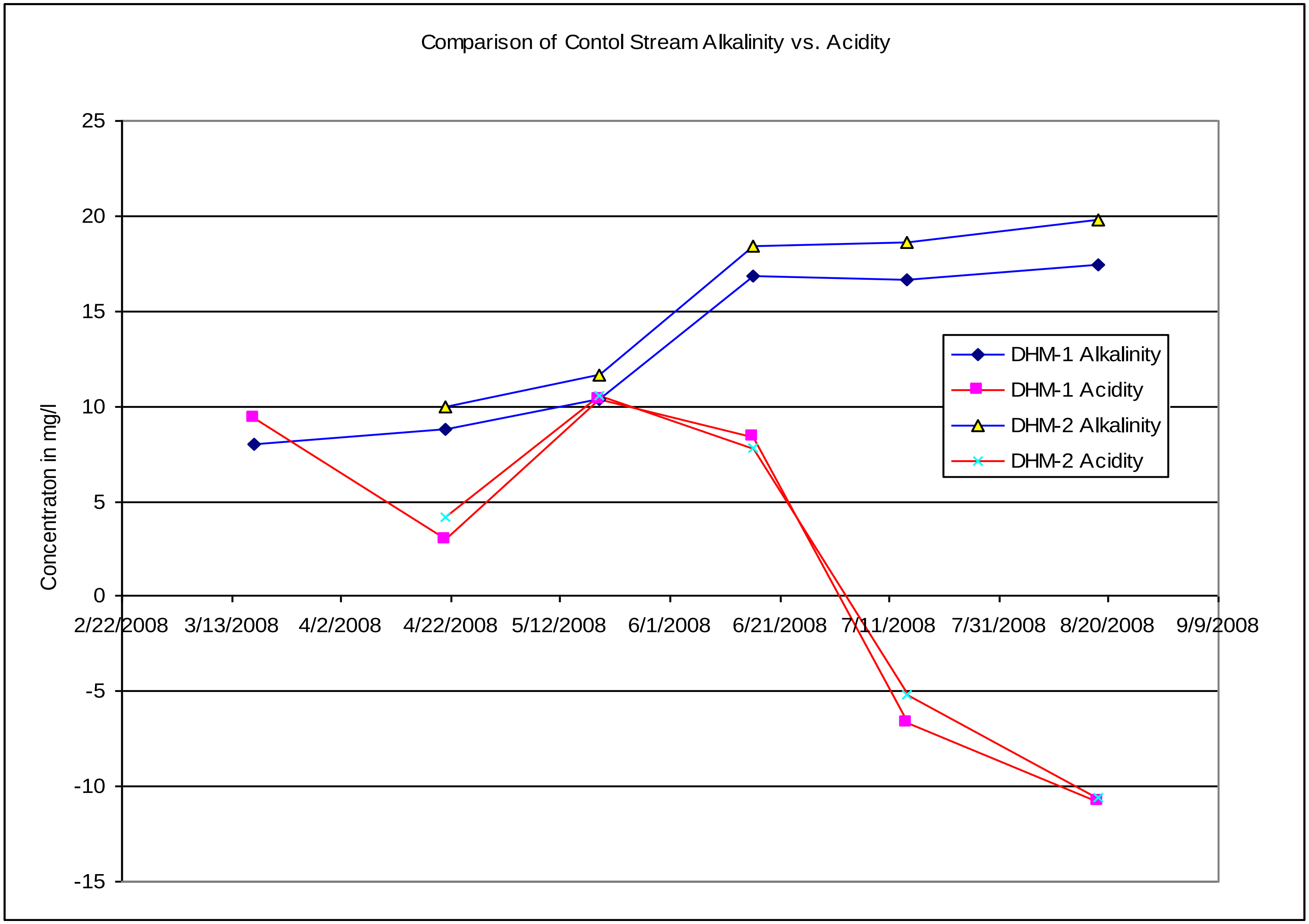
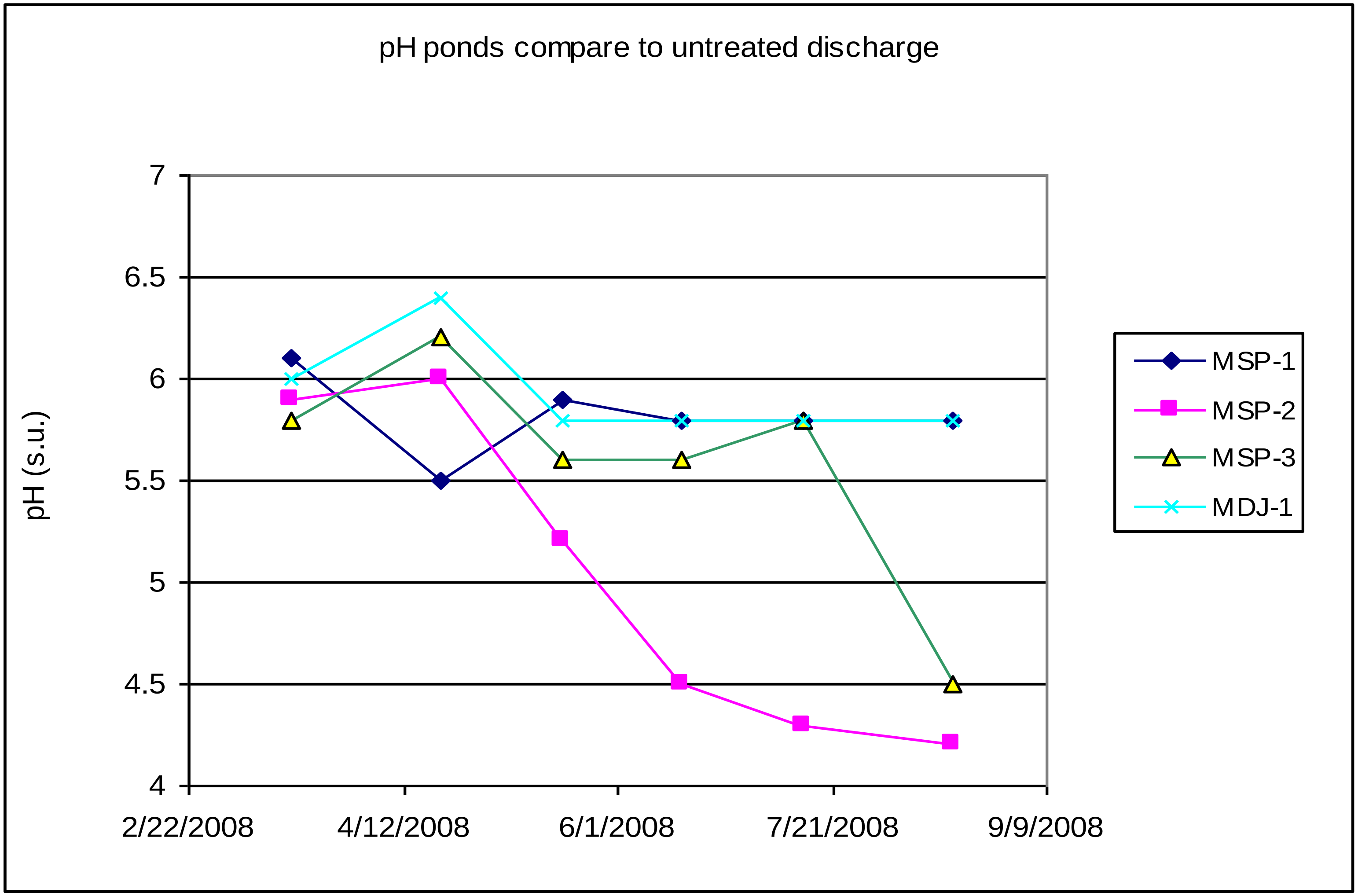


Figure 34 – Graph of Control Stream Alkalinity vs. Acidity



pH ponds compare to untreated discharge
pH (s.u.)
7
6.5
6
5.5
5
4.5
4
2/22/2008
4/12/2008
6/1/2008
7/21/2008
9/9/2008
MSP-1
MSP-2
MSP-3
MDJ-1

Figure 35

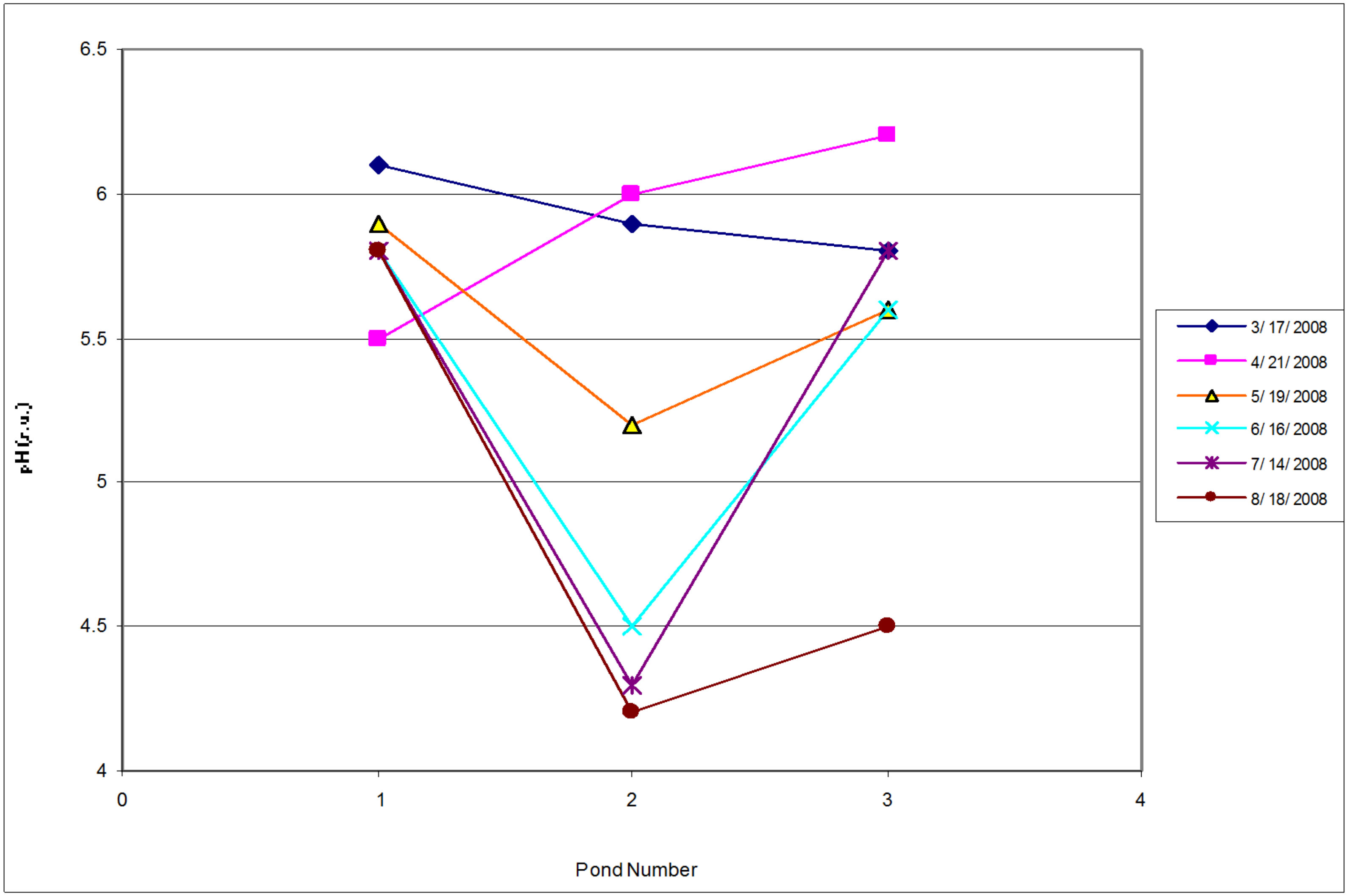


Figure 36 – Graph of pH through the Treatment Ponds

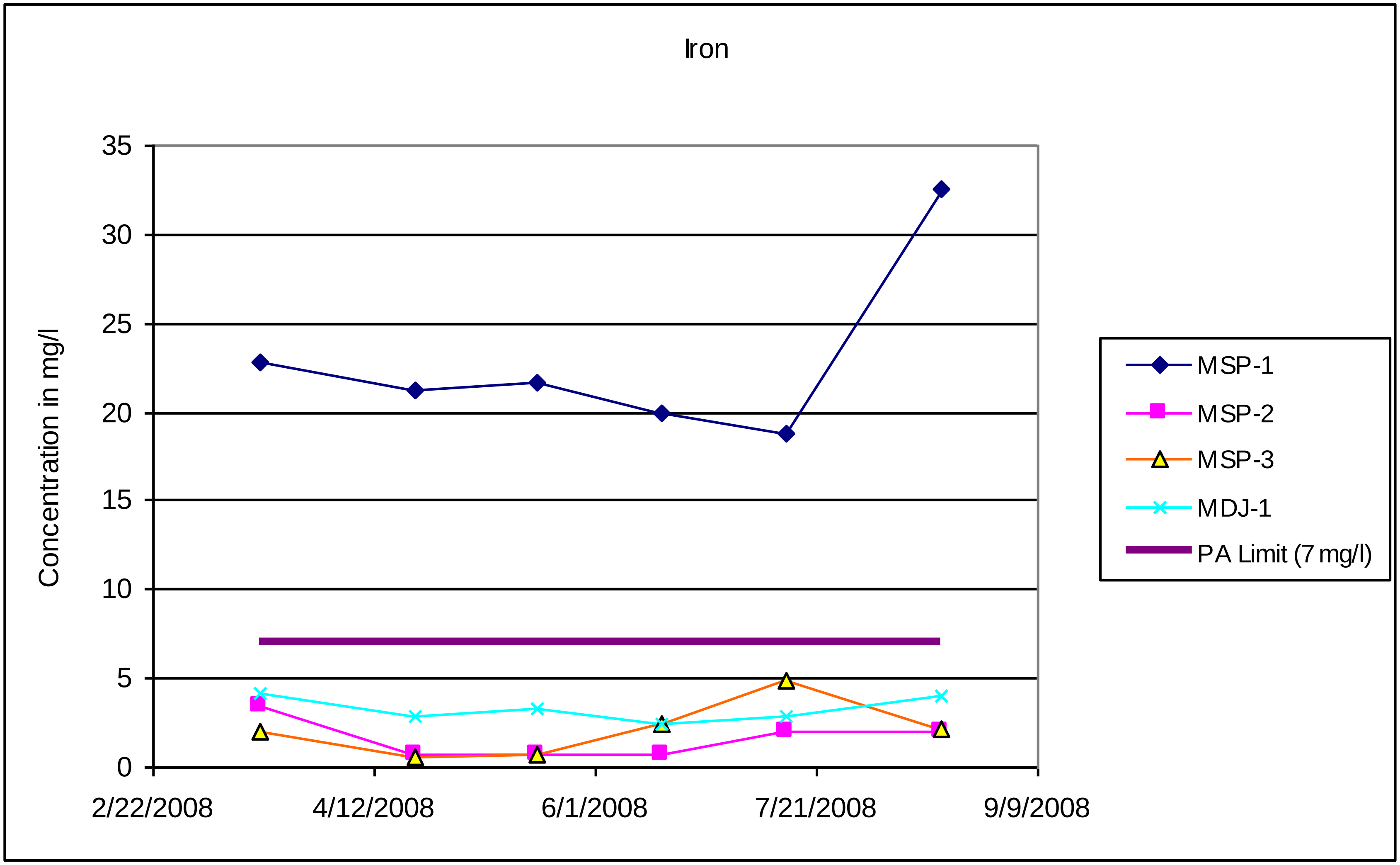
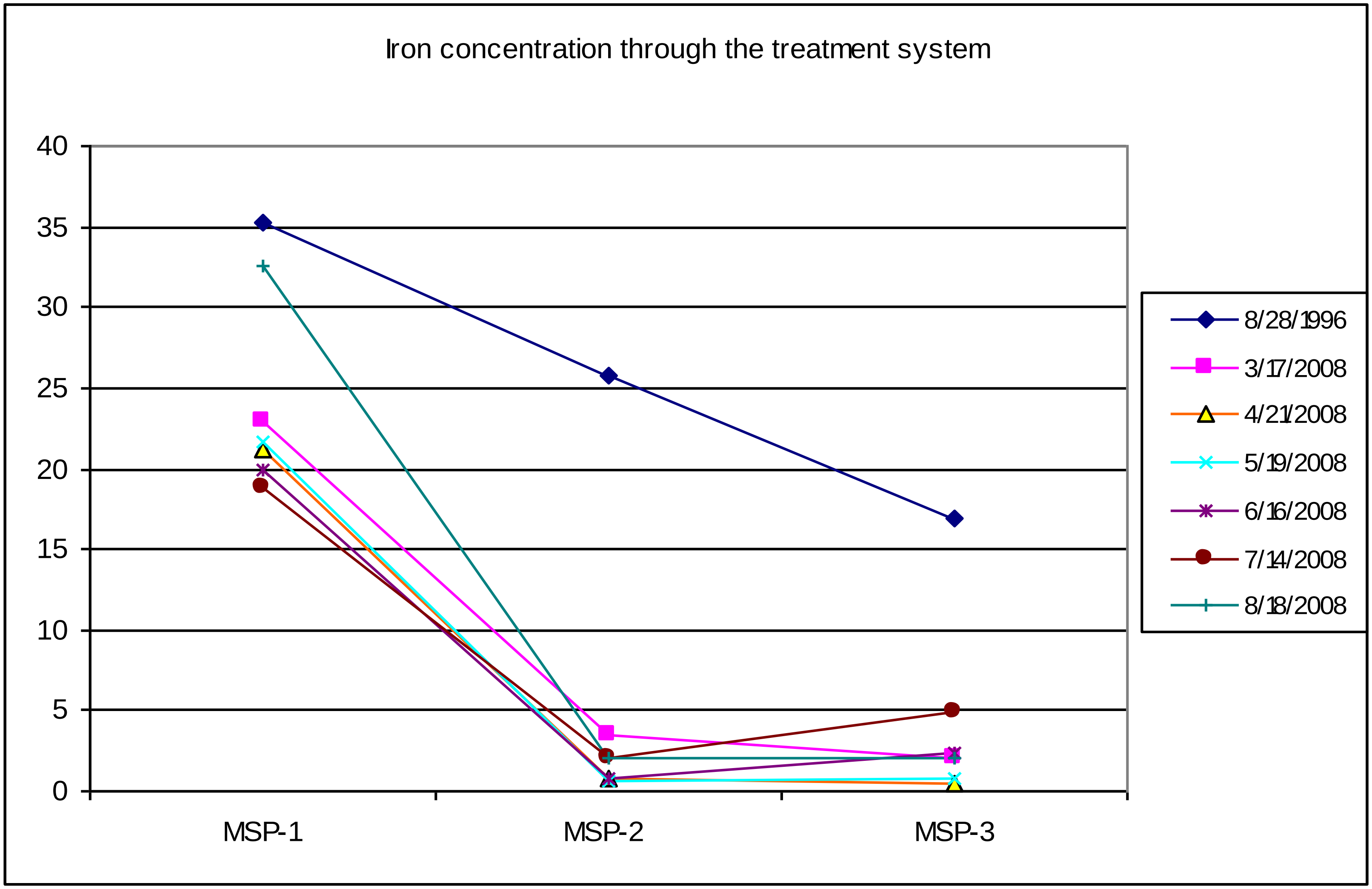

Iron
Concentration in mg/l
35
30
25
20
15
10
5
0
2/22/2008
4/12/2008
6/1/2008
7/21/2008
9/9/2008
MSP-1
MSP-2
MSP-3
MDJ-1
PA Limit (7 mg/l)

Figure 37


Iron concentration through the treatment system
40
35
30
25
20
15
10
5
0
MSP-1
MSP-2
MSP-3
8/28/1996
3/17/2008
4/21/2008
5/19/2008
6/16/2008
7/14/2008
8/18/2008
Figure 38

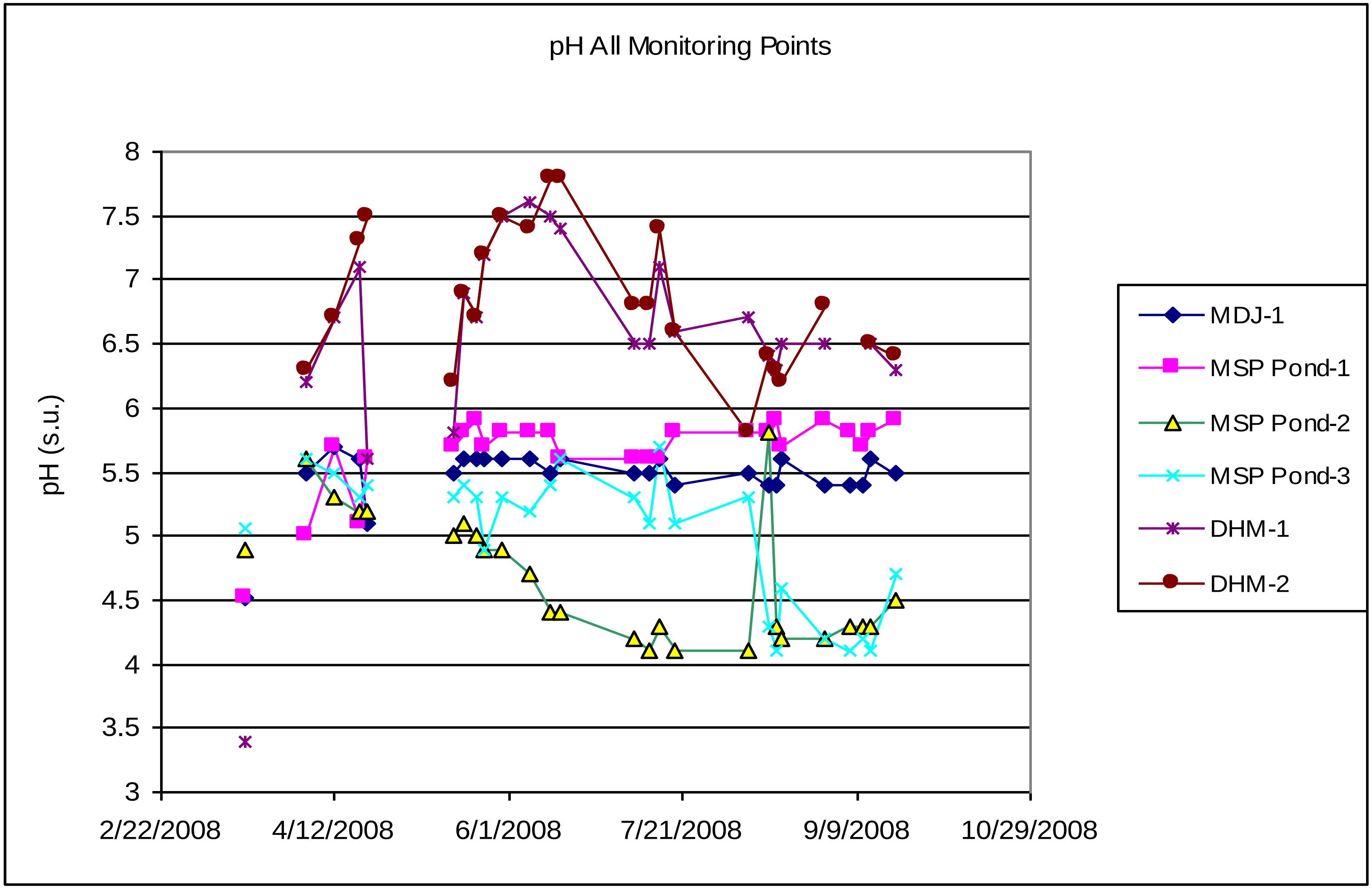
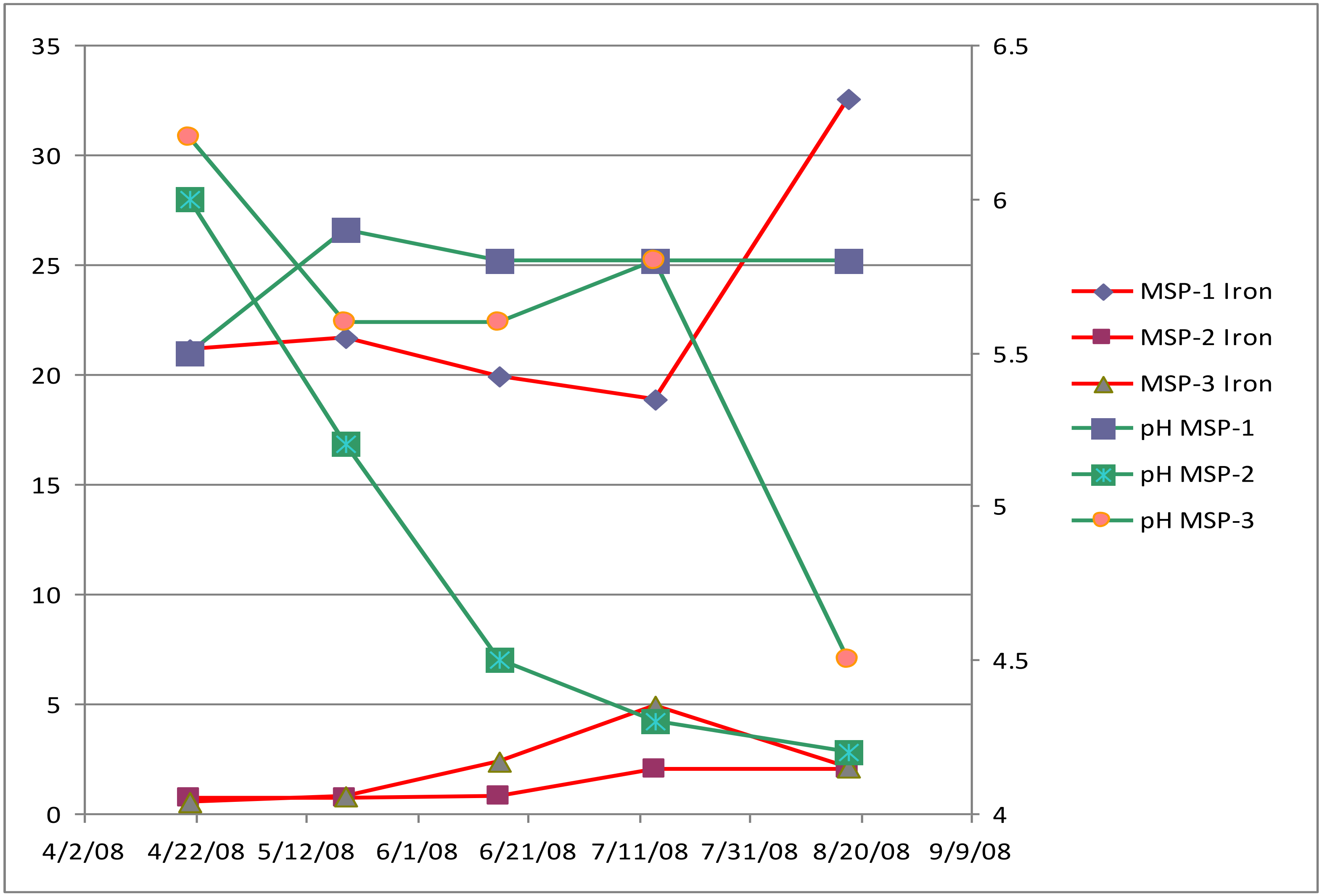
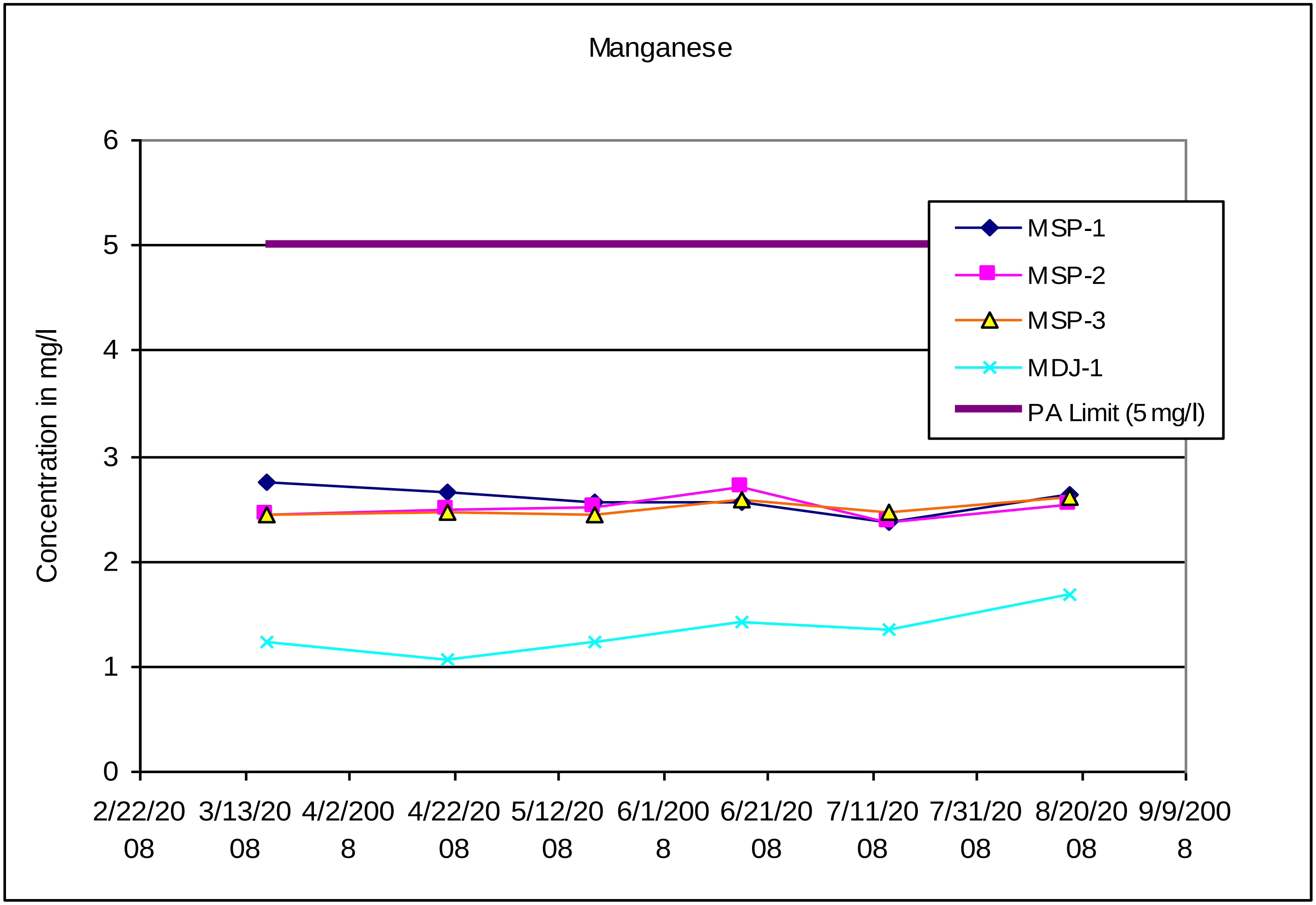

pH All Monitoring Points
pH (s.u.)
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2/22/2008
4/12/2008
6/1/2008
7/21/2008
9/9/2008
10/29/2008
MDJ-1
MSP Pond-1
MSP Pond-2
MSP Pond-3
DHM-1
DHM-2

Figure 39



35
30
25
20
15
10
5
0
6.5
6
5.5
5
4.5
4
4/2/08
4/22/08
5/12/08
6/1/08
6/21/08
7/11/08
7/31/08
8/20/08
9/9/08
MSP-1 Iron
MSP-2 Iron
MSP-3 Iron
pH MSP-1
pH MSP-2
pH MSP-3

Figure 40



Manganese
Concentration in mg/l
0
1
2
3
4
5
6
2/22/2008
3/13/2008
4/2/2008
4/22/2008
5/12/2008
6/1/2008
6/21/2008
7/11/2008
7/31/2008
8/20/2008
9/9/2008
MSP-1
MSP-2
MSP-3
MDJ-1
PA Limit (5 mg/l)

Figure 41 .

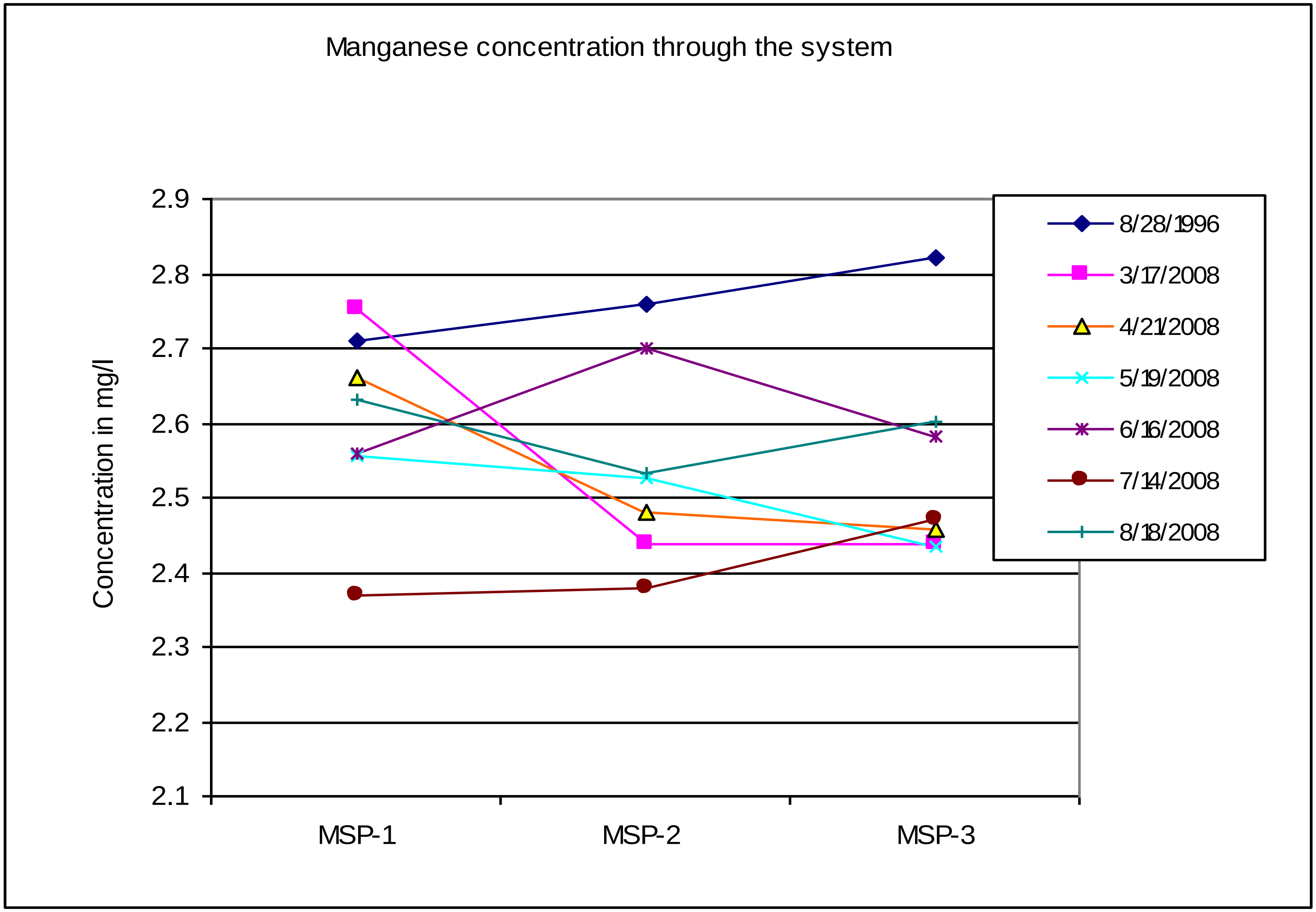

Manganese concentration through the system
Concentration in mg/l
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
MSP-1
MSP-2
MSP-3
8/28/1996
3/17/2008
4/21/2008
5/19/2008
6/16/2008
7/14/2008
8/18/2008

Figure 42

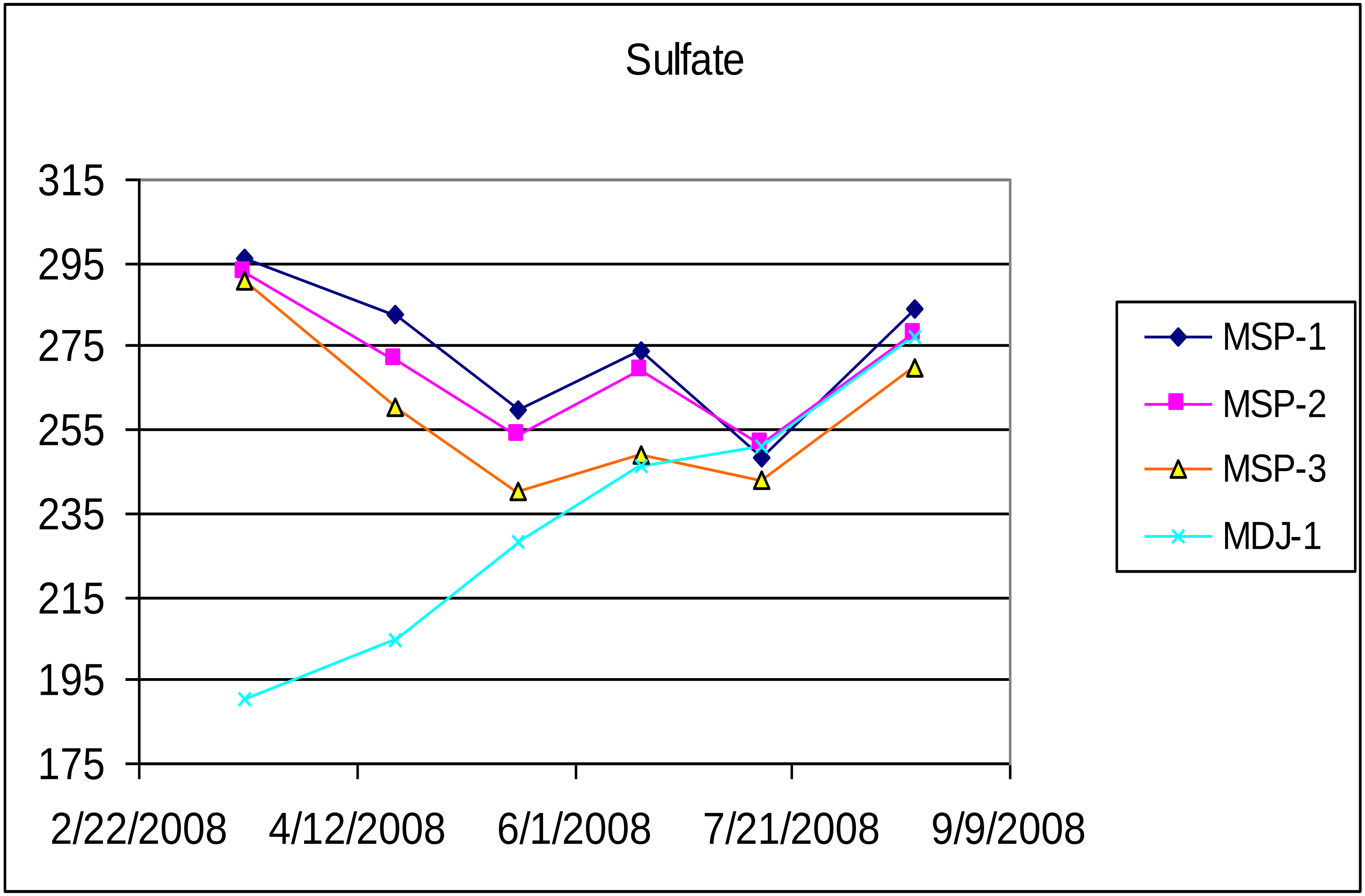

Sulfate
315
295
275
255
235
215
195
175
2/22/2008
4/12/2008
6/1/2008
7/21/2008
9/9/2008
MSP-1
MSP-2
MSP-3
MDJ-1

Figure 43

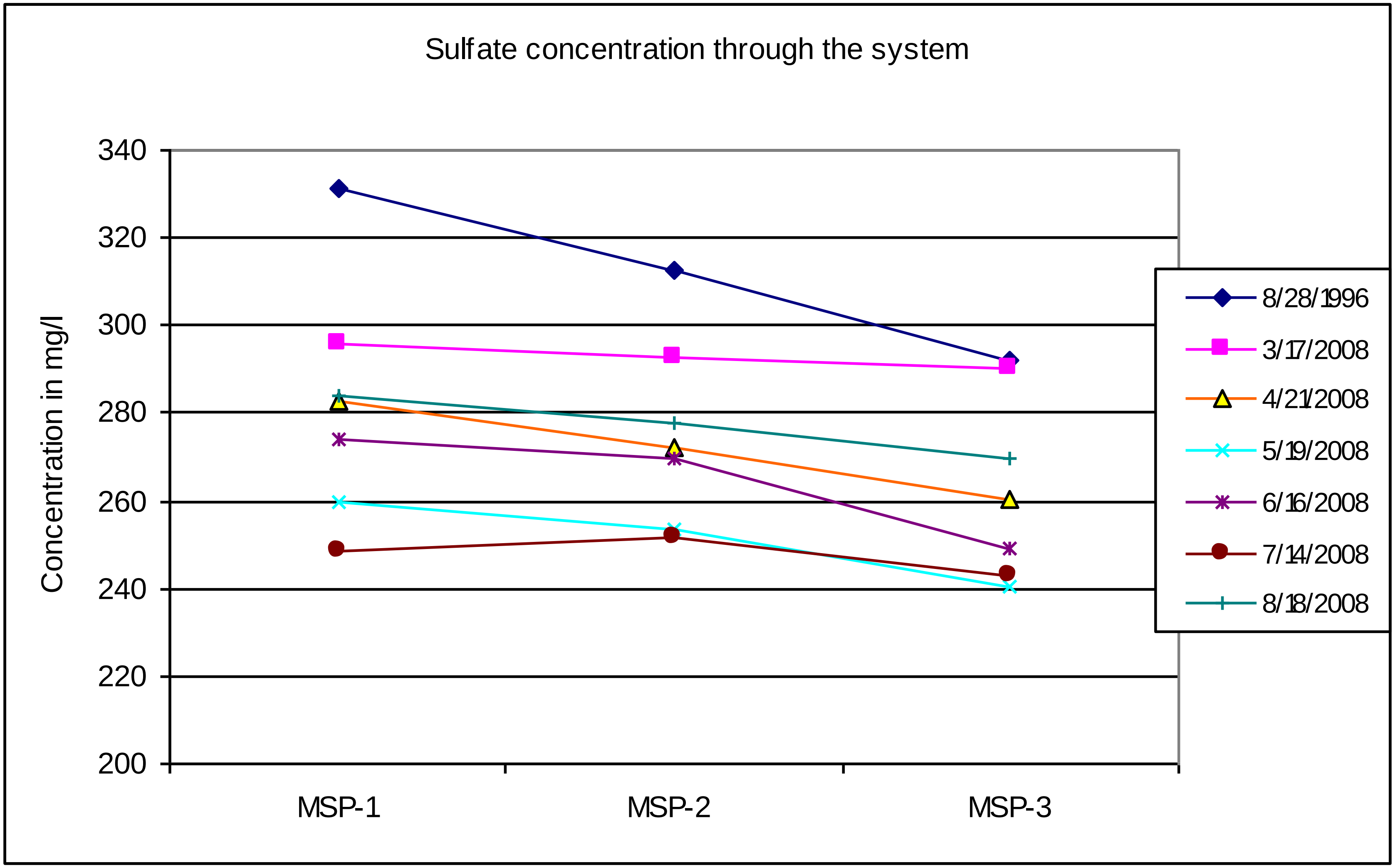

Sulfate concentration through the system
Concentration in mg/l
340
320
300
280
260
240
220
200
MSP-1
MSP-2
MSP-3
8/28/1996
3/17/2008
4/21/2008
5/19/2008
6/16/2008
7/14/2008
8/18/2008

Figure 44

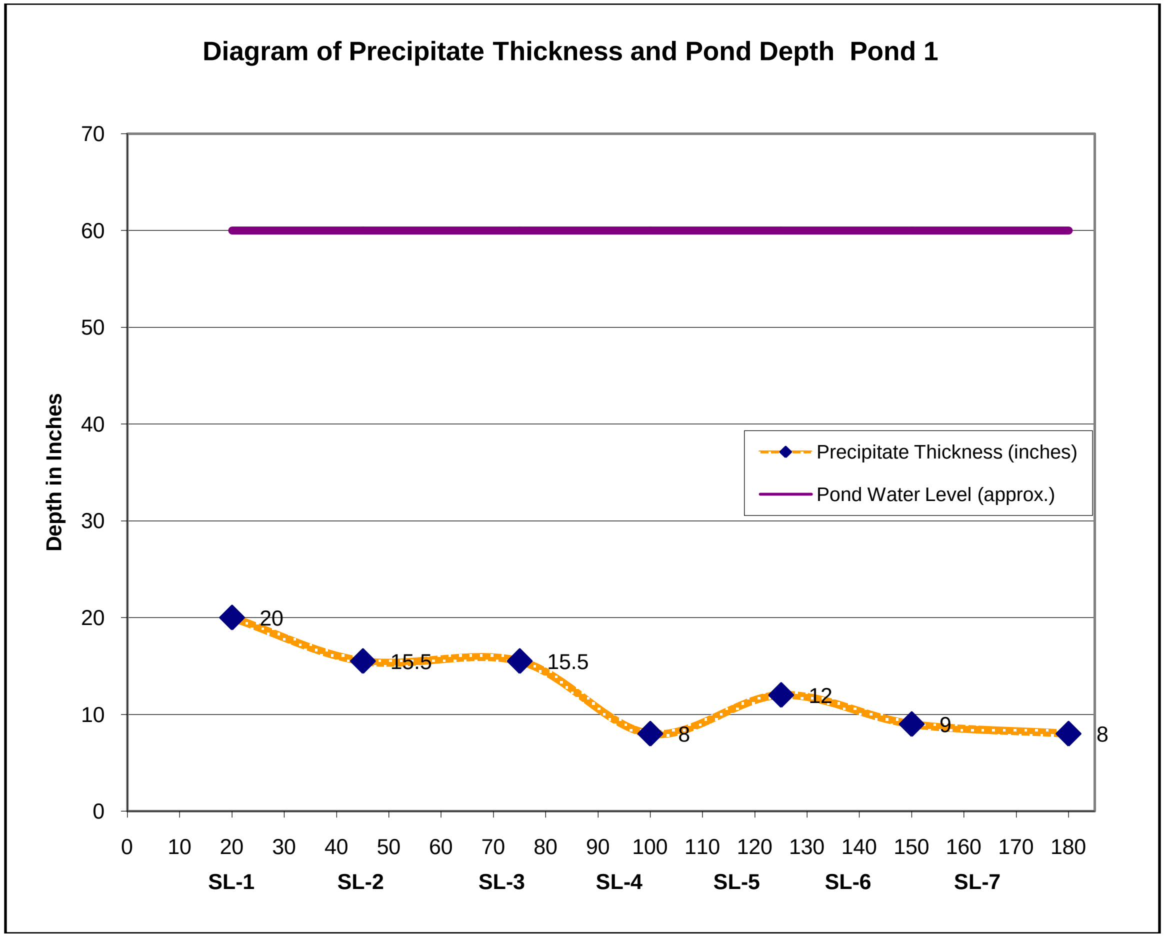


Diagram of Precipitate Thickness and Pond Depth Pond 1
Depth in Inches
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
SL-1
SL-2
SL-3
SL-4
SL-5
SL-6
SL-7
20
15.5
15.5
8
12
9
8
Precipitate Thickness (inches)
Pond Water Level (approx.)

Figure 45