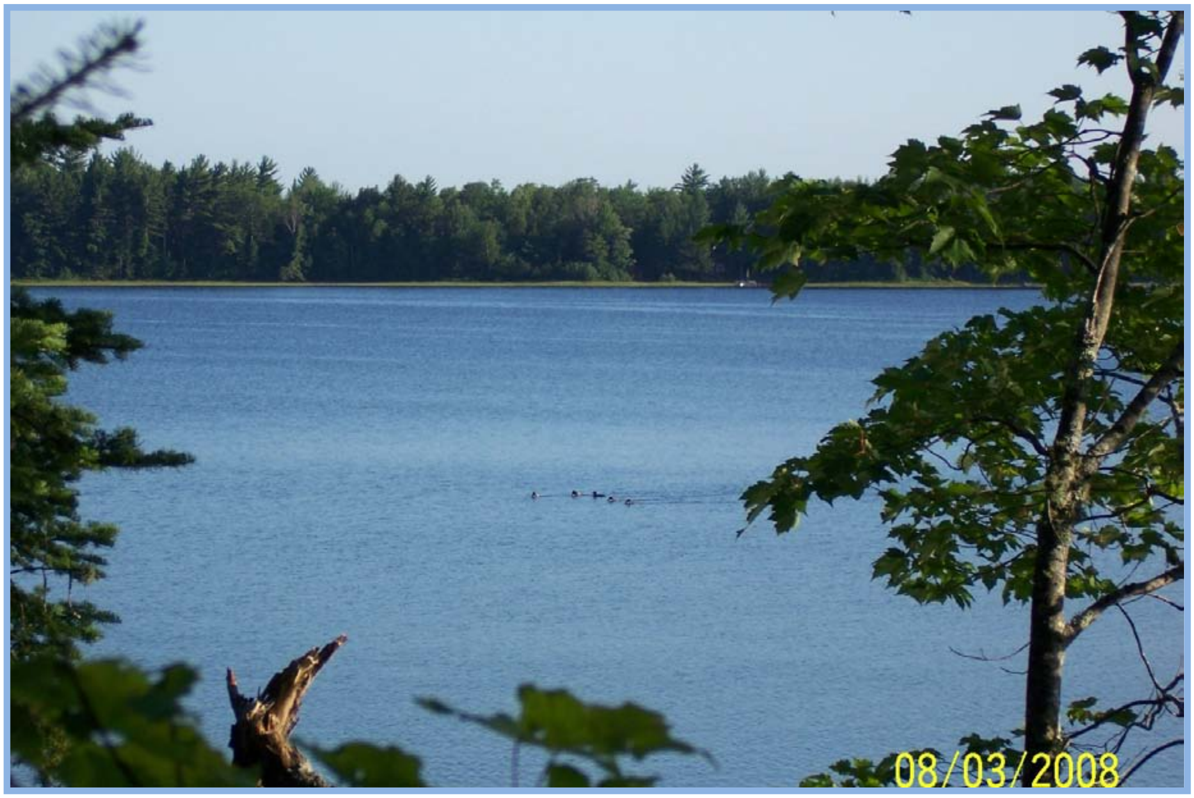
Dead Pike Lake Management Plan

Prepared in Cooperation with The Dead Pike Lake Association

January 2011



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Executive Summary

In June 2007, the Dead Pike Lake Association committed to engage in a scientific study to investigate the cause and effect of elevated iron and manganese discharges from the Powell Marsh into Dead Pike Lake and to determine the extent to which current management practices on the Marsh contribute to excessive water level fluctuations within the lake. This Lake Management Plan is the outcome of that work. The management plan was supported by three Wisconsin Department of Natural Resource grants (LPL-1188-09, LPL-1189-08, LPL-1348-10) and the submission of this Plan fulfills the requirements of these grants. In addition the WDNR arranged for and funded an aquatic plant survey of Dead Pike Lake which then became an integral part of the Management Plan.

The study included the following evaluations: (1) Dead Pike Lake water quality and effects of Powell Marsh discharge on water quality, (2) hydrologic evaluation of Powell Marsh and effect of Powell Marsh management on Dead Pike Lake water levels, (3) Powell Marsh iron and manganese export; quantification and mechanisms. (4) fisheries in Dead Pike Lake, (5) aquatic plants in Dead Pike Lake, (6) potential toxicity of iron discharges from the Powell Marsh and its effect upon Dead Pike Lake aquatic life, (7) survey of Dead Pike Lake users and residents.

Characteristics of Dead Pike Lake

- Natural and largely undisturbed shoreline with low resident population density.
- An abundant and diverse aquatic plant community with no invasive aquatic plant species and 2 species of ”special concern”.
- A water habitat with high levels of oxygen, capable of nurturing a high quality sport fishery.
- A mesotrophic level of biological production and an absence of nuisance algal blooms.
- An extensive littoral zone with the potential for a high quality fish spawning habitat if not covered by iron and manganese floc.

Effects of Powell Marsh Discharges on Dead Pike Lake

Below are the findings of investigations to evaluate the causes and potential effects of Powell Marsh development and management activities on Dead Pike Lake:

- Sediment record in Dead Pike Lake. Iron measurements at the inlet to Dead Pike Lake, and a historical investigation of the Powell Marsh, indicate that elevated levels of iron and manganese floc discharging from the Powell Marsh are the result of development within the Marsh (Section 3.0, 5.0, and 6.0).

- A historic account (Section 3.0) of the degree of Marsh development (primarily ditch and conveyance construction) shows a relationship between the extent of Marsh development and the level of iron and manganese export from the Marsh. Construction of a railroad spur through the Powell Marsh in 1894 (presumably completed by that year) corresponds to a 1.5 times increase in iron export compared to pre-settlement; ditch construction and hydrologic reconstruction of the Marsh by 1937 (apparently for agriculture-See Figure 3-1) corresponds to an iron export increase of 3.5. Beginning in 1955, expanded development of the Marsh with ditches and dikes as well as control structures and management activities by the WDNR corresponds to an iron export increase of 3 to 5 times compared to pre-settlement.

- The mechanism responsible for the iron and manganese export from the Powell Marsh is the oxidation of iron and manganese sulfide (sulfide minerals) in Powell Marsh soils and ditches. The sediment record (Section 6.0, Figure 6-14) showing a relationship between sulfur and iron + manganese accumulation in Dead Pike Lake sediments indicates that sulfide mineral oxidation causes iron and manganese export from the Powell Marsh. Oxidation is likely caused by a lowering of the water table and exposure of anoxic groundwater to the oxygen rich water in the ditches. The open ditches and a lower water table increase oxygen exposure to Marsh soils previously covered by water and vegetation. The region in which the Marsh lies is well known to contain rock and till with sulfide minerals (see http://dnr.wi.gov/org/es/science/crandon/maps/penokean.pdf).

- There is a direct link between recent Powell Marsh management practices and metals export from the Marsh. Liming activities in the Marsh (Section 3.0) led to an approximate 3 times increase in calcium export from the Marsh while these activities (which raise pH) also reduced aluminum export (Section 6.0, Figure 6-7).

- Elevated iron and manganese export directly affects:
    - Recreational use of the lake by raising turbidity, discoloring the water, causing odor, and by promotion of iron and manganese accumulation on littoral zones (Section 2.0).

  - Lake water clarity (Section 5.0, Figures 5.6 and 5.8). There is a direct relationship between iron levels in Dead Pike Lake and Secchi disc depth and between periods of iron loading from the Powell Marsh and Secchi disc depth in Dead Pike Lake. There is also a direct relationship between the rate of iron deposition in Dead Pike Lake sediments (a proxy for iron loading to the lake) and annual average Secchi disc depth.

- Potential iron toxicity to aquatic life in Dead Pike Lake. A literature review of iron toxicity (Section 7.0) indicates that iron can be toxic at levels being discharged from Powell Marsh to several aquatic species, some of which may be found or related to forms found in Dead Pike Lake. Water from one of two outlets of the Powell Marsh was shown to measurably reduce *C. dubia* reproduction in whole effluent toxicity tests. Safe iron levels for aquatic life have been identified by researchers and Canadian Provincial Governments to range from 1 to 1.74 mg/L.

- Elevated concentrations of phosphorus in Marsh discharges. Concentrations of total phosphorus observed in the Marsh discharge and in the inlet (south) bay of Dead Pike Lake were found to be well in excess of levels associated with the eutrophication of Wisconsin lakes (Section 5.0).

- Hydrologic manipulation of the Marsh in order to drain portions to maintain ponds for water fowl in other areas can cause magnified fluctuations in Dead Pike water levels (Section 2.0 and 4.0). Large releases of water from the Marsh can cause significant increases in the lake water level causing property damage and may endanger littoral habitats for aquatic plants.

Regulatory Basis for Action

Wisconsin rules, as well as existing impairment designations and total maximum daily load allocations for iron, provide the regulatory basis and precedent to mitigate the discharge of iron, manganese, and solids from the Powell Marsh.

(1) Wisconsin “Narrative Criteria” which regulates for pollutants not provided with explicit numeric criteria in the rules. See below.

NR 102.04 Categories of surface water uses and criteria.

(1) GENERAL. To preserve and enhance the quality of waters, surface water uses and criteria are established to govern water management decisions. Practices attributable to municipal, industrial, commercial, domestic, agricultural, land development or other activities shall be

controlled so that all surface waters including the mixing zone meet the following conditions at all times and under all flow and water level conditions:

> (a) Substances that will cause objectionable deposits on the shore or in the bed of a body of water, shall not be present in such amounts as to interfere with public rights in waters of the state.
>
> (b) Floating or submerged debris, oil, scum or other material shall not be present in such amounts as to interfere with public rights in waters of the state.
>
> (c) Materials producing color, odor, taste or unsightliness shall not be present in such amounts as to interfere with public rights in waters of the state.
>
> (d) Substances in concentrations or combinations which are toxic or harmful to humans shall not be present in amounts found to be of public health significance, nor shall substances be present in amounts which are acutely harmful to animal, plant or aquatic life.

(2) Wisconsin Criteria for Phosphorus

NR 102.06 Phosphorus.

(4) RESERVOIRS AND LAKES. Except as provided in sub. (1), to protect fish and aquatic life uses established in s. NR 102.04 (3) and recreational uses established in s. NR 102.04 (5), total phosphorus criteria are established for reservoirs and lakes, as follows:

> (a) For stratified reservoirs, total phosphorus criterion is 30 µg/ L. For reservoirs that are not stratified, total phosphorus criterion is 40 µg/L.
>
> (b) For the following lakes that do not exhibit unidirectional flow, the following total phosphorus criteria are established:
>
> 1. For stratified, two-story fishery lakes, 15 µg/L.
> 2. *For lakes that are both drainage and stratified lakes, 30 µg/L.(eg Dead Pike Lake)
> 3. For lakes that are drainage lakes, but are not stratified lakes, 40 µg/L.
> 4. For lakes that are both seepage and stratified lakes, 20 µg/L.
> 5. For lakes that are seepage lakes, but are not stratified lakes, 40 µg/L.

(3) Iron has been identified as a cause of impairment by the US EPA. The US EPA conducted a TMDL study on Duck Creek in Alaska (October, 2001), the result of which was a load allocation and a requirement to control iron entering the creek with a filter screen.

1.0 Introduction and Statement of Goals

Dead Pike Lake is located near the western border of Vilas County in North Central Wisconsin. This lake is a medium sized (297 acre), deep (maximum depth upwards of 80 feet), soft water lake, which is moderately productive with a long term average Secchi disc depth of 2.7 meters (annual average ranges from 1.9 to 4.8 meters). Dead Pike Lake is unique in that it is largely undeveloped (approximately 60 percent of the shore line is public land), has few permanent residents and enjoys a littoral community which is largely undisturbed (see Figure 1-1).

The lake is fed by both surface and ground water inputs. The total watershed area of the lake is estimated in this study to be approximately 2,951 acres. Surface water inputs are provided almost exclusively by the Powell Marsh with approximately 2,071 acres contributing directly to two lake inlets. The remainder of the watershed drains to Dead Pike Lake either through subsurface (vadose) or groundwater flows. A USGS study conducted in 2002 estimated that approximately 30 percent of the water inputs to Dead Pike Lake were from surface water.

The Dead Pike Lake Association was formed in 1999 after numerous property owner complaints, regarding poor water quality (Figure 1-2) and fluctuating water levels, were largely ignored by the WDNR. People feared that deteriorating water quality threatened recreational use of the lake as well as its aquatic life. They also were concerned about the extreme water level fluctuations they were experiencing with waterfront damage to piers and watercraft during water surges and conversely, exposed beaches and docks during periods of water retention by the Department as it sought to preserve the Marsh's flowages. It was assumed that a collective effort with a unified appeal would result in a more desirable response.

The department did respond in 2002 by authorizing the USGS to conduct a hydrologic study (Krohelski et al 2002) which concluded that the Marsh structures did not affect the "water budget" for Dead Pike Lake. This conclusion ignored the main issue, which is the Department's practice of manipulating that "budget" by periodically withholding and/or releasing large volumes of water which then cause the lake's fluctuating water levels.the study stated that without the structures, "it is *likely* that the floc formation *may* be redirected to the near-shore environment of Dead Pike Lake," a highly qualified conclusion which the Department chose to interpret as a declarative statement. This too ignores the issue of iron load which is the major concerns for the lake. In addition, close review of the computer generated figures for the comparative "path lines" of this *redirection* indicate that the flow would actually be *away* from Dead Pike Lake, moving instead in a north -easterly direction to the shores of the Second and Third Stepping Stone Lakes. So the statement is both inaccurate and irrelevant and inaccurate.

However, the study did produce two important findings, both related to the filling of the ditches. First it stated that if the ditches were eliminated, the ground water level of the Marsh would be raised approximately 2 feet (to its natural level) anad "If ditches were removced, floc production in the ditches would no long be available for transport because the environment that is suitable for floc formation would be removed" (Summary and Conclusions, Page 14)

The development of a "Certified" Lake Association, with its more formal status, still failed to result in a satisfactory response from the Department. The Association was informed that "all of its questions had been addressed and that further inquiries would likely go unanswered." It was then that the Association turned to its legislators for assistance, resulting in a hearing before the Assembly Natural Resources Committee at which time both the Department and the Association presented its positions on the issue.

This was followed by the Association's contact with Region V of the Federal EPA whose representatives then made a site visit and later arranged for a joint meeting between the DNR and DPLA in Madison to discuss resolutions. It was during this meeting that the Department consented to authorize a formal review of the Powell Marsh Master Plan, an exercise which had not been conducted since 1979. The EPA concluded the meeting by insisting that the option of filling the ditches (Marsh restoration) must be a viable option for consideration.

In anticipation of that review and seeking assurance that there would be scientific data upon which to base the Department's deliberations, the DPLA sought and secured a series of grants for the purpose of formulating a Lake Management Plan for Dead Pike Lake. Begun in 2007, that plan is now completed, with extensive analysis of the effects of the Powell Marsh and its current management upon the conditions within Dead Pike Lake. The Department, being as it claims, "science driven in its decision making" will now have ample data upon which to make conclusions regarding the future of the Marsh as well as the future of Dead Pike Lake.

Based upon the values of the Dead Pike Lake Association members, the results of the user survey, and the findings of the scientific studies conducted as part of this lake management investigation, the association has adopted the following ***lake management goals***:

(1) **Lake Water Quality**. Achieve lake water quality that is commensurate with inflows from an undisturbed and natural wetland watershed. This includes littoral and shoreline zones that are free of excess iron and manganese floc accumulation, iron levels in all areas of the lake below nuisance conditions (e.g., does not impair recreation) and below levels that would threaten to be harmful to aquatic life (1.0 to 1.7 mg/L), nutrient levels that can support a healthy fishery but not cause algal blooms, and balanced and natural levels of dissolved ions and cations such that aquatic life is protected. Water quality should also be achieved such that average summer transparency (Secchi disc) is maintained at levels that are minimally affected by iron (estimated to be greater than 3.5 meters Secchi disc depth).

(2) **Water Levels**. To protect property, recreational habitat, and the exceptional aquatic plant community in Dead Pike Lake, changes in water levels should not be greater than that due to natural climatic variation and inflows commensurate with a naturally functioning, uncontrolled, and undisturbed wetland complex. Such natural fluctuations will be accepted by the Association as a part of regular water level variations within a drainage lake.

(3) **Nurture a High Quality Sport Fishery.** Work with the WDNR to assess the impact of current Rainbow Smelt populations within the lake and to encourage the stocking of larger Walleye fingerlings, both for better survival rates as well as to provide predation upon the smelt. Additionally the traditional spawning habitat for Walleye should be restored both by controlling further floc accumulation and by allowing the action of natural fetch to clear the rocks or providing for the addition of clean gravel to suitable shoreline habitat to encourage natural reproduction.

(4) **Maintain the Current Natural and Undeveloped Shoreline to Maximize and Protect Wildlife Habitat and Water Quality** Educate lake residents and Lake Association members regarding the importance of maintaining a natural lakeshore to promote wildlife habitat and protect water quality of the lake. Work with WNDR to promote sensible management practices on State land adjacent to Dead Pike Lake shoreline.

The lake management goals provided in this document were the outcome of a scientific investigation, research on the history of the region and a survey of the uses and observations of Association members and visitors to the Lake. There were several contributors to this effort. Research data was collected by a number of members of the Association including President, Peter Guzzetta and his wife Nancy along with Water Chairman Gale Wolf and his wife Jean. Treasurer Florence

Weiesendanger and her husband William provided backup when needed as did Vice President Bill Hembrookand. Ms. Weisendanger is credited with the photography within the report. Association member Ron Dassler offered services of his pontoon boat for doing the sediment coring.

Gale Wolf constructed the user survey, compiled the data, and wrote Section 2.0 describing the results of the survey. He also conducted research on the history of the region and the Powell Marsh reaching back to the "logging era" and the time of settlement in Northern Wisconsin. He wrote Section 3.0 on the History of the Powell Marsh and was a significant crafter and contributor to Section 1.0 (Introduction). Dr. Paul Sager, Professor Emeritus at UWGB and a friend of the Dead Pike Lake Association, wrote Section 10.0, describing the importance of Powell Marsh ecology on Dead Pike Lake. Sections 4.0 through 8.0 (scientific evaluations) were written by Dr. Keith Pilgrim of Barr Engineering. Dr. Pilgrim also provided document-wide editing and final document production. The Executive Summary, Section 11.0 (Discussion) and Section 12.0 (Management Resolution) were cooperative products of Lake Association Members, Dr. Pilgrim and Dr. Sager.

2.0 User Survey

The document provided herein is a Lake Management Plan, implying that Dead Pike Lake will be managed in some way. Management also implies that actions can be taken to affect some change to achieve an outcome. The WDNR recommended that a user survey be conducted as an activity under the lake management planning grant to better understand how Dead Pike Lake is being used so that management can be tailored in accordance with those uses.

The concept of "uses" is a basic tenet of water quality regulation in the United States. Water quality rules have been developed to protect the "uses" of a given water body. The Clean Water Act, which serves as the structural basis of clean water laws in the United States, identified "fishable and swimmable" as the basic use that should be attained for all water bodies in the United States. The user survey described below was tailored to some extent to better understand the uses of the lake and whether the basic fishable and swimmable uses, as provided by the Clean Water Act, are being met.

A user survey was developed and conducted first in 2008 and again in 2009 to satisfy the required language of the WDNR. The results of the 2008 survey are not provided, however, the results of the 2009 survey are provided below. In May 2009, surveys were distributed to Dead Pike Lake association members and provided at the boat launch on the south side of the lake. A total of 26 surveys were returned and compiled. The survey consisted of simple "yes/no" questions, comprehensive multiple choice, and ranking exercises. There was also an opportunity for subjective comment which does not lend itself to numerical analysis but will be largely interpreted in summary form. Provided below are the results of the surveys as well as the survey questions. Note, responses tabulated below are provided primarily as percentages, when percentages could not be calculated because of the nature of the survey question, the number of respondents was provided.

Question 1. *Are you a Wisconsin resident?* 83 percent responded yes.

Question 2. *Do you own property on Dead Pike Lake?* 83 percent responded yes.

Question 3. *How many years of experience do you have with Dead Pike Lake?* Only one response was a first time user. Other distributions included: 1-10 years (1), 11-15 years (5), 16-30 years (8), 31-40 years (5), and 41-60 years (6).

Question 4. *<u>If you do not own property on Dead Pike Lake, how far away do you live?</u>* Responses: 8, 11, 18, 25, and 320 miles. Property owners and "locals" represent the major users of this resource with only one user traveling a significant distance.

Question 5. *<u>During which time periods do you use the lake?</u>* Monthly periods provided for this question include: (12-2) (3-5) (6-8) (9-11).

June/August (6-8) were the most popular with 28 responses, followed by September/November (9-11) with 18. Thirteen responded March/May (3-5) while 5 responded December/February (12-2).

Question 6. *<u>How do you use the lake?</u>* Options provided for this question included: Fishing, Silent Boating, Power Boating, Swimming, and Viewing Nature.

Every single respondent listed fishing as their primary activity, followed closely by "nature viewing" (80 percent). Swimming is also a popular activity with 60 percent of respondents indicated that they use the lake for swimming. Silent boating (56 percent) is a more common activity than power boating (44 percent). 12 percent of respondents use personal water craft on the lake.

Question 7. *<u>In your opinion, what are the most important aspects of a quality lake?</u>* Options provided for this question include: Stable water level, Clear water, Diverse native aquatic plants, Good fishing, Fish safe to eat, Abundant wildlife, Limited lakeshore development, Natural shoreline, Limit motorized activity, Good water skiing, Other. Respondents were asked to choose 5 and rank them.

Good fishing was included in 92 percent of the responses, with 1/3 of the respondents listing it as the #1 most important aspect of a quality lake. 64 percent included limited lakeshore development as a priority however about 2/3 of those responses were lower rankings (3 to 5). From the survey respondents, it is clear that a lake with clear stable water, healthy native plants, and abundant fish population which is safe to eat, with limited motorized activity, in a natural, wildlife-filled environment is the desire of the sample users.

Question 8/9. *Has the lake water level affected your use of the lake in the last 10 years? If so, how has the water level affected your use?*

80 percent of the respondents stated that the water level had affected their use. All reported difficulty with launching their boats or reaching their docks during low water while a little over half complained of difficulty installing their docks and/or retaining them at a desirable height as the water level fluctuated and was unpredictable, year to year. High water events tended to wash docks out and one comment complained of shore erosion during such extreme fluctuations.

Question 10. *Has the density of weeds in the lake increased over the last 10 years?* Choices provided in the survey included: “Definitely no” “Probably no/yes” “Unsure” “Yes” “Definitely yes”

60 percent of the respondents replied “definitely yes”, 20 percent replied “probably yes,” 7 percent said they were ”unsure” with 4 percent saying “Probably no/yes” and another 4 percent saying “no”.

Question 11. *During the years of experience you have had with Dead Pike Lake, how would you say that the water clarity has changed, if at all?* Choices provided in the survey included: “Much clearer” “Somewhat clearer” “Somewhat less clear” “Much less clear” “Not much change”

12 percent of the respondents left the question bank while 10 percent said the lake was “Much clearer,” 21 percent said the lake was “somewhat clearer,” 13 percent observed “Not much change,” while 16 percent said the lake was “Somewhat less clear” and 28 percent said it was “much less clear.”

Question 12. *Just giving us your best recall, in what year would you say you first noticed a change in the water quality of Dead Pike Lake?*

As a group, the respondents picked nearly all the time periods between 1950 and 2009. A large number of respondents noted a change in water clarity from 1950 through 1969 as well as in the early 1990s.

Question 13. *During the past 10 years how, if at all, has the fish population changed?* Options provided on the survey included: “No opinion-I’m not sure,” “Fewer large fish,” "More large fish," Fewer small fish," "More small fish," "Less Fish Variety," "More fish variety," "More introduced (non-native) fish," "I haven't noticed any change," "Some other way."

A third of the respondents said that there are fewer large fish and there is less variety. About 18 percent said there were more small fish or that they say no change. 22 percent complained about the lack of walleye while four 16 percent blamed the demise on rainbow smelt. 7 percent said there were more big fish while 4 percent had no opinion.

Question 14. *<u>Rainbow smelt is a non-native fish which has been found in Dead Pike Lake. What impact, if any, do you think the smelt have had on the native fish populations of Dead Pike Lake? Would you say the smelt have…</u>*

… acted as predators and thereby been responsible for a decline in the native fish population?
… provided forage (food) and thereby benefitted the native fish population?
… had some other impact on the native fish population?
… had no impact at all on the native fish population?
… no opinion - I'm not sure.

Nine percent did not answer and another 9 percent said they were not sure. 47 percent claimed smelt were a benefit while 35 percent saw them being responsible for the decline of the game fish population.

Question 15. *<u>How would you rate your ability to launch a boat at the existing boat landing</u>*? Options provided included "Poor," "Fair," "Adequate," "Good," "Excellent," and "I have not parked at the landing"

One (4 percent) reported that the landing was excellent. 23 percent said that they had never launched a boat at the landing. One (4 percent) said that he sold his boat because he couldn't get it in the water while only one (4 percent) called the landing "Excellent." 50 percent saw the landing as "poor" while 39 percent considered it "adequate" and one (4 percent) considered it "good."

Question 16. *How would you rate your ability to park your vehicle and/or boat trailer at the existing boat landing*? Options provided included "Poor," "Fair," "Adequate," "Good," "Excellent," and "I have not parked at the landing"

Only one respondent (4 percent) thought parking was excellent. 23 percent said they had not parked at the landing. Another 32 percent thought parking was poor and approximately a 22 percent thought it was adequate while 8 percent thought it was good.

Question 17/18. *Has the water quality of the lake ever deterred you from using the lake? If yes, please describe the conditions that deterred you from using the lake.* Options provided in the survey included: "Definitely no," "Probably no," "Unsure," "Probably yes," "Definitely yes."

Thirty-seven percent of the responses were in the "Probably yes" and "Probably no" or "Unsure" categories. Those definitely certain—26 percent "Definitely no" and 37 percent "Definitely yes" were the bulk of the responses (note that the percentages add up to greater than 100 percent because more than once response was allowed). Those that responded "Yes" provided additional comments:

> "Iron floc on the sand. 'Greasy' scum on the shoreline."
>
> "Water has been atrocious, that you would not walk in it and certainly not swim in. How can fish or waterfowl and other wildlife not be adversely affected by it?"
>
> "Quit swimming in the 1970's due to red color from ion floc."
>
> "Too muddy in the bay where the inlet is."
>
> "Some years I have not fished."
>
> "We don't swim as much because of the iron floc and other sediments in the lake."
>
> "Swimming-boating. Lake is too dirty."
>
> "For the past 15 years there has been a scum, iron floc on the water and shore.—Impossible to allow grandchildren to swim! Aesthetically unpleasing!"
>
> "At times the lake in the bay becomes cloudy. This has been going on for years."

> "When water was released from the marsh into the lake, iron floc floated in the water, creating unsafe swimming conditions. Water clarity improved when water was not released from the marsh and the lake level dropped."

Summary and Analysis

The results of this user survey indicate that those who either visit or live on the lake use the lake in a way that is in line with those who drafted the goals and policies of the Clean Water Act of 1987. In this act, Section 101 (2), it states "it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for the recreation in and on the water…" This has been called the "fishable/swimmable" clause of the clean water act. The survey results demonstrate that Dead Pike Lake is used for fishing, swimming, and for wildlife viewing. The survey also demonstrates that users of the lake see these protected uses of the lake being damaged by discharges from the Powell Marsh.

It is notable that most of the users of the lake have been observing the lake from one to several decades. The respondents have noted changes in clarity from 1950 through 2009, with some respondent noting more significant changes in clarity in the 1950s to 1960s and 1990. The sediment record of the lake (see Section 6.0) supports these observations because higher iron accumulation rates (e.g., high iron inputs to the lake) occurred during these time periods compared to the more recent decade. Respondents have also noted that plants have become more dense in the last 10 years. This is also likely a result of reduced iron input during the last 10 years and the effect of reduce iron inputs on lake clarity (e.g., lower iron= improved lake clarity).

According to the survey, the number one recreational activity on the lake is sport fishing. Therefore, the condition of the fishery is of prime importance. It is notable that the Clean Water Act identified "<u>propagation</u> of fish" as a fundamental tenant of the act. As noted in the Fisheries section of this plan (see Section 8.0), walleye are not naturally propagating in Dead Pike Lake. It is the opinion among many of the respondents that poor water quality in Dead Pike Lake due to iron has affected fishing.

According to the respondents the use of the lake is also being affected by several factors including fluctuating water levels, poor water clarity, and accumulation of iron floc. However, it is clear from the responses that the public does not view this lake as something simply to be "used" but rather as something to be respected, preserved. A large number of individuals (56 percent) that boat on the lake use "silent boating" and 80 percent engage in nature viewing. Clearly, Dead Pike Lake is seen by the public as an extremely valuable water resource that needs to be respected, protected, and preserved.

3.0 Historical Account of Dead Pike Lake and the Powell Marsh

The history of the United States as well as much of the world is of development. Settlement meant alteration (sometimes on a large and significant scale) of the landscape. Not well understood at the time of settlement (approximately 1850 to 1870 in northern Wisconsin) was the connection of the landscape (e.g, the watershed- consisting both of terrestrial and aquatic environments) to water. The undeveloped watershed provides the measured release of water, balanced levels of dissolved minerals and carbon, and energy in many forms including biological life. Clearly, since development countless numbers of water bodies are in peril because the watershed no longer provides a chemically and biologically balanced water supply. Around the country attempts are being made to undo what has been done.

Although the development history of the Powell Marsh is disheartening, it can also be encouraging. The Association engaged in this effort to better understand how human activities have affected the geochemical, biological, and physical functioning of the Marsh. A comprehensive understanding of how the Marsh has been altered provides a framework from which to begin restoration. The Association believes that the history of the Marsh and data collected as part of this Plan provide extensive evidence that restoration of the Marsh can be undertaken to reduce the discharge of high levels of metals (e.g., iron and manganese) and suspended solids restore the input of the water to historic proportions of surface and groundwater, and return the Marsh and Dead Pike Lake to pre-development conditions.

The Early Years: 1830 – 1950

The land/water mass of the Marsh lies within both Vilas and Iron Counties, occupying the better part of 9 sections. The western region of the Marsh is in Iron County (Mercer/Sherman Township – Sections 25 and 36) and contains the greatest portion of forested, high ground offering early opportunity for both logging and subsequent homesteading activity.

Although Iron County was not established until 1883, earlier records from Ashland County-which at the time encompassed this area – indicate that vast amounts of land were acquired by eastern interests. The federal government, in an attempt to promote “internal improvements,” especially within the vast expanse of Midwestern Territories, passed the Morrill Act of 1862. This legislation provided for states that no longer had public lands of their own, to be allocated “scrip” based upon the number of congressional seats they held in Washington at the time. The state of New York, under the leadership of Ezra Cornell, determined that it would exercise this right to public domain by claiming almost a million acres of timberland in Northern Wisconsin.

So it was in 1870, along with thousands of acres of surrounding timberland, Cornell University (through the influence of Ezra Cornell upon the NY State legislature) laid claim to those parcels of land under discussion, two sections which would later define the western boundaries of the Powell Marsh. Of interest is the fact that the mineral rights of this extensive transaction were also exercised by Cornell University promoting the mining era in the Hurley area and they have never been rescinded. Obviously the intent of this vast acquisition was speculative and was to provide generously for the future development of this Ithaca-based institution. “By 1922, Cornell University has received over seven million dollars from its Wisconsin lands, more than five million of which was clear profit.” (Lumbering in Wisconsin, 1951, Fries, page 173).

Almost immediately, regional lumber companies began logging the Cornell holdings. Records show that Knapp, Stout and Company, along with the Chippewa Logging Company paid handsomely for the timber rights to tens of thousands of acres. It is reasonable to assume that the parcels under discussion, located as they were in proximity to developing railroad access from the south (The Soo Line and Chicago Northwestern) as well as the Flambeau-Manitowish River waterway, were prime prospects for immediate logging operations. However, potentially most import was the construction of a railway spur (by the Flambeau Lumber Company) through the Powell Marsh from Lac du Flambeau to Little Starr Lake in 1894 (presumably construction was completed by this year). It is this construction activity, which likely included ditch digging and other necessary drainage features to support construction equipment and a railway bed, which likely triggered the initial release of iron from Powell Marsh soils. It seems reasonable to assume that this railway bed was later used as a road which is now called Marsh Road.

By the end of the 19th century, this total area had been clear cut and it was then that the push for homesteading began. With the timber exhausted, the State government began promoting the “The Great Cut Over” for agricultural settlement in northern Wisconsin. Opportunities for homesteading were offered by the State of Wisconsin similar to those given by the Federal Government for public lands in the west. In concert with this promotion, Cornell sold Section 25 and 36 (in Iron County, on the western edge of the Powell Marsh) to Mr. Arron Reilly in 1900.

Clearly, one can imagine the seemingly futile effort of farming the sandy, acidic upland soils of this region even though it had only recently so successfully supported a towering white pine forest. Stumps needed to be pulled which in many instances exposed the elevated water table of the adjacent marsh (now called the Powell Marsh). Crude cultivation methods further scarred the region leaving their mark. After wasting seven years trying to farm stump land that wasn't meant for diversified crop farming, Reilly sold out to the State of Wisconsin in 1907 leaving behind only passing reference to his effort by naming the water body next to his holdings – Homestead Lake, which retains that name to this day. The state held title to the property from that time forward.

Aerial photographs from 1937 show the accumulated human influences on the Marsh up to this time (Figure 3-1). There was an 18 acre agricultural operation in the Marsh just south of Vista Overelook and running (east, southeasterly) along what appears to be the former natural stream bed. A road (currently called Marsh Road) stretched clear across the Marsh from the northeast intersecting the Powell Road and extending to the south to Highway 47. There are ditches along this road, some apparently draining water to the north and some south to Chewelah Lake on the southwestern edge of the Marsh. Also visible on the photo is a ditch extending from the middle of the Marsh in a location that is just south of an area now called the "Main Pool." It can be seen on the 1937 photo that this ditch extends north, draining to natural and manmade conveyances and ultimately to Dead Pike Lake. This aerial photograph shows that in 1937, conveyances were in place that drain a region of the Marsh where the iron stained ditches are so clearly visible today. It is also interesting that many of these man-made features are still visible today with current development structures simply an extension of past developments.

In late 1940's a devastating fire, started by sparks from the Chicago/Northwestern Railroad, consumed a substantial portion of the 6,000 acre watershed, of which the Powell Marsh is a significant part. It prompted a semi-panic within the local population, many of whom helped fight the fire. These people grew progressively more accepting of the creation of a checkerboard of roads within this region for the purpose of "fire protection." It is interesting to note that not a single fire has occurred in the Marsh since the Chicago/Northwestern line was discontinued in mid-1900's and the railroad bed was converted into a snowmobile trail.

One of the unsuspected benefits of this burn, occurring as it did in early fall, was the attraction of huge flocks of migrating snow geese, which descended to feed on the newly emerging green shoots within the burned-over areas. The "Conservation Congress" was petitioned by local sportsman to create a goose refuge which coincided nicely with the public's desire for fire protection and prompted grandiose plans for the “development” of the resource into its current state. Unfortunately, no master plan for that development can be found within the records. It should also be noted that at that time there was no requirement for either an Environmental Assessment or an Environmental Impact Statement before such dramatic alterations of a wetland could occur.

The East Side

Meanwhile on the eastern edge of the Marsh (whose central portion was still held by the Federal Government as useless marshland) there was a more diversified development. The Manitowish Chain of Lakes was already established and with it small parcels had been claimed and developed throughout the area beginning in the early 1900's. None of these appear to have had any significant connection to the Marsh until the development of adjacent cranberry marshes in the late 1940's.

Frank and Betty Koller planted the first cranberry bog in the summer of 1945, cultivating a total of nine acres. By 1948 that modest beginning grew to a total of five “family farms” covering over 100 acres and has now burgeoned into an agricultural industry encompassing the better part of 3 1/2 sections north and northeast of Little Trout Lake. These areas were all within the original boundaries of the Marsh.

The impact of this development on the Marsh is difficult to determine but the early unregulated use of fertilizers and pesticides has likely contributed to the accumulation of trace chemicals and heavy metals within the sediment of Little Trout Lake (Winkler and Sanford, 2000). Recent studies conducted by the USGS in 2002 (Water-Resources Investigations Report 02-4034) show Little Trout to be at the highest elevation within the Marsh area with gradation decreases flowing to the northwest, or directly into the heart of the Marsh. Drawing water from this lake is discussed within the records as a means for replenishing the flowages. It is unknown whether or not direct discharges were made from the cranberry bogs although groundwater seepage would have flowed in that northwesterly direction.

State Ownership: 1950 – 2000

While the early years were dominated by private enterprise, the latest history of the marsh is predominantly, if not exclusively, a record of public initiative taken by the Wisconsin Department of Natural Resources. Following the fire of 1948 and the sportsmen’s pressure for a goose hunting experience within the north woods, the old “Conservation Commission” sought control of the interior of this extensive wetland. Reports from retired DNR personnel indicate that there was also a state-wide initiative to disperse goose concentrations from the Horicon Marsh in east-central Wisconsin by establishing “satellite facilities” throughout the state.

Concurrently the Federal Government had just passed legislation stating in summary that:

> “*By this act of the U.S. Congress, Arkansas and any other states within the Union, may lay claim to any and all of the swamp lands which lie within their specific limits*.”

So in 1955, the Commissioner of Lands (by patent) granted and conveyed to the State of Wisconsin all of Sections 29,30,31,32, and 33 in the Township of Manitowish Waters, County of Vilas. This acquisition resulted in the transfer of 3,125 acres in the center of the Marsh to the State of Wisconsin.

This did not include that portion of the Marsh lying within the boundaries of the Lac du Flambeau Reservation to the south. In an effort to exercise complete control of this watershed, the State arranged to lease that portion owned by the Lac du Flambeau tribe and manage the expansive 6,000-plus acre complex by installing roads, dikes and ditches. Discussions with the tribe began in 1954 culminating in a formalized lease on August 1, 1957, an arrangement which lasted through July 31, 1982. Although the records give no indication of cost adjustments throughout the life of this contract, the initial annual payment was $1,238.89.

By the late 50's the entire complex had been altered by the State’s wildlife managers in a manner considered to be in the best interest of the hunting public. This resulted in a patchwork of 14 miles of dikes to block the natural flow of the water, thereby creating a series of flowages which submerged 1300 acres of aquatic plant life. Interspersed throughout were 14 control structures, called “tin whistles” by department personnel which, through manual control are used to move water as deemed beneficial for waterfowl production and the encouragement of select plant life for consumption by these species.

Two major flowages were created: Stepping Stone Flowage lying within the northeastern portion of the Marsh and the main Vista Flowage located along the northern boundary. Another major flowage was envisioned, extending from below the main dike westward and flooding an additional 200 + acres of aquatic vegetation alongside the Powell Road. It was to be called the Dead Pike Flowage and was cancelled only because the private land owners along its northern boundary refused to support the effort and sacrifice portions of their property which would have been flooded. This effort was resurrected in the early 2000's and promoted by the Department’s partner Ducks Unlimited as an incentive to solicit support from the hunting membership within its local chapters, indicating that it would provide an additional 200 acres of "duck habitat" within the complex. This cooperative effort also resulted in a 25 year binding contract between Ducks Unlimited and the WDNR, wherein the continuation of this process of water control was mandated by Ducks Unlimited as a condition for their financial involvement. It was also stipulated that any deviation from this "management directive" would result in a repayment of Ducks Unlimited's monetary investment for this project, an amount determined to be approximately $75,000. These funds were used to reinforce 1/3 mile of the main dike at a cost of over $160,000. This figure is one of the few records available to document any financial expenditure within the Marsh according to the Marsh Manager. "There is no specific financial data for Powell Marsh" (Correspondence, 20 July 2010)

Finally, immediately below and running alongside each mile of dike, corresponding ditches were dug, which together have, according to a USGS study conducted in 2002 (Krohelski et al, 2002), significantly lowered the water level of the entire Marsh a total of two full feet. The intent of this drainage effort is confirmed repeatedly throughout the records from the 50's and early 60's; it was designed to drain the Marsh, destroy the native aquatic vegetation and create a more desirable "grassland community" in order to support the production of grains for waterfowl (goose) consumption.

Even with this amount of change, the full impact of the effort was not sufficient. The upland portions of the Marsh needed to be transformed as well. Terrestrial vegetation limited the appeal of a wide expanse for migrating geese and therefore needed to be cut. Additionally, the cleared land could be cultivated for agricultural crops, adding to the attraction of the refuge to waterfowl.

In all, the files record a total of seven major timber cuttings independently contracted between 1959 and 1972. How many cords of pulp and how many board feet of timber were cut, will never be known. There is also no record of the "girdling" of two forties of poplar in the southwest corner of Manitowish Waters Township section 19 by the Department itself in the early 60's (observed by Gale Wolf and Bill Hembrook). Also independent cutting continues to this day along the Marsh's boundaries (correspondence with NHAL Superintendant). As justification, internal memos list it as necessary "t*o help remove timbered areas and improve the Powell Marsh for goose management."*

But the challenge of the wetland, the conversion of this leatherleaf, sedge-type bog into a dry environment capable of "intensive agricultural food production," was replete with problems. Most immediate were the "floating bogs" which refused to dissipate and thereby cluttered up the newly created flowages.

The U.S. Department of the Interior advocated that they “blow them out” with dynamite. The State of Michigan suggested that they “break them up mechanically and physically remove them from the impoundment area.” If that didn’t work, “*chemically treat them so they sink. If they green up, retreat them*.” Neighboring Minnesota’s Department of Conservation thought that “wiregrass” could be planted after chemicals destroyed the native vegetation and they could act as “nesting platforms” for the geese.

Of more import was the condition of the soil; it was sandy, infertile and acidic. It is here that the connection between Marsh management activities and the chemistry of water and sediment in Dead Pike Lake become clear. Fertilizer was applied in mixes ranging from a phosphorous low of 3-9-27 to a high of 17-17-17 (nitrogen-phosphorus-potassium). Application amounts began in 1955 at a rate of 500 pounds per acre- 20 tons of fertilizer were spread over each 80 acres under cultivation. Documentation shows that this was done annually. It is notable that lime was also applied to the Marsh land at a rate of “***8 tons*** of lime per acre, to be applied in four separate years....” (Memo: J.R. Berkhahn to R.B. Hovind, March 13, 1958). The sediment record of Dead Pike Lake (see Section 6.0 and Figure 6-7) shows a significant increase in calcium (presumed to be from the lime application) in lake bottom sediment starting after 1977. It is also interesting that aluminum export from the Marsh began to decline between 1950 and 1960 and has continued throughout the present (Figure 6-7). Aluminum is insoluble at pH 6.3 but its solubility increases below that pH. Liming efforts likely had the effect of increasing the pH of the Marsh soils.

In the late 1950’s the Marsh became a veritable research center. Quarter acre experimental plots were formed to compare the productivity of various combinations of fertilizer concentrations/quantities with differing lime applications. Even with all this effort, the project met with only limited success and the review document of 1979 written by the Department, indicated a declining waterfowl utilization rate and diminished enthusiasm for the project. What little crop production remained was rapidly being consumed by even the limited migrating flocks it attracted. A 1959 internal memo explains that “*two captive geese will eat all the grain in a 12 X 12 pen in a single day and leave an average of 92.2 droppings per goose to show for it.*”

But the department persevered. If more acreage could be added, probably the experiment could still be salvaged. So a directive from March 13, 1959 stated: “*As much peat land as funds and manpower will permit will be broken during the first half of the summer, this in addition to the already broken peat land and the cleared high islands will be put into production ...*” The process was not easy. “*The peat should be plowed the fall preceding the spring when crops are to be planted to give the* *material time to compact over winter. A* ***breeding plow*** *which cuts a furrow 20-24 inches must be used. This buries the turf and even brush up to 15 feet high can be pushed down with a push-bar equipped caterpillar tractor and covered. The following spring the new breaking should be disced."* The Minnesota Department of Conservation recommended a ***Norwegian Plow***. *"It is an ideal piece of equipment for plowing lands where there is a foot or 18 inches of peat on top of the mineral soil. By plowing a 2 foot deep furrow one can bury the peat with a layer of mineral soil while also plowing under trees 3/4 inches in diameter."* It is interesting to see the extent to which WDNR was willing to go in its attempt to improve the Marsh ecosystem

The Department of Natural Resources was intent upon going into an agricultural enterprise. But finding crops responsive to this climate and soil was also a problem. Buckwheat and German Millet were the initial choices. Yet actual lists of suggested grain crops were provided by the Agriculture Department of the University of Wisconsin, listing the probabilities of success under these limiting circumstances. They were not encouraging. Thought was given to importing exotic varieties from Germany and even Russia, where comparable conditions existed. All this only to have "crows consume the seeds before they could germinate and field mice eat through the stalks before they could mature."

Additionally, insects and a short growing season also posed a challenge. Besides the use of "Dalapon from Dow Chemical Company and Ureabor from Pacific Coast Borax Company" for the eradication of unwanted plant life, various insecticides were also utilized to protect plants favored by the geese. Most troublesome was the short growing season which was addressed by the UW Extension in a memo from 1961. *"Frost prevention can be accomplished in early spring and late fall by the use of smudges. One of the most successful ways is to use old automobile tires. These are stacked on the windward side of the field and ignited by using kerosene."*

In addition, the draining of huge portions of the Marsh by the extensive ditching system led to the encroachment of upland vegetation. These terrestrial invaders needed to be controlled. The obvious solution was burning. In addition to the controlled burns which supposedly provided a replication of the "fresh green shoot" phenomenon of 1948, now large sections of major brush invasions below the dikes were ignited when dry conditions warranted.

Corn was finally considered to be the solution. Again, a review of all the varieties was made and it was determined that planting could best be accomplished within the high sand ridge which spanned the interior of the refuge, next to the holding pens. The crop production was far from adequate and a plea went out "*If you have any corn lying around, would you let me know. We could use 5 or 6 ton anytime.*" This practice of spreading corn to attract geese was eventually deemed un-lawful by the Feds which considered it to be "baiting." It was discontinued on the Federal and State portions of the Horicon Marsh for that reason and is assumed to have affected the practice at other refuges including the Powell Marsh.

Recent History: 2000 – present

Clearly there has been significant activity in the Powell Marsh during the last decade, however, the files at the DNR from late 1999's to the present are lacking and history of the last decade had to be reconstructed from other sources. Significant events occurring over the past decade include:

1) Feature article "Age Takes Toll on Powell Marsh" by Larry Jonas, (DNR Wildlife Technician) discussing the impaired integrity of the entire ditch/dike system and the significant investment needed to remedy it (March17, 2000).
2) A $35,000 USGS study of the hydrology of the Marsh and its relationship to Dead Pike Lake (Krohelski et al, 2002).
3) A $160,000 reinforcement of 1/3 mile of the Vista Pool Dike done in conjunction with Ducks Unlimited and select donors. (2003 - 2004)
    a. The signing of a 25 year binding contract which DU negotiated to mandate future management practices by the DNR (the contract's *cooperator*). This included a $75,000 forfeiture clause if DU's directives were not followed. (August 5th, 2002)
    b. Dedication ceremony for DNR and DU dignitaries at the Marsh to celebrate the "rejuvenation" of the Vista Pool made possible by the dike reinforcement. The public received no notice of this event and did not participate. (August 7th, 2004)
    c. The purchase and placement of a bronze plaque at the entrance to the Marsh commemorating the event and its contributors. (August, 2004)
4) DNR study by Kreitlow, (2006) to determine phosphorous and iron concentrations emanating from the Marsh.
5) A $25,000 (estimated) "Dam Failure Analysis" study to evaluate the necessity of the dike reinforcement by showing that a failure would have washed out the Powell Road. The study *disproved* the assumption (July 31, 2007).

6) Commencement of compliance by the Department with the “minimal flow” requirements of Statue 31:34 providing a constant discharge of 2cfs from the Marsh (2006).

7) The Department’s appearance before the Assembly Natural Resources Committee to publicly respond to Marsh complaints registered by the Dead Pike Lake Association (August 14th, 2004).

8) An on-site field investigation conducted by the Federal Environmental Protection Agency. (August 25, 2006)

9) A major meeting in the Department’s Madison offices, with EPA representatives which resulted in the agency’s concession to finally conduct a review of the Marsh’s antiquated Management Plan, a responsibility which had not been exercised since 1979. (December 15, 2006)

10) Dead Pike Lake Association conducts extensive research project in preparation for a formal Lake Management Plan. As the lake’s primary watershed, Powell Marsh is included within the study. (2008-2009 with final completion by early 2011)

Given the lack of recent information included in the “Powell Marsh Files,” the Dead Pike Lake Association inquired about the location of the Master File and records of all the recent financial transactions. The response of July 20, 2010 from the Marsh Manager stated: “*The files you’ve been reviewing are what we have as a master file. There is no specific financial data for the Powell Marsh. We don’t have budgets for individual properties*.”

As recently as August 8, 2010, a request was made by the Dead Pike Lake Association to indicate whether the extensive use of chemicals within the Marsh such as herbicides, insecticides and fertilizer were still being used and if not, when they were discontinued. The department responded that “*Fertilizer was used at Powell Marsh Wildlife Area on crop fields. Raising crops for waterfowl and other wildlife was discontinued and the last time fertilizer was used when the crop fields were converted over several years to permanent grasses. That was finished by 2003*.”

The lack of records for this past decade is disappointing, particularly because this has been a decade of significant change for Dead Pike Lake. Completing the story and gaining understanding of how recent Marsh management affects the geochemistry of the Marsh and hence the water chemistry, biology, and ecology of Dead Pike Lake is made more difficult.

Summary

Powell Marsh has experienced extensive exploitation and modification from human activity beginning in the late 1800’s and continuing to the present. Railroad construction in the 1890s, drainage ditch construction that likely coincided with railroad construction and early farming attempts, fertilizer and lime application, and hydraulic structure construction and water level manipulations, have left their mark on this magnificent wetland; dramatically altering its natural structure and functions to the point where its discharge now is a source of numerous stresses on the quality and future well being of Dead Pike Lake.

4.0 Hydrologic Balances for Dead Pike Lake and the Powell Marsh

Purpose and Methods

The Dead Pike Lake Association is concerned that the control (e.g., ponding and release) of water in the Powell Marsh is having an adverse effect on Dead Pike Lake. The Association members have noted that Marsh discharges to Dead Pike Lake can vary widely and rapidly. With these highly variable inflows (discharges), Association members have noted highly variable water levels. For example, in 2002 a sudden rise in water level led to the displacement and damage of lake resident docks. Most recently (September 2010), water levels rose to the extent that lake resident property was damaged (see Figure 4-1). The primary concerns with highly variable inflows include the effect on recreation, the effect of the high inflow rates on the enhanced transport of iron floc from the Main Inlet to the interior of Dead Pike Lake, and the overall impact of highly variable hydrology on the biota of Dead Pike. The Lake Association is also concerned with declining water levels and the potential for hydraulic control of Marsh water to aggravate water level declines in Dead Pike Lake. Hydrologic balances for Dead Pike Lake and hydrologic models for the Powell Marsh were developed to investigate the above concerns and observations.

Marsh and Lake Setting

The Powell Marsh is located approximately 3 miles south of Manitowish Waters in Vilas County, Wisconsin. The Marsh extends from Manitowish Lake to the southwest approximately four miles to Highway 47**.** The eastern boundary of the Marsh touches Little Trout Lake. The Marsh then extends approximately 2 miles west to Homestead Lake and Sherman Lake while also expanding in a northerly direction to the southern shores of Dead Pike Lake. The northern portion of the Marsh drains into Dead pike Lake while the southern half of the Marsh, controlled by the Lac du Flambeau Tribe, drains westerly along Sugarbush Creek, crossing under Highway 47 and emptying into the Little Bear River. A fraction of the northwest portion of the Marsh drains north across the Powell Road into Lost Creek, partially as subsurface flow or groundwater. According to a Krohelski et al (2002), subsurface flow for a portion of the Marsh south of Manitowish Lake is directed to Stepping Stone Lakes which in turn drain to Dead Pike Lake. From aerial photographs and elevation data, the portion of the Powell Marsh tributary to the Main Inlet has been estimated to have a size of approximately 1,771 acres and the area tributary to an unnamed creek 301 acres (see Figure 4-2). As has been discussed previously, the Marsh hydrology and hydraulics are controlled by a series of ditches and control structures. It is estimated that about 6 miles of ditches direct Marsh drainage to Dead Pike Lake.

Monitoring

An extensive hydrologic monitoring study was conducted from May 1, 2008 through early November 2008. Monitoring conducted as part of this study included: (1) paired flow (cross sectional measurements of depth and velocity using a Marsh McBirney velocity meter) and level measurements at the Main Inlet to Dead Pike Lake, at unnamed creek on the east side of the lake, and at the lake outlet--see rating curves in Figure 4-3, (2) continuous level measurements (In-Situ Level Troll) at the Main Inlet to Dead Pike lake and frequent staff gauge measurements at unnamed creek, the lake outlet, and the lake level, and (3) in-lake temperature measurements.

Model Development

From the 2008 hydrologic monitoring study, a water balance was developed for the lake. The balance consisted of measured surface water inflows and outflows from the lake, direct precipitation on the lake surface (precipitation data from the National Climatic Data Center for the Mercer Ranger Station), evaporative loss from the lake surface, and net groundwater inflow and outflow. Evaporative loss was estimated from lake and air temperature data, wind speed, and relative humidity using an equation developed by Adolph Meyer (see Introduction to Hydrology, pp. 49-51). Net groundwater inflow and outflow was calculated from the difference between inflows, outflows, net evaporative loss, and lake level changes.

Using the rating curve and level measurements at the Main Inlet to Dead Pike Lake and Pete's Creek, a hydrologic model was developed for the Powell Marsh. This daily time step model was developed in a spreadsheet and contained several different equations and algorithms. The primary inputs into the model included precipitation, average air temperature, geographic location, watershed area, and several different coefficients. This model included functions for precipitation, snowfall, snowpack build up, snowpack melt, evapotranspiration, surface water runoff, subsurface water runoff, groundwater flow, and subsurface storage. Precipitation was considered to be rain when average temperature was above 32 degrees F. Snowmelt was estimated using a function developed by the Army Corps of Engineers (see Wanielista et. al., 1997-Hydrology, Water Quantity and Quality Control).   Evapotranspiration was calculated using an adaptation of the Penman-Montieth equation as described in the Handbook of Hydrology (Maidment, 1993). This equation provides maximum potential evapotranspiration provided inputs or estimates for solar radiation, cloud cover, wind speed, and air temperature. This equation, like others, requires the conversion of potential evaportranspiration to actual evapotranspiration throughout the growing season. This was accomplished by developing a function that adjusted potential evapotransipiration to actual in accordance with changes in potential solar radiation. Surface runoff was assigned a triangular hydrograph (peaking in day 5 of a precipitation event) and a runoff coefficient (0.12). Water that does not run off as surface water is delivered to storage. Storage fluctuates in the model as a function of evapotranspiration (loss), subsurface flow (loss), and groundwater flow (loss). Subsurface and groundwater flow rate is a function of total storage volume. It was assumed in the model that subsurface (or vadose) flow is eventually delivered to the Main Inlet near Powell Road (also to Pete's Creek for the watershed tributary to this creek. It should be noted that the rate of delivery is much lower for subsurface flow compared to surface runoff (provides for base flow). Groundwater was considered a loss from the surface water system.

It should be noted that the hydrologic model does not include any hydraulic control structures (e.g., weirs with stop logs) and estimates the water delivered by a Powell Marsh that is not managed by fall storage in impoundments and drawdown in late spring to early summer. In essence, the model output demonstrates the pattern and magnitude of surface water flows that would be expected without these hydraulic controls. Because the model simulates surface water runoff with the use of a hydrograph, and the model was calibrated such that peaks in runoff matched runoff peaks for inflows to the Marsh, the travel time effects of drainage ditches and impoundments in the Marsh are included in the calibrated model.

Hydrologic Model Calibration

Calibrated hydrologic models are typically evaluated by comparing model results and measured values with respect to the following metrics: (1) yield-the amount of runoff (in inches) generated per inch of precipitation, (2) the magnitude of runoff events, (3) the timing of runoff events, meaning, does the peak runoff for the model correspond to the observed peak runoff, and (4) examination of how the model simulates seasonal effects such as spring snowmelt and evapotranspiration.

Once the model was built, the first step was to calibrate the surface runoff travel time and peak flow rates. This was done by changing the triangular runoff hydrograph such that timing and magnitude of the model peak flow rate matched the observed peak flow rate for individual precipitation events at the Main Inlet. Figure 4-4 shows that in general the travel time and peak flow rates are similar for the model and observed flows after about mid June. Because of seasonal storage and release efforts in the Marsh, there is a large difference for model and observed flows for the spring.

Because water is stored in the Marsh on a seasonal basis and flow was monitored for just over 6 months of the year, yield from the Marsh model cannot be compared to yield for the Powell Marsh measured in the spring, summer, and fall of 2008. Since the Marsh model was developed for a sixty year time period beginning in 1948, the model yield was compared to the yield for the Bear River near Manitowish Waters (USGS gauge 05357335). The Bear River at this gauging station has an 18 square mile undeveloped tributary watershed and a period of record extending from 1991 through the present. This watershed is primarily composed of wetlands and upland areas with virtually no development. The yield for this watershed over the entire period of record is 0.40 (inches of runoff per inch of precipitation). The yield for the Marsh model was 0.43 for the same period of record.

The Bear River flow data also provide a means to judge how well the snowmelt and evapotranspiration algorithms of the Marsh model perform compared to a natural watershed. Figure 4-5 shows that there is very close concurrence of snowmelt runoff in the spring for the Marsh model and Bear River. This figure also shows similar timing for runoff peaks and declines as well as concurrence of summer low flows due to lower precipitation and evapotranspiration. The comparison of the Marsh model and Bear River shows that the Marsh model accurately simulates the hydrology of a natural system dominated by wetlands in northern Wisconsin (see Figure 4-6).

Water Balance and Modeling Results

According to the Powell Marsh Master Plan (WDNR, 1979), the “maximum water acreage is maintained in the spring to enhance waterfowl nesting. An annual summer drawdown is employed on 2/3 to ¾ of the flowages on a rotational basis, thus enabling late summer burning and mowing. When surface runoff is available, impoundments are reflooded and maintained as near maximum for the fall migration.” This statement in the plan indicates that flow from the Marsh to Dead Pike Lake is restricted in the fall to fill the impoundments in the Marsh, and depending on snowfall and precipitation in the spring, water is released in a manner in the spring to maintain the impoundment levels. Conceptually, this management approach should look something like that shown in Figure 4-7. In the fall the storage capacity of the Marsh is used, and depending upon snowpack and spring rains, all of the stored water is discharged in a rapid manner in the late spring to early summer. This is what was observed with flow monitoring activities conducted in 2008. Flows were high in the late spring/early summer followed by a rapid decline in flow rate, and low flows in mid to late summer.

The hydrological model of the Powell Marsh provides a comparison of what unrestricted flows would look like compared to the current approach of active control of flow to facilitate seasonal impoundment flooding (Figure 4-7). The result of the hydraulic controls is that flow into Dead Pike

Lake is magnified during certain months of the year and reduced during others (see Figure 4-7). Since the storage capacity of the Marsh is used in the fall (i.e., impoundment filling), years with high spring precipitation are expected to produce magnified runoff rates. The magnified discharges from the Marsh are significant because: (1) iron transport from the Marsh into the interior of Dead Pike Lake is enhanced with higher flows, and (2) lake levels in Dead Pike Lake are directly affected by the rate of inflows to the lake. It can be concluded that an increase in the magnitude and variability of seasonal flows from the Powell Marsh has the potential to cause larger swings in lake water levels.

The effect of seasonal water flow rate controls in the Marsh on lake levels was evaluated using the lake water balance developed for Dead Pike Lake in 2008. The water balance consisted of inflows to the lake (Figure 4-8), the net effect of precipitation to and evaporation from the lake surface (Figure 4-9), the effect of lake level changes on water volume in the lake, and net groundwater inflows and outflows by difference (Figure 4-10) of all the monitored flow volumes and rates. Using the output from the Marsh hydrologic model, a simulation was conducted assuming that flows from the Marsh were restricted to 1.5 cubic feet per second starting on October 1, 2007 (see Figure 4-11). When flow was greater than 1.5 cubic feet per second, storage occurred in this model. The Marsh hydrologic model also provides an indication of when spring snowmelt and runoff occurred in 2008 (around April 1). Assuming that discharge from the Marsh started with snowmelt runoff and the rate was similar to that observed when monitoring began on May 1, 2008, it can be seen that the volume stored was very nearly the same as the volume discharged. These two model flow rates were put into the water balance model to determine the effect of impoundment filling and discharge on lake levels. It can be seen in Figure 4-12 that water management in the Marsh has the effect of lowering water levels in Dead Pike Lake in the fall and raising them in the spring. Because 2007-2008 was a dry year, the effect of impoundment management on the lake was just below 0.2 feet. During wet years, it is expected that this lake level effect will be magnified and lake level changes with impoundment management will be much larger compared to natural flow conditions. It should also be noted that it does not appear that impoundment management is responsible for nor has it exaggerated the decline in lake levels observed in Dead Pike during the extended drought period in northern Wisconsin.

Observed Lake Levels

Lake level data collected by Pete Guzzetta (a resident of Dead Pike Lake) for the last 10 years provides some additional understanding of past lake level changes. Lake levels were recorded on his dock each year, and since he removed his dock every fall, the lake level changes can only be evaluated on an annual basis. It should be noted that the lake level changes recorded by Mr. Guzzetta in 2008 were similar to the levels recorded for the staff gauge specifically installed for the hydrologic study. The graphs in Figure 4-13 show lake levels changes for 2001, 2002, and 2003. The lake level changes for each year are compared with lake levels recorded for Big Muskellunge Lake (North Temperate Lakes LTER database). Clearly the watersheds of the two lakes are different and the lake levels are not directly comparable, however, the relative difference and timing of lake levels changes can provide some additional understanding of the effect of Powell Marsh hydrologic controls on lake level. Although the magnitude of lake level changes and the variability is much greater, the general pattern of lake level increases and decreases was the same for both lakes in 2001. For 2002, it can seen that in the spring the lake level for Dead Pike lake dropped by 0.6 feet while over the same time period there was virtually no change in level for Big Muskellunge Lake. This rapid change in lake level demonstrates the effect of routine impoundment management in the Powell Marsh. In the fall of 2002, Vista Pond in the Powell Marsh was drained as part of a dike enforcement project, leading to a 1 foot rise in lake water level. In the spring through early fall of 2003, the lake level dropped nearly 1.4 feet as a result of construction activities in the Powell Marsh. These three graphs show that routine or other less frequent management activities in the Marsh can have dramatic and sudden effects on lake levels in Dead Pike Lake.

Summary

A hydrologic model was developed for the Powell Marsh and Dead Pike Lake to determine the effect of water control and release activities in the Powell Marsh on Dead Pike Lake levels. The modeling exercise and monitoring data indicate:

- According the hydrologic modeling results, seasonal control of water in the Powell Marsh has the effect of increasing the magnitude of lake level fluctuation though seasonal ponding and magnified releases (e.g., discharge rates) of water from the Marsh.

- Lake level monitoring data in Dead Pike Lake and observation of lake residents show severe lake level fluctuations (increases and declines) with seasonal ponding and release of water from the Powell Marsh to Dead Pike Lake during wet years and when maintenance is conducted. In 2010, water releases from Powell Marsh resulted in property damage.

- Seasonal control of water in the Marsh does not appear to aggravate lake level declines during drought conditions

References

Krohelski, J., W. Rose, and R. Hunt. 2002. Hydrology investigations at Powell Marsh and its relation to Dead Pike Lake, Vilas County, WI. USGS. Water Resource Investigation Report. 02-4034

Maidment, D. R. 1993. *Handbook of Hydrology*. McGraw-Hill, inc.

Viessman, W.; Knapp, J.; Lewis G., and T. Harbaugh. 1977. *Introduction to Hydrology*. pp.49-51. Harper and Row.

Wanielista, M.; Kersten, R., and R. Eaglin. 1997. *Hydrology Water Quantity and Quality Control*. John Wiley and Sons, Inc.

5.0 Water Quality Monitoring

Water quality monitoring was conducted at the Main Inlet (just downstream of Powell Road) and near the deep hole of Dead Pike Lake from April 27 through October 7, 2008. Inlet data collected included total iron, total phosphorus, total suspended solids, total volatile solids, pH, specific conductance, dissolved oxygen, and temperature. Samples for laboratory analysis were taken as grab samples. Temperature, dissolved oxygen, and specific conductance were taken at 2 meter intervals (using a Kemmerer water sampler) near the deep hole of Dead Pike Lake. Secchi disc depth was also measured in the lake during each sampling event. These field measurements were conducted monthly from May through October. Lake surface water samples were also collected monthly for laboratory analysis and included total phosphorus, total iron, chlorophyll *a*, total solids, and total volatile solids. Samples were also collected every 2 meters from the lake surface to the lake bottom on June 17, July 15, and August 18. These samples were analyzed for total iron and phosphorus. Surface samples of iron, phosphorus, chlorophyll *a*, total solids, and total volatile solids were taken as 6 foot composites sampled with a plastic tube. .

Monitoring Results

Water quality monitoring was conducted primarily to quantify iron, solids, and nutrient loading from Powell Marsh to Dead Pike Lake and to evaluate the effect of these loads on lake clarity, iron and phosphorus levels, as well as general lake qualities such as dissolved oxygen.

Main Inlet

Iron levels entering the lake in 2008 from the Main Inlet were high for natural surface waters, averaging 9.6 mg/L and ranging from 3.2 to a high of 16.0 mg/L. This is similar to the iron levels monitored by Kreitlow (2006). pH at the Main Inlet ranged from 6.4 to 7.1, averaging 6.9 (see Table 5-1 for all monitoring data). Measurements of pH by (Kreitlow (2006) were lower in 20005 and 2006, ranging from 6.25 to 6.7. Dissolved oxygen at the Main Inlet averaged 4.8 mg/L and ranged from 3.3 to 7.2 mg/L in 2008. Under these pH and dissolved oxygen conditions it is expected that iron will exist at the Main Inlet entering Dead Pike Lake in both the reduced (Fe^{+2}) and the oxidized (Fe^{+3}) form. At the prevailing pH and dissolved oxygen conditions at the Main Inlet (pH=6.6, and DO=4.8 mg/L), about half of the reduced iron converts to oxidized iron in 70 minutes while at a pH of 6.3, the half life is approximately 280 minutes (see Stumm and Morgan, 1996, page 683 for the kinetic equation. Water clarity is often observed to change in the Main Inlet which originates in the Powell Marsh. Given the kinetics of iron oxidation, changes in clarity of water from the Powell

Marsh can be assumed to be primarily a function of fluctuating pH and dissolved oxygen (and hence a change in the rate that Fe^{+2} converts to Fe^{+3}) and secondarily a function of iron concentration in the water.

Total phosphorus entering Dead Pike Lake at the Main Inlet (from the Powell Marsh) ranged from 45 to 143 µg/L and averaged 93 µg/L . Kreitlow (2006) reported that total phosphorus levels on pools and ditches ranged from 30-143 ug/l and from 65-96 ug/l in the Main ditch outlet. Phosphorus can be elevated in undisturbed watersheds depending upon soils and bedrock material, however, this is not common and phosphorus levels that approach and exceed 100 µg/L (for example) are more often found in urban or mixed agricultural and forest runoff rather than wetland drainage (Panuska and Lillie, 1995). Nevertheless, elevated levels of phosphorus are being discharged from the Powell Marsh at the Main Inlet to Dead Pike Lake (Figure 5-1-also, see elevated phosphorus in Dead Pike Lake profiles in Figure 5.2). It is possible (although not known) that residual effects of agricultural practices and application of phosphorus in the Marsh and or cranberry operations are having an effect on phosphorus export from the Powell Marsh. It is apparent that further investigation of phosphorus in this system is warranted.

Samples collected at the inlet were also analyzed for total suspended and volatile suspended solids to try to distinguish between inorganic (total suspended solids minus volatile suspended solids) and organic solids (approximately equal to volatile solids) loading from the Powell Marsh to Dead Pike (Figure 5-1). Total suspended solids at the Main Inlet were very high and averaged 134 mg/L--approximately half of the solids were inorganic and half organic. It is reasonable to assume that the inorganic solids fraction consists mainly of metal hydroxides.

Dead Pike Lake

Water quality monitoring data collected in Dead Pike Lake in 2008 show that the lake has the potential to be a high quality lake with good water quality (Tables 5-2, 5-3, 5-4). Phosphorus levels at the lake surface ranged from 12 to 17 µg/L and averaged 15 µg/L during the monitoring period. Phosphorus profiles taken in June, July, and August did not show any internal phosphorus loading from the lake sediment. Clarity was good in 2008 with Secchi disc readings averaging 2.92 meters (9.6 feet). Phytoplankton populations were low (average chlorophyll *a* of 2.7 µg/L) and stable throughout the monitoring period. Dissolved oxygen was stable and at high levels throughout the summer and ranged from 7.0 to 9.6 mg/L at the lake surface. The bottom waters of the lake had high dissolved oxygen levels until mid-August when dissolved oxygen began to decline to 4.5 mg/L. The lowest dissolved oxygen readings (1.9 mg/L) were at the bottom of the lake in October.

Figures 5-3 and 5-4 show that changes in iron concentration at the Main Inlet and hence iron loading (calculated from iron concentration and flow monitoring data) has a direct effect on iron concentrations in Dead Pike Lake. Iron was highest in Dead Pike Lake surface (samples taken at zero and two meters depth) in the spring when water inputs and iron loads from the Powell Marsh at the Main Inlet were also the highest (Figure 5-3). When iron loads declined in the summer, iron concentrations in Dead Pike Lake also declined. Iron profiles show that iron fluctuations and settling in Dead Pike Lake are very dynamic (Figure 5-5). There are several peaks of iron at different depths in the lake in June (at 12 meters), July (at 4 meters), and August (at 4 meters). These peaks show that iron enters Dead Pike Lake and then begins to settle down through the water column and into the lake bottom sediment. These peaks are below the surface in the summer likely because the temperature of the Powell Marsh water is cooler than the surface waters of Dead Pike Lake in the summer, causing water entering Dead Pike Lake to insert below the surface.

It can be concluded from the monitoring data that iron coming from the Marsh directly affects lake clarity. The steady and consistent increase in water column clarity in Dead Pike Lake is accompanied by a decline in iron concentrations in the lake (Figure 5-6). This change in lake clarity (Secchi disc) is not due to an algal bloom or die off (Figure 5-6) since algal concentrations were largely unchanged during the monitoring period. No natural lake process that affect lake clarity can account for this clarity change (it should be noted that iron in the concentration range in Dead Pike Lake is visible in a one liter jar as an orange tint—this effect is multiplied as one looks through several meters of lake water).

The WDNR lake citizen lake monitoring database was searched for lakes in Vilas County with similar watershed, bathymetry and size to compare how clarity in these lakes changed during 2008. Little Star and Fence Lake were identified as “similar” lakes to Dead Pike Lake. Little Star Lake is a low nutrient lake that does not experience algal blooms and the watershed is largely composed of wetlands. Fence Lake also has a wetland dominated watershed but this lake experiences loss of clarity due to phytoplankton growth in the summer. Little Star Lake clarity was largely unchanged during 2008 monitoring and Fence Lake clarity declined (Figure 5-7). These lakes show that 2008 was not unusual with regards to how lake clarity normally changes during the open water season—the observed change in clarity for Dead Pike Lake is in direct contrast to these lakes. A historical look at changes in clarity in Dead Pike Lake shows that since 1996 (when data gathering began) clarity has improved dramatically up to the present (Figure 5-8). Secchi disc depth went from a summer average of 1.6 meters (5.2 feet) in 1996 to 2.92 meters (9.6 feet) in 2008. During this same time period, the rate of iron deposition in Dead Pike lake sediment (e.g., analogous to iron export from Powell Marsh) declined. Based upon the iron concentration data in Dead Pike Lake, the iron loading data at the Main Inlet to Dead Pike Lake, the consistent level of phytoplankton in Dead Pike Lake, other reference lakes (e.g., Fence and Little Star Lakes) in Vilas county, and a comparison of historical changes in Dead Pike water clarity and iron deposition rates, it is reasonable to conclude that iron from the Powell Marsh is responsible for changes in lake clarity in Dead Pike Lake.

Discussion above focused on the aesthetic effect of Powell Marsh iron discharges. However, lake clarity is an indicator of light penetration and in turn light penetration affects habitat. The most obvious is aquatic plant habitat. More light penetration equals more habitat for aquatic plant growth. As a general rule, for each meter of clarity measured as Secchi disc depth, aquatic plants can grow to about 1.5 meters in lake depth (e.g., 10 meters of Secchi depth equals plant growth up to 15 meters- (Canfield, 1985). Another less obvious effect of light penetration is lake temperature, lake dissolved oxygen, and hence the available habitat for zooplankton and fish. For example, temperature measured in Dead Pike Lake in 2008 is shown in Figure 5-9. It can be seen that temperature can be the same for several meters extending from the surface to depths as great as 8 meters. This layer where the temperature is uniform is called the "completely mixed layer." Water in this layer freely mixes because the water density is the same. The depth of the mixed layer is a function of wind but also lake clarity. Lakes that are clear have a much greater mixed layer than lakes that are turbid (the reason for this is that light penetrates deeper and warms the lake water column more uniformly). A small mixed layer reduces the lake volume that can take up oxygen from the atmosphere. Lakes with a large mixed layer have more water contacting the atmosphere and gathering oxygen. The result is that lakes with a larger mixed layer have more oxygen. The data from Dead Pike Lake show this. In the spring, most of the water column of Dead Pike Lake is mixed and the water column has high and uniform dissolved oxygen. By June the lake is stratified and the mixed layer is about 6 meters (the Secchi disc depth is about 2.7 meters). Oxygen is still uniform in June but by July dissolved oxygen begins to decline at the bottom of the lake. In July the mixed layer is about 5 to 6 meters but it begins to increase in August and into September and October. This increase in mixed layer depth also corresponds to an increase in Secchi disc depth. This increase in mixed layer also increases the depth to which higher oxygen penetrates. The most notable change in oxygen occurs from August to September. To summarize, clarity directly affects the depth to which oxygen can penetrate from the lake surface. When clarity is low, the mixed depth is small and the water layer with high oxygen is also small. Because fish and zooplankton prefer high oxygen water, clarity can affect the size of the habitat in which zooplankton and fish can reside. For Dead Pike Lake, the change in clarity, stratification and hence habitat was not extensive in 2008, however, lake association members have noted years in which lake clarity changes measurably with iron plumes discharging into Dead Pike Lake during rain events. During these events the habitat effects may be very pronounced. In 2006 the average Secchi disc depth was 3.4 meters, compared to 9.6 meters in 2008. In 2006, the completed mixed layer (Figure 5-9) ranged between 3 to 6 meters while in 2008 the completely mixed layer ranged from 6 to 8 meters. As a result, surface temperatures were higher in 2006 and dissolved oxygen levels (Figure 5-10) lower when compared to 2008 (due to the mechanisms discussed above; however the data in 2006 were not at the same resolution and accuracy as 2008). Clearly other climatic factors can be involved; however, average June through September in 2006 and 2008 air temperature was 17 ^{o}C. Average wind speed in 2006 was 1.2 miles per hour while in 2008 it was 0.8 miles per hour (a lower wind speed should lead to smaller mixed layer-opposite or what was observed). Given the significant variation in Dead Pike Lake clarity due to fluctuating iron inputs into the lake from the Powell Marsh, it can be seen that available zooplankton and fish habitats can change dramatically annually.

Summary

- Overall, water quality in Dead Pike Lake in 2008 was commensurate with a mesotrophic lake with respect to phosphorus and Secchi disc depth but was oligotrophic with respect to phytoplankton.

- Because of dry conditions, lake clarity in 2008 was much higher than past years when precipitation was greater.

- Iron levels entering Dead Pike Lake in 2008 from the Main Inlet were significantly high for natural surface waters and ranged from 3.2 to 16.0 mg/L (similar to WDNR measurements in 2005 and 2006). Suspended solid concentrations from the Powell Marsh (Main Inlet) were abnormally high and averaged 134 mg/L. Total phosphorus levels discharging to Dead Pike Lake from the Main Inlet were high and appeared to be elevated compared to natural-undisturbed wetland systems.

- Monitoring data collected in 2008 and during past years indicate that clarity in Dead Pike Lake is directly affected by the concentration of iron in the lake and iron loading into the lake. Years with low iron loading had greater clarity (e.g., Secchi disc depth) and years with high loading had low clarity.

- Fluctuations in iron concentrations in Dead Pike Lake due to variable and elevated iron discharges from the Powell Marsh may potentially affect habitat availability for aquatic plants due to changes in light availability which may in turn affect overall aquatic life abundance and health.

References

Canfield, D.E, Langeland, K.A, Linda, S.B, and Haller, W.T., 1985. "Relationship Between Water Transparency and Maximum Depth of Macrophyte Colonization in Lakes." J. Aquat. Plant Manage. Vol. 23.

Kreitlow, J. 2006. Differences in water chemistry of Powell Marsh as it relates toholding or passing water from the wildlife impoundments. Draft Reprt. WDNR Rhinelander.

Panuska, J.C., and R.A. Lillie. 1995. "Phosphorus Loading from Wisconsin Watersheds Recommended Phosphorus Export Coefficients for Agricultural and Forested Watersheds." WNDR. Findings No. 38.

6.0 Sediment Record in Dead Pike Lake

Purpose and Methods

Iron monitoring data collected by Kreitlow (2006) and by the Dead Pike Lake Association in 2008 demonstrates that iron levels are significantly above background and that high levels of iron enter Dead Pike Lake throughout the open water season. Lake Association members have observed large plumes of iron discharging into and covering much of the lake, particularly during large storm events. With the exception of several years in the 2000's which have coincided with a persistent drought, Association members have observed that the magnitude of the iron plumes has been increasing over time. The primary contention is that WDNR's management of the Powell Marsh is responsible for the export of high iron concentrations as well as loads entering Dead Pike Lake.

Sediments were collected from the bottom of Dead Pike Lake in 2007 and 2008. In October 2007, several cores were taken at different locations in the lake using a Willner corer. The sediment collected from these cores was used to determine the extent (coverage) of iron deposition in the lake. The data from these cores were also used to estimate the mass of iron that has been discharging to and depositing in the lake over time. In October of 2008 a piston corer was used to collect an 80 cm core of sediments at a water depth of approximately 66 feet in the southwest area of the lake. This core was taken to reconstruct the history of iron inputs into Dead Pike Lake by identifying the rate of iron deposition upon the lake sediments from 1800 through the date of core collection in 2008. The historical record of iron deposition was reconstructed by identifying sediment age at different depths within the sediment profile using a process called Lead 210 Dating. Sediment from the dated core was analyzed for several metals, organic carbon by loss on ignition, total sulfur, and several phosphorus forms (phosphorus bound by iron, aluminum, calcium, and organically bound phosphorus).

Dated Sediment Core

Sediment dating was performed at the Saint Croix Watershed Research Station. According to Dr. Daniel Engstrom, the director of the facility, core dating was of high quality with no abnormalities. Two important pieces of information are provided with dating: (1) the age of sediment at different depths within the sediment profile, and (2) the rate of sediment accumulation. Sediment age and sediment accumulation rate for the core collected in Dead Pike Lake is shown in Figure 6-1 and 6-2. These figures show that sediment 44 centimeters below the lake bottom was deposited around 1800. Sediment was collected at depths greater than 44 centimeters; however, the lead 210 dating method cannot be used to determine sediment dates beyond 1800. Sediment deposited in the 1950s to the present is represented by sediment depth from approximately 23 centimeters to the sediment surface (0 centimeters). Figure 6-2 shows the rate of sediment accumulation over time. This sedimentation rate was determined at the Saint Croix Watershed Research Station. It can be seen that sediment deposition was lowest around 1800 to 1873 and then began to rise through the 1950s to around 1990. It appears that the rate of sediment deposition has declined in the last decade, possibly due to drought conditions. Overall, sediment deposition rates in recent years have increased by 3 to 5 times compared to deposition rates that occurred prior to settlement of the region (around 1870).

Metals, Carbon, and Phosphorus

Sediment collected to a depth of 44 centimeters (the limit of lead 210 dating) as well as sediment collected to a depth of 78 centimeters was analyzed for several metals, including calcium, magnesium, iron, aluminum, and manganese. The mobility of metals, meaning the dissolution of metals from bedrock, till, or sediment, is primarily determined by pH and redox conditions (the presence or absence of oxygen). Manganese and iron are redox sensitive metals while the solubility of aluminum, calcium, and magnesium are not influenced by the presence or absence of oxygen. The solubility of all these metals increases when pH declines. The solubility of only iron and manganese hydroxides (not iron and manganese sulfides-discussed in more detail later) increases when oxygen declines. So, changes in the pH and redox condition of water and soil in the Powell Marsh affects the solubility of metals in Marsh soils and bedrock and the capacity of the Marsh to deliver metals to the lake. Because the water in Dead Pike Lake is high in oxygen and has a pH higher than water delivered by the Powell Marsh, metals precipitate, settle, and deposit on the lake bottom. Changes in the concentration of metals in the lake sediment then reflect changes in metal export from the Powell Marsh.

There are two primary ways to examine the sediment data---concentration basis (e.g., milligrams of a constituent per dry weight of sediment) and an accumulation basis (milligrams of a constituent deposited over a given area for a year-*calculated by multiplying the sedimentation rate in milligrams dry sediment per area per year by the metal concentration as milligrams metal per milligram dry sediment*). The concentration basis can be used to see changes in sedimentation history of given constituents from year to year and to compare the relative composition of the different components of sediment. Using a concentration basis it is difficult to compare sediments that have deposited during distant time periods because the sedimentation rates can be very different. For example, the iron and manganese data in Figure 6-3 show that iron on a concentration basis increased somewhat after 1950. It also shows that historically, iron concentration in the sediment has not changed significantly.

However, since the sedimentation rate has changed significantly sometime between 1870 and 1894, the iron deposition rate (e.g., mass of iron deposited per unit time) in Dead Pike Lake and hence export from the Powell Marsh has increased significantly since this time. The manganese data is even more distinctive in that manganese increased suddenly in the Dead Pike Lake sediments sometime between 1870 and 1894. Manganese export appears to have increased by over twenty times from the early 1800s to today. Both of these metals are redox sensitive, meaning transport of these metals requires the maintenance of low oxygen in surface waters of the Marsh or the delivery of Marsh waters in some matter that minimizes exposure of water with iron and manganese to oxygen. It appears that prior to the arrival of settlers to the region, iron export was significantly lower and manganese export essentially nonexistent.

The iron data also indicate that iron export has continued to increase in magnitude since management of the Powell Marsh was adopted by the WDNR. Clearly, iron export increased starting in the late 1800s and the increase has been steady. However, it can be seen in Figure 6-3 and 6-4 that export has continued to increase further since the WDNR began to actively manage the Marsh in the mid-1950s. Residents of Dead Pike Lake have noted that iron discharges have been variable but generally worse over time (with exception of part of the last decade). This observation is validated to some degree with this sediment data. Also, it is likely that manganese is contributing measurably to the observed brown plume that enters Dead Pike Lake and manganese export from the Powell Marsh has increased significantly since 1950. In recent years manganese deposition was 2.4 milligrams per square centimeter per year while iron was 6.5 milligrams per square centimeter per year. Manganese is more redox sensitive than iron, meaning, oxygen does not need to be as low for manganese to remain soluble compared to iron. It appears that in this region this change is somewhat unique to Dead Pike Lake. A study (Bortleson and Lee, 1974) of several lakes in Vilas County did not show a notable increase in manganese for cores taken to sediment depths as great as 100 cm. Although sedimentation rates may be different between these lakes and Dead Pike Lake, none of these lakes indicated the notable increase in manganese seen for the Dead Pike Lake core.

The phosphorus and aluminum data provide additional evidence that chemical conditions in the Powell Marsh have been in flux since 1870 and 1894 and these changes have been maintained today (Figure 6-5 and 6-6). Phosphorus in sediments is found chemically bound to metals and incorporated into organic carbon. Phosphorus can be bound to calcium, iron and manganese (typically referred to as iron bound phosphorus), and it can be incorporated into organic carbon (organically bound phosphorus). Chemical conditions such as pH and oxygen (redox) can affect the capacity of iron and aluminum to bind phosphorus. It can be seen in Figure 6.5 and 6.6 that prior to the 1870s, phosphorus was primarily bound to iron in Dead Pike Lake sediments, but there was a significant and rapid shift that increased the concentration of aluminum bound form sometime between 1870 and 1894. This change does not appear to be due to an increase in aluminum in Dead Pike Lake sediments. While it is not clear if this chemical change is due to pH or redox or some other transport mechanism, there was clearly a rapid and sudden change that corresponds to the same period that iron and manganese export increased. . It should be noted that monitoring data in Dead Pike Lake indicate that the lake has oxygen levels (even in the bottom waters for most of the year) that would oxidize iron and manganese in water entering the lake . Experience with iron and manganese sampling in lakes has shown that there is little iron or manganese mobility at oxygen levels currently found in Dead Pike Lake.

It appears that metals not sensitive to redox conditions were also mobilized from the Powell Marsh at the same time as iron and manganese (Figure 6.7 and 6.8). Aluminum and calcium accumulation (e.g., export from the Powell Marsh) increased from around 1870 to 1950. After 1950 it appears that aluminum export declined while calcium export continued to rise. Recent measurement of pH at the Marsh outlet indicate that Marsh waters fluctuate from below to above 6.3 (it is recognized that pH may be higher or lower within Marsh). Aluminum solubility is at a minimum at pH 6.3. Operation of the Marsh ponds may be capturing aluminum in the insoluble hydroxide form. Calcium mobilization (starting sometime between 1870 and 1894) could have been driven initially by a shift to lower pH in the Marsh but it appears more likely that there was an increase in connectivity between the Marsh and Dead Pike Lake due to drainage ditch construction. This suggests that physical changes to the Marsh may have been responsible for enhanced delivery of these constituents to Dead Pike Lake. With the understanding that lime was applied to the Marsh in the 1960s, it is now clear that recent increases in calcium in Dead Pike Lake sediment are the result of lime application. If these applications were also successful at raising the pH of the Marsh soils, the decline of aluminum export (e.g., aluminum levels in Dead Pike Lake sediments) over the last 50 years may be explained by pH controls.

Adding up all of the metals analyzed for these sediments, it can be seen that just prior to 1870 metals were approximately 26 percent of the total mass of solids in the sediment (see Figure 6.9). This has increased to approximately 37 percent in 2008. Correspondingly, in Figure 6.10 it can be seen that organic carbon decreased from 1870 (37 percent) to a low in 1970 (29 percent) but has increased since 1970. Because organic carbon decays, it is hard to determine a direct relationship between metals increases and organic carbon decline over time. However, the observed increase in the inorganic solids content of lake sediment and a decline in the organic carbon content is a classic indicator of settlement and land development.

Short Cores and Reconstruction of Historic Iron Concentrations at the Lake Inlet

The dated sediment core provides a clear indication of metals loading to Dead Pike Lake from the Powell Marsh over time. Although visual observation at the Main Inlet near Powell Road clearly shows highly stained iron-rich surface water inputs to Dead Pike Lake, questions remain as to how the source of the iron load can be apportioned between surface or ground water transport.

Two approaches are available to determine the relative contribution of groundwater and surface water iron loads to Dead Pike Lake, they include: (1) measurement of iron in piezometers around Dead Pike Lake coupled with a groundwater model and measurement of surface water inputs and iron in the inflows, (2) sediment dating and iron analysis (this study) and surface water inflow and iron measurements. We chose to evaluate the contribution of surface waters to iron in Dead Pike Lake by making use of the dated core and surface water measurements.

Based upon flow data collected in 2008, the hydrologic model constructed for the Marsh (see Section 4.0), and an average iron concentration of 9.6 mg/L at the Main Inlet, it is estimated that iron loading at the Main Inlet was approximately 25,593 kilograms for the 2008 water year (October 1, 2007 through September 30, 2008). From the dated core and analysis of the spatial distribution of iron in Dead Pike Lake sediment (described in more detail below), it is estimated that iron accumulation in 2008 was approximately 21,374 kilograms. These numbers are very close and suggest that surface flow transports more iron to the Lake than groundwater. It was assumed in this analysis that all iron entering the lake deposits in the lake sediments, however, it is more realistic to assume that some is lost through the outlet. Iron in the Dead Pike Lake water column was approximately 0.300 to 0.500 mg/l liter in 2008. This is about 3 to 5 percent of the inlet concentration and suggests that possibly 5 percent of the inflow mass (2,559 kilograms) is lost through the outlet. It should also be noted that some iron loads may be coming from the unnamed creek on the east side of the lake, however, flows were low in this creek in 2008 and likely did not contribute significant iron during this year.

Several short cores were taken in Dead Pike Lake in an attempt to determine the spatial distribution of iron in Dead Pike Lake sediment. Figure 6-11 shows a map of Dead Pike Lake, the long and short coring locations, the lake depth at which the cores were taken, and the distribution of iron in the surface sediments. It can be seen that iron accumulates in the deeper regions of the lake (an area of approximately 81.25 acres). The dated core was taken at a depth of 66 feet and it is estimated that short cores taken within the region outlined in the map define the region in which the iron and sedimentation data in the long core is representative (e.g., iron deposition rates). Field observation of the sediment and similar iron deposition patterns between the cores taken in this area and the long core were used to make this determination (see Figure 6-12). The lake area in this region was used to estimate total annual iron loading to Dead Pike Lake in 2008 and the recent past (since 1959).

Figure 6-13 shows the estimated concentration of iron coming into Dead Pike Lake from the Main Powell Marsh Inlet since 1959. This estimate is based upon iron deposition rates in Dead Pike Lake (from the dated core and the estimated area of deposition), and modeled annual average surface water inflows. Measured values in the graph are provided for 2008 (Dead Pike Lake Association monitoring) and for Kreitlow 2006. It can be seen that the concentrations in 2008 and 2006 are similar to the reconstructed concentrations for all of the reconstructed years except for 1977 (severe drought year) and 2007. Even though some of the methods (e.g., lake area that can be represented by the long core and accuracy of the hydrologic model) used in this analysis have some degree of error, it is clear that because of the similarity of the reconstructed iron concentrations and the measured concentrations, this approach has value in determining the concentrations of iron that entered Dead Pike Lake prior to man-made alterations of the Powell Marsh. Based upon average and a range of estimated surface water inputs from the Powell Marsh from 1948 through 2008, it is estimated that iron coming into the Marsh prior to man-made alteration averaged 3.3 mg/L and commonly ranged between 2.5 to 4.5 mg/L (estimated from the 20th and 80th percentile of surface water inflows and iron deposition rates in Dead Pike Lake prior to man-made alterations to the Marsh).

Mechanism for Iron and Manganese Export from the Powell Marsh

From the sediment record in Dead Pike Lake it is clear that manmade alterations in the Marsh led to increased export of iron and manganese from Marsh soils and into Marsh drainage waters. The primary manmade alteration was the construction of the drainage ditches. Krohelski,(2002) suggested that the ditches lower the water table. Lowering of the Marsh water table provides an opportunity for oxygen to penetrate further into soils previously covered with water (because water inhibits the diffusion of oxygen into the soils). If soils in the Marsh have elevated levels of reduced sulfur species (iron and manganese sulfides), exposure to oxygen would cause oxidation and hence liberate iron and manganese from sulfur (see Pankow, 1991, Appelo and Postma, 2005, Brezonik, 1993, and Stumm and Morgan, 1996). If this were true, then it would be expected that changes in iron and manganese concentration over time in Dead Pike Lake sediments should correspond to changes in sulfate concentration over time. The graph in Figure 6-14 shows that changes in sulfur in

Dead Pike Lake sediments correspond to changes in iron and manganese, and hence, there is direct link between iron and manganese export from the Marsh with sulfur export from the Marsh (it should be noted that the concentration of sulfur in lake sediments is not equal to the concentration of iron and manganese because iron and manganese accumulate in lake sediment due to deposition while sulfur accumulates due to the less complete process of dissolved chemical flux into sediment and chemical binding to reduced sediment species) . These data suggest that iron and manganese sulfide oxidation in Marsh soils (and hence export to Dead Pike Lake) could be inhibited by returning the groundwater in the Powell Marsh to historic levels.

It is also important to discuss the subtleties of metal-sulfide oxidation. Although the terminology implies that much oxygen is present, the oxidation process can occur under just slightly oxic conditions. Levels of oxygen may be high enough to promote the liberation of iron and manganese from sulfide, but more oxygen is needed to convert iron and manganese to insoluble hydroxides. Hence, oxidation of iron and manganese sulfides can result in the build-up of reduced iron (Fe^{+2}) and manganese (Mn^{+2}) whileliberation of iron and manganese from sulfide is not incompatible with the mobilization and transport of these metals in reduced form.

Summary

- The sediment record of Dead Pike Lake clearly demonstrates that iron and manganese export from the Powell Marsh has increased with Marsh development. Rates of iron and manganese export from the Powell Marsh (deposition in Dead Pike Lake sediment) also correspond to the degree of Marsh development and there appear to have been three development stages each coinciding with an increase in the rate or iron and manganese export.
    - **Stage 1-** ***Completion of railway construction through the Powell Marsh in 1894***. The rate of iron export from the Marsh increased by approximately 1.5 times during this period.
    - **Stage 2-** ***Agricultural development***. By 1933, iron export had increased by 3.5 times compared to pre-development. An aerial photograph from 1937 (see Figure 3-1) shows that at that time there had already been significant alterations of the Marsh with roads and ditches draining a large portion of the Marsh and evidence of agricultural development.

    - **Stage 3-*WNDR ownership***. With the adoption of the Marsh by the WDNR and the construction of additional ditches, conveyances, and control structures, the iron export rate increased by 3 to 5 times compared to pre-development.

- The correlation of sulfur accumulation in Dead Pike Lake sediments with iron and manganese deposition in the lake sediments indicate that iron and manganese export from the Powell Marsh is regulated by sulfide complexes (iron and manganese sulfide complexes) in Marsh soils. These complexes are immobile until exposed to air (oxygen). Lowering of the Marsh water table as a result of drainage ditch construction provides mechanism by which soils previously protected from oxygen can become exposed.

- Although there was considerable development of the Marsh prior to WDNR ownership, development and management activities by the WDNR show how the Marsh and Dead Pike Lake are connected. In the historical evaluation of Marsh activities (see Section 3.0), it was discovered that lime (calcium hydroxide) was added to the Marsh to control pH. The concentration of calcium in Dead Pike Lake sediment increased significantly at the time of these activities. Aluminum export also dropped, likely due to an increase in soil pH. Manganese export from the Marsh clearly increased at the time of Marsh management activities by the WDNR, although it is not clear if this is due to further lowering of the water table or recent ponding of water upon soils with manganese hydroxide complexes.

- The sediment record indicates that the rate of change in metals export has largely been a function of the intensity of man's development. Since man made alterations of the Marsh are responsible for increased metals export, it is reasonable to expect that the carful and well executed return of the Marsh to its unaltered and natural state will reduce metals export to pre-settlement and pre-management conditions.

References

Appelo, C.A.J., and D. Postma, 2005. *Geochemistry, Groundwater, and Pollution*. CRC Press. Second Edition.

Brezonik, P. 1993. *Chemical Kinetics and Process Dynamics in Aquatic Systems*. Lewis Publishers.

Pankow, J.F. 1991. *Aqautic Chemistry Concepts*. Lewis Publishers.

Stumm, W., and J. Morgan, 1996. *Aquatic Chemistry*. John Wiley and Sons Publishers.

7.0 Iron Toxicity

Literature Review

The chemical properties and the aquatic toxicity of iron have been well characterized. Iron chemistry, and in particular, the chemistry of the water in which iron resides can have a significant bearing on iron toxicity. For example, iron is a charged particle that can exist in natural waters with a charge of Fe^{+2} or Fe^{+3} (see Stumm and Morgan, 1996). At near neutral pH but below, and under oxygen poor conditions, iron is soluble and exists as Fe^{+2}. When in the presence of oxygen and pH generally greater than 6.0, iron is primarily in the Fe^{+3} form under equilibrium conditions. However, hydroxide (OH-) quickly binds with Fe^{+3} to form an insoluble complex of $Fe(OH)_3$. $Fe(OH)_3$ is a floc (solid) and settles. The chemical behavior described above alludes to factors that determine the potential for iron toxicity: (1) pH, (2) presence or absence of oxygen, (3) reactivity and formation of different compounds, and (4) the speed at which these reactions occur. A literature review was conducted to evaluate the potential toxicity of iron that is discharged into Dead Pike Lake from the Powell Marsh at the Main Inlet and at Pete's Creek on the east side of the lake Particular attention was placed upon relating the chemical conditions of each study with the chemical conditions of iron rich waters that discharge from the Powell Marsh to Dead Pike Lake.

Aquatic toxicological studies have been conducted on a wide range of test organisms and the range of species tested in the literature represents the range or ecological niches that biota may occupy in Dead Pike Lake. Organisms tested (in the literature) include fish, benthic crustaceans, pelagic crustaceans, worms, and aquatic insects. Tests can be placed into two general groups, acute and chronic. Both the acute and chronic tests are relevant to Dead Pike Lake as there are episodic events where very high iron concentrations are flushed into the lake (acute event), and there is also a constant discharge or iron (chronic event) at lower flow rates and lower levels throughout the open water season. Acute toxicity is quantified as mortality. The duration of acute toxicity is generally defined as 2 to 4 days. Chronic toxicity (testing conducted for seven days or more) is quantified by measuring mortality, reproduction, growth, and several sub-lethal effects such as gill deformation, oxygen consumptive stress, and blood chemistry.

Acute Toxicity

Iron as Fe^{+2} and Fe^{+3} can be acutely toxic. Toxicity tests with iron are conducted using a range of iron concentrations to determine the level at which iron is toxic. Two important statistics are typically calculated, the LC50 or the lowest concentration (iron) at which fifty percent of the test species die, and the NOEC, the concentration at which no mortality is observed (NOEC-no observed effect concentration). In some cases these toxicological endpoints are not calculated because a range of doses were not used for a particular study.

According to the literature reviewed, iron can be acutely toxic to several species that should either be present in Dead Pike Lake or are representative of groups of aquatic organisms (e.g., zooplankton) that exist in lakes. In a study conducted using iron sulfate (Randall et al., 1999), iron was acutely toxic (LC50 = 11.48 mg/L (2 day exposure period) to *Daphnia longispina* (zooplankton). This indicates that when iron reaches a concentration of 11.48 mg/L, half of zooplankton are expected to die. The NOEC (no acute effects concentration) was 8 mg/L total iron. In this study and many others, there appears to be very fine line between high levels of mortality (e.g., the LC50) and no mortality (e.g., the NOEC). Because iron sulfate was used in this study, iron was in the Fe^{+2} form at the start of the test. It is expected that iron would oxidize during the test (e.g., become Fe^{+3}) although iron species were not measured in this study. Regardless, the speciation of iron in this study is likely very similar to the speciation that would exist in the ditch that discharges from the Powell Marsh or Pete's Creek to Dead Pike Lake. At pH 6.0, the half life of Fe^{+2} is approximately 16 days, however, at pH 7 the half life is 3.9 hours, and at pH 8 the half life is just over 2 minutes (Hiradide et. al. 1998, Davidson and Seed, 1982, and Vuori, 1995). This means, for example, with a 16 day half life, over a 16 day period half of the iron would convert from Fe^{+2} to Fe^{+3}. It is possible that iron in the Powell Marsh ditch is predominantly Fe^{+2} during much of the year, but as the water is discharged into Dead Pike Lake, it converts to Fe^{+3}. This same phenomenon may have occurred in the test described above. Because of the high pH of the test water (natural lake water) in the study (pH=8), Fe^{+3} was likely the predominant iron species by the end of the test period. Other studies reporting acute toxicity testing data for zooplankton include Mukahopadhyay and Konar, 1984 (LC50 =35-36 mg/L total iron for pH 6.5 to 8.5 for *Clyclops viridis*), and Biesinger and Christensen, 1972 (LC50=5.9 mg/L total iron for *Daphnia magna*).

Fish appear to be more tolerant of acute (but not chronic) iron exposure compared to zooplankton. The LC50 was 28 to 47 mg/L total iron (iron sulfate) for brown trout fingerlings (1.5 to 3 months old) exposed to iron for four days (Dalzell, 1999). It should be noted that test species become more resistant to toxicants with age and accordingly the LC50 value increases with age. In the study by Dalzell, 1999, fingerlings were used and it is expected that fingerlings would be less sensitive than fry (standardized test procedures for compliance toxicity testing require the use of fry). Iron has been found to be more toxic to fish at low pH. One-summer old brown trout exposed to iron at pH 5 and 6 for three days (acute exposure period) and at an iron concentration of 2 mg/L (half the dose was Fe^{+2} and half Fe^{+3}) exhibited acute symptoms such as mortality as well as sublethal effects such as gill damage (necrosis) and reduced oxygen consumption. The addition of humic acids at a dose of 15 mg/L reduced the sublethal effects. At a pH of 6.5, four day tests with *Tailapia mossambica* fry resulted in an LC50 value 119.6 mg/L and an LC5 (approximately equivalent to the NOEC) value of 110.8 mg/L (Mukhopadhyay, 1984). pH above 7 appears to lead to significant reduction in acute toxicity. Brenner and Cooper, 1978, noted no acute (and chronic) toxicity for coho salmon fry exposed to 3 mg/L iron ($Fe(OH)_3$) and pH 7.8.

There are a few studies that have evaluated acute toxicity to insects and crustaceans. The Province of British Columbian, 2008, conducted testing on *Hyallela azteca*, a common lake crustacean that is also an important food for fish. The LC50 for *Hyallela* was 3.5 mg/L total iron. From this and other studies, the Province developed an iron guideline of 1 mg/L for total and 0.35 mg/L for dissolved iron. Maltby et al., 1987, calculated the LC50 for Fe^{+2} to the freshwater crustacean *Asellus aquaticus*. The LC50 at pH of 4.5 ranged from 255.9 to 428.5 mg/L. At pH 6.0 the LC50 ranged from 419.2 to 466.9 mg/L. Gerhart, 1992, demonstrated that iron as Fe^{+2} and Fe^{+3} (pH 4.5 and 7.0 respectively) was not acutely toxic to the aquatic insect *Leptophlebia marginata* (a mayfly) at iron doses as high as 50 mg/L.

It appears that with respect to acute toxic effects from short term exposure, the freshwater crustacean *Hyallela* and zooplankton are the most sensitive and likely affected aquatic species by periodic high iron discharged from the Powell Marsh. Fish do not appear to be as sensitive as *Hyallela* and zooplankton to acute affects; however, acute testing with fish appears to be incomplete as tests were largely conducted with older and less sensitive fish. The results of Dalzell, 1999, are notable in that there was significant acute mortality in this study at a fairly low dose of 2 mg/L. The intent of this study was to evaluate chronic morphological effects and hence the acute affects were not well quantified.

Chronic Toxicity

Results of chronic toxicological studies are applicable throughout the Powell Marsh and Dead Pike Lake system--begging in the ditch that feeds Dead Pike Lake to the bays in the south and east of the lake that receives concentrated levels of iron, and extending into the lake itself which experiences elevated iron levels but at lower concentrations.

Iron speciation (Fe^{+2} or Fe^{+3}), pH, and the presence or absence of natural organic matter are significant determinants of aquatic toxicity. If iron is in the hydroxide form (e.g., $Fe(OH)^{+2}$,

$Fe(OH)_2^+$, $Fe(OH)_3$) and pH is high, it is much less toxic. Brenner and Cooper, 1978, demonstrated that iron (ferric) hydroxide was not toxic to coho salmon fry when exposed to 3 mg/L for approximately 50 days. Iron hydroxide also did not affect embryonic development and maturation. In studies with newly-hatched grayling fry, Vuorinen, 1998, demonstrated the effect of pH and natural organic matter on mortality and sublethal indicators of stress. In this study with a dose of 5 mg/L iron (added as Fe^{+3}) and 10 mg/L natural organic matter (called humus in the text), approximately 80 percent morality at pH 5.5 and 20 percent mortality at pH 6.0 was observed. Without humus added, mortality was 100% at pH 5.5 and approximately 40% at pH 6.0. Mortality was not significantly different from controls for doses below 5 mg/L. Some sublethal effects (exchangeable sodium) were noted in one summer old grayling exposed to doses as low as 1 mg/L (with humus) at pH 5.5 and 5.0. Sublethal effects were not observed at pH 6.0 (with humus). Although humus reduced mortality or sublethal effects of iron exposure, the benefit of humus (natural organic matter) appeared to be limited and overwhelmed by higher iron doses (e.g., 5 mg/L).

Two series of sublethal tests were conducted with brown trout fingerlings to determine the effect of iron exposure on several sublethal indicators of stress, including plasma iron accumulation, gill iron accumulation, and gill morphology (DalZell and Macfarlane, 1999). The first series of tests were conducted with iron concentrations of 10.97 and 12.31 mg/L iron and pH of 6.38 and 6.53 (test water was Nottingham mains water which is presumably purified drinking water originating from a reservoir). This test was prematurely terminated on day three because of fish morality which was likely due to the high dose and more acidic test conditions. The second sublethal test was conducted at iron doses of 6.74 and 7.4 mg/L at pH of 7.07 and 7.1. No fish died during this 14 day test. For this test there was no evidence of iron accumulation on gills (there was in the test conducted for 3 days and with mortality) and there was no evidence of mucus formation (a sign of stress). The authors evaluated the effect of iron exposure (doses of 6.74 and 7.4 mg/L) on gill morphology and noted that there was either little effect on the gills (when they used high purity iron sulfate-analar grade) or there was thickening of the secondary lamellae of the gills and epithelial cell hypertrophy (meaning the cells got bigger) when a less pure iron sulfate sources was used (commercial grade iron sulfate). In this study and others (Peuranen et. al., 1994), mortality was clearly associated with a disruption of gill function and morphology (e.g., the gills were degraded).

Randall et. al., 1999, conducted a thorough investigation into the chronic effects of a zooplankton (*Daphnia longispina*) exposed to iron and evaluated the mechanistic basis for the observed toxicity. This study identified a chronic LC50 (reported as ED50 in the study) of 4.49 mg/L iron and a safe level of 1.69 mg/L. Daphnia reproduction ceased at 15.9 mg/L. Iron used in this study was initially in the Fe^{+2} form, but since the test period was 15 days it is expected that most of the iron converted to Fe^{+3} and became particulate (the authors noted that iron was in the particulate form). The authors hypothesized that iron in the particulate form causes chronic toxicity by inhibiting feeding. The authors demonstrated that iron concentrations greater than 1 mg/L inhibited filter feeding activity and that filter feeding activity declined with increasing iron concentrations. The length and area of the filter feeding mechanism called the third thoracic limb also increased in size in the presence of iron. This observation was confirmed by the authors with field studies conducted in an English reservoir that is intentionally dosed with iron. Where the reservoir was dosed with iron the thoracic limb was larger (more area) compared to areas of the reservoir without iron dosing.

Chronic toxicity test with a mayfly (*Leptophlebia marginata*) at pH 4.5 and 7.0 and a range of iron (10 to 50 mg/L) indicates that iron toxicity to this mayfly and potentially other aquatic insects would not be significant in the presence of elevated iron. However, at pH 4.5 sublethal affects were noted. At all of the doses tested, mayfly in water adjusted to pH 4.5 were less active and feeding rates declined significantly over the 30 day test.

Field Studies

A few studies have used field-based approaches to identify iron levels that would be protective of aquatic life (primarily aquatic insects) in streams. It should be noted that the effects in these field studies are more likely physical due to sedimentation rather than toxicological, however, physical and toxicological effects can both cause mortality. A study by Linton et. al., 2007, identified an iron level of 1.74 mg/L or less which would be protective of aquatic invertebrates in streams. The study used field measurements of aquatic insects (in West Virginia) and iron and statistically analyzed these data to identify a level that would protect 95% of the invertebrate species present in the streams. This study applied an approach that is consistent with US EPA methodology used to develop water quality criteria. The primary weakness of this study is the disproportionate number of streams sampled with low iron compared to sites with high iron.

A study in Denmark in a lowland river system investigated the relationship between iron levels and macroinvertebrates in this stream system (Rasmussen and Lindegaard, 1988). Iron was hypothesized to be elevated in several streams because of hydrologic alteration (water level lowering) in this region. This study noted that when Fe^{+2} was greater than 0.3 mg/L in a given stream, there was a significant drop in the number of taxa found. There was a very strong correlation (r^2 ranging from 0.74 to 0.92 depending on whether maximum or average iron concentration was used in the relationship) between iron and the number of taxa observed in a stream. This study is significant in that it demonstrates the effect of long term exposure to elevated iron—the elimination of sensitive species and substitution of those species with more tolerant ones. The number of species was also observed to decline at sites with high (> 1.0 mg/L) iron. This study demonstrates that aquatic ecosystems exposed to consistently high iron can lead to lower biological diversity and species abundance.

Chronic Toxicity Tests with Powell Marsh Water

Because the results of the literature review indicate that iron can be toxic to aquatic life at concentrations entering Dead Pike Lake from the Powell Mash, water was collected and submitted to a whole effluent toxicity testing laboratory in July and September, 2010. This work was outside of the scope of the management plan grant and grant resources were not expended in this effort (pro-bono toxicity testing services were provided by the laboratory *Environmental Toxicity Control* in Woodbury, Minnesota). The tests were done using the test species *Ceriodaphnia dubia*, using standardized whole effluent toxicity testing methods. Testing was conducted for seven days and the primary endpoint was mean young production. A reference condition (typically upstream of an effluent discharge) is typically used to determine the degree of effluent toxicity, however, because there is not an “upstream” location in this case and only a limited number of free tests were provided by the toxicity testing laboratory, tests conducted using Saint Louis River water for another study were used as the reference condition. The Saint Louis River is in northern Minnesota and has characteristics similar to northern Wisconsin waters such as a tea stained color due to wetland drainage. Tests on Saint Louis River water were conducted from June 1 through October 5, 2010.

The whole effluent toxicity tests using water collected from the Main Inlet and from Pete’s Creek show a slight but insignificant reduction in reproduction for the Main Inlet but there was approximately 33 percent reduction (average of 2 tests) in reproduction for water from Pete’s Creek when compared to St. Louis River water (see Figure 7-1). The results show that the water coming from Pete’s Creek can be classified as having toxic properties; however, water from the Main Inlet did not show a significant level of toxicity. Iron in the Main Inlet samples was 8.9 to 14 mg/L while in Pete’s Creek it was 11.0 for both testing events. The difference in toxicity of the two inlet waters is likely due to pH. For example, for the September sample the pH of the Pete’s Creek sample was 6.03 while the pH of the Main Inlet water was 6.45. These tests show that the water from the Powell Marsh has the potential to be toxic to aquatic life, particularly when pH at the Marsh outlet approaches 6.0.

Iron and Dead Pike Lake

The average concentration of iron coming into Dead Pike Lake at Powell Road (Main Inlet) from the Powell March was 9.6 mg/L in 2008 (see Section 5.0). Samples were collected by the Lake Association from May 27 until September 20. The total iron concentration ranged from a low of 3.2 to a high of 16.0 mg/L. Similar results were found in a conducted by (Kreitlow. (2006). Total iron measured in the ditch coming into Dead Pike Lake at Powell Road (called Ditch #3 and sampling location #5 in the report) ranged from 6.6 mg/L to 18.8 mg/L in 2005-2006. Dissolved iron (presumably Fe^{+2}) ranged from below detection to as high as 9.1 mg/L. These data collected by the WDNR indicate that iron discharged into Dead Pike Lake from the Powell Marsh is likely in the Fe^{+3} and Fe^{+2} forms. Also notable in this study is that pH was monitored at the inlet and ranged from 6.25 to 6.7. Dissolved oxygen ranged from 3.45 to 9.3. These data suggest that iron chemistry in the ditch is likely in flux, often changing from reduced Fe^{+2} to the oxidized form Fe^{+3}. It is very likely iron in the reduced form in the ditch is oxidized and forms particulate iron hydroxide when discharged into Dead Pike Lake.

The findings of the toxicological studies discussed above are directly applicable to understanding how the chemistry and iron content of water discharging into Dead Pike Lake from the Powell Marsh may be affecting the biota of the lake. Iron at the Marsh outlet is clearly high, the chemistry is in flux, and the levels in the ditch feeding the outlet are in the range of iron levels tested in the previously discussed toxicology studies. For example, the acute toxicity study conducted by Randall et al., 1999, indicates that iron is acutely toxic to Daphnia (zooplankton) at 11.48 mg/L. Iron in this study was introduced in the reduced form but likely quickly oxidized during the test to Fe^{+3}. This is similar to what would happen when iron rich water from the Marsh discharges into the southernmost bay of Dead Pike Lake. Iron concentrations in the ditch commonly exceeded 11.48 mg/L indicating that discharges into the southernmost bay of Dead Pike Lake could be acutely toxic to zooplankton in that bay and potentially areas extending out of that bay. The extent that the iron plume pushes into Dead Pike Lake and causes acute toxicity is a function of turbulent flow, meaning large storm events would likely lead to greater distribution of iron in the lake.

Inputs of iron occur continuously during the open water season. The WDNR demonstrated with the 2005 data that iron can be high in the spring (16.9 mg/L on 4/28/2006) and the fall (15.1 mg/L on 10/14/2005). Data collected in 2008 by the Association confirms this. Because iron inputs are continuous, chronic toxicological data are also relevant. Randall et. al.1999, reported a chronic LC50 of 4.49 mg/L for Daphnia used in this study (meaning half of the organisms die with this iron exposure level) and a safe iron level with chronic exposure is 1.69 mg/L. Iron monitoring data in

Dead Pike Lake at the lake surface ranged from approximately 300 to 500 µg/L Profile data (samples taken at depth) show that iron below the surface can be much higher and on July 15, 2008 iron was at 1.6 mg/L at a depth of 4 meters. Because iron settles once it is oxidized, it is expected that there is a gradient of high iron at the lake inlet to lower concentrations in the middle of the lake (monitoring is conducted in the middle of the lake). With respect to zooplankton, it is expected that there is a zone of acute and chronic toxicity potential due to high iron that extends from the southernmost bay into the lake. So far this discussion has been focused on zooplankton, however, based upon the sediment coring data and observations of the Association members, iron plumes cover many areas of the lake and likely affect the ecological niches in which different biota reside.

It is possible that acute toxicity may occur for fish in the southern most bay of Dead Pike Lake where iron has the potential to be most elevated during large storm events (DalZell and Macfarlane, 1999). However, it appears that acute toxicity to fish is largely unlikely ((Mukhopadhyay, 1984; Brenner and Cooper, 1978) for most of the lake. There are potentially chronic toxicological and sublethal effects for fish exposed at iron levels and pH that would be expected in the southern most bay of the lake and under some hydrologic circumstances extending outward in the southern half of the lake. Vuorinen, 1998 showed 20 percent mortality at pH 6.0 with grayling fry used in chronic tests with iron doses of 5 mg/L and natural organic matter of 10 mg/L and 40 percent mortality with 5 mg/L iron and no organic matter.   Peuranen et. al., 1994, demonstrated that sublethal effects can occur at pH 6.0 and iron doses of 2.0 mg/L. However, because it is expected that the pH in the main body of Dead Pike Lake is likely to be near 7.0 for most of the year, chronic mortality or sublethal effects are expected to be largely confined to the lake area near the inlet.

The study by Rasmussen and Lindegaard, (1988) indicates that aquatic insects, which should reside in the littoral areas of Dead Pike Lake, are likely affected throughout the entire littoral area of the lake. This study demonstrated that iron as low as 0.3 mg/L reduced the number of invertebrate (primarily aquatic insects) taxa. The Rasmussen and Lindegaard study demonstrated a convincing and strong relationship between the number of aquatic insect taxa and iron levels. The number of aquatic insect taxa declined significantly as iron concentrations increased from 1 to 10 mg/L and when concentrations approached 10 mg/L only tolerant aquatic insects remained.

The aquatic toxicological data and the iron and water chemistry monitoring data collected at the inlet to Dead Pike Lake and in Dead Pike Lake itself indicate that iron is at levels that can cause acute and chronic toxicity to several different biological niches in which biota reside: aquatic invertebrates and insects in the littoral areas of Dead Pike Lake, zooplankton residing in the south bay and the southern half of Dead Pike Lake, and fish that reside near the inlet and possibly in the south bay of Dead Pike Lake. Although direct toxic effect to fish may be limited to the south bay of Dead Pike Lake and areas that receive water from Pete's Creek, there may be stress on fish lake wide if populations of zooplankton and aquatic insects are diminished to a level that affects food availability to the resident fish.

Summary

- Iron is acutely and/or chronically toxic to several aquatic life species and groups (crustaceans, aquatic insects, zooplankton, and fish) at the levels being discharged from the Powell Marsh into Dead Pike Lake and at the levels expected to be transported from the Main Inlet throughout the entire lake.

- Safe iron levels for aquatic life have been identified by researchers and Canadian Provincial Governments to range from 1 to 1.74 mg/L.

References

Rasmussen, K. and C. Lindegaard. 1988. "Effects of Iron Compounds on Macroinvertebrate Communities in a Danish Lowland River System." *Water Research*, Vol. 22, No. 9, pp. 1101-1108.

Linton, T.K., Pacheco, M.A.W., McIntyre, D.O., Clement, W.H., and J. Goodrich-Mahoney. 2007. "Development of Bioassessment-Based Benchmarks for Iron." *Environmental Toxicity and Chemistry*, Vol. 26, No. 6, pp. 1291-1298.

Gerhardt, A. 1992. "Effects of Subacute Doses of Iron (FE) on *Leptophlebia marginata* (Insecta: Ephemeroptera)." *Freshwater Biology,* Vol 27, pp. 79-84.

Randall, S., Harper, D., and B. Brierley. 1999. "Ecological and Ecophysiological Impacts of Ferric Dosing in Reservoirs." *Hydrobiologia,* Vol. 395/396, pp. 355-364.

Province of British Columbia. 2008. *Ambient Aquatic Life Guidelines for Iron*.

Peuranen, S., Vuorinen, P.J., Vuorinen, M., and A. Hollender. 1994. *The Effects of Iron, Humic Acids and Low pH on the Gills and Physiology of Brown Trout* (*Salmo Trutta*).

Maltby, L., Snart, O.H., and P. Calow. 1987. "Actue Toxicity on the Freshwater Isopod, *Asellus Aquaticus* using $FeSO_4$*$7H_2O$, with Special Reference to Techniques and the Possibility of Intraspecific Variation." *Environmental Pollution,* Vol. 43, pp. 271-279.

Dalzell, D.J.B., and N.A.A Macfarlane. 1999. "The Toxicity of Iron to Brown Trout and Effects on the Gills: a Comparison of two Grades of Iron Sulphate." *Journal of Fish Biology*, Vol. 55, pp. 301-315.

Vuorinen, P.J., Keinanen, M., Peuranen, S., and C. Tigerstedt. 1998. "Effects of Iron, Aluminum, Dissolved Humic Material and Acidity on Grayling (*Thymallus Thymallus*) in Laboratory Exposures, and a Comparison of Sensitivity with Brown Trout (Salmo Trutta)." *Boreal Environment Research*, Vol. 3, pp. 405-419.

Brenner, F. J., and L. Cooper. 1978. "Effect of Suspended Iron Hydroxide on the Hatchability and Embryonic Development of the Coho Salmon." *Ohio Journal of Science*, Vol. 78, No. 1, pp. 34-38.

Vuori, K. M. 1995. "Direct and Indirect Effects of Iron on River Ecosystems." *Annales Zoologici Fennici*, Vol. 32, pp. 317-329.

Mukhopadhyay, M.K. and S.K. Konar. 1984. "Toxicity of Copper, Zinc and Iron to Fish, Plankton, and Worm." *Geobios*, Vol. 11, pp. 204-207.

8.0 Fisheries

Fisheries in the Lake

According to the WDNR in Woodruff, WI, Dead Pike Lake is being managed as a smallmouth bass, muskellunge, and walleye fishery. Other fish that have been found in the lake (2005-2006 Creel Survey conducted by the WDNR), include largemouth bass, yellow perch, northern pike, black crappie, bluegill, dogfish, common shiner, golden shiner, pumpkinseed, rock bass, white sucker, and yellow bullhead. General fish regulations apply to Dead Pike Lake for walleye (daily limit of 5, no minimum but only one over 14 inches in length), largemouth and smallmouth bass (no daily limits for most of the year, 5 for June 18 through March 4, and minimum length of 14 inches), muskellunge (daily limit of 1 for May 28 through November 30, maximum length of 34 inches), and Northern Pike (daily limit of 5 for May 7 through March 5 and no length restrictions).

A file search was conducted at the WDNR offices in Woodruff, WI to gather all available historical information regarding Dead Pike Lake fisheries management activities. From what could be gathered, it appears that fish stocking activities extend back to 1950 with the introduction of walleye fingerlings. Walleye were stocked in the lake in 1950, 1952, 1953, 1966, 1971, 1977, 1989, 1991, 2000, 2002, 2004, 2006, and 2008. For all of those years walleye were stocked as fingerling, but most recently in 2008 it appears that they were stocked as 7 to 8 inch yearling. Muskellunge were stocked in 1970 and 1978.

The earliest DNR fisheries correspondence that could be gathered was from 1965. It appears from this correspondence that a survey conducted in July 1965 showed that "very few fish were found in much of the lake," however, it was noted that "good spawning areas are available." Notes in this WNDR report indicated that "visibility was poor along the south side of the lake, and the entire lake bottom other than on the far north side has a film on it." Another observation included "Siltation such as this could have a bearing on the natural reproduction of fish, especially the walleye." The report noted an abundant supply of minnows from the Powell Marsh. The report also noted that "Operations of the Powell Marsh shall be watched so as to enable proper action in decreasing this pollution caused by siltation". This report seems to indicate, however, that the fish population in 1965 was not much different from the population currently residing in Dead Pike Lake (e.g., muskellunge, northern pike, smallmouth bass, and pan fish). Jumping forward over forty years to the most recent creel survey, it appears that the same fish are present in Dead Pike Lake and according to the Wisconsin Department of Natural Resources the catch rate (hours to catch a fish) for smallmouth bass, largemouth bass, and muskellunge was similar to other lakes surveyed recently in Vilas County.

The primary issue with the Dead Pike Lake fishery appears to be the inability of the lake to support walleye. Fish survey reports and correspondence from 1965 through the present have consistently reported that Dead Pike Lake cannot reliably support a naturally reproducing walleye population (meaning, fish are unable to spawn successfully in the lake). The walleye population in Dead Pike Lake is currently being supported by stocking. Empirically it appears that something is inhibiting walleye in this lake given the seemingly suitable deep water and spawning habitat for walleye. From a brief literature search on walleye spawning, three primary factors have been identified that affect walleye spawning when rainbow smelt are not present (see following paragraph), they include: (1) chemical conditions-- primarily the need for ample oxygen availability and low hydrogen sulfide and ammonia, (2) habitat, and (3) temperature. As part of a series of experiments, Auer and Auer, 1990 identified sediment habitat as the primary factor inhibiting walleye recruitment in the lower Fox River, Wisconsin. Auer and Auer were able to eliminate water quality (of the Fox River) as a cause of poor recruitment in the Fox River and hypothesized that sedimentation and hydrogen sulfide levels directly above the sediment water interface were responsible for poor walleye recruitment. Walleye prefer gravel-cobble substrate. This was demonstrated by Paragamian, 1989 as part of a radiotelemetry study of walleye spawning in the Cedar River, Iowa. Sedimentation and poor substrate was also cited by Fielder, 2002, as possible causes of poor walleye recruitment in Saginaw Bay, Lake Huron. It is not clear from these studies if it is the physical or chemical effect of sediment accumulation that causes poor larval development. Sediment that is organic can enhance dissolved oxygen depletion and cause anaerobic conditions that lead to ammonia and hydrogen sulfide production. Sedimentation of inorganic particles can cover bottom sediments and cause anaerobic conditions to form due to the formation of a physical barrier to oxygen flux. Monitoring data collected at the Main Inlet to Dead Pike Lake (see Section 5.0) indicates that high concentrations of sediment enter Dead Pike Lake and consists equally of organic and inorganic matter. The inorganic matter consists of iron and other amorphous metal hydroxides that can block oxygen flux to sediments. It can be seen in Figure 8-1, which was taken on the south shore of Dead Pike Lake, that iron and other metal hydroxide floc accumulate in potential spawning grounds in Dead Pike Lake. Without further biological and experimental study it is difficult to conclude with certainty that floc, originating from the Powell Marsh, by itself stops walleye recruitment in Dead Pike Lake. However, fisheries data collected by the WDNR since 1950 demonstrate that walleye are being supported in the lake by stocking and recruitment is being prevented in the lake despite seemingly suitable habitat.

As a result of fisheries discussions during a public meeting of the Dead Pike Lake management plan (September, 2010), more information was sought from the WDNR in order to better understand the potential effect of rainbow smelt on walleye recruitment in Dead Pike Lake. Questions regarding the potential effect of rainbow smelt on walleye recruitment were forwarded to Steven Gilbert, a fisheries manager at the WDNR. In an email response, Mr. Gilbert provided some additional facts regarding rainbow smelt and also provided a published paper which he coauthored regarding the subject.   According to Mr. Gilbert and the work he has conducted, rainbow smelt were first found in Dead Pike Lake in 1990, however, he suspects that they were “probably introduced several years before this given the decline of walleye recruitment since.” Mr. Gilbert indicated that the last year of documented natural walleye recruitment was 1990. Mr. Gilbert also indicated that “There is also no evidence to indicate that DPL ever supported a significant natural walleye fishery.” The journal article (Mercado-Silva, 2007) provided by Mr. Gilbert indicates that lakes with rainbow smelt had an average young of the year density of 6.92 per kilometer of shoreline. Lakes without rainbow smelt had 25.7 (natural recruitment) and 13.2 (stocked) young of the year walleye per kilometer of shoreline. Clearly, rainbow smelt have an effect but there was no discussion in the journal article about the near complete elimination of young of the year in the study lakes as is the case for Dead Pike Lake (for years in which stocking had not been conducted).

Summary

The primary issue with the fishery in Dead Pike Lake is the persistent lack of lower age class walleye in the lake indicating that a lack of successful, natural reproduction of this species is a concern. It appears likely that the dual stressors of sediment from the Powell Marsh and rainbow smelt inhibit spawning and the establishment of a naturally reproducing walleye population in Dead Pike Lake. According to the DNR there is no evidence that Dead Pike Lake ever supported a significant natural walleye fishery. This suggests that prior to rainbow smelt’s arrival in Dead Pike Lake, walleye were affected by other factors such as high levels of sediment export from the Powell Marsh—the arrival of smelt likely just made this situation worse. Because of the lack of understanding regarding this issue, controlled scientific experiments in Dead Pike Lake and better quantification of the rainbow smelt population in Dead Pike Lake may be necessary to isolate the effect of iron floc deposition from rainbow smelt.

References

Auer, M. T, and N. A. Auer. 1990. “Chemical Suitability of Substrates for Walleye Egg Development in the Lower Fox River, Wisconsin.” *Transcripts of the American Fisheries Society*, Vol. 119, pp. 891-876.

Fielder, D. G. 2002. “Sources of Walleye Recruitment in Saginaw Bay, Lake Huron.” *North American Journal of Fisheries Management,* Vol. 22, pp. 1032-1040.

Mercado-Silva, N., Sass, G.G., Roth, B. M., Gilbert, S., and Vander Zanden, M. J. 2007. “Impact of Rainbow Smelt (Osmerus mordax) Invasion on Walleye (Sander vitreus) recruitment in Wisconsin lakes.” *Can. J. Fish. Aquat. Sci.*, Vol. 64.

Paragamian P. L. 1989. “Seasonal Habitat Use by Walleye in a Warmwater River System, as Determined by Radiotelemetry.” *North American Journal of Fisheries Management*, Vol. 9, pp. 392-401.

9.0 Dead Pike Lake Aquatic Plant Survey Summary

Summary

A team of lake specialists performed a point-intercept aquatic plant survey on Dead Pike Lake (WBIC 2316600) on July 29-31, 2008. The sampling grid included 708 points and 244 sites were vegetated. We found 51 plant species including emergent, floating and submersed species growing at a maximum of 22 feet. Floristic Quality Index was 47.2 and Aquatic Macrophyte Community Index was 67. There was a diversity of plant growth types and no invasive species. Together, all of these factors combine to indicate a robust aquatic plant community.

Introduction and Methods

On July 29-31, 2008, a team of lake specialists including Joe Pallardy, Lindsay Watch, Matt Wagner Sandy Wickman, Kyle McLaughlin and Susan Knight conducted a plant survey on Dead Pike Lake in Manitowish Waters, WI (WBIC 2316600). Using a point intercept sampling technique, we used a rake on a pole (at depths up to 15') or rake on a rope (for greater depths) to sample aquatic plants at 708 potential sampling points. Initially, we sampled all sites regardless of depth, and through a defined protocol, determined the maximum depth to which any plant grew. Once this depth was determined, deeper sites were not sampled though many deeper sites were sampled in order to come to this determination.

We worked as a team of three, with one person driving the boat and navigating to each point, a second person recording data and a third person raking, identifying each species and determining abundance. At each site we determined depth and bottom substrate (as muck, sand or rock). We recorded the total rake fullness as 0 (no plants), 1 (a few plants on the rake), 2 (rake approximately half full) or 3 (rake overflowing with plants). We also rated the abundance (using a scale of 1 to 3) of each species found at each point. At each site we looked for species observed within 6 feet of the boat, but not actually collected on the rake (visuals). As we neared shore, we also conducted a boat survey to collect comments about the shoreline and shoreline vegetation.

Using data collected in the survey, we calculated Floristic Quality Index (Nichols 1999) and Aquatic Macrophyte Community Index (Nichols et al. 2000) as tools for assessing the floristic integrity of

Dead Pike Lake and to compare it to other nearby lakes. FQI is a computation assessing lake quality using two parameters: the number of species present and the coefficient of conservatism (C). C ranges from 1-10 and indicates how pristine an environment a species requires. These values were assigned by a panel of botanists for each plant species in Wisconsin. FQI is based on species recognized by Nichols (1999) as native aquatics. Some species collected are not included in this measure for several reasons: not all aquatic/wetland transition species are included (e.g. *Lysimachia terrestris*), identification is uncertain (e.g. moss or *Sparganium* sp.), or it may be an introduced species (none in this study). Also, visuals are not included in the FQI. Therefore, the total number of plants identified is greater than the number of species contributing to the FQI. AMCI is a sum of seven parameters, each scaled 1-10 (for a maximum total of 70), and is another assessment of lake quality from plant data.

Results and Discussion

The grid included 708 sampling points. We visited 410 points and, by initially sampling all sites regardless of depth, we determined the maximum depth of the plants to be 22 feet. However, sites at approximately 5' deep were most likely to have vegetation (Figure 1). We determined there were 327 points shallower than this depth and, of these, 244 sites, or 74%, had vegetation (Table 1).

We found a variety of substrate types, with muck dominating the south bay and sand in much of the shallow areas of the lake (Figure 2). The depth determination indicated broad shallow areas on the east and west sides of the lake, and a much narrower band of shallow depths on the north and south sides of the lake. The south bay sites had a range of depths and mostly muck sediments. A large central area of the lake was too deep for plant growth (Figure 3).

We found a total of 51 species, including 41 found on the rake, and 10 as visuals (seen within 6' of the boat, see Tables 2 and 3). We found no exotic invasive plant species. Together, the extremely high species diversity and the lack of exotics indicate exceptional water quality and a robust aquatic plant community. We found a variety of plant types, including emergent, floating and submersed species. There was also variety of plant growth forms, with both short, stiff rosette species, such as *Lobelia dortmanna* and *Eriocaulon aquaticum*, typical of sandy, low nutrient and often wave swept sites and also leafier, taller plants, such as *Potamogeton amplifolius* and *Elodea canadensis*, typical of richer, calmer sites. This diversity is further indication of a healthy lake community.

We found an average of almost 3 species per site, with many sites having 7 or more species (Figure 4). Sites of both high diversity and high plant density (rake fullness of 3, Figure 5) were distributed throughout the lake. There were many sites in the south bay with both high plant density and large species diversity despite the fact that the water in some of these sites was often orange (from iron deposits, Figures 4 and 5).

Dead Pike Lake has a high Simpson diversity index (measuring diversity and evenness of species distributions) of 0.92 (out of a maximum of 1.0, Table 1). The Floristic Quality Index (FQI, Nichols 1999,) was 47.2 (Tables 1,4) and compares favorably with other nearby lakes, such as the Manitowish Chain Lakes Wild Rice and Rest Lakes and Nichols' (1999) findings of Lakes in the Northern Lakes and Forests Region (Table 4). FQI can be high because the average coefficient of conservatism is high and/or the number of species is high. In Dead Pike, the species diversity was especially high. The Aquatic Macrophyte Community Index (AMCI, Nichols et al. 2000), was 67 out of a maximum of 70 (Tables 1, 5). AMCI takes into account seven variables, all scaled to a maximum of 10. The maximum plant depth, the percent of the sites vegetated, the number of species and the fact that there are no invasive species all rated the maximum score of 10. Three other factors ranked 9, including the Simpson Diversity Index, the percent of submersed species and the number of sensitive species. The score of 67 is exceptional for lakes in the northern lakes and forest region and among all lakes in Wisconsin.

We found two species of Special Concern (not considered Threatened or Endangered, but on a watch list): small purple bladderwort (*Utricularia resupinata*) and Robbins' spike rush (*Eleocharis robbinsii*). The bladderwort was found at several sites along the north shore from west to east and the spike rush was found in one place on the western shore area. These species are especially indicative of high quality aquatic plant conditions, and is more evidence of the high quality of the Dead Pike aquatic plant community.

Overall, Dead Pike Lake has a rich aquatic plant community, with high diversity throughout the lake littoral zone. Several factors, including high AMCI and FQI scores, the lack of any invasive species, the presence of two Special Concern species and high plant diversity combine to indicate that Dead Pike has an exceptional plant community and excellent water quality.

Table 1. Dead Pike Lake Summary

Total number of points sampled	410
Total # of sites with vegetation	244
Total # of sites shallower than maximum depth of plants	327
Frequency of occurrence at sites shallower than maximum depth of plants (%)	74.62
Simpson Diversity Index	0.92
Maximum depth of plants (ft)	22.00
Average # of native species per site (veg. sites only)	2.75
Species Richness (including visuals)	50
FQI (n=44)	47.19
AMCI	67

Table 2. Species List for Dead Pike Lake

	Species	Common name		Species	Common name
	Brasenia schreberi	Watershield		*Nitella sp.*	Nitella
*	*Carex sp.*	Sedge		*Nuphar variegata*	Spatterdock
	Ceratophyllum demersum	Coontail		*Nymphaea odorata*	White water lily
	Chara	Muskgrasses		*Pontederia cordata*	Pickerelweed
	Dulichium arundinaceum	3-way sedge		*Potamogeton alpinus*	Alpine pondweed
	Eleocharis palustris	creeping spikerush		*Potamogeton amplifolius*	Large-leaf pondweed
	Eleocharis robbinsii	Robbins spikerush		*Potamogeton epihydrus*	Ribbon-leaf pondweed
	Elodea canadensis	Common waterweed		*Potamogeton foliosus*	Leafy pondweed
	Elodea nuttallii	Slender waterweed		*Potamogeton gramineus*	Variable pondweed
	Equisetum fluviatile	water horsetail		*Potamogeton pusillus*	Small pondweed
	Eriocaulon aquaticum	Pipewort		*Potamogeton richardsonii*	Clasping-leaf pondweed
*		filamentous algae		*Potamogeton robbinsii*	Robbins pondweed
	Heteranthera dubia	Water star-grass		*Potamogeton spirillus*	Spiral-fruited pondweed
*	*Hypericum perforatum*	St. John's Wort		*Potamogeton zosteriformis*	Flat-stem pondweed
	Isoetes echinospora.	Quillwort		*Sagittaria latifolia*	Common arrowhead
*	*Juncus effusus*	Soft rush		*Schoenoplectus acutus*	Hardstem bulrush
	Juncus paleocarpus f. submersus	Brown-fruited rush		*Schoenoplectus subterminalis*	Water bulrush
	Lemna minor	Small duckweed		*Sparganium fluctuans*	Floating-leaved bur-reed
	Lobelia dortmanna	Water lobelia	*	*Sparganium sp.*	
*	*Lysimachia terresris*	Swamp candles		*Spirodela polyrhiza*	Large Duckweed
	Megalodonta beckii	Water marigold		*Utricularia cornuta*	Horned Bladderwort
*		moss		*Utricularia gibba*	Creeping bladderwort
	Myriophyllum sibiricum	Northern water milfoil		*Utricularia resupinata*	Small purple
	Myriophyllum tenellum	Dwarf water milfoil		*Utricularia vulgaris*	Common
	Myriophyllum verticillatum	Whorled water milfoil		*Vallisneria americana*	Wild celery
	Najas flexilis	Bushy pondweed			
	* Not included in FQI				

Table 3. Most common species in Dead Pike Lake

Species Name	Common Name	Frequency of Occurrence (%)
Chara sp.	Muskgrass	54.5
Potamogeton gramineus	Variable pondweed	36.5
Najas flexilis	Slender naiad	19.7
Potamogeton amplifolius	Large-leaf pondweed, cabbage	18.0
Elodea canadensis	Common waterweed	13.5
Myriophyllum sibiricum	Northern water-milfoil	12.3

Table 4. Floristic Quality Index

	# species	Mean C	FQI
No. Lakes & Forests Region (median)	23	6.7	24.3
Rest	23	7.0	33.8
Wild Rice	38	6.8	41.9
Dead Pike	50	7.1	47.2

Table 5. Aquatic Macrophyte Community Index

	Northern Lakes and Forests Region*	**Dead Pike**		**Maximum**
	Median	AMCI raw value	AMCI scaled value	AMCI Value
Max depth of plant growth (m)	3.5	6.7	10	10
Littoral area vegetated %	75	75	10	10
Submersed Species Relative %	80	87.9	9	10
Taxa Number	18	50	10	10
Exotic Species (relative %)	0	0	10	10
Simpson's Diversity Index	88	0.92	9	10
Sensitive species (relative %)	20	28.36	9	10
Total	**56**		**67**	**70**
	*Data collected prior to 2000, Nichols et al. 2000			

Figure 1. Vegetated Sites of Dead Pike Lake and Manitowish chain lakes by depth

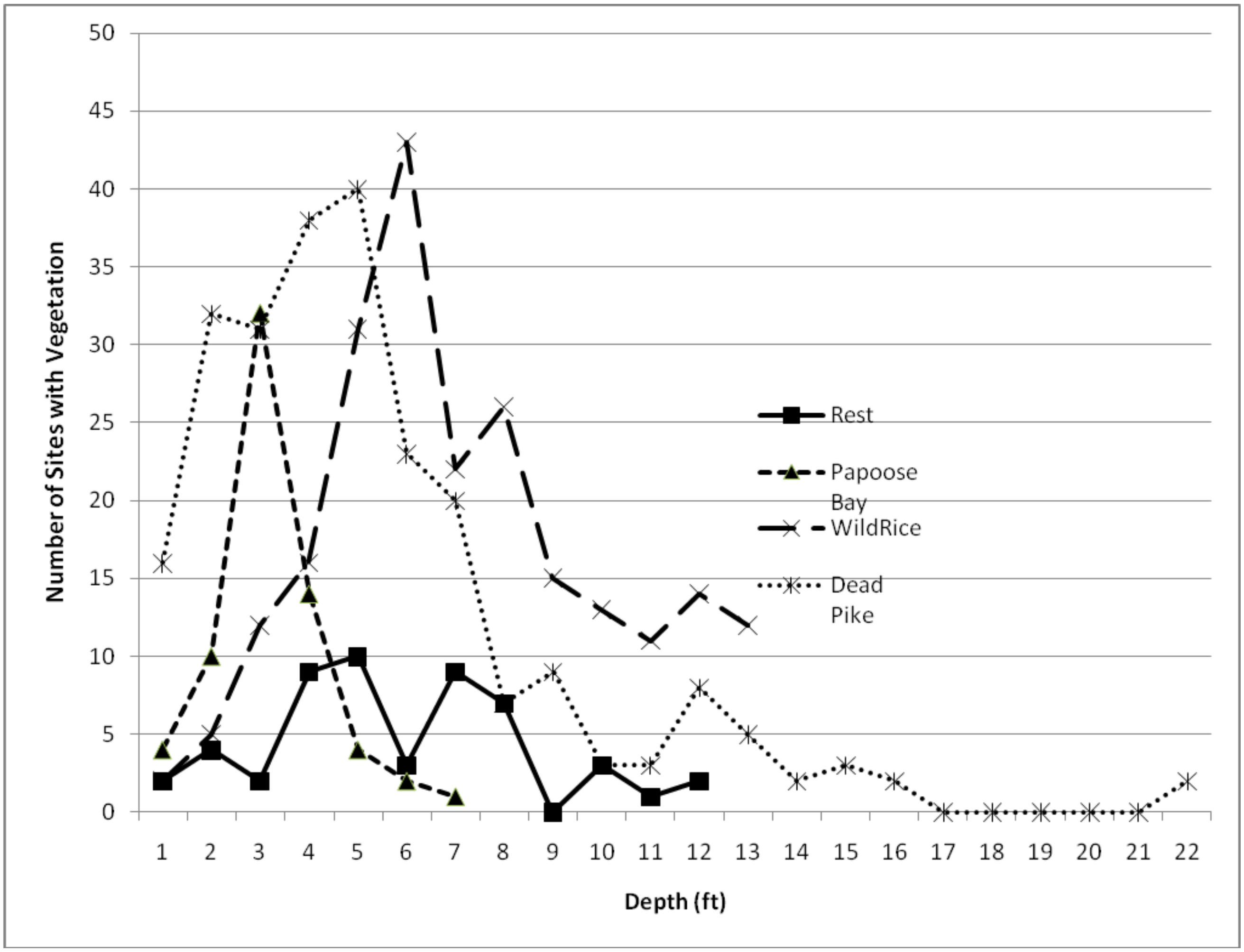


Figure 2. Sediments in Dead Pike Lake

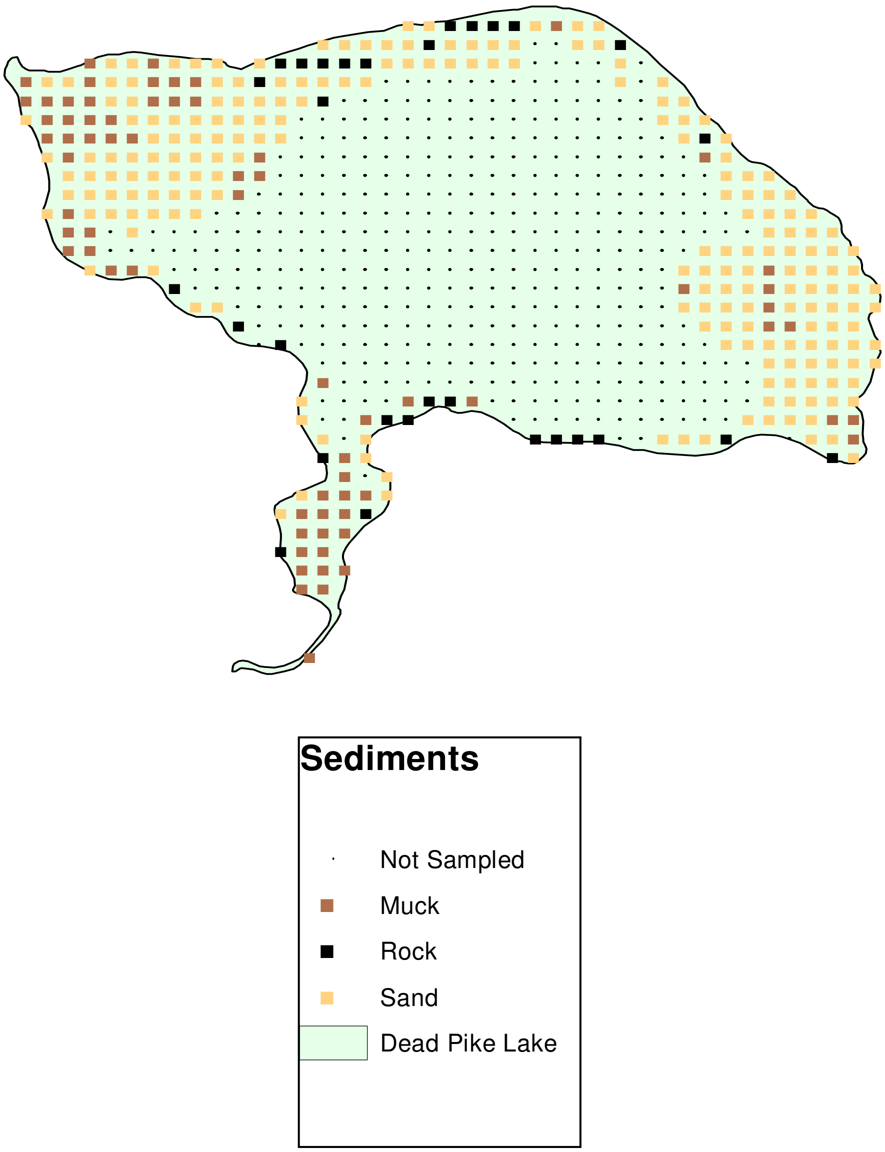


Figure 3. Depth distribution in Dead Pike Lake

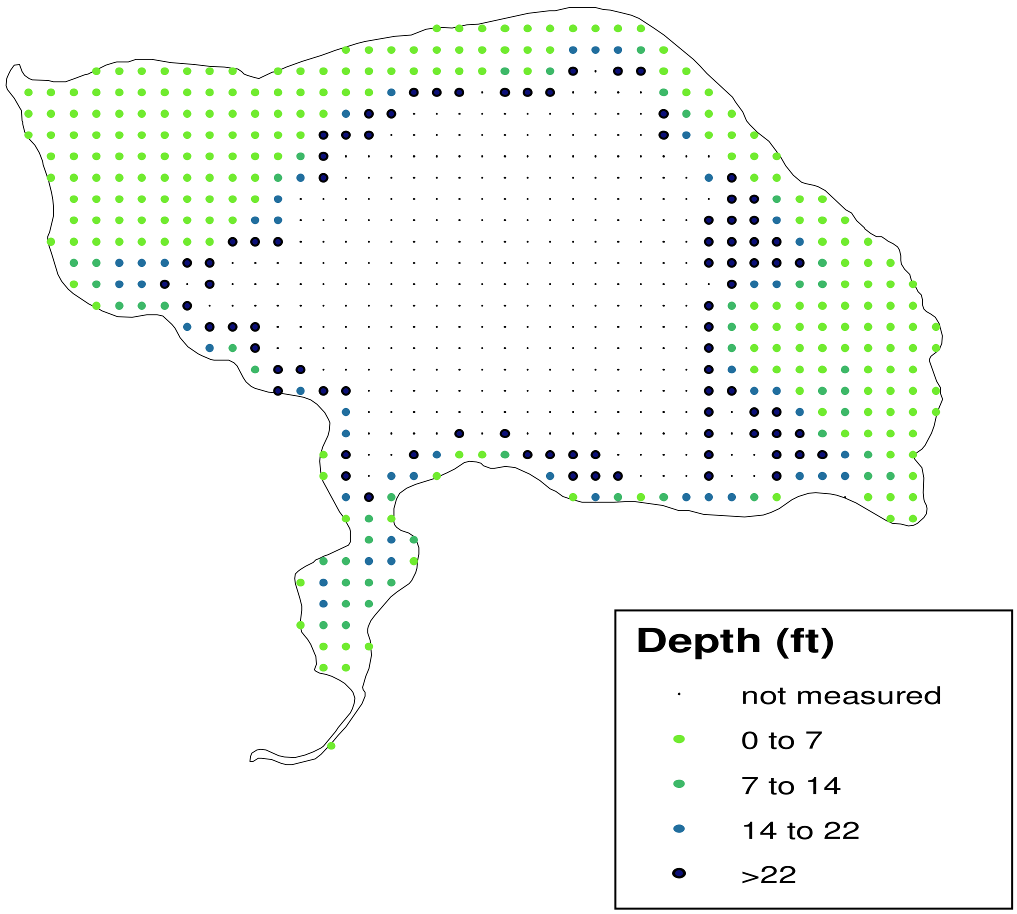


Figure 4. Species density in Dead Pike Lake.

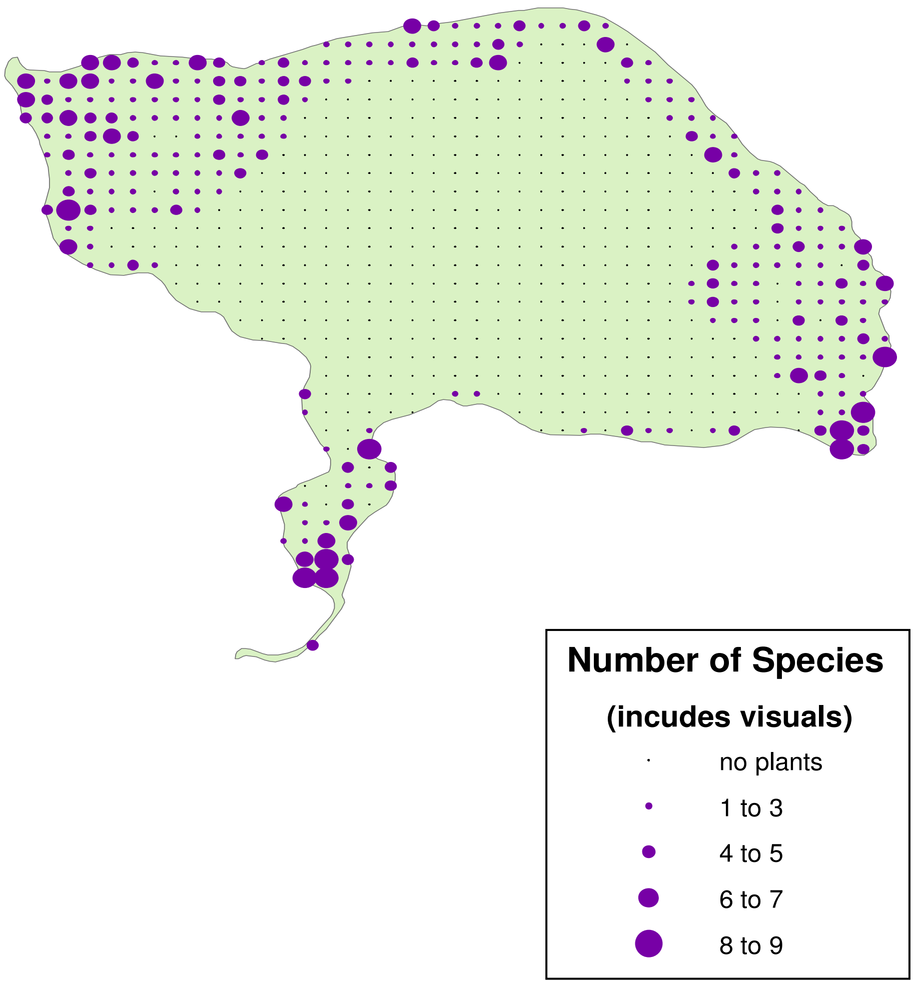
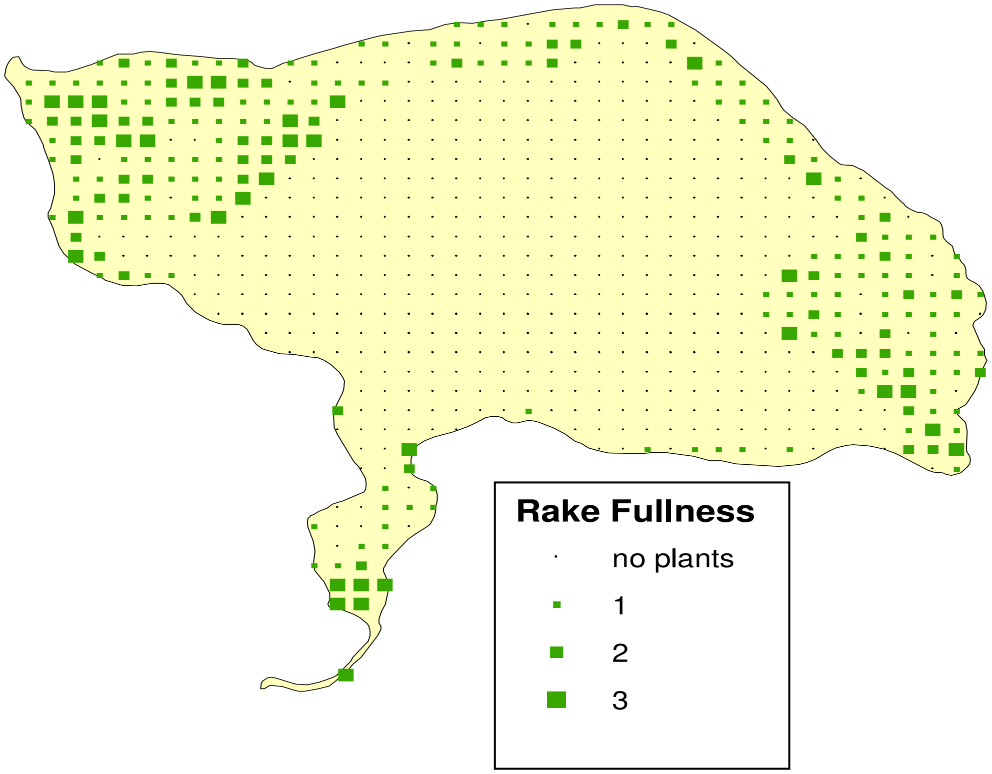


Figure 5. Rake fullness in Dead Pike Lake



References

Nichols, S. 1999. Floristic quality assessment of Wisconsin lake plant communities with example applications. Journal of Lake and Reservoir Management 15(2):133-141.

Nichols, S., S. Weber and B. Shaw. 2000. A proposed aquatic plant community biotic index for Wisconsin lakes. Environmental Management 26(5):491-502.

10.0 Integrating the Ecology of Powell Marsh and Dead Pike Lake

The rapid growth in our understanding of lake ecosystems over the past 25 years or so has revealed the sensitivity of lakes to the condition of their watersheds. Decades ago, G.E. Hutchinson (1941) suggested that lakes attain a trophic equilibrium with their watershed in terms of nutrient inputs. Both natural events such as storm damage and fires or human activities such as agriculture and urban development in the watershed can alter this equilibrium. The result is an increase in nutrient and sediment loading to lakes.

Powell Marsh is a dominant feature of the watershed of Dead Pike Lake. Approximately 2,000 of the 4,300 acres of the Marsh drain to Dead Pike Lake. Normally a wetland would be a positive watershed feature in light of typical wetland ecosystem services such as runoff moderation and retention of sediments and nutrients. In this case, ditches, dikes , water level control structures, roads and other alterations have compromised many of the natural functions of the wetland such that it is now a source of problems rather than benefits and concerns for Dead Pike Lake:

- Discharge of high concentrations of phosphorus
- Effect of the oxidizing conditions in the ditches which extend into the iron-rich groundwater leading to the production of unsightly iron floc that is subsequently delivered to Dead Pike Lake.
- Production and discharge of iron (dissolved and floc forms) at concentrations known to be toxic and unsightly
- Discharge of elevated concentrations of suspended sediments
- Effect of highly variable discharge and retention of water from the Marsh on lake levels
- Effect of ditches on loss of wetland functions associated with the important sheet flow of water through the wetland vegetation instead of the now channelized drainage of the Marsh to Dead Pike Lake.
- Effect of iron floc on spawning areas of major game fishes, both in reducing quality of the spawning areas and sedimentation of the floc on deposited eggs.

Recent studies (Scheffer, et. al., 2001) note that nature is usually assumed to respond in a slow, smooth way to gradual changes in external influences such as climate, nutrient loading and watershed conditions, but that certain ecosystems including coral reefs, forests, and lakes have been shown to undergo sudden shifts to altered states in response to such influences. The result can be major ecological changes, as in lakes subjected to human-induced eutrophication where loss of transparency due to heavy growth of blue-green algae leads to greatly diminished submerged vegetation and the associated biota.

In a related study, Schefffer et. al.,2009, explore the concept of “tipping points” or early warning signals at which an ecosystem could suddenly shift to a different state. Studies on various ecosystems in transition including lakes are beginning to reveal the presence of critical thresholds in response to external influences.

The high concentrations of phosphorus in the Marsh discharge and the south inlet bay of Dead Pike Lake (see Section 5) are well above the critical levels of 20 to 30 ug/l noted by Bartsch and Gakstatter, (1978) and Lillie and Mason (1983) for Wisconsin lakes and above the water quality standard for total phosphorus (30 ug/l) for Dead Pike Lake (NR 102.06). These high concentrations should be taken as an early warning signal that the Dead Pike Lake ecosystem could be on the threshold of undergoing a shift to an altered state through the process of eutrophication. Of particular concern with this process is the development of unsightly blooms of cyanobacteria (Blue-Green algae) which among other effects lead to a reduced water clarity and diminishment of the underwater light environment. At risk with this development would be the depth and area of the exceptionally diverse submerged plant community and associated invertebrates and fish.

The potential for a Dead Pike Lake ecosystem shift is not however only related to the threat of high phosphorus loadings. Rather, it is a lake under the influence of multiple stressors including levels of iron approaching toxicity concentrations, deposition of iron floc on spawning areas of major game fish species and varying water levels as a result of retention and release of water from Powel Marsh. It is apparent that the main watershed source of these stressors is Powell Marsh and in particular its current state and current management plan.

References

Bartsch, W.F. and Jack Gakstatter. 1978. “Management decisions for lake systems based on a survey of trophic status, limiting nutrients and nutrient loading.” *USEPA Report 600/9-78-024*, pp 372-396.

Hutchinson, G.E. 1941. “Limnological studies in Connecticut. IV Mechanisms of Intermediary metabolism in stratified lakes.” *Ecol. Monogr.* 11: 21-60.

Lillie, Richard and John Mason. 1983. “Limnological characteristics of Wisconsin lakes.” *Tech. Bull. 138*. Department of Natural Resources.

Scheffer, Martin, Steve Carpenter, Jonathon Foley, Carl Foley and Brian Walker. 2001. “Catastrophic shifts in ecosystems.” *Nature*, Vol. 413, 591-596

Scheffer, M.,J. Bascompte, W. Brock, V. Brovkin, S. Carpenter, V. Dakos, H. Held, E. van Ness, M.Reitkerk and G. Sugihara. 2009. “Early-warning signals for critical transitions.” *Nature*, Vol. 461, 53-59.

11.0 Discussion

Development of this management plan has been a process of discovery. One of the projects first tasks was to determine whether the high levels of iron and manganese export seen today have always been discharging from Powell Marsh into Dead Pike Lake. A deep sediment core was taken from the lake, dated and analyzed for these metals and for phosphorus. It clearly showed that prior to human settlement the export of these compounds was lower than it is today.

A historical investigation was under taken to determine what triggered these increased discharges. It was found that as long ago as 1894, the Marsh began to be altered with the construction of a railroad spur spanning the Marsh from Lac du Flambeau to Little Star Lake, a route which now is called Marsh Road. This construction coincides exactly with the beginning of increased iron and manganese export from the Marsh and demonstrates that physical disturbance through human manipulation in the Marsh is a cause of the enhanced export of these metals.

From the time of this construction until the late 1930s, additional human activity appears to have occurred along the northern edge of the Marsh. A 1937 aerial photo (Figure 3-1) reveals a plot of tilled acreage, marginal agricultural activity, which reportedly confirms the presence of a “squatter” at this site whose name, interestingly enough, was “Powell”. Iron export likewise increased during this period, coincidental with this development activity.

But most notably, in the 1950s the WDNR under the ownership of the State constructed an extensive network of 14 miles of ditches and control structures for the purpose of creating impoundments in some areas and draining of others. This management strategy led to at least two important changes in the character of the Powell Marsh ecosystem. Both changes led to a greatly accelerated discharge of iron and manganese to Dead Pike Lake. First, the waters of the ditches, which extend into the anoxic, iron-rich groundwater, provide an oxidizing medium for precipitating the reduced, ferrous form of iron into the ferric precipitate or floc form found in the ditches today. At this time also, agricultural projects were initiated, plowing under acres of indigenous wetland vegetation, exposing the soil to the atmosphere, applying lime and fertilizers and transforming huge sections of the Marsh into grain-yielding crops to attract waterfowl.

The second change noted in the Marsh was a lowering of the groundwater table by as much as 2 feet (Krohelski, 2002) providing a mechanism whereby previously anoxic, water-covered soils containing the sulfides of iron and manganese would become exposed to oxygen. This would cause the release of iron and manganese from the sulfur, allowing all three elements to be mobile in the water. This reaction is substantiated by sulfur analysis (Huser, Pers comm.) on a Lake sediment core showing a direct relationship between increased sulfur export and that of iron and manganese. Because of these continuing oxidation reactions in the Marsh, mitigation approaches that prevent the reactions are doomed fail.

With all these facts and correlations established, it is obvious that man-made influences within the Marsh, primarily those which have targeted the alteration of its hydrology, are directly responsible for the increasingly high levels of iron and manganese export observed today. This provides the rationale for remedial action, based as it is upon solid scientific investigation. Furthermore, it is strongly believed that the increased metal export from the Marsh can be returned to its pre-settlement hydrologic functioning by removing the objects of human intervention – the ditches and water control structures – and returning the Marsh to its natural hydrologic state.

It is now clear that the accelerated iron and manganese export to Dead Pike Lake warrants action in order to affect mitigation:

- **Iron is toxic to aquatic life at levels entering and within Dead Pike Lake**
- **Iron deposits in Dead Pike Lake impair recreational use. (“Swimmable/Fishable tenet of the Clean Water Act”).**
- **Iron floc has the potential to alter water clarity and subsequently the underwater light climate and the depth distribution of the aquatic plant community.**
- **Iron may well be affecting walleye reproduction through floc deposition on spawning habitat.**

The restoration of Powell Marsh to pre-settlement hydrologic functioning is without doubt a key strategy for this Plan. It addresses all of the stressors identified in this Plan. It means that a clear water discharge to Dead Pike Lake would be re-established. The benefits of this restoration are many, both to the Marsh itself and to Dead Pike Lake:

- Protection of water clarity and the littoral community that includes the exceptional aquatic plant community and associated fish and invertebrates.
- Moderated effect on water levels from the discharge of water from the Marsh.
- Retention of nutrients, especially phosphorus, in the Marsh.

- Protection of wetland vegetation from succession to woody species through improved groundwater levels in the Marsh.
- Enhancing the visual, esthetic values of Powell Marsh.

References

Huser, Brian. 2011. Personal communication. Uppsala University. Sweden.

12.0 Management Resolution

The sediment record indicates that the increase in metals (iron and manganese) and phosphorus export from the Powell Marsh has been a function of the intensity and extent of human alteration of the Marsh. It is reasonable to expect that these alterations are reversible. A careful and well executed restoration of the Marsh to its original, unaltered, natural state will reduce its export of metals and phosphorus to pre-settlement/ pre-management conditions.

The Dead Pike Lake Association will continue to call for the restoration of the chemical, physical, and biological integrity of Dead Pike Lake by:

(1) Requesting the Wisconsin Department of Natural Resources to return the Powell Marsh to its predevelopment condition by removing the ditches, dikes, hydrologic control structures, and roads in the Marsh so that the water table will return to original levels found prior to development and that the discharge of water from the Marsh to Dead Pike Lake will be filtered and moderated by the natural functioning of the wetland. The return of indigenous vegetation upon completion of a restoration project has been well documented. (Restoring Ecological Health to your Land, and Nature's Second Chance, Apfelbaum and Harvey)

(2) Working with the WDNR on a specific plan for protecting the integrity of the uniquely diverse aquatic plant community in Dead Pike Lake that would include: (1) conducting annual surveys of the lake's aquatic plants in order to ensure that AIS do not become established in the lake, (2) monitoring the health of the current rare species, (3) taking the necessary steps to preserve the water clarity required for sustaining the thriving littoral community and (4) conducting an annual sampling program to determine the status and origin of phosphorus levels in Powell Marsh and Dead Pike Lake.

(3) Working with the Wisconsin Department of Natural Resources to (1) better document the abundance of the rainbow smelt population in Dead Pike Lake and evaluate methods to control the smelt, if needed and (2) consider other walleye management strategies such as monitoring recruitment and continued stocking of yearling fish.

(4) seek to restore the traditional walleye spawning grounds which have been silted over with iron floc.

(5) Applying for “Protected Habitat Designation” for Dead Pike Lake in order to maintain its natural, scenic beauty..

Finally, it is the position of the DPLA, that the State, by the responsibilities it has for Powell Marsh, a portion of which is a dominant feature of the Dead Pike Lake watershed, has an obligation, not unlike that of any other private land owner in the watershed, to be a good neighbor and steward. It is also clear that substantial violations of both the Clean Water Act and Wisconsin’s Public Trust Doctrine are occurring as a result of these practices.

The Association has invested extensive effort, time and money to substantiate and call attention to the alterations and current management practices that are detrimental to the health of Dead Pike Lake. It is time for the State to take the actions necessary to correct the problems they have created in the Dead Pike Lake Watershed.

Tables

Table 5-1. Measurements of pH, specific conductance, dissolved oxygen, and temperature taken at the Main Inlet to Dead Pike Lake.

Measurement Date	pH (su)	Specific Conductance (us/cm)	Dissolved Oxygen (mg/L)	Temperature (^oC)	Iron (ug/L)	Total Phosphorus (mg/L)	Total Volatile Solids (mg/L)	Total Suspended Solids (mg/L)
5/27/2008	no data	no data	no data	no data	9600	0.074	108	156
6/17/2008	no data	no data	no data	no data	8600	0.143	88	124
6/30/2008	6.4	no data	no data	no data	16000	no data	no data	no data
7/7/2008	6.7	76.1	3.3	27.5	11000	no data	no data	no data
7/15/2008	no data	75.6	3.6	26	9000	no data	no data	130
7/18/2008	7.2	no data	no data	no data	14000	no data	no data	no data
7/22/2008	7	64.3	3.6	26.3	no data	no data	no data	no data
7/28/2008	7.1	60.4	4.6	19.8	no data	no data	no data	no data
8/5/2008	6.7	60.4	3.9	23.3	16000	no data	no data	no data
8/11/2008	7.1	70.5	4.5	22.1	11000	no data	no data	no data
8/18/2008	6.9	43.4	5	22.6	no data	0.089	70	110
8/29/2008	6.9	33.9	6.1	22.1	6200	no data	no data	no data
9/6/2008	7.1	30.2	4.8	14.9	no data	no data	no data	no data
9/10/2008	no data	no data	no data	no data	3200	no data	no data	no data
9/15/2008	7	194.0	6.4	15.7	7000	0.045	54	168
9/20/2008	7.1	117.9	5.1	15.9	3800	no data	no data	no data
10/7/2008	no data	109	7.2	10.8	no data	0.116	50	116
Average	6.9	77.9	4.8	20.6	9617	no data	no data	no data

Table 5-2. Dead Pike Lake profile data for laboratory results.

Date	Site	Depth (m)	Total Phosphorus (mg/L)	Total Iron (ug/L)
6/17/2008	Lake-surface	0	0.016	no data
6/17/2008	Lake-2 m	2	0.015	510
6/17/2008	Lake-4 m	4	0.017	520
6/17/2008	Lake-6 m	6	0.015	550
6/17/2008	Lake-8 m	8	0.010	340
6/17/2008	Lake-10 m	10	0.032	310
6/17/2008	Lake-12 m	12	0.017	500
6/17/2008	Lake-14 m	14	0.009	300
6/17/2008	Lake-16 m	16	0.01	310
6/17/2008	Lake-18 m	18	no data	135000 (1)
7/15/2008	Lake-surface	0	0.019	no data
7/15/2008	Lake-2 m	2	0.111	470
7/15/2008	Lake-4 m	4	0.029	1600
7/15/2008	Lake-6 m	6	0.016	500
7/15/2008	Lake-8 m	8	0.011	310
7/15/2008	Lake-10 m	10	0.012	290
7/15/2008	Lake-12 m	12	0.013	310
7/15/2008	Lake-14 m	14	0.009	310
7/15/2008	Lake-16 m	16	0.011	330
7/15/2008	Lake-18 m	18	0.011	330
8/18/2008	Lake-surf	0	0.012	no data
8/18/2008	Lake-2 m	2	0.013	360
8/18/2008	Lake-4 m	4	0.013	440
8/18/2008	Lake-6 m	6	0.012	350
8/18/2008	Lake-8 m	8	0.013	310
8/18/2008	Lake-10 m	10	0.01	290
8/18/2008	Lake-12 m	12	0.01	300
8/18/2008	Lake-14 m	14	0.011	320
8/18/2008	Lake-16 m	16	0.012	330
8/18/2008	Lake-18 m	18	0.013	360

(1) It is assumed that the water collection device contacted sediment and contaminated the sample.

Table 5-3. Water measurements at the surface of Dead Pike Lake.

Date	Temperature (oC)	Secchi disc depth (ft)	Dissolved Oxygen (mg/L)	Conductivity (us/cm)	Chlorophyll *a* (ug/L)	Total Iron (ug/L)	Total Phosphorus (ug/L)
5/27/2008	13.3	7.5	8.90	85.0	2.65	430	17
6/17/2008	17.0	8.5	8.40	83.5	2.95	510(1)	16
7/15/2008	20.8	9.0	7.30	86.4	2.35	470(1)	19
8/18/2008	22.4	10.0	7.30	89.6	no data	360(1)	12
9/15/2008	16.9	11.5	7.10	89.5	2.87	310	10
10/7/2008	13.3	11.0	8.10	90.3	2.20	no data	16

(1) Sampled at 2 meters.

Table 5-4. Field measurements at depth in Dead Pike Lake.

5/27/2008

Depth (m)	Temperature (°C)	Dissolved Oxygen (mg/l)	Conductivity (us/cm)
0	13.3	9.6	85
1	13.3	8.9	85
2	13.3	9.1	84.8
3	13.3	8.8	84.8
4	13.2	8.8	84.8
5	11.6	9.1	85.2
6	10.8	9.3	85.6
7	10.1	8.9	85.8
8	9.1	8.9	86.1
9	8.1	8.7	86.5
10	7.1	8.7	87
11	6.5	8.9	87
12	6.2	8.8	87.4
13	6.1	8.6	87.5
14	6.0	8.9	87.8
15	5.9	9.0	87.8
16	5.8	8.9	87.9
17	5.8	8.6	87.9
18	5.8	8.5	88
19	5.7	8.7	88.1
20	5.1	8.7	88.1

6/17/2008

Depth (m)	Temperature (°C)	Dissolved Oxygen (mg/l)	Conductivity (us/cm)
0	17	8.5	83.5
1	17	8.4	83.5
2	17	8.3	83.5
3	17	8.5	83.5
4	17	8.3	83.5
5	17	8.3	83.5
6	16.9	8.3	83.5
7	11.8	8.1	86.3
8	9.1	8.6	86.7
9	7.6	8.5	87.7
10	7.1	8.6	87.7
11	6.4	8.6	87.9
12	6.3	8.5	88.2
13	6.2	8.4	88.2
14	6.2	8.4	88.4
15	6.1	8.5	88.4
16	6	8.2	88.7
17	6	8.1	88.7
18	6	8.2	88.7
19	6	8.1	88.8
20	no data	no data	no data

7/15/2008

Depth (m)	Temperature (°C)	Dissolved Oxygen (mg/l)	Conductivity (us/cm)
0	25	7.3	81
1	20.8	7.3	86.4
2	20.4	6.6	86.6
3	20.4	6.5	86.5
4	20.3	7	86.6
5	19.6	7	86.8
6	18.1	5.8	86.5
7	13.7	5.9	87.1
8	9.3	6.1	89.2
9	8.4	6.7	88.2
10	7.2	6.8	88.7
11	7	6.9	88.8
12	6.6	6.6	89.2
13	6.4	6.5	89.5
14	6.4	6.5	89.4
15	6.3	5.8	89.3
16	6.2	6.4	89.5
17	6.2	6.1	89.6
18	6.2	6.5	89.7
19	no data	no data	no data
20	no data	no data	no data

8/18/2008

Depth (m)	Temperature (°C)	Dissolved Oxygen (mg/l)	Conductivity (us/cm)
0	22.4	7.4	89.6
1	22.4	7.3	89.6
2	22.3	7.2	89.7
3	22.3	7.3	89.7
4	22.3	7.4	89.7
5	21.8	5.7	90.0
6	19.1	3.9	88.1
7	14.4	3.4	80.1
8	10.7	4.4	89
9	8.2	5.2	89.2
10	7.4	5.5	89.7
11	7.1	5.4	89.9
12	6.8	5.3	90.2
13	6.6	5.0	90.3
14	6.5	4.9	90.5
15	6.5	4.7	90.4
16	6.4	4.6	90.7
17	6.4	4.6	90.7
18	6.3	4.5	90.8
19	no data	no data	no data
20	no data	no data	no data

9/15/2008

Depth (m)	Temperature (°C)	Dissolved Oxygen (mg/l)	Conductivity (us/cm)
0	17	7	87.9
1	16.9	7.1	89.5
2	16.7	7.4	89.5
3	16.7	7.3	89.5
4	16.6	7.2	89.5
5	16.6	6.9	89.6
6	16.6	7.2	89.6
7	16.4	7.1	89.7
8	11.4	3.1	90.1
9	9.1	3.3	89.9
10	7.9	3.7	90
11	7.2	3.6	90.2
12	6.8	3.1	90.6
13	6.7	3.4	90.9
14	6.6	3.1	91.1
15	6.5	3.1	91.2
16	6.5	2.9	91.4
17	6.4	2.8	91.4
18	6.4	2.9	91.4
19	6.4	2.4	91.4
20	no data	no data	no data

10/7/2008

Depth (m)	Temperature (°C)	Dissolved Oxygen (mg/l)	Conductivity (us/cm)
0	13.3	7.7	89.9
1	13.3	8.1	90.3
2	13.3	8	90.4
3	13.3	7.8	90.5
4	13.3	8	90.5
5	13.3	8.1	90.5
6	13.2	8	90.7
7	13.2	7.9	90.7
8	12.9	7.3	90.6
9	10.4	3.2	90.7
10	8.7	2.9	90.4
11	7.6	2.7	90.8
12	7.2	2.7	90.9
13	6.9	2.4	91.2
14	6.7	2.4	91.5
15	6.6	2.3	91.5
16	6.6	2.1	92.1
17	6.5	2.1	92.3
18	6.5	2.06	92.2
19	6.5	2.02	92.8
20	6.4	1.9	93.3

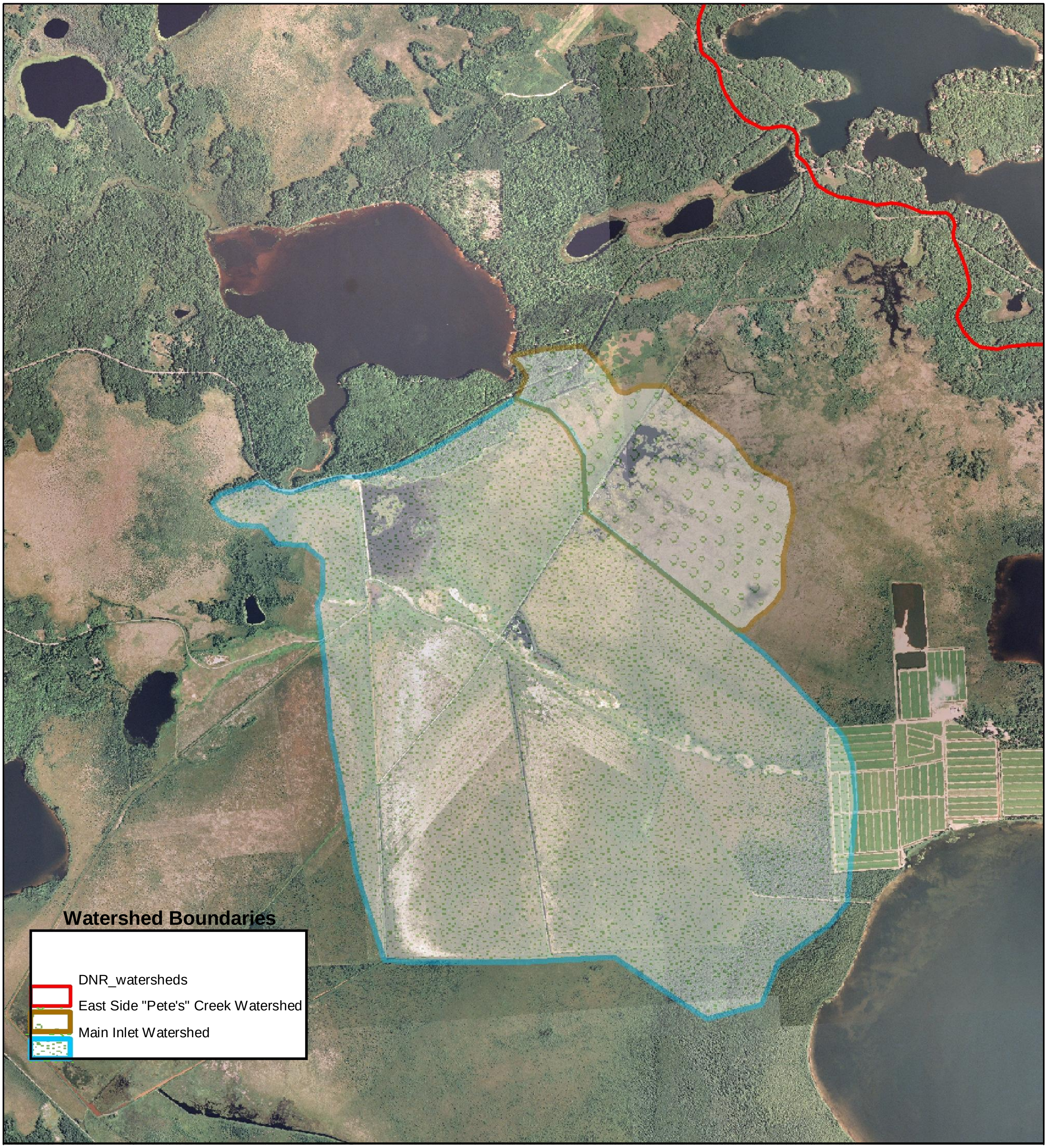
Figures

Figure 1-1
Aerial photograph of
Powell Marsh and Dead
Pike Lake from 2005

Figure 1-2. Iron stained water entering Dead Pike Lake from the Powell Marsh at the Main Inlet to Dead Pike Lake.

Figure 3-1
Aerial photograph of
Powell Marsh and Dead
Pike Lake from 1937

Figure 4-1. **Pictures taken at Dead Pike Lake on September 25, 2010 following elevated discharges of water from the Powell Marsh control structures.**



Imagery: NAIP, 2005

N
!

Feet
1,200 0 1,200 2,400 3,600

Figure 4-2
Estimated Powell Marsh Watershed Area Contributing to the Main Inlet and Creek

Near East Side of Dead Pike Lake

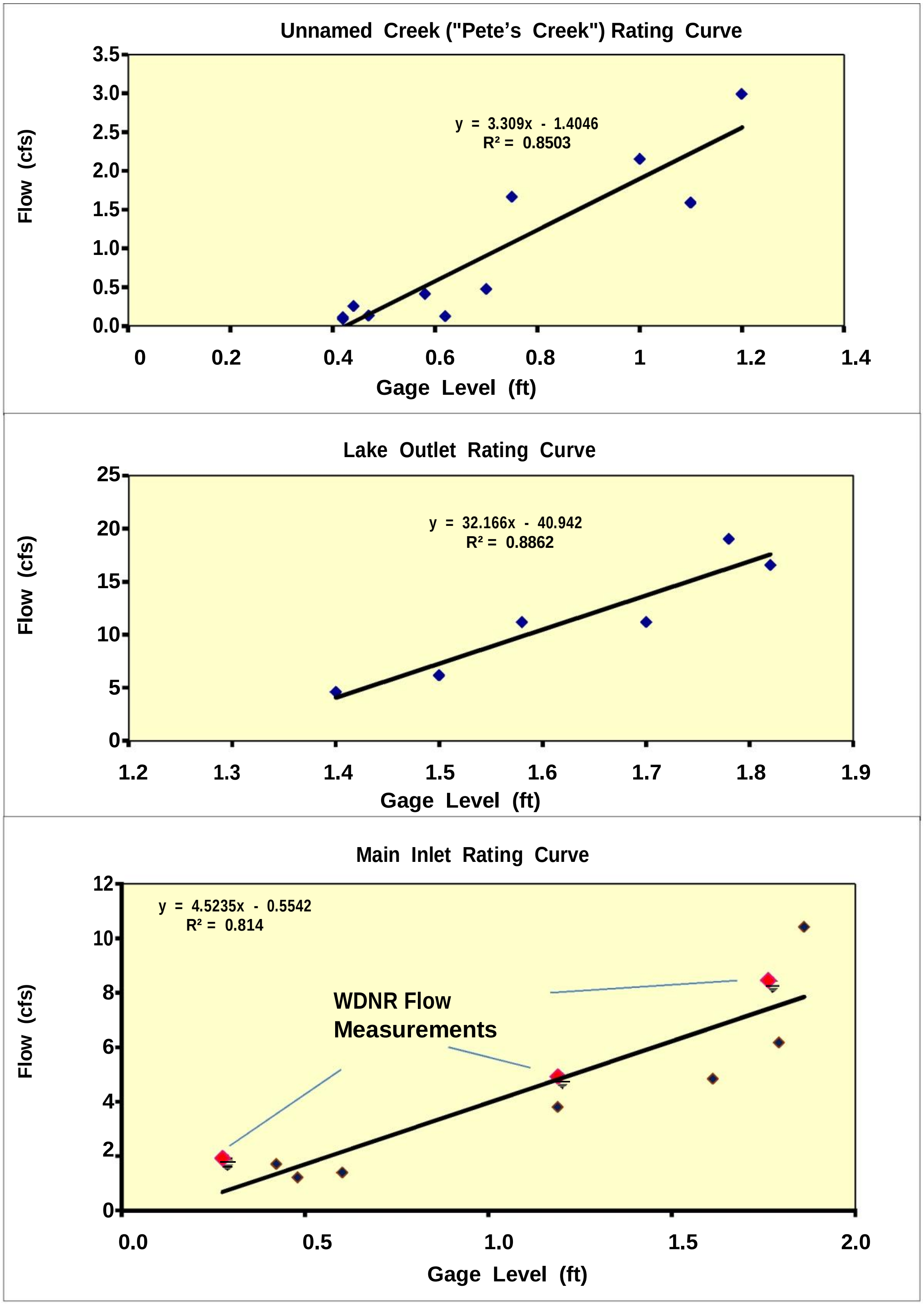


Figure 4-3. Rating curves for the main inlet, the unnamed creek inlet, and the outlet from Dead Pike Lake.

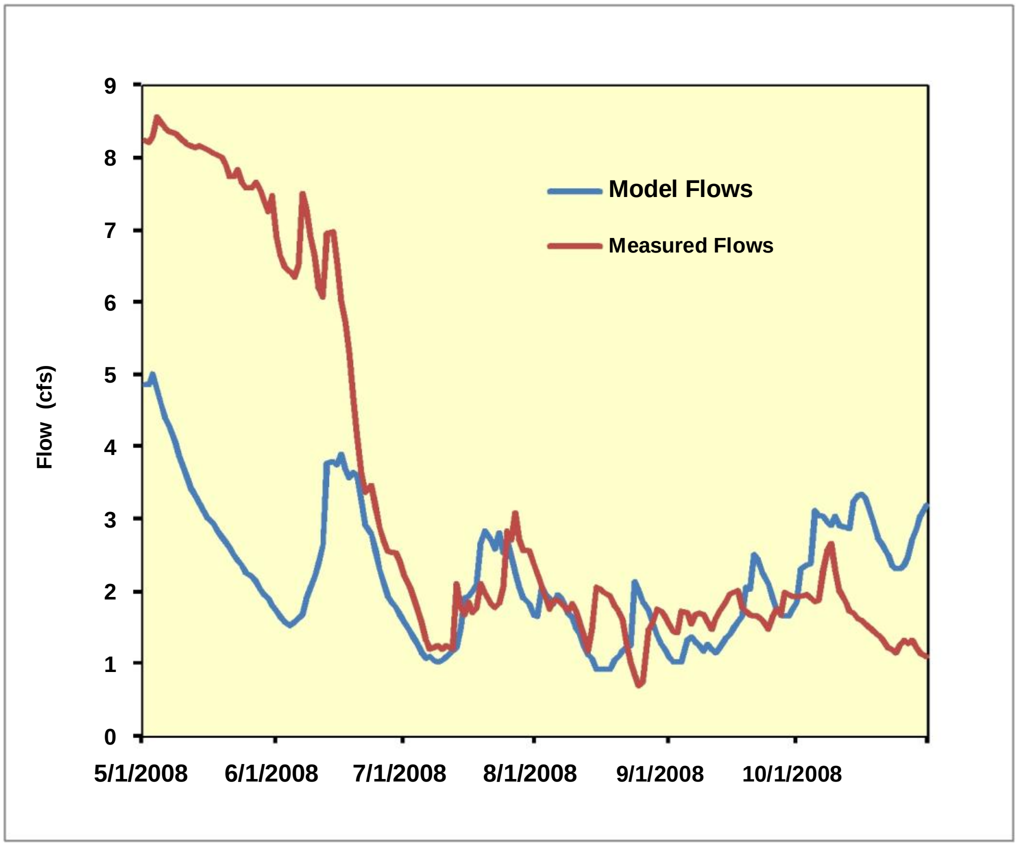


Figure 4-4. Comparison of measured and modeled flows at the main outlet of the Powell Marsh at Powell Road.

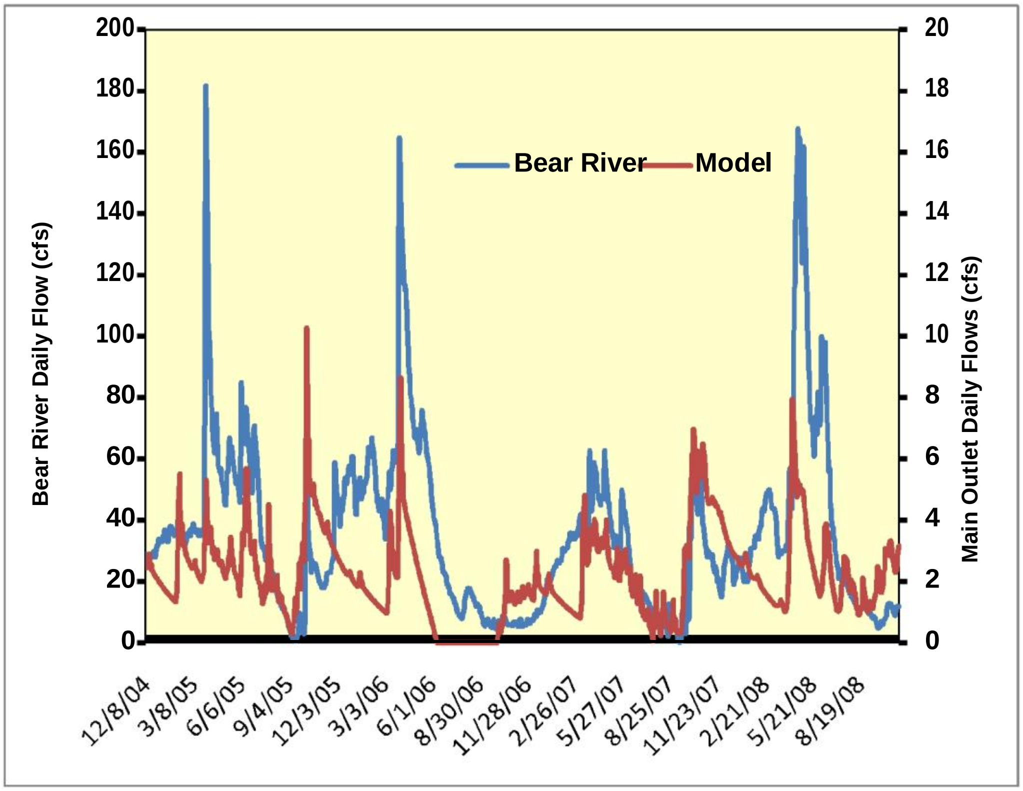


Figure 4-5. Comparison of modeled flows at the main outlet of the Powell Marsh at Powell Road with flow in the Bear River at USGS gauge 05357335.

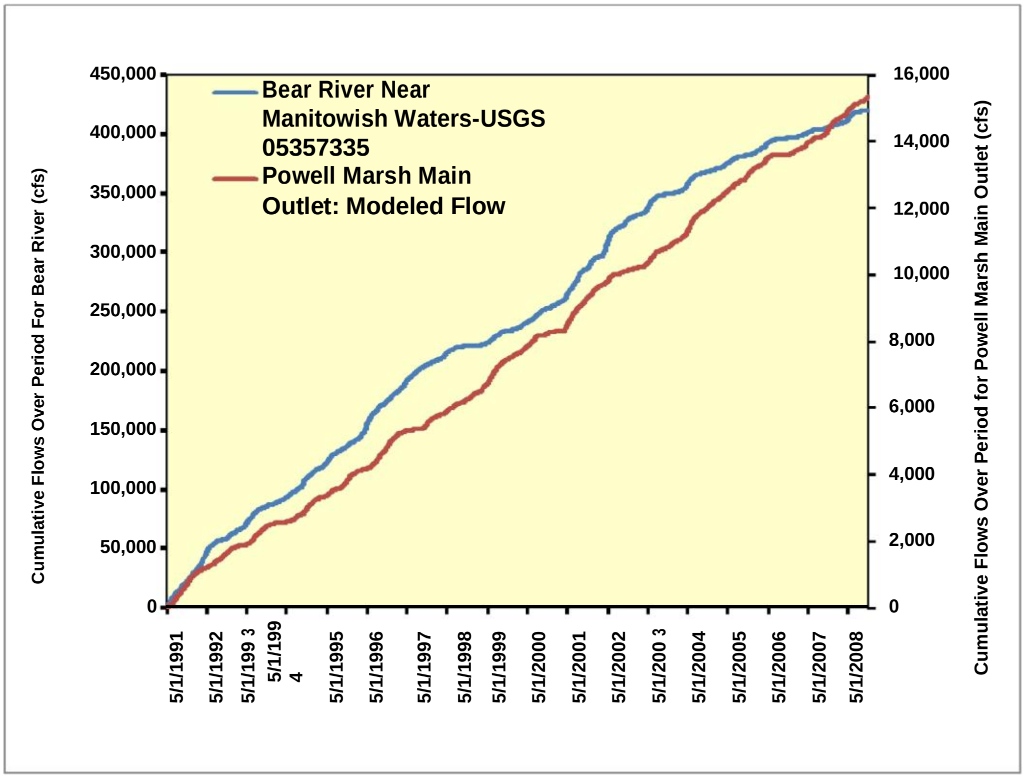


Figure 4-6. Comparison of cumulative modeled flows at the main outlet of the Powell Marsh at Powell Road with flow in the Bear River at USGS gauge 05357335.

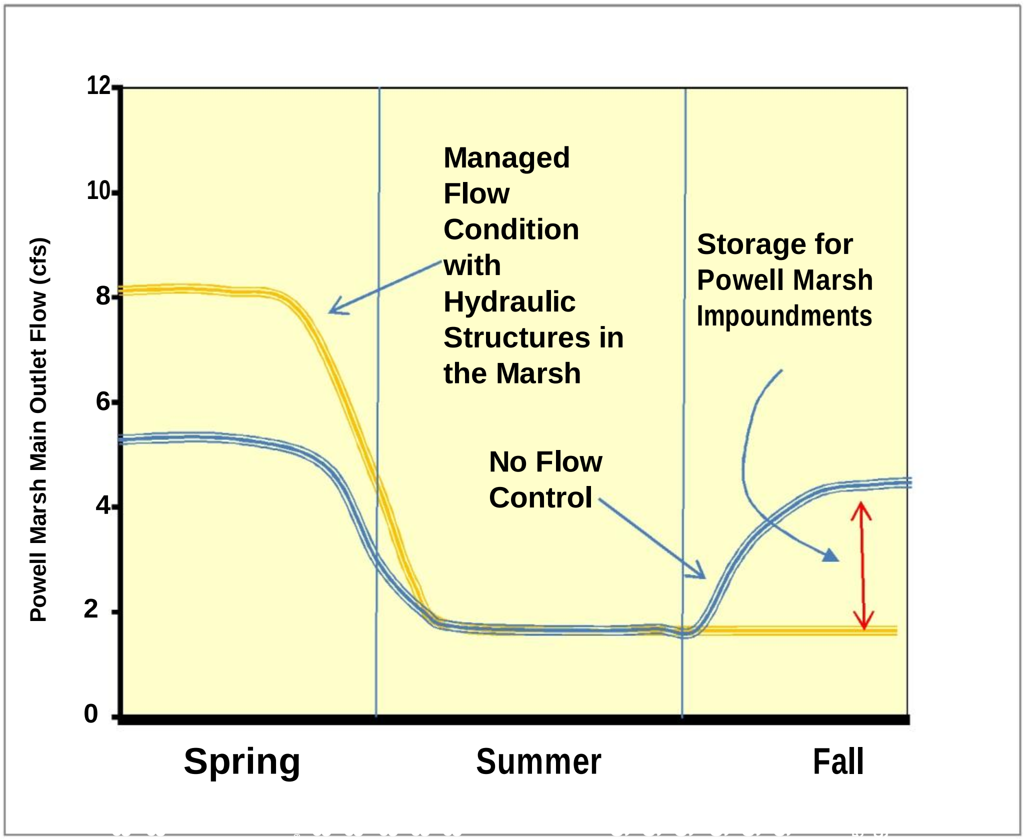


Figure 4-7. Conceptual working model of water control and release from the Powell Marsh.

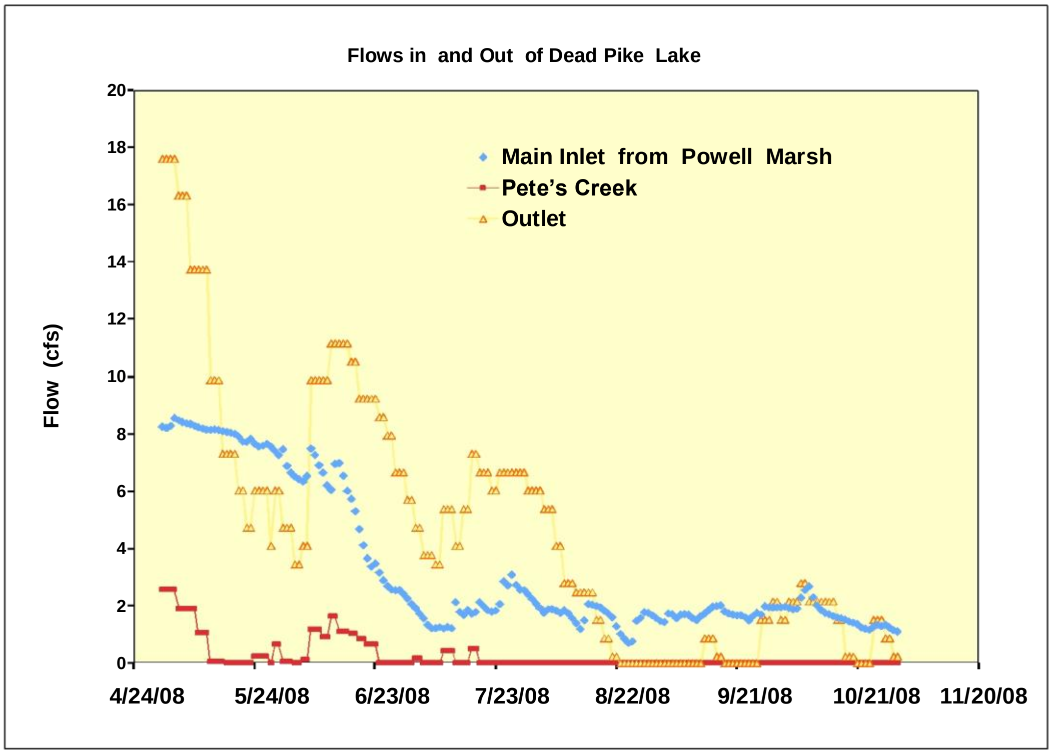


Figure 4-8**. Rating curves for the main inlet, the unnamed creek inlet, and the outlet from Dead Pike Lake.**

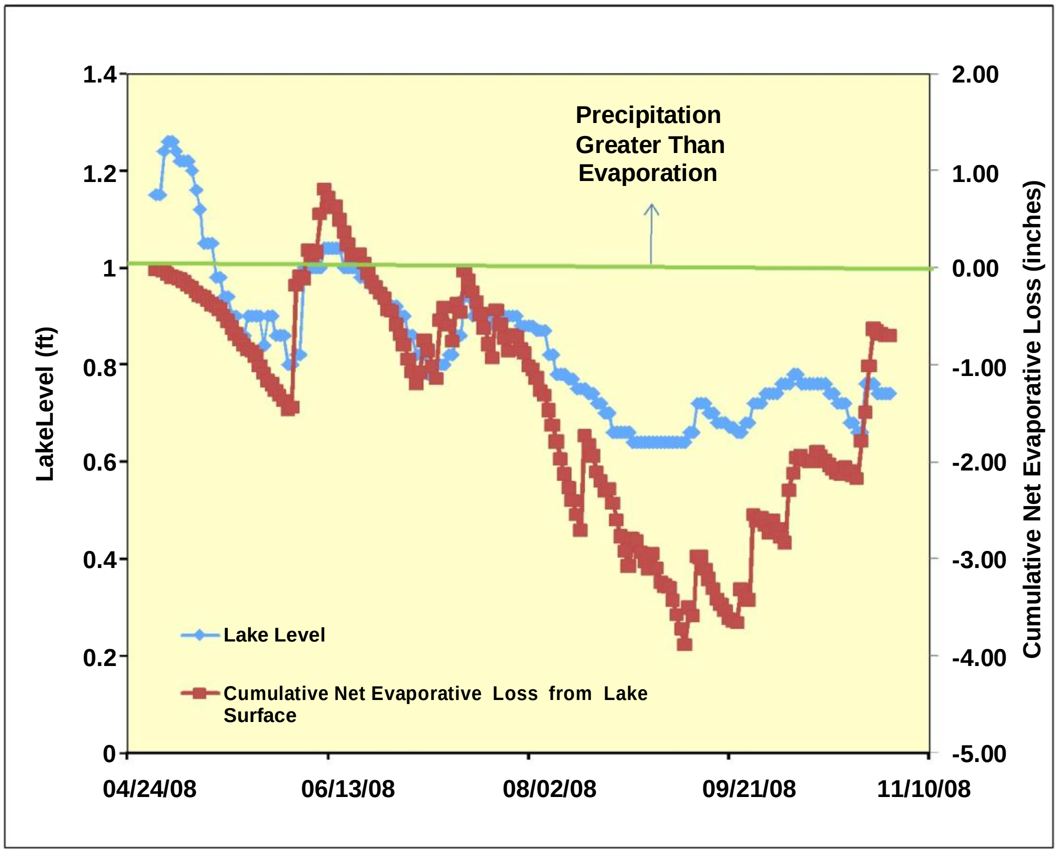


Figure 4-9**. Estimated net evaporative loss (precipitation minus evaporation) and measured lake levels for Dead Pike Lake.**

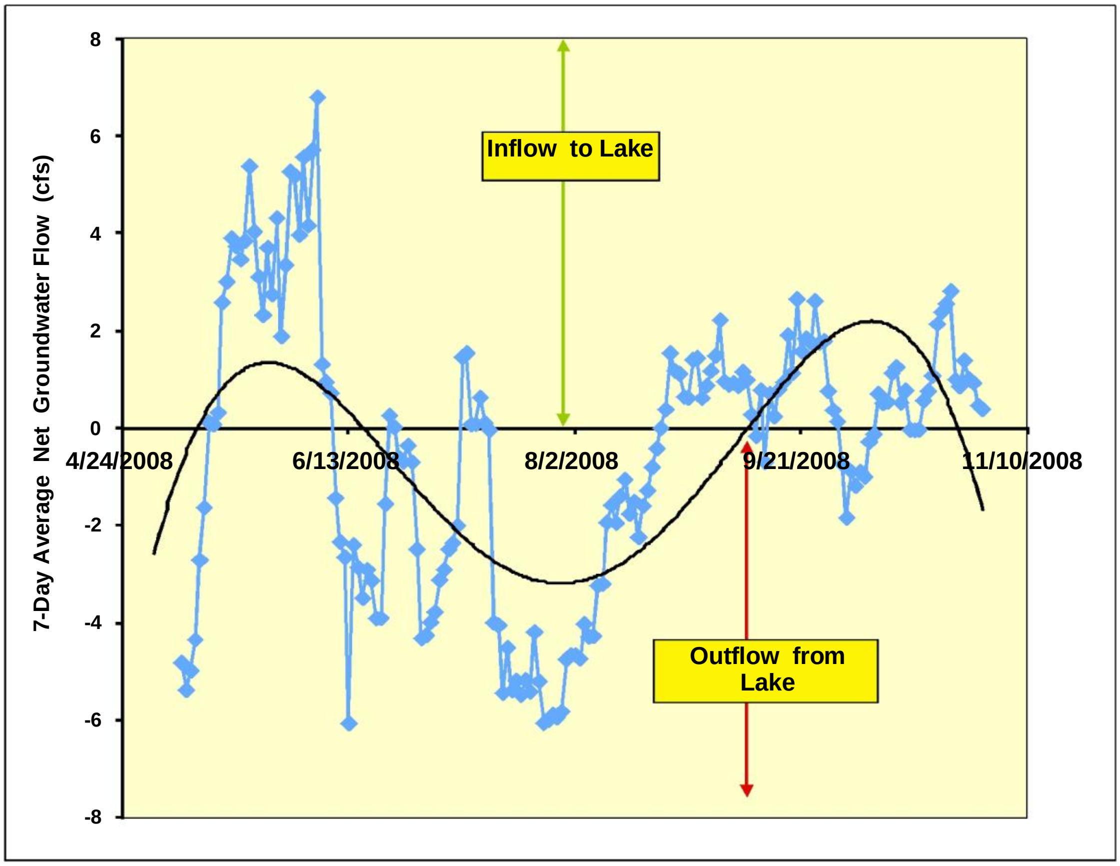


Figure 4-10**. Calculated net groundwater inflows and outflows from Dead Pike Lake. Net groundwater inflow is equal to the difference between groundwater inflows minus outflows from the lake. Net groundwater inflow calculated as the difference of all water balance components that were measured for the Dead Pike Lake.**

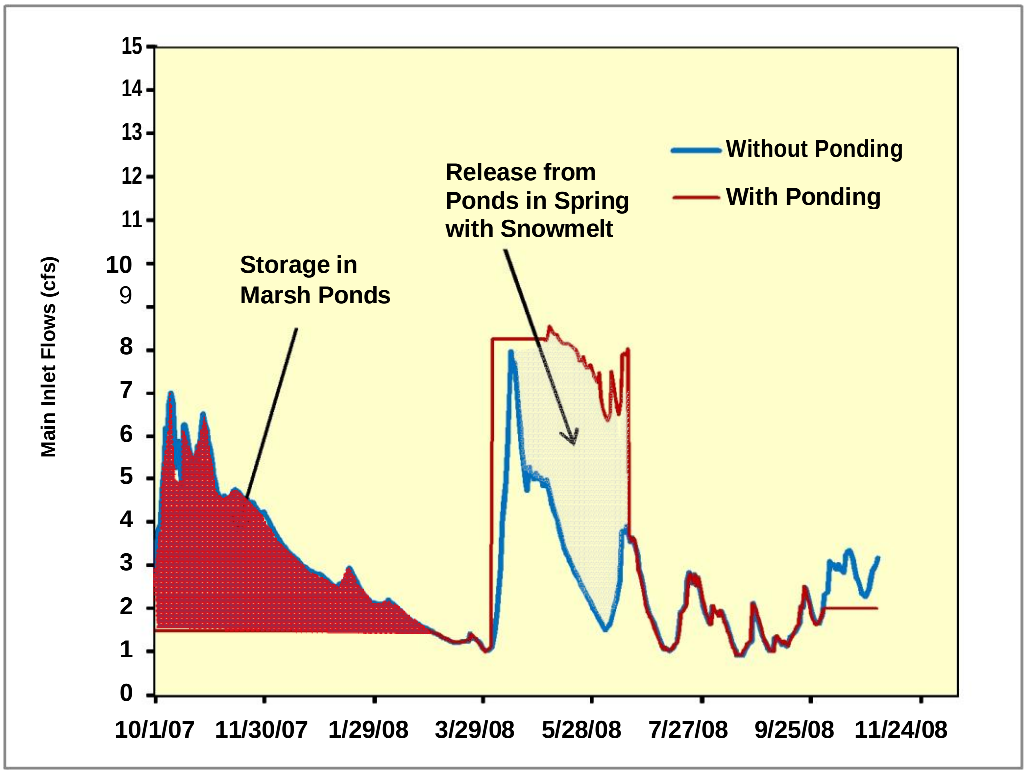


Figure 4-11. Modeled flows at the Main Inlet to Dead Pike Lake with and without the application of controls in the Powell Marsh to manage water levels in the Marsh ponds.

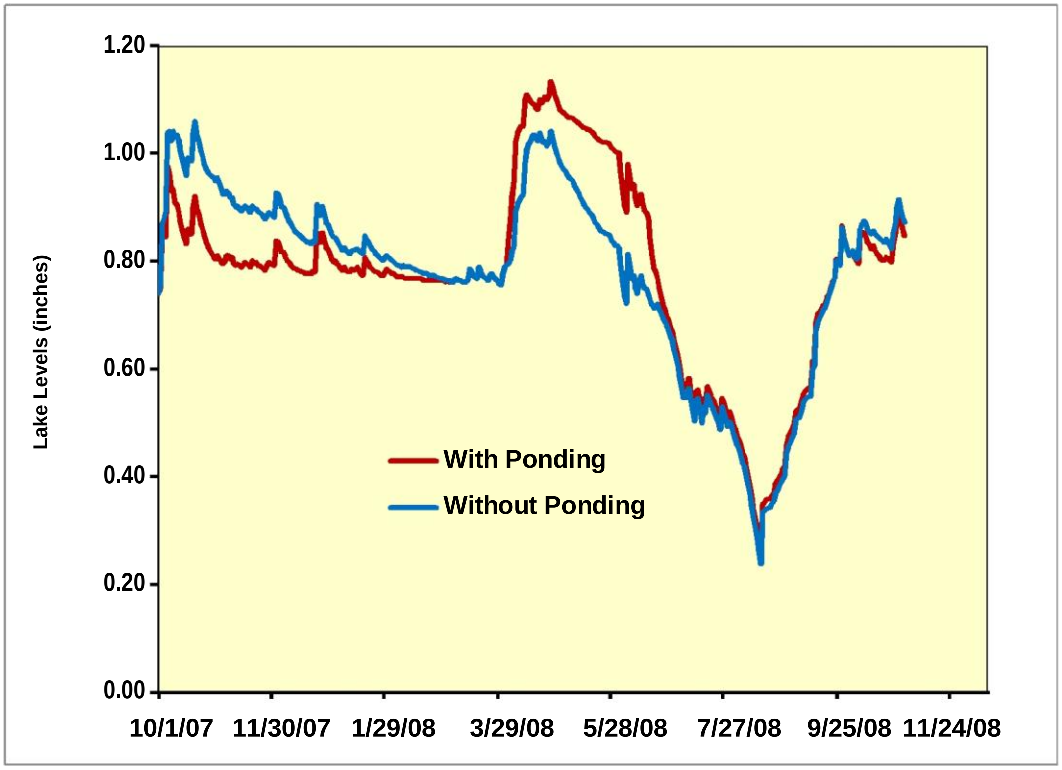


Figure 4-12. Estimated effect of controlled water releases from the Powell Marsh to Dead Pike Lake on water levels in Dead Pike Lake for the 2008 water year.

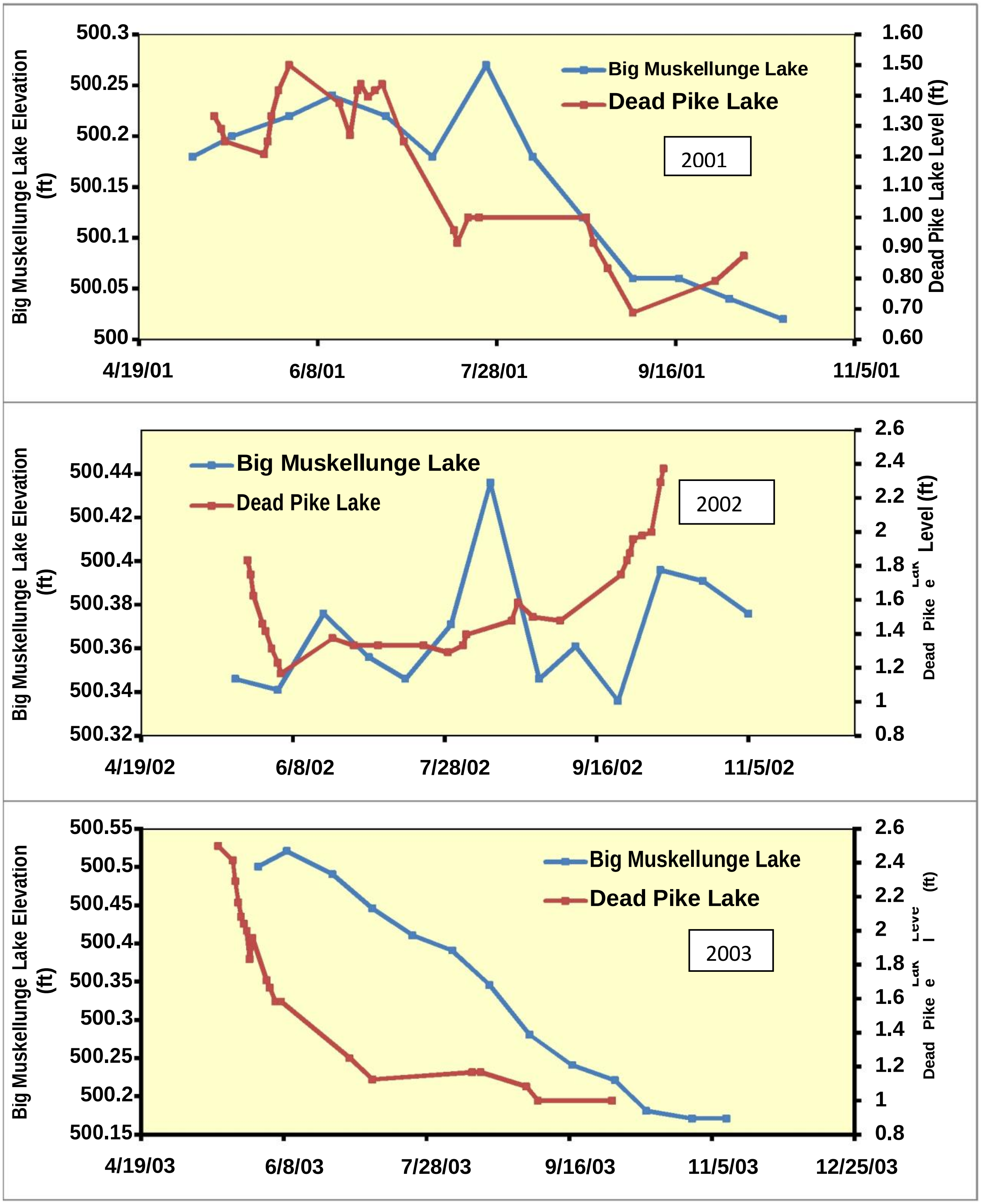


Figure 4-13. Comparison of lake levels changes for Big Muskellunge Lake near Sayner, Wisconsin and Dead Pike Lake.

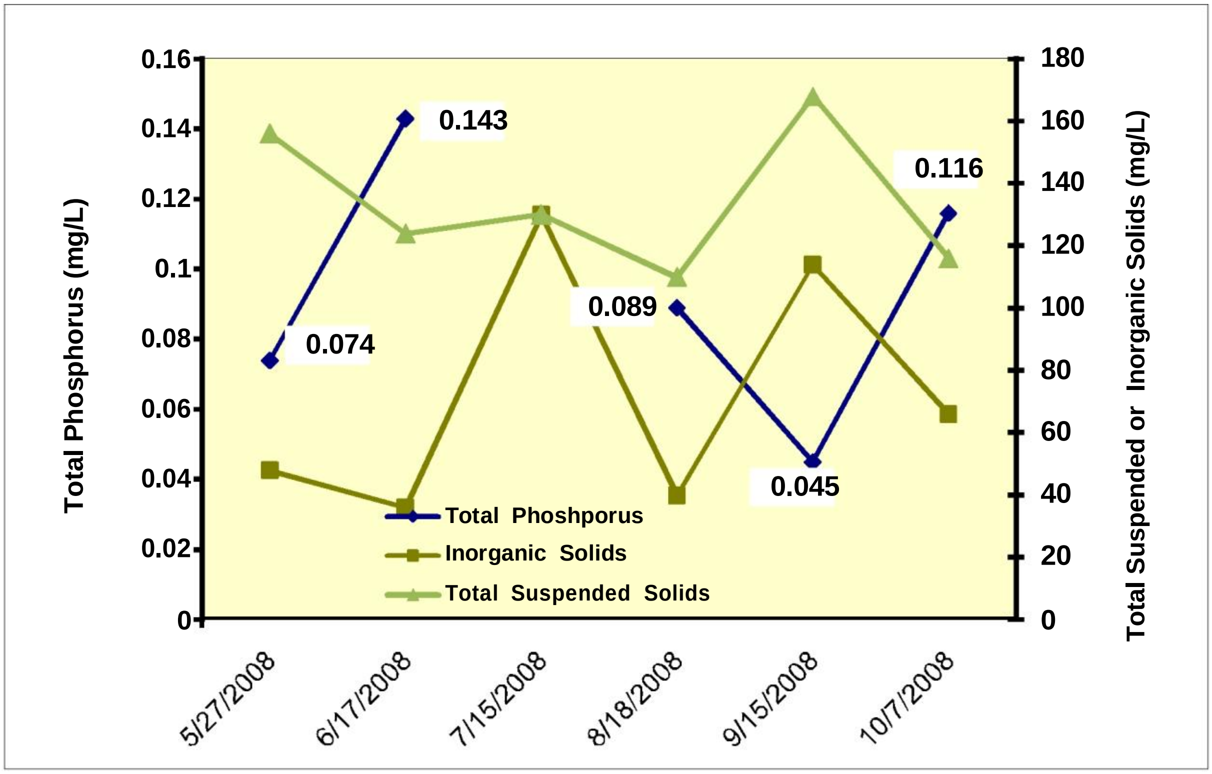


Figure 5-1**. Total phoshporous, total suspended solids, and inorganic solids (estimated) monitored in 2008 at the Main Inlet to Dead Pike Lake.**

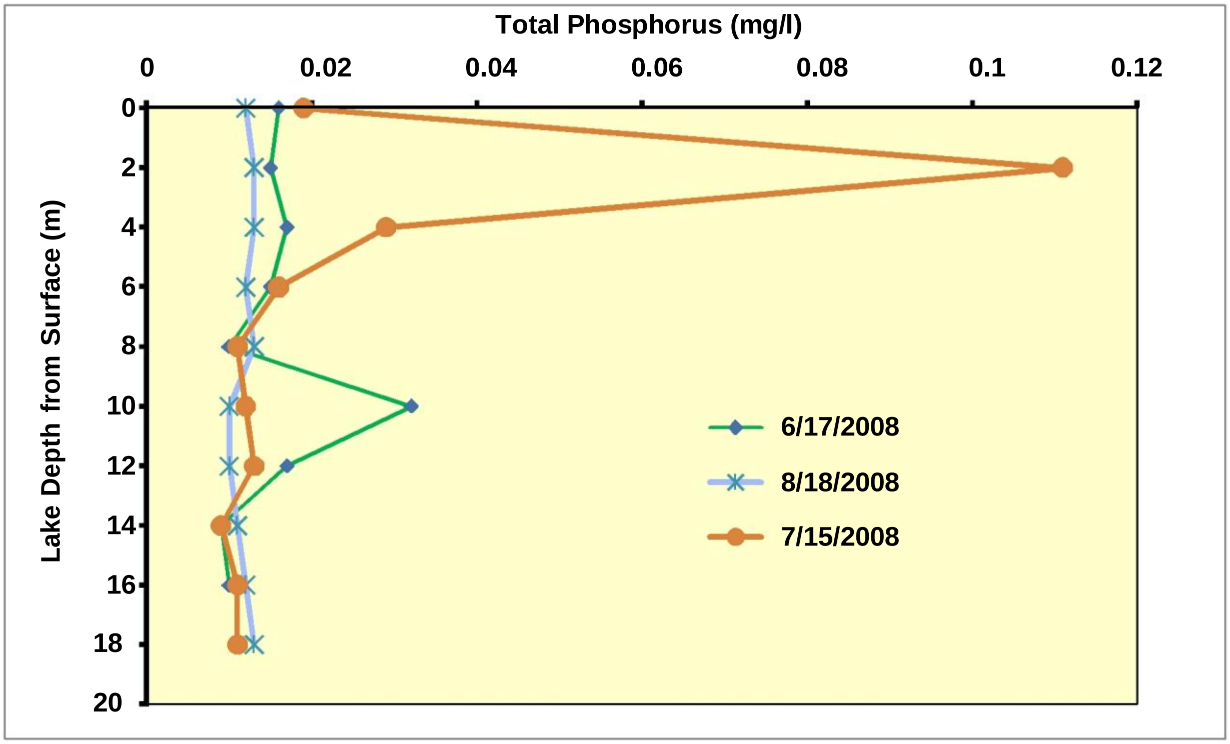


Figure 5-2**. Total phosphporus at two meter intervals from the surface to the bottom of Dead Pike Lake at the deep hole.**

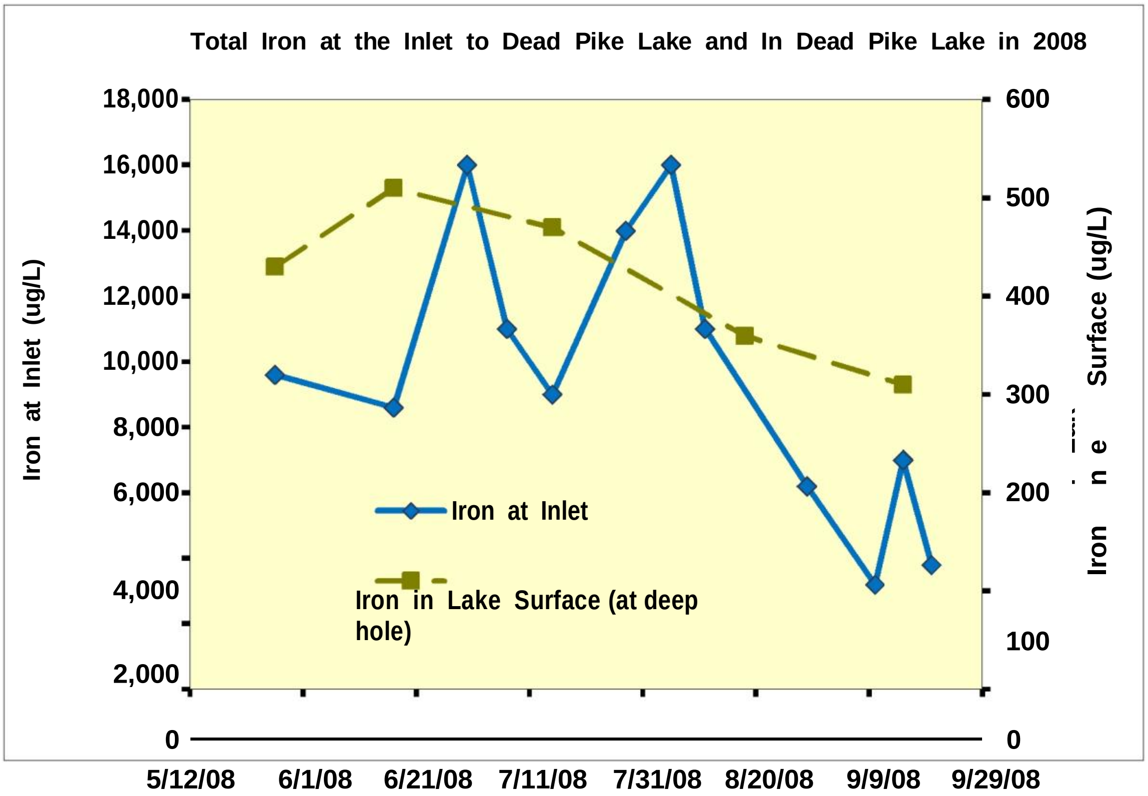


Figure 5-3. **Total iron monitored in 2008 at the Main Inlet and in the surface of Dead Pike Lake.**

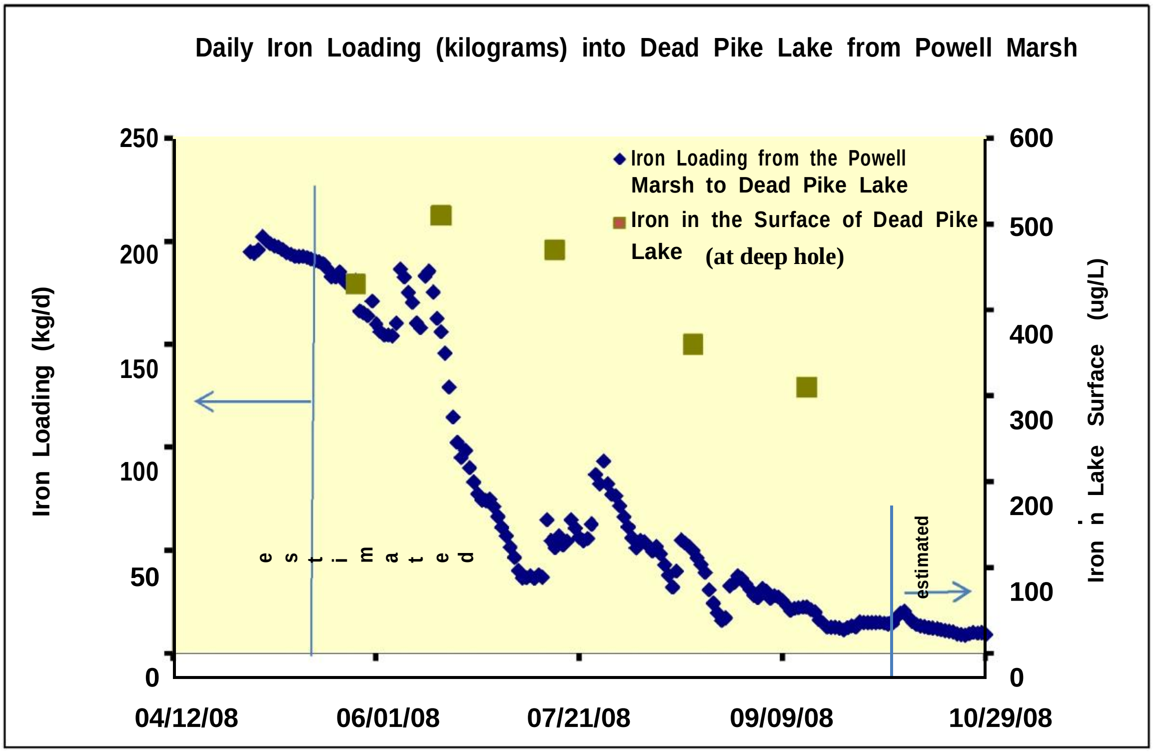


Figure 5-4. **Total iron loading at the Main Inlet to Dead Pike Lake (calculated from flow and iron concentrations) compared to iron at the surface of Dead Pike Lake.**

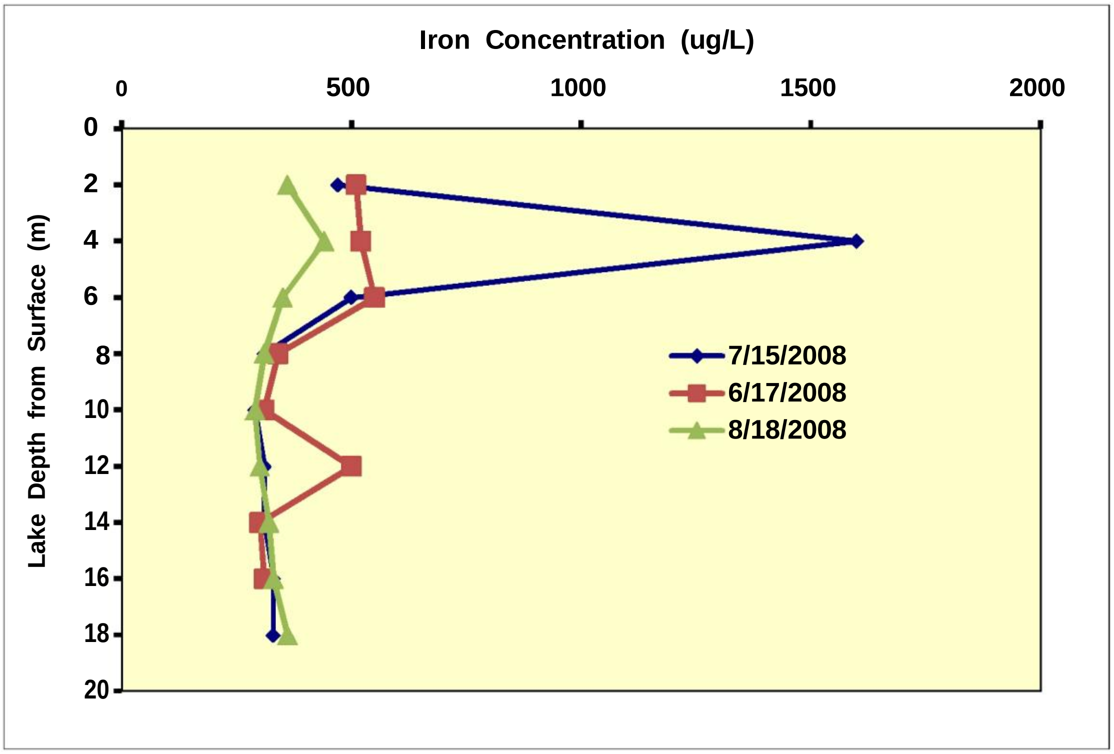


Figure 5-5. **Iron concentration at the deep hole of Dead Pike Lake.**

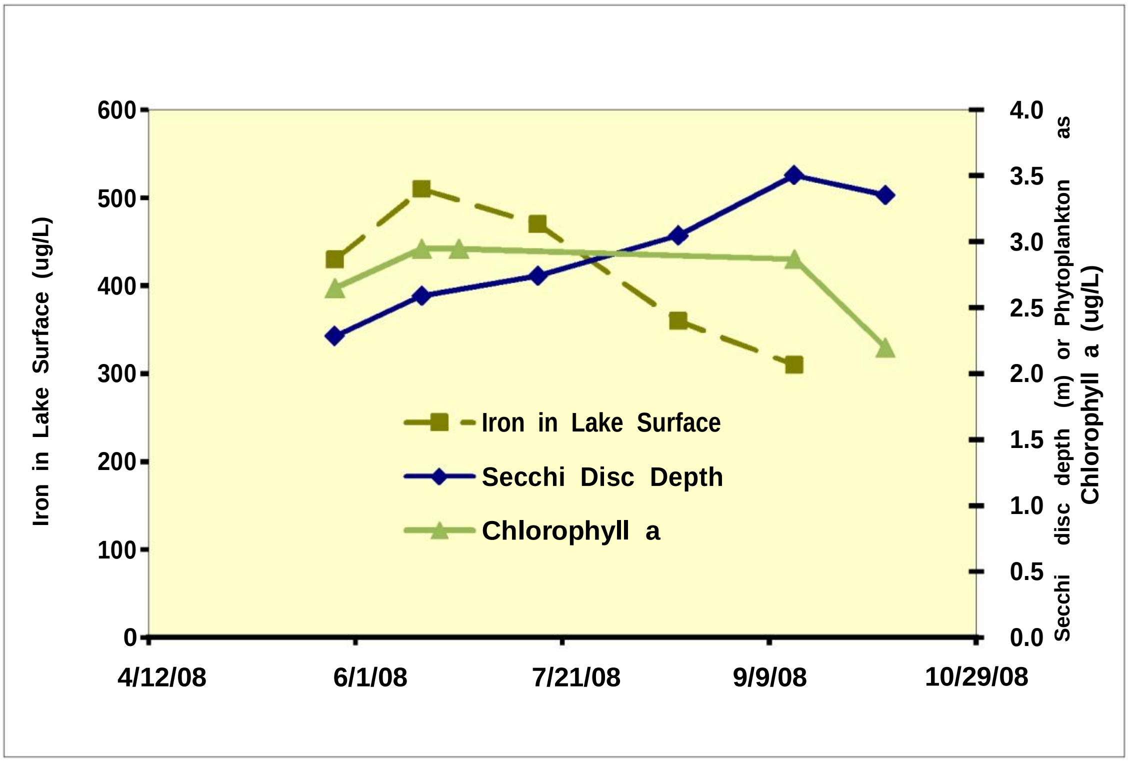


Figure 5-6. **Comparison of iron concentration, lake clarity, and chlorophyll a concentrations in the surface of Dead Pike Lake. Sampling conducted at the deep hole of the lake.**

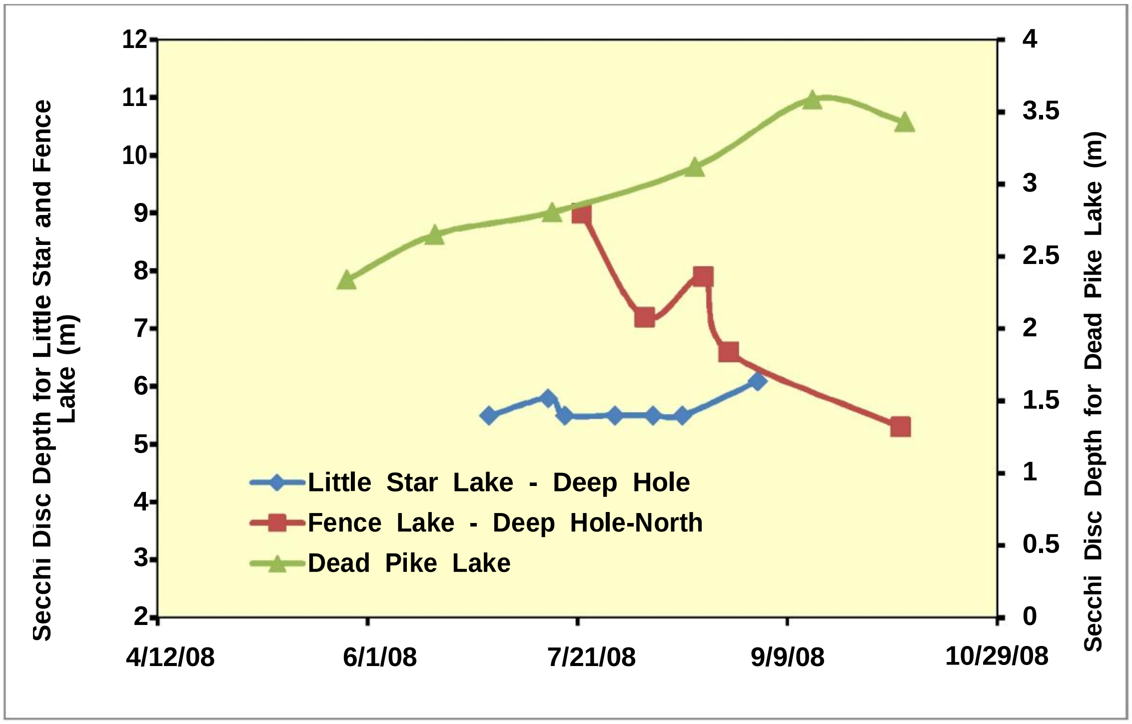


Figure 5-7. **Comparison of Secchi disc depth in Dead Pike Lake with two lakes near Dead Pike Lake.**

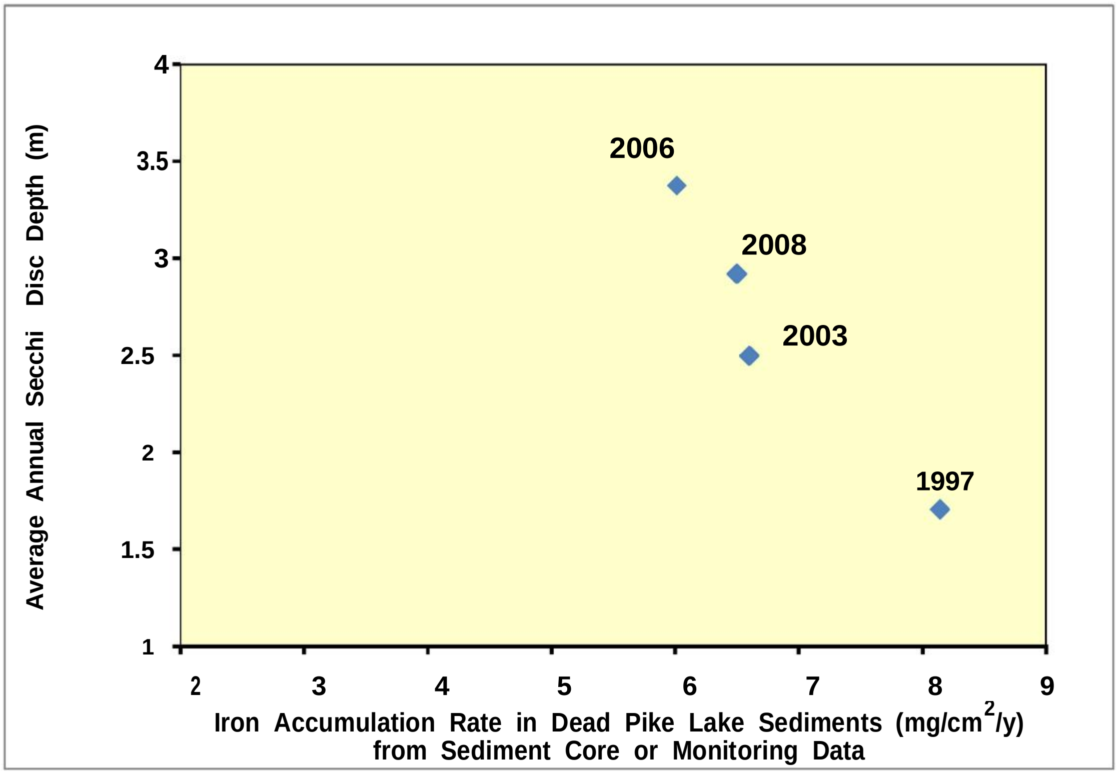


Figure 5-8. **Comparison of Secchi disc depth in Dead Pike Lake and the rate of iron accumulation in lake sediments. Note that the data point for 2006 is an estimate from average iron concentration measured by the WDNR at the Main Outlet of the Powell Marsh and estimated flow from the Powell Marsh hydrologic model (Main Outlet plus Pete's Creek).**

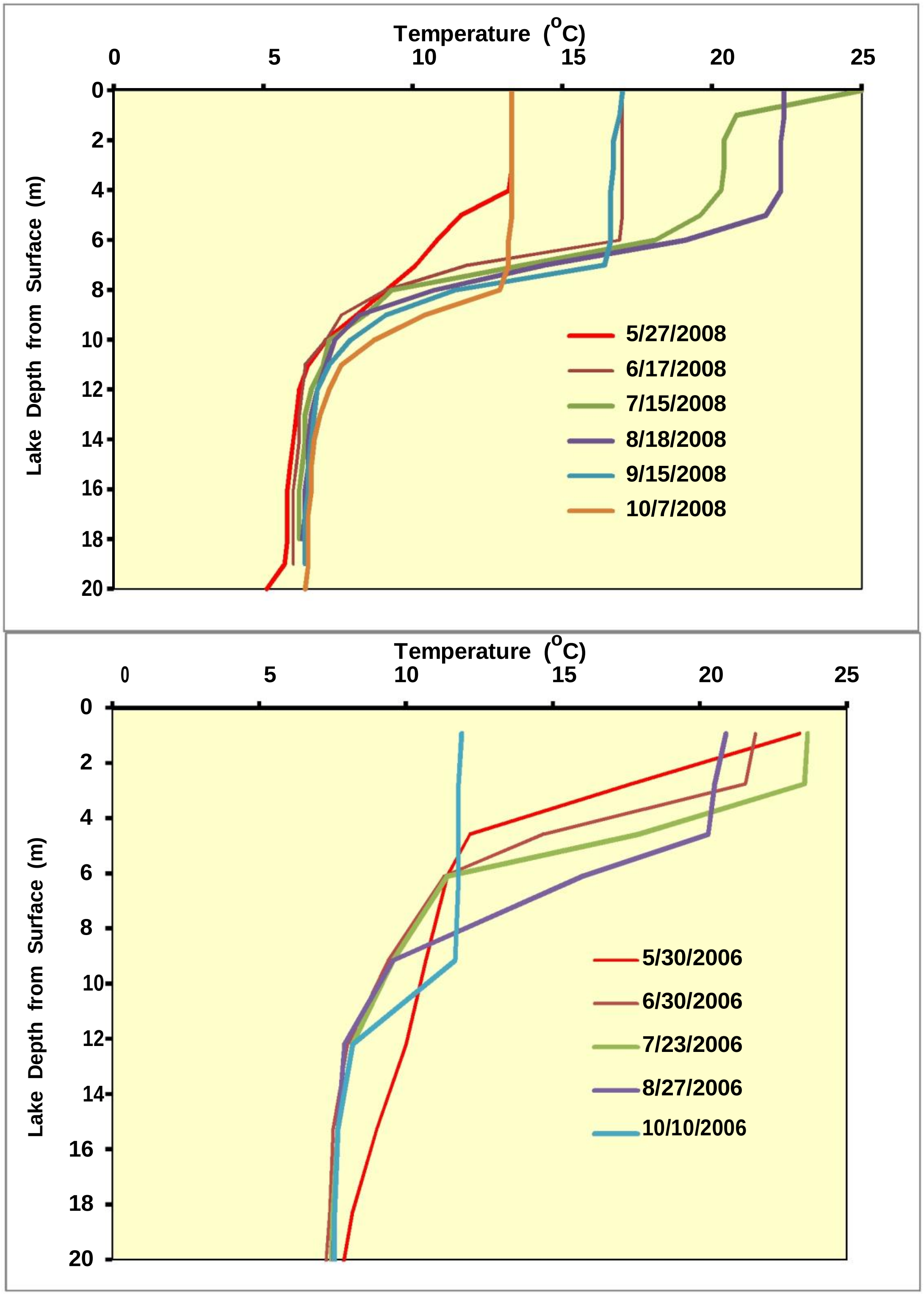
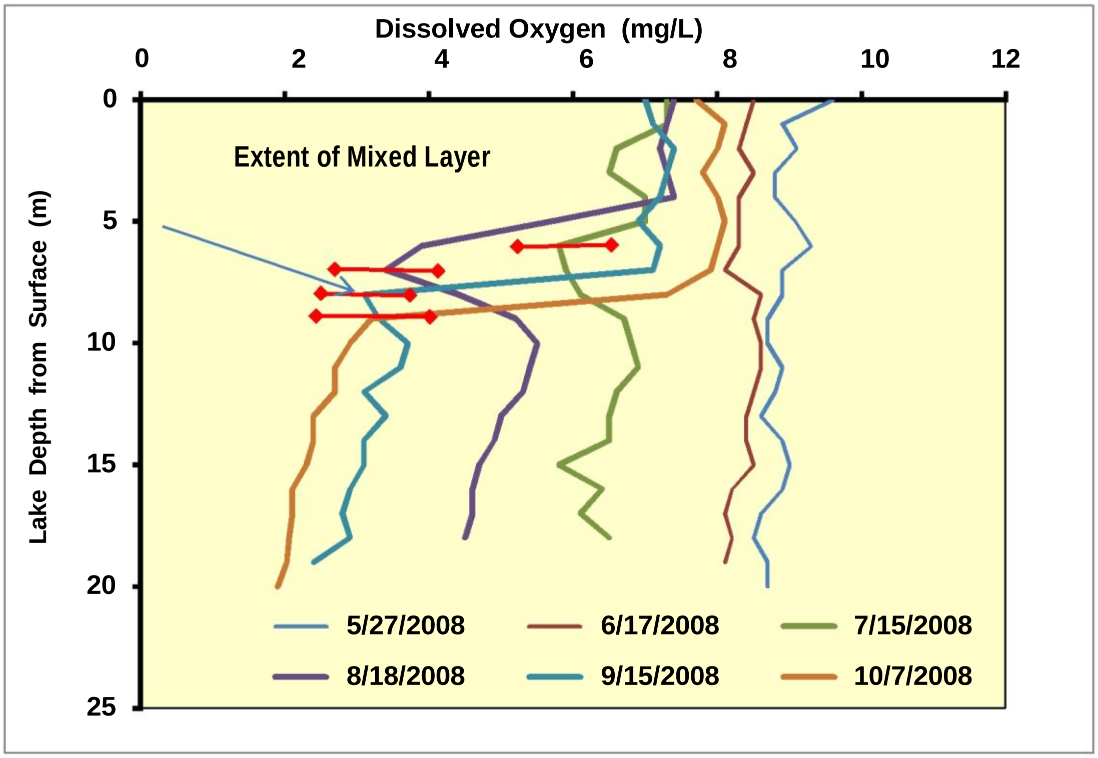


Figure 5-9. **Lake temperature profiles in Dead Pike Lake in 2008 and 2006.**



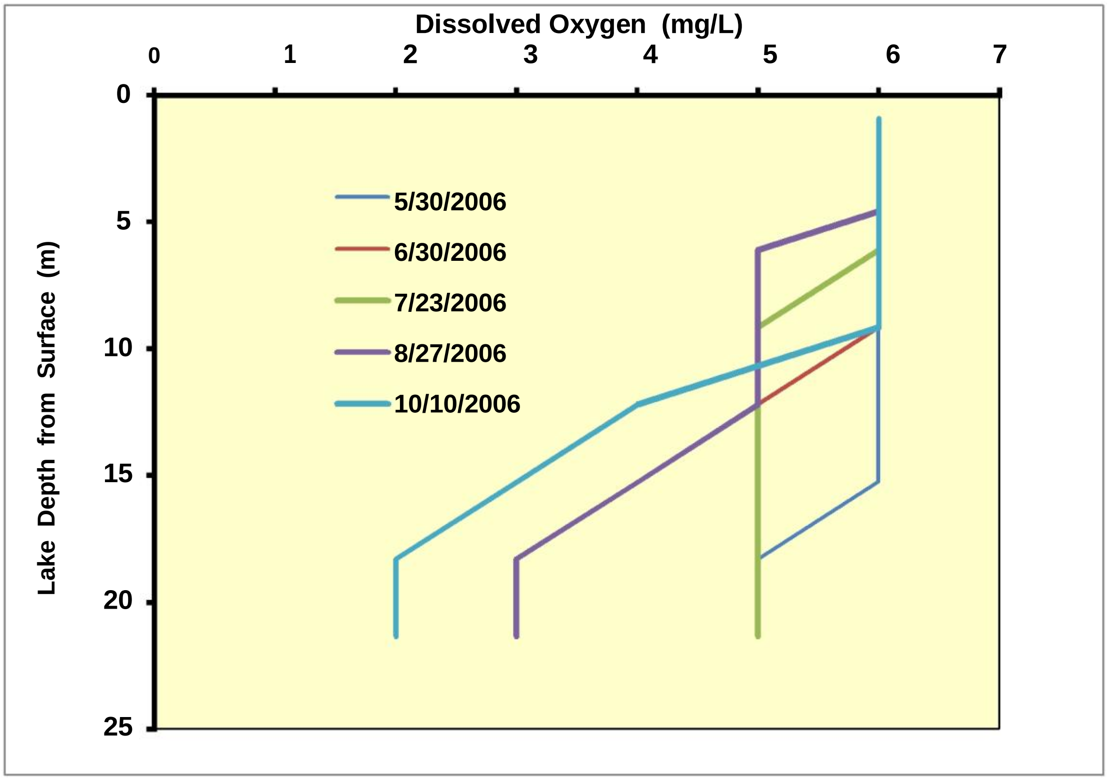


Figure 5-10. **Lake dissolved oxygen profiles in Dead Pike Lake in 2008 and 2006.**

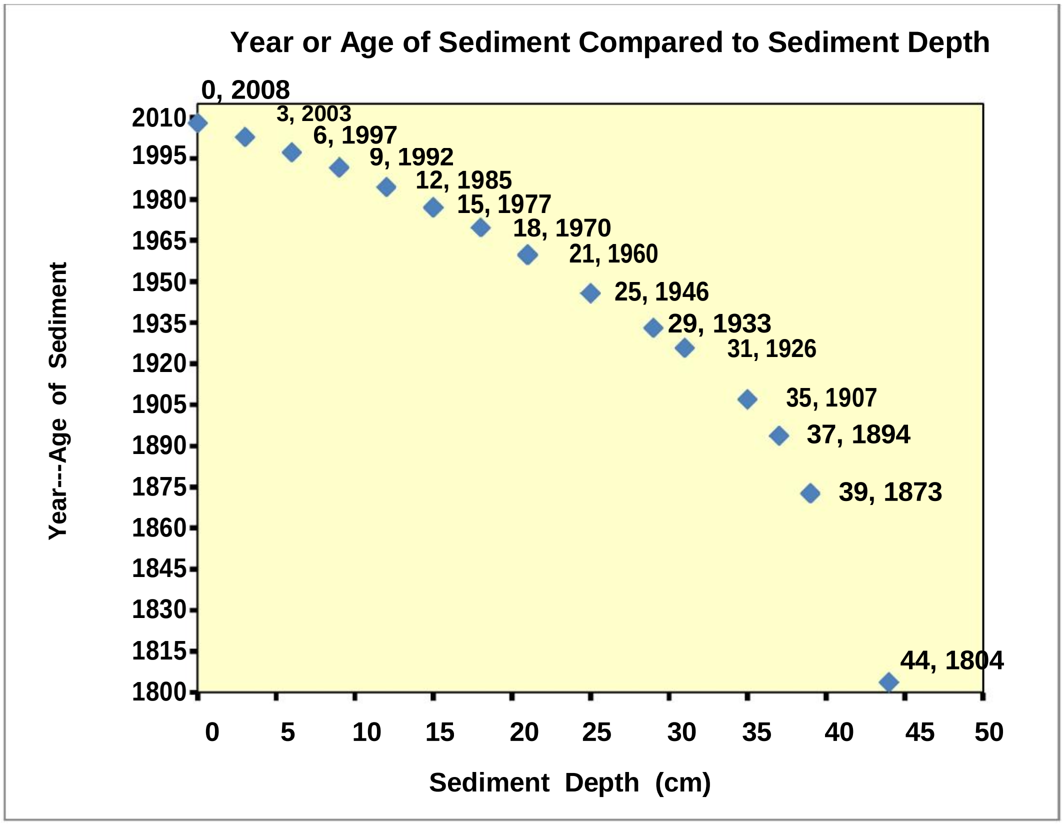


Figure 6-1. Age of sediment by date versus sediment depth.

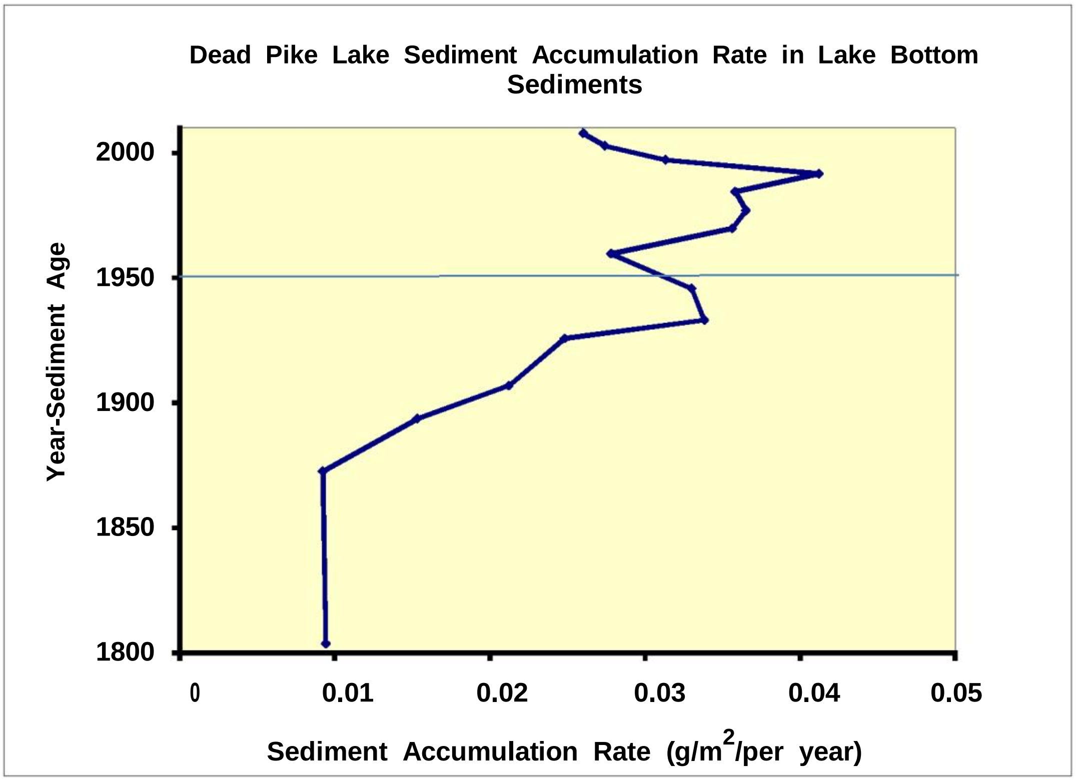


Figure 6-2. Rate of sediment accumulation for depositional zones in Dead Pike Lake.

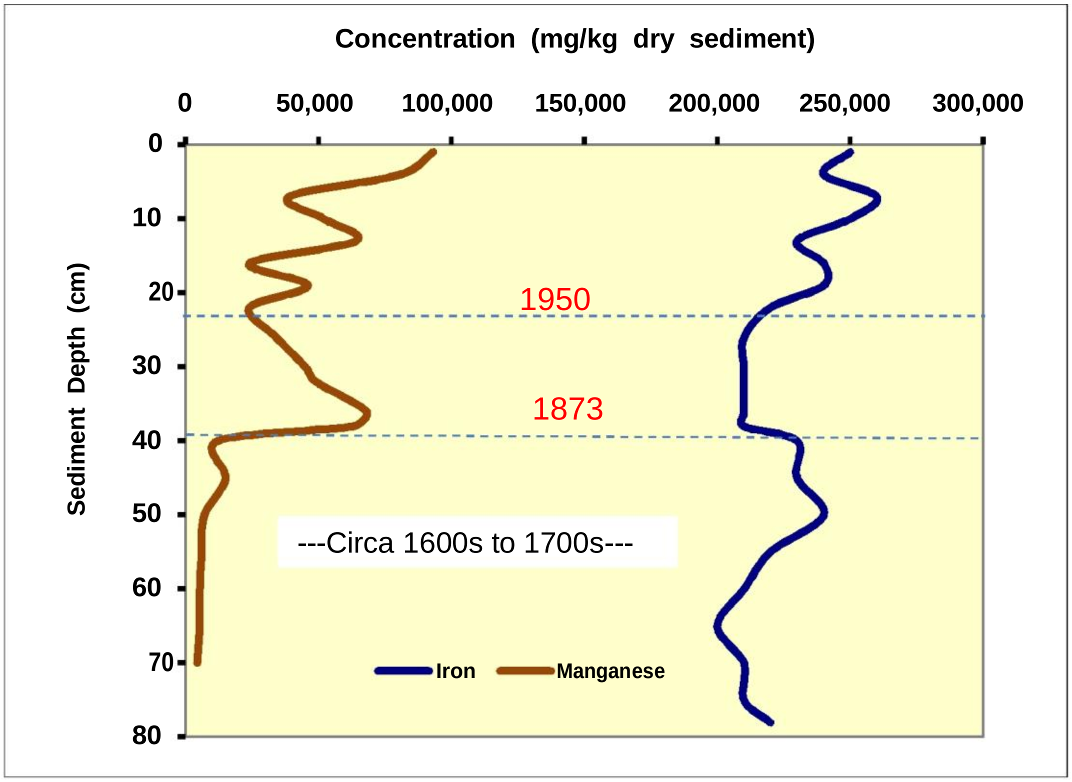


Figure 6-3. **Concentration of iron and manganese in Dead Pike sediment taken with a piston correr at 66 feet depth.**

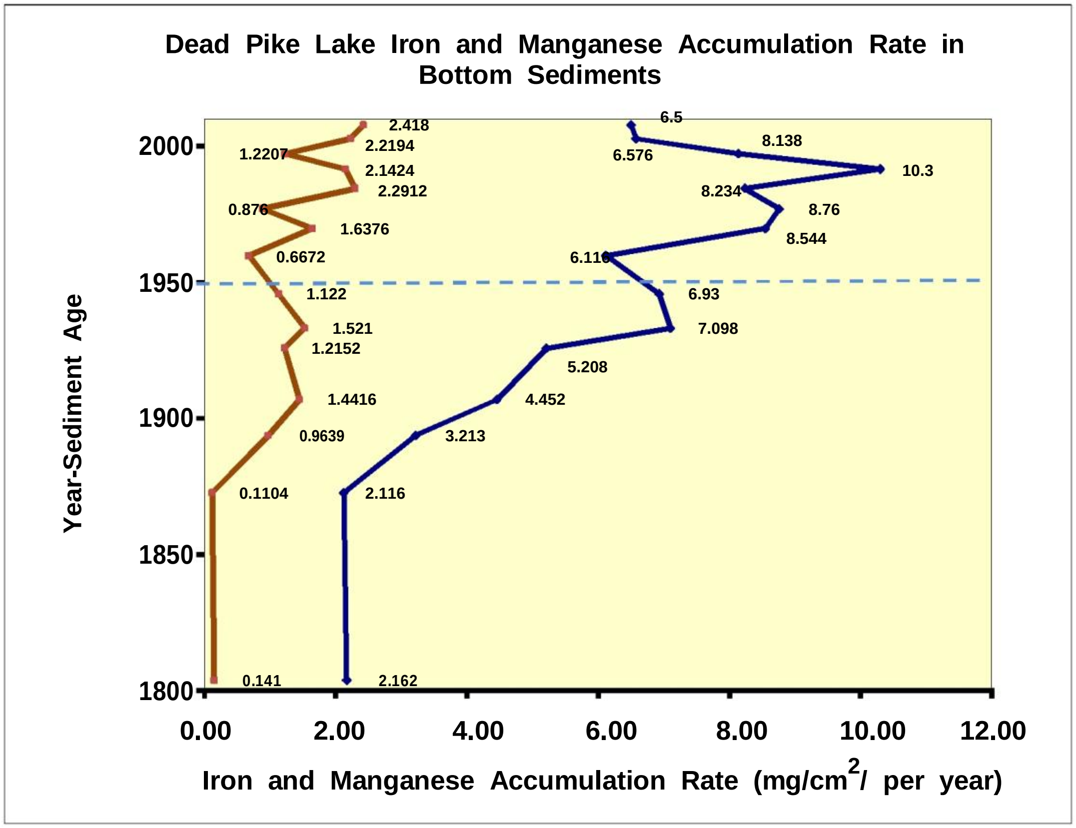


Figure 6-4. **Rate of of iron and manganese accumulation in Dead Pike sediment depositional zones. Core was taken with a piston correr at 66 feet depth.**

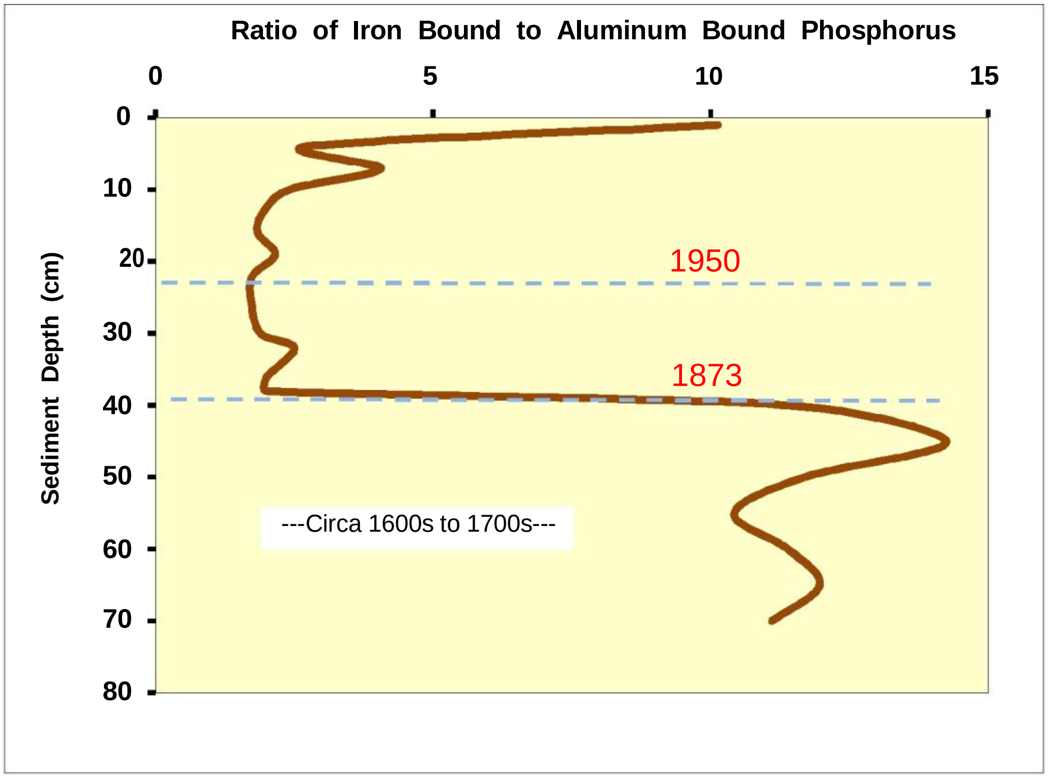


Figure 6-5. **Ratio of iron bound phosphorus to aluminum bound phosphorus in the dated sediment core.**

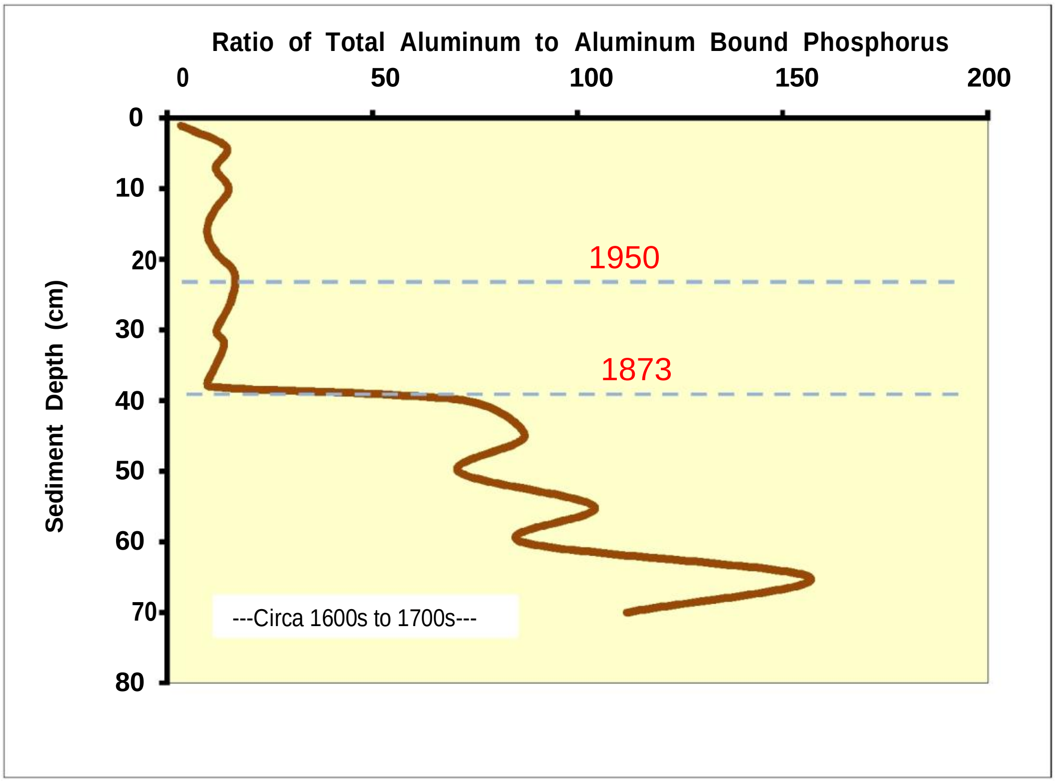


Figure 6-6**. Ratio of total aluminum to aluminum bound phosphorus in the dated sediment core.**

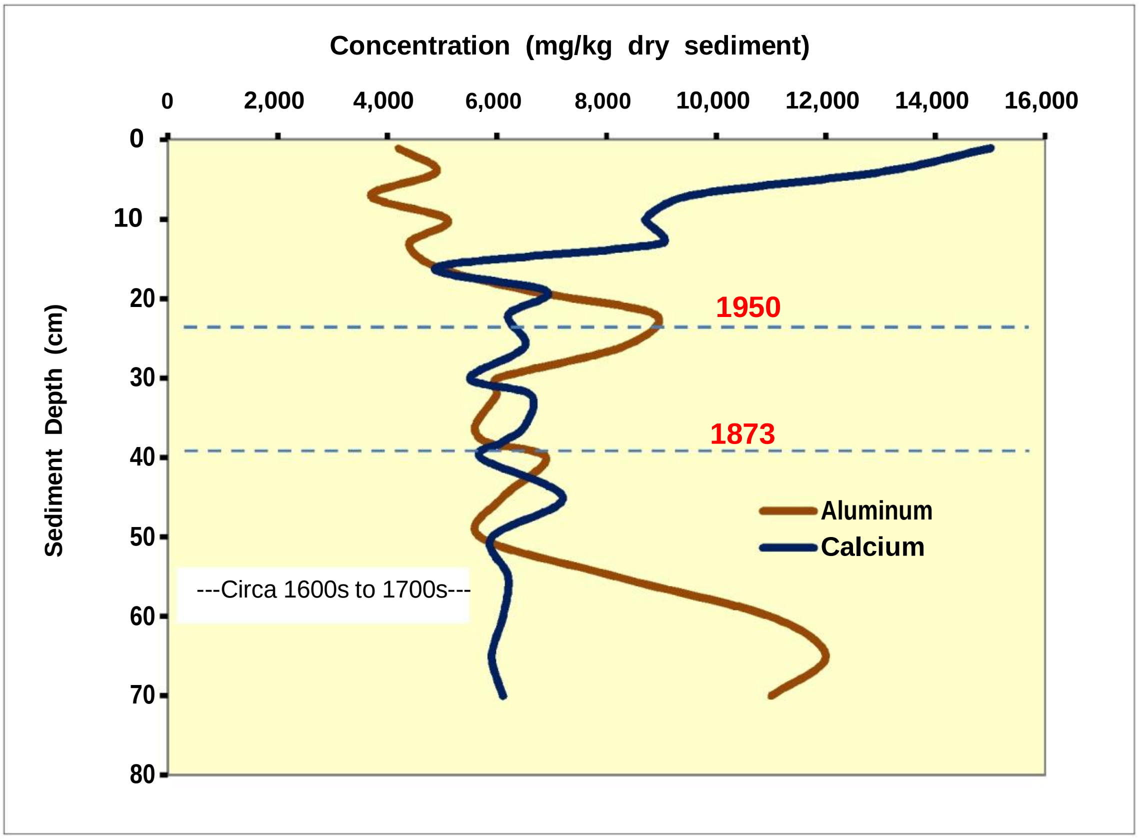


Figure 6-7**. Concentration of calcium and aluminum in the dated sediment core.**

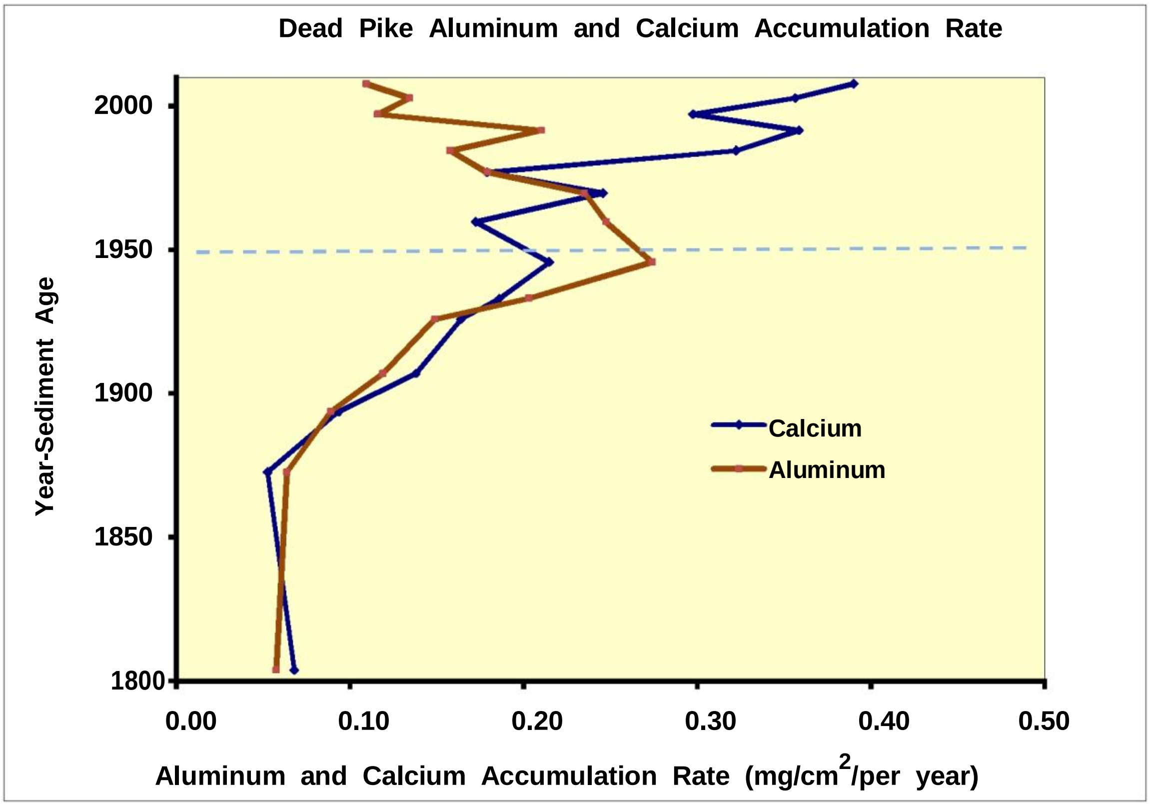


Figure 6-8**. Rate of calcium and aluminum accumulation in the dated sediment core.**

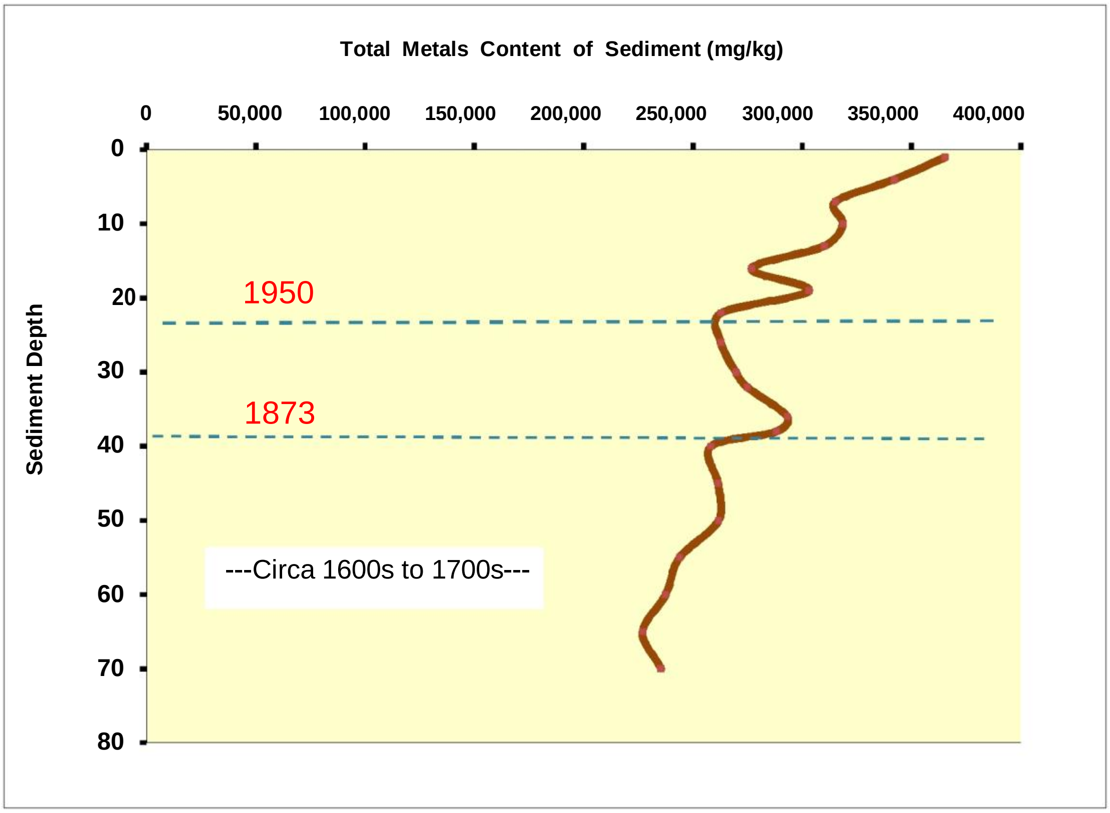


Figure 6-9**. Concentration of all metals anlyzed in the dated core.**

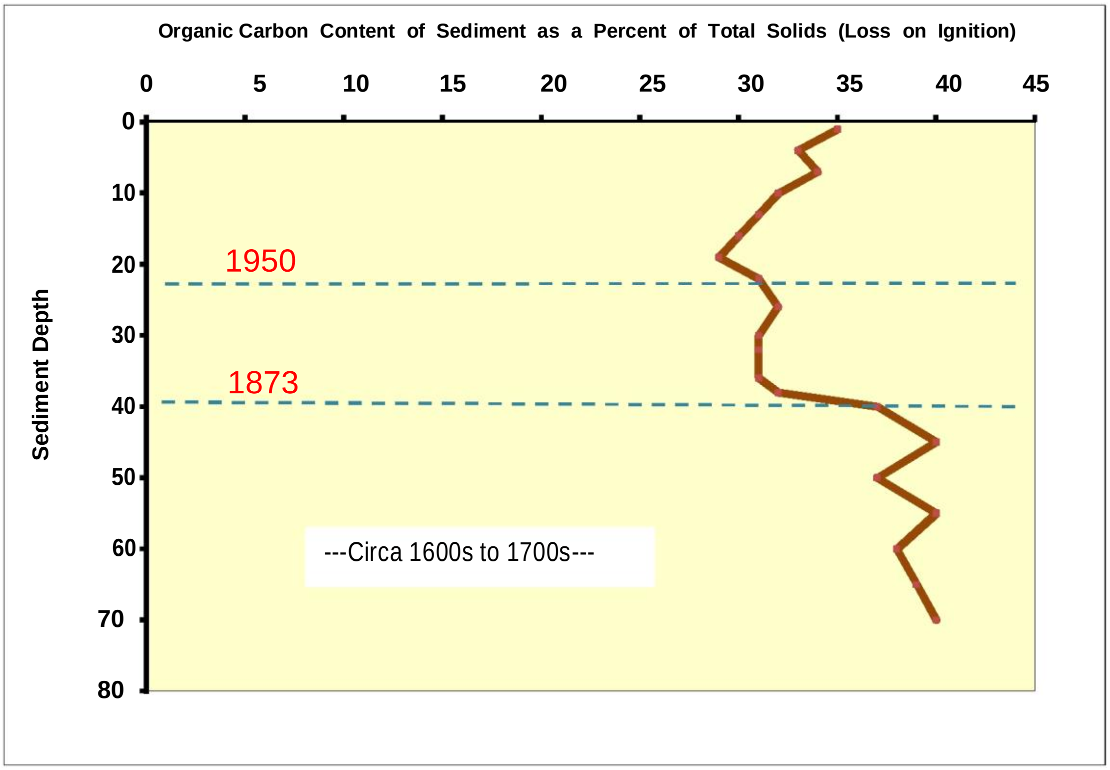


Figure 6-10**. Organic carbon concentration in the dated sediment core.**

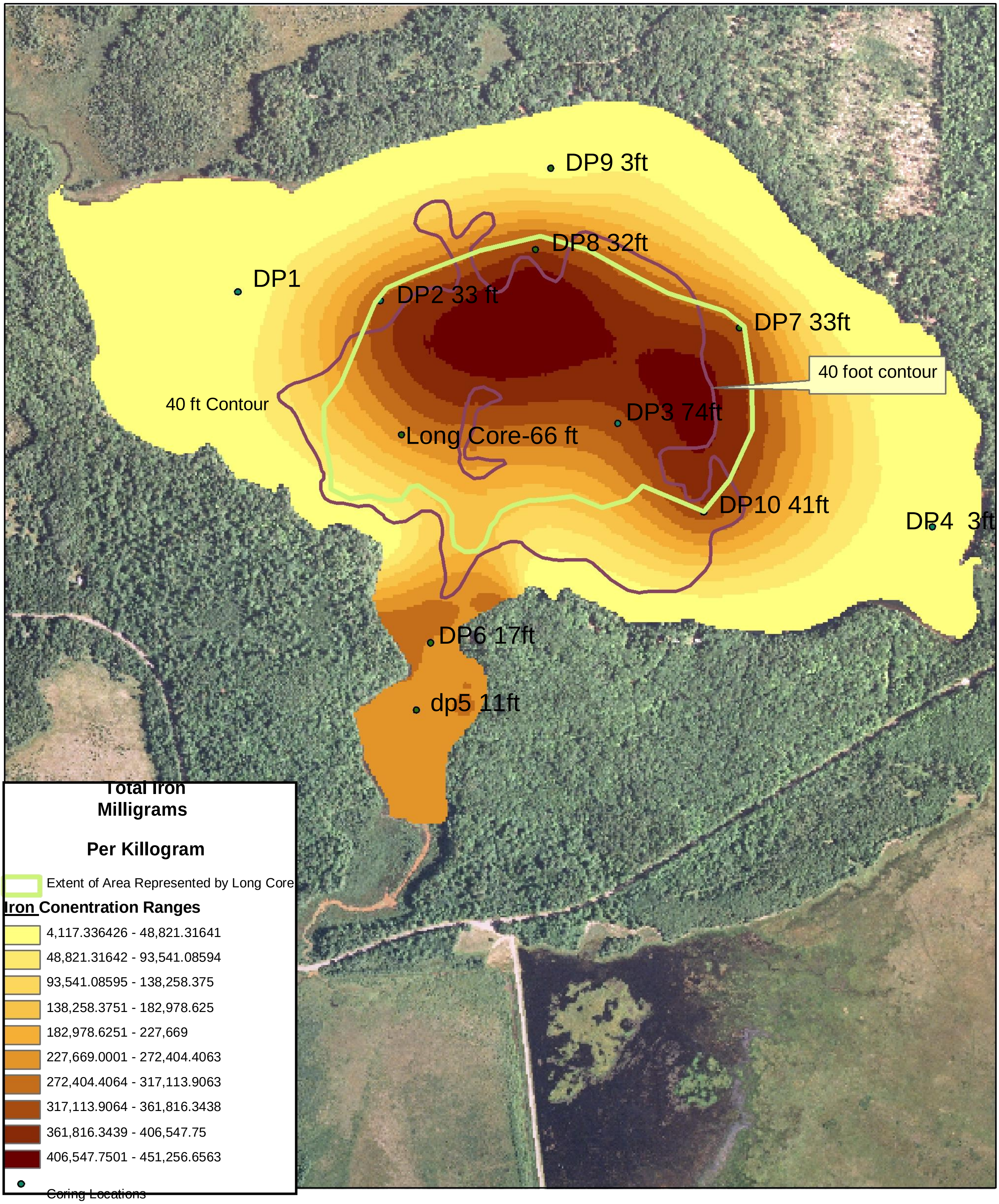


Figure 6-11.
Spatial Distribution of Iron in Dead Pike Lake Sediment and Estimated area Where the Long Core is Representatitve of Iron Deposition Rates

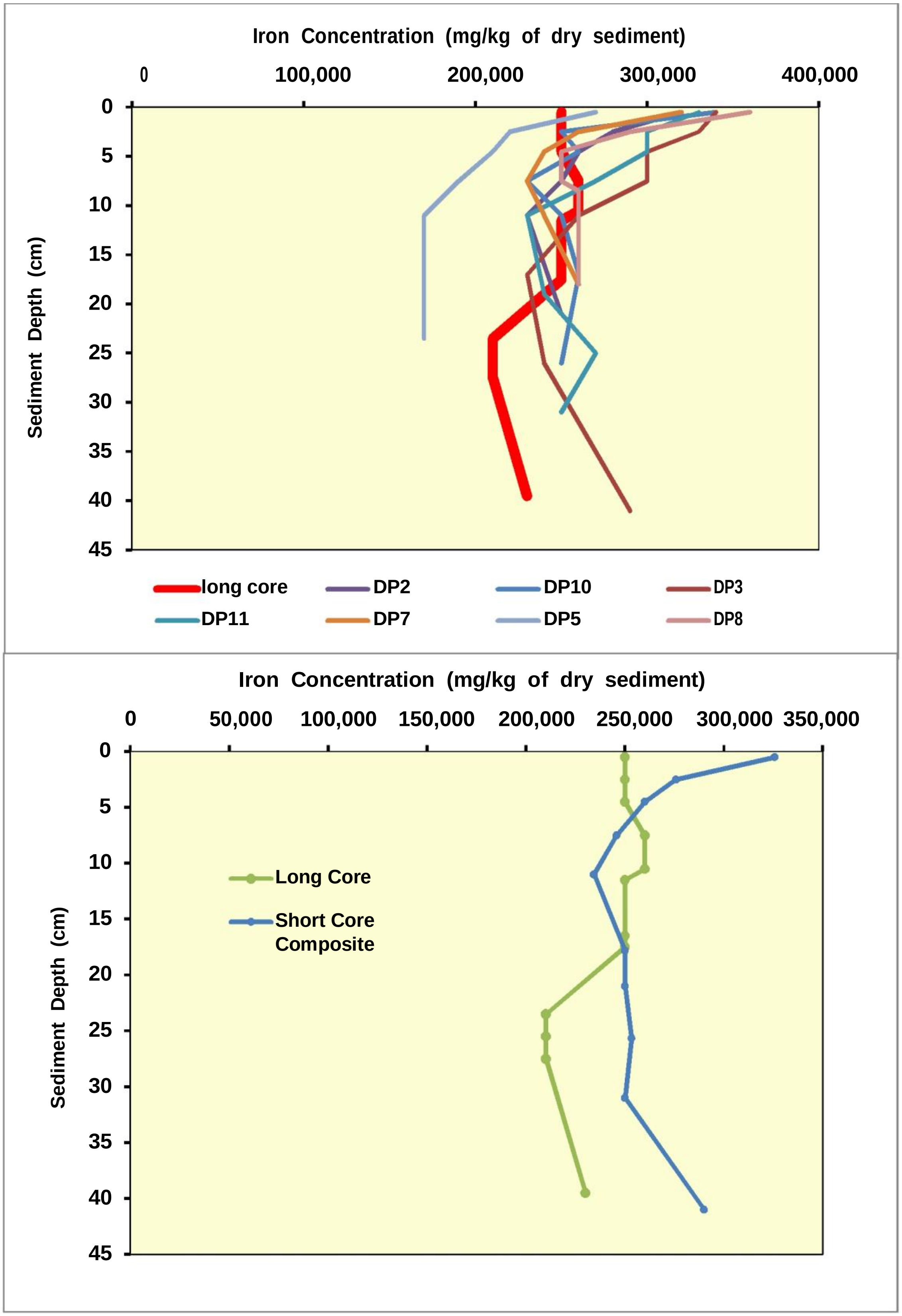


Figure 6-12. **Comparison of iron in short cores and the dated long core.**

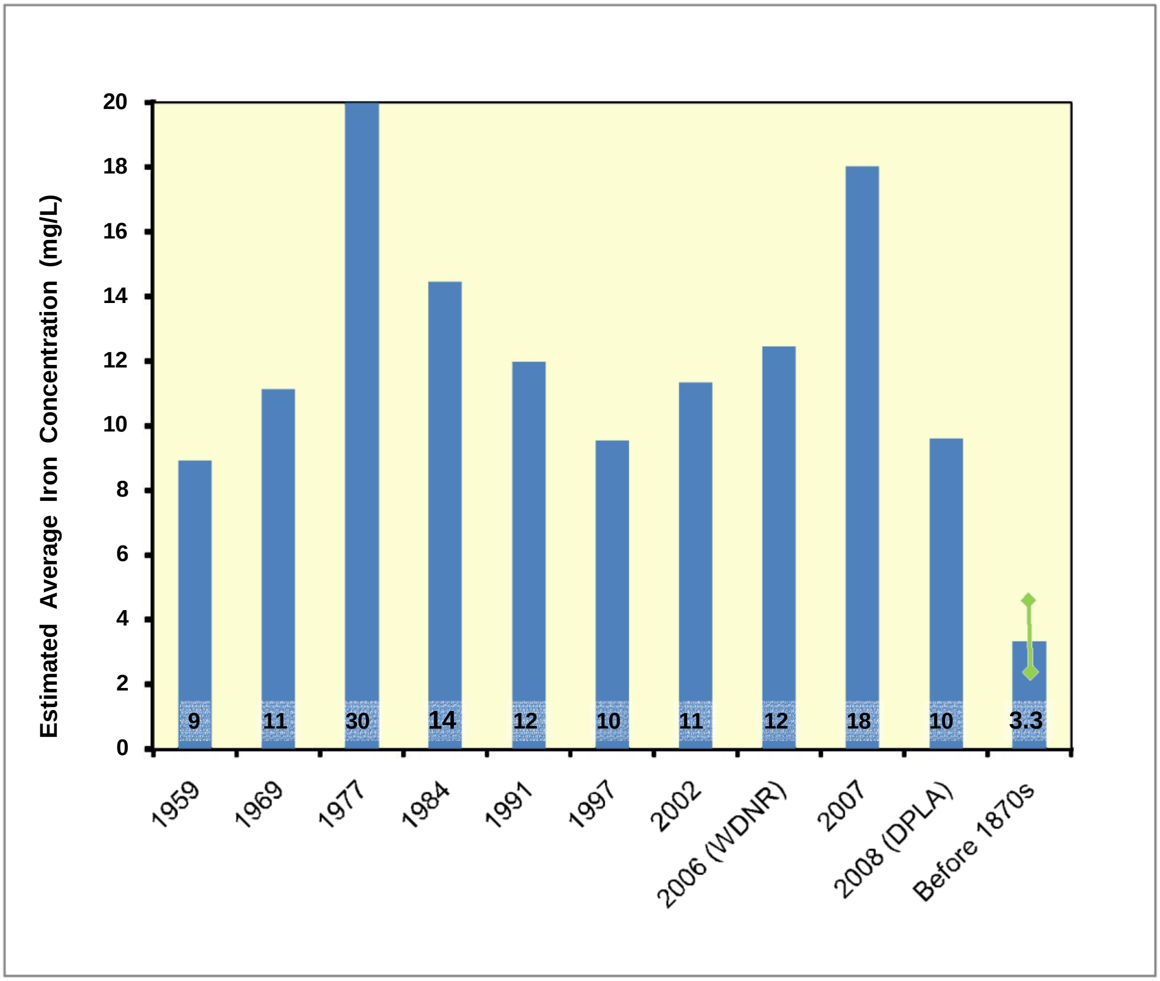


Figure 6-13**. Historical reconstruction of average iron concentrations at the Main Inlet based upon iron deposition rates in Dead Pike Lake and estimated annual average surface water discharge from the Powell Marsh. Iron concentrations in 2006 and 2008 were from water samples taken in those years. The error barr for the pre-1870s iron concentration estimate is based upon the 80th and 20th percentile of estimated flows.**

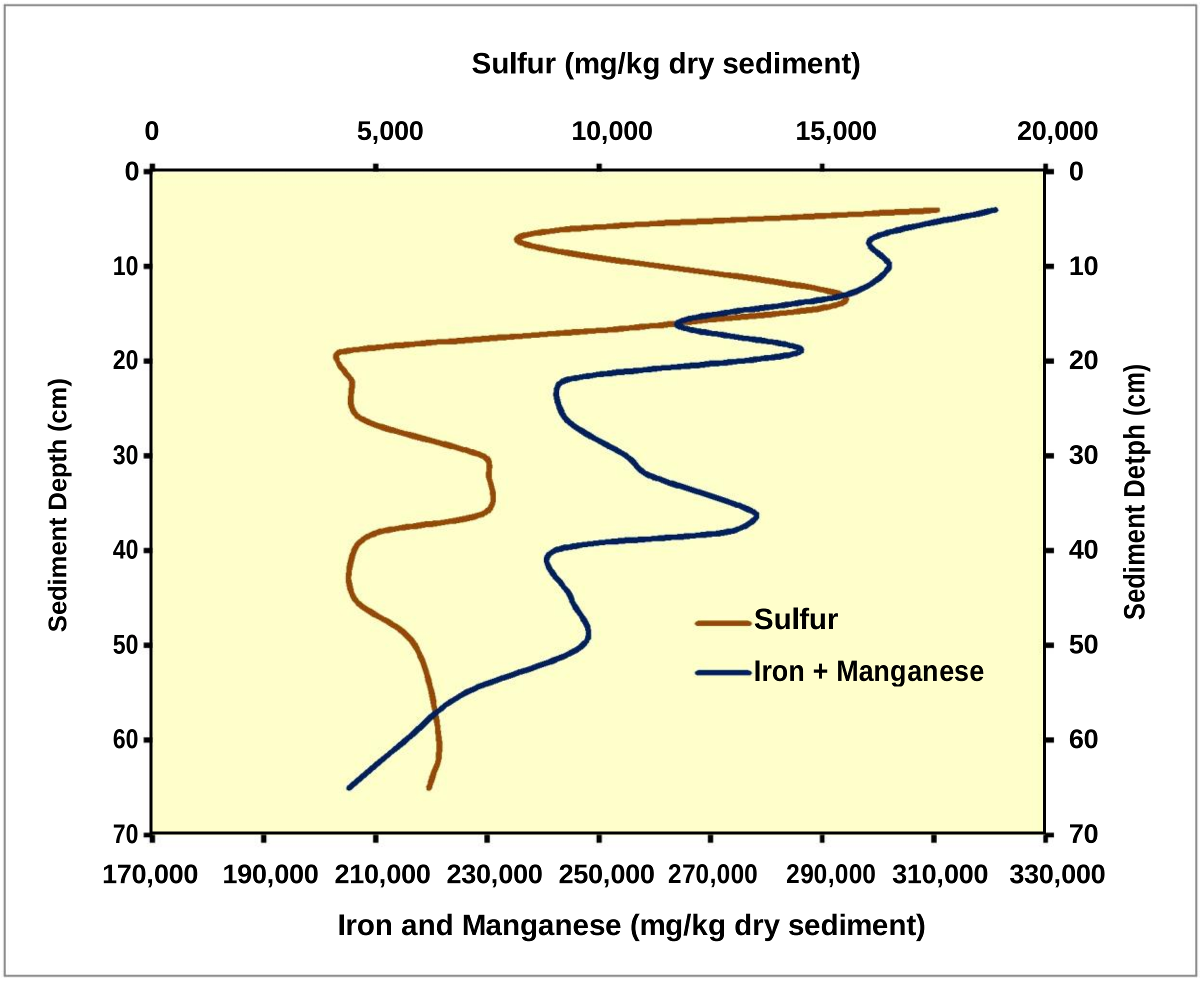


Figure 6-14. Comparison of sulfur and iron plus manganese in Dead Pike Lake sediments.

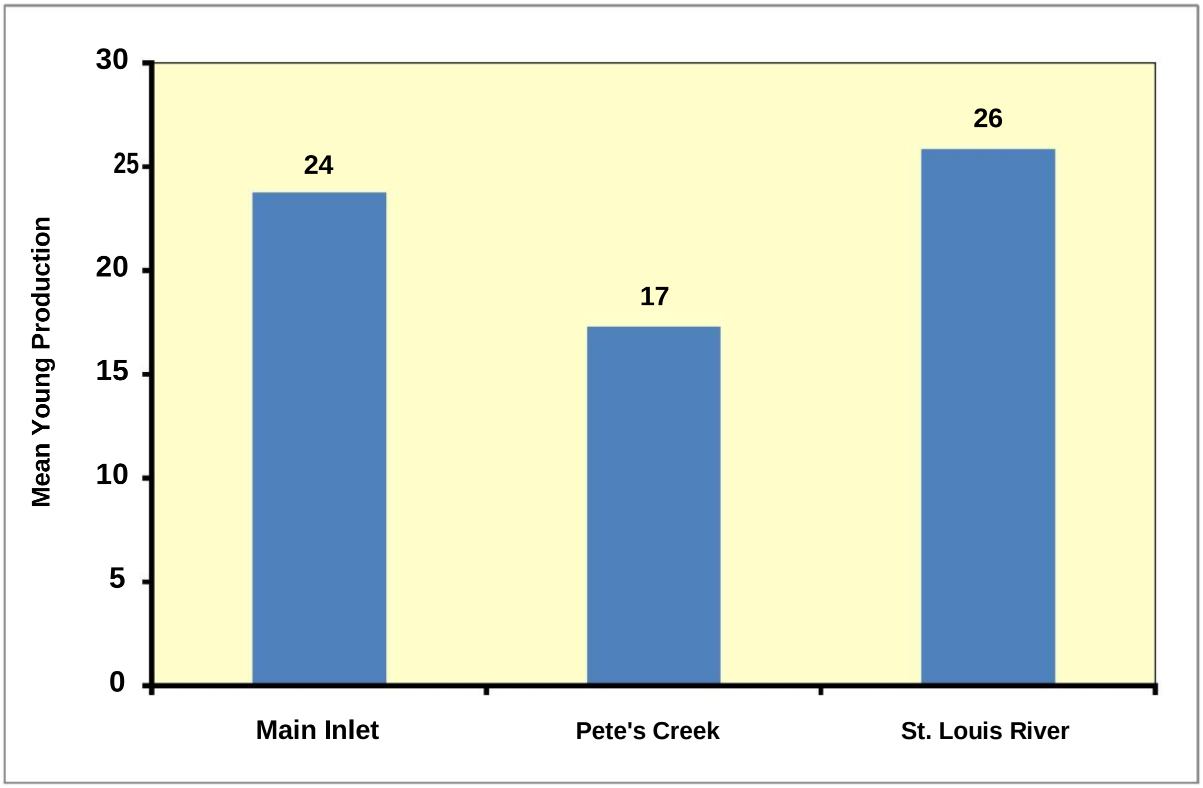


Figure 7-1. Mean young production for a 7-day toxicity test using the test species Ceriodaphnia dubia **and water collected at two inlets to Dead Pike Lake and a reference water from northern Minnesota.**

06/03/2010

Figure 8-1**. Photograph showing the accumulation of sediment on rocks in Dead Pike Lake.**

Appendices

(all electronic data-on CD)

Attachments