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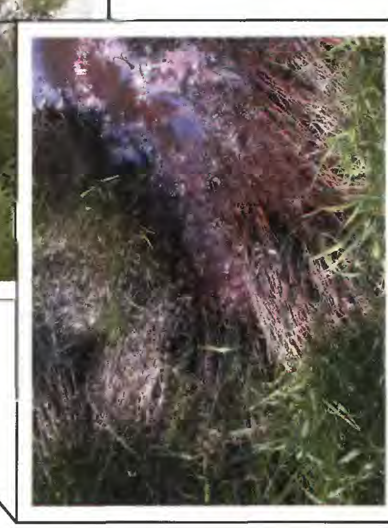
Hydrologic Investigation of Powell Marsh and its Relation to Dead Pike Lake, Vilas County, Wisconsin

Water-Resources Investigations Report 02–4034



Prepared in cooperation with the
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By James T. Krohelski, William J. Rose, and Randall J. Hunt

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Middleton, Wisconsin
2002

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To Obtain
	Length	
inch (in)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre (A)	0.4047	hectare
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer
	Volume	
cubic foot (ft^3)	0.02832	cubic meter
	Hydraulic Conductivity*	
foot per day (ft/d)	0. 3048	meter per day

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

***Hydraulic conductivity:** The standard unit for hydraulic conductivity is cubic foot per day per square foot of aquifer cross-sectional area (ft^3/d)/ ft^3. In this report, the mathematically reduced form, feet per day (f/d), is used for convenience.

<u>Other abbreviations</u>:

ft^3/s	cubic feet per second
gpm	gallons per minute
mg/L	milligrams per liter
in/yr	inches per year

The stratigraphic nomenclature used in this report is that of the Wisconsin Geological and Natural History Survey and does not necessarily follow usage of the U. S. Geological Survey.

Hydrologic Investigation of Powell Marsh and its Relation to Dead Pike Lake, Vilas County, Wisconsin

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Abstract

An analytic element ground-water-flow model was constructed to help understand the ground- and surface-water hydrology in the vicinity of Dead Pike Lake and Powell Marsh, Vilas County, Wisconsin. The model was used to simulate the effect of removing Powell Marsh control structures (ditches and Vista Pond) on the hydrology of Dead Pike Lake. Measurements and model simulation results show that ground water in the vicinity of Powell Marsh moves to the northwest and west. If Powell Marsh structures are removed from the simulation, it does not affect the general direction of ground-water flow nor the total flow to Dead Pike Lake. Without the simulated structures, slightly more ground-water flow enters Dead Pike Lake and slightly less surface-water flows at the Dead Pike Lake inlet than with the simulated structures.

Ground-water levels measured in piezometers installed along a flow path indicated that ground-water flow primarily is horizontal in the marsh and moves upward in the vicinity of a ditch where it discharges. Flow from Vista Pond is downward to the ground-water system but eventually also discharges upward to the ditches. Based on analyses of water samples from piezometers, the ditch, and Vista Pond, it was shown that dissolved iron is transported in the ground water. When ground water is discharged, iron and manganese react with dissolved oxygen, then precipitates, and forms the oxyhydroxide floc present in the Powell Marsh ditches. The processes involved in the transport and floc formation are not unique to the ditches, but are an expected outcome where discharging ground water and oxygenated surface water meet. Therefore, although floc formed in the ditches would no longer be available for transport if ditches were removed, it is likely that the floc formation would be redirected to the near-shore areas of Dead Pike Lake where increased ground-water discharge is expected.

INTRODUCTION

Dead Pike Lake and Powell Marsh are located in western Vilas County, Wis. (fig. 1). Local residents are concerned that iron floc from Powell Marsh ditches is damaging the aesthetic quality of their lake. The U.S. Geological Survey (USGS) in cooperation with the Wisconsin Department of Natural Resources (WDNR) began a study in June 2000 to evaluate the effects of Powell Marsh on the hydrology of Dead Pike Lake and to determine the source of iron floc and the potential for transport from Powell Marsh to Dead Pike Lake.

Purpose, Scope, and Sources of Data

This report describes the hydrologic relation between Powell Marsh and Dead Pike Lake, and characterizes the distribution of iron (Fe) and manganese (Mn) in the hydrologic system. Also, the processes responsible for iron transport at various points in the hydrologic system including Vista Pond, marsh, aquifer, ditch, and lake are described. Finally, the effects of altering the ditch system conveying the iron floc to Dead Pike Lake are summarized.

Available geologic and hydrologic data used during this study consisted of interpretive geologic maps presented by Attig (1985), and measured hydraulic conductivity, ground-water levels and contour maps of the water table and depth to rock by Patterson (1989) and Batten and Lidwin (1996). These data form the basis for development of a ground-water-flow model by providing estimates of saturated thickness, the hydraulic properties of the shallow aquifer, and estimates of water-table elevation. These previous studies (Patterson, 1989; Batten and Lidwin, 1996) reported that extremely

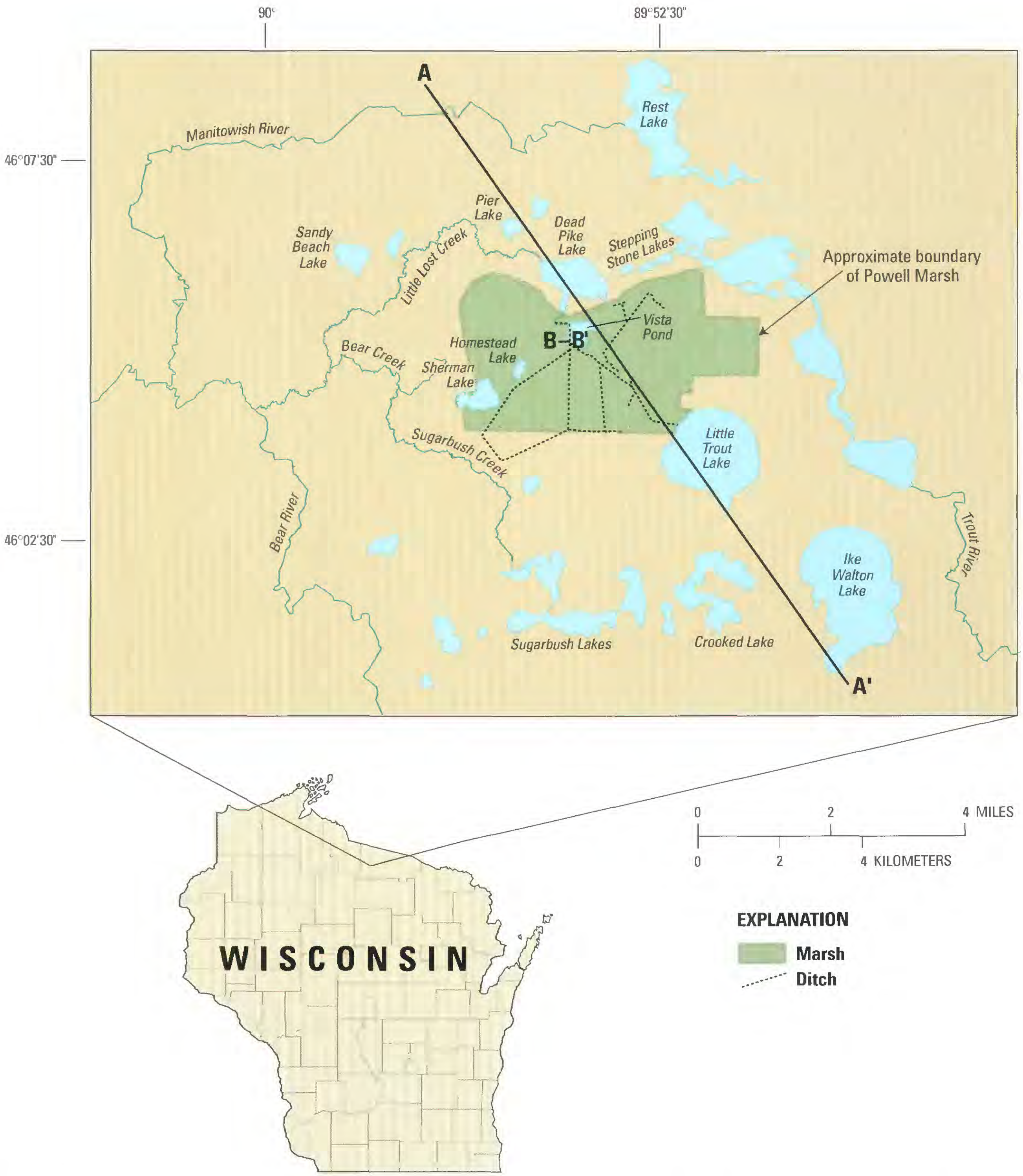

Figure 1. Location of Powell Marsh and Dead Pike Lake, Vilas County, Wisconsin. (A-A' section shown in figure 2; B-B' section shown in figure 7.)

high iron concentrations (greater than 20 mg/L) could be present in the sand-and-gravel sediment in the vicinity of Powell Marsh.

In addition to the available data, field data were collected for the study. A Global Positioning System (GPS) was used to locate and determine elevations of surface-water features, such as streams and lakes throughout the study area and above and below control structures at Powell Marsh. Elevations and site locations of lakes, streams, control structures, and piezometers were measured (Michael T. Anderson, Wisconsin Department of Natural Resources, written commun., 2000). The coordinates and elevations of the sites measured by GPS are listed in appendix 1.

Piezometers, some nested, were installed along a west to east section in Powell Marsh and used to determine the direction of ground-water flow, the relation between the ground-water system, Powell Marsh ditches, and Vista Pond, and to obtain water samples for analyses of dissolved organic carbon (DOC), iron and manganese. Surface-water samples were collected from the main ditch and Vista Pond for DOC, iron, and manganese. Streamflow measurements were made at five sites during the study. Some of the ground-water-level measurements and the streamflow measurements were used in model calibration. The ground-water-level and streamflow measurements are listed in appendix 2.

Hydrologic Setting

Dead Pike Lake is a 297-acre drainage lake (fig. 1). An inlet flowing to the south side of Dead Pike Lake drains a portion of Powell Marsh. The marsh consists of an extensive system of drainage ditches constructed in the 1950s, some of which drain into the Dead Pike Lake inlet. Sand-and-gravel deposits of the Copper Falls Formation (Pleistocene age) are present throughout the area. These deposits range in thickness from 100 to 200 ft (Attig, 1985). In low-lying areas, 1 to 5 feet of peat overlie the sand and gravel. Reported values of horizontal hydraulic conductivity range from about 1 to 50 ft/d based on slug tests and 950 ft/d based on a multi-well aquifer test (Patterson, 1989; Batten and Lidwin, 1996). An aquifer test generally integrates a much larger volume of aquifer compared to a slug test and often yields higher and more representative values of hydraulic conductivity (Bradbury and Muldoon, 1990).

STUDY METHODS

Methods used to understand the hydrogeology and geochemistry of the study area include development of a ground-water-flow model and analysis of ground water and surface water along a flow path. These methods are described in the following section.

Hydrogeology

An analytic element ground-water-flow model, using the computer program GFLOW (Haitjema, 1995), was constructed to simulate the shallow ground-water system and its interaction with surface-water features. A complete description of analytic elements is beyond the scope of this report; a brief description is given below. The reader is referred to Strack (1989) and Haitjema (1995) for detailed discussions of this method.

Unlike most modeling methods, the analytic element method assumes an infinite aquifer and does not use a grid or involve interpolation between grid cells. To construct an analytic element model, features important to ground-water flow and surface-water features are entered as mathematical elements or strings of elements. Each element is represented by a mathematical equation. The effects of these individual solutions are superposed or added together to arrive at a solution for the larger ground-water-flow system. Unlike finite-difference modeling where the solution is calculated only at grid nodes, with analytic-element modeling, heads and flows can be computed anywhere in the model domain without nodal averaging. The GFLOW model used here is an areal model and the analytic elements are two-dimensional and only can simulate steady-state conditions (that is, heads do not vary with time). The analytic element method (Strack, 1989; Haitjema, 1995) and the comparison of analytic element to finite-difference numerical model techniques (Hunt and Krohelski, 1996: Hunt and others 1998) have been discussed by others.

The GFLOW model was calibrated by trial-and-error; that is, by varying hydraulic conductivity and stream resistance until there was a reasonable match between measured and simulated ground-water levels (heads) and streamflows.

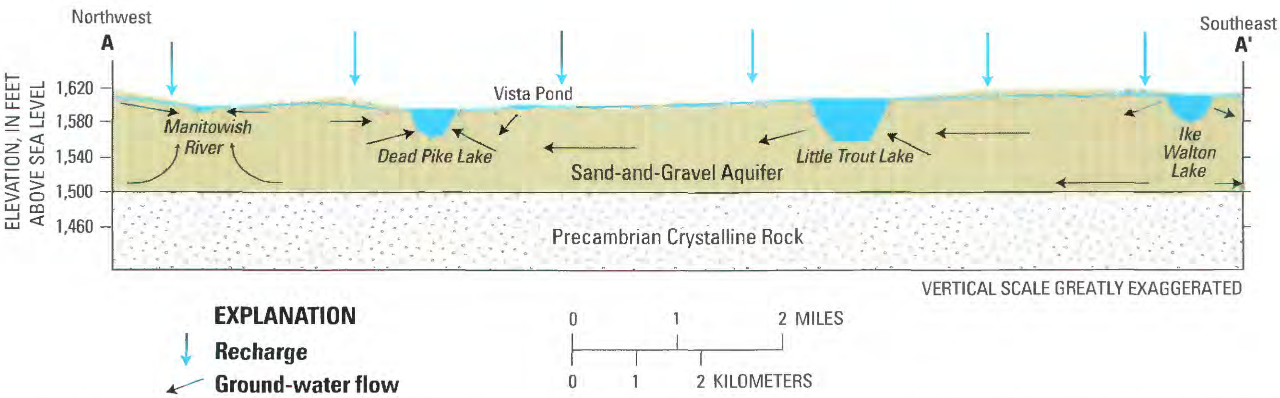

Figure 2. Conceptual model of the hydrologic system in the vicinity of Dead Pike Lake. (Line of section is shown in figure 1.)

Geochemistry

Ground and surface waters were sampled and analyzed in the field for pH, temperature, specific conductance, redox potential (Eh) and dissolved oxygen (field parameters), and in the laboratory for iron, manganese, and DOC. Field parameters were sampled and measured by pumping the water through a flow-through chamber enclosing the multi-parameter meter sensors. Two sets of samples were taken, one filtered through 0.45 micron filters and one filtered through 0.1 micron filters to assess the potential of colloidal transport. Ground-water samples were collected using a peristaltic pump and an in-line filter. Surface-water samples from Vista Pond and the main ditch were "grabbed" near shore using a 5-gallon pail. Because Vista Pond and the main ditch are shallow and therefore well mixed, the "grab" samples are representative of these surface-water bodies. The surface-water samples then were filtered using the in-line apparatus. Field and laboratory analyses of sampled water are listed in appendix 3.

CONCEPTUAL MODEL

Prior to construction of the ground-water-flow model, a conceptualization of the system is essential because it forms the framework for model development. The conceptualization reduces the actual flow system into important component parts. This reduction is a necessary simplification of the natural system because inclusion of all of the complexities of the natural system into a computer model is not feasible. Steps in the development of the conceptual model include: (1) definition of aquifers and confining units, (2) identification of sources and sinks of water and, (3) identification and delineation of hydrologic boundaries. A conceptualization in cross section of the shallow ground-water/surface-water system in the vicinity of Dead Pike Lake and Powell Marsh is shown in figure 2. The cross section is based on well drillers' construction reports and information collected as part of other studies (see previous cited reports).

The shallow ground-water system consists of laterally extensive deposits of sand and gravel about 100 ft thick. The underlying bedrock unit (Precambrian crystalline rock) forms the base of the aquifer system and is assumed to be nearly impermeable. Therefore, the model included only the most transmissive upper deposits. The water table in the vicinity of the Powell Marsh and Dead Pike Lake is near the land surface except in areas of high relief or elevation. In these areas, the depth to the water table may be more than 50 ft (Batten and Lidwin, 1996).

Ground water moves from higher to lower potentials (or heads) as indicated by the flow arrows in figure 2. As a result, ground water generally moves toward and discharges to lower-lying surface-water features and recharges (as indicated by the vertical arrows above the section in figure 2) elsewhere. Recharge is that portion of precipitation that does not evaporate, transpire, or run off, and is the primary water source to the ground-water system.

Dead Pike Lake receives surface water from Powell Marsh by way of an inlet channel and because of its position in the ground-water basin, it is likely that Dead Pike Lake receives ground-water flow on all sides as well. Other inlet channels may intermittently provide water to Dead Pike Lake during periods of high flow (spring snowmelt and intense precipitation). Outflow from Dead Pike Lake is through Little Lost Creek, which begins at the west end of the lake. When Little Lost Creek is flowing, the stage of Dead Pike Lake largely is controlled by the elevation of this outlet. In addition to ground-water flow, other hydrologic budget components for Dead Pike Lake include precipitation falling on the lake and water evaporating from the lake surface. In northern Wisconsin, annual precipitation exceeds evaporation by about 6 in/yr (Novitzki, 1982). Overland flow is assumed to be insignificant because infiltration rates of the sandy surface deposits are rarely exceeded by precipitation rates. Thus, overland flow is not included in the hydrologic conceptual model for the lake.

CONSTRUCTION OF THE GFLOW MODEL

Initial model development included estimating the elevation of the base of the shallow aquifer system, an areally uniform recharge rate, and a horizontal hydraulic conductivity. The base of the model approximates the bottom of the high-conductivity unconsolidated sediments (approximately 1,500 ft above sea level). The recharge rate and horizontal hydraulic conductivity, along with streambed resistance were considered calibration parameters, and thus were varied during model calibration. Recharge was set to 10.0 in/yr and horizontal hydraulic conductivity set to 100 ft/d. These parameters are similar to those used by Hunt and others (1998) in the construction of a ground-water-flow model of the nearby Trout Lake area.

Based on the conceptual model, the location and elevation of far-field surface-water features were added (fig. 3). These features are distant rivers and lakes that are simulated with coarse linesinks and no resistance between the surface-water features and the ground-water system (that is, simulated as having a good hydraulic connection). The purpose of simulating the far field is to have the model explicitly define the regional ground-water-flow field near Dead Pike Lake and Powell Marsh (called the near field). The near field encompasses the features in the area of interest, as well as other nearby features that affect the hydrology of the lakes (fig. 3). Streambed sediment resistance in the near field initially was set equal to 0.3 day. Resistance in analytic element modeling is calculated by dividing the streambed sediment thickness by the vertical hydraulic conductivity. In this model, the value of 0.3 day corresponds to a 1-ft sediment thickness with a vertical hydraulic conductivity of 3.3 ft/d, which is representative of a good connection between the ground-water and surface-water systems. The width of the stream was assigned according to stream order, and ranged from 10 to 50 ft.

Streams and lakes in the far field are not used for flux calibration, thus are simply modeled as individual linesinks. In near-field streams, a special more sophisticated type of linesink was used, called a "stream element" (Mitchell-Bruker and Haitjema, 1996). This element consists of linked linesinks that route water from high-elevation linesinks to low-elevation linesinks. During the routing through the stream network, the amount of water captured and lost by the stream is tabulated. This accounting allows the modeler to easily obtain a flux from any linesink in the stream network that includes flows from all the upstream linesinks. More importantly, the accounting also ensures that the amount of stream water lost to the ground-water system is restricted to the amount of water available (that is, captured from upgradient linesinks in the network). For streams where the headwaters are not included in the model domain, a headwater inflow term can be specified. This option was utilized for Sugarbush Creek, a steam with an appreciable headwater reach that is in the far field (fig. 3). Based on field measurements at the outlet of Sugarbush Lake, the amount of headwater inflow was set equal to 2.3 ft^3/s, and was added to the stream element immediately downgradient of the lake (fig. 3). Lakes were simulated using linesinks with resistance. Dead Pike Lake was linked to the stream network with stream elements based on the methodology of Hunt and others (1998).

MODEL CALIBRATION

Calibration targets are measured field data, which are used to evaluate how well the model represents the actual ground-water system. The targets used here include both ground-water levels and streamflows (fig. 3). Ground-water levels for two wells (VI-761 and VI-653) were obtained from previously published reports (Patterson, 1989; Lidwin and Batten, 1996) and one well drilled for this study (A30). In addition to the ground-water levels, targets representing the lake levels for Sherman, Homestead, Pier, Sandy Beach and Little Trout Lakes also were used. The stage of these lakes is assumed to represent water-table elevation. Streamflow

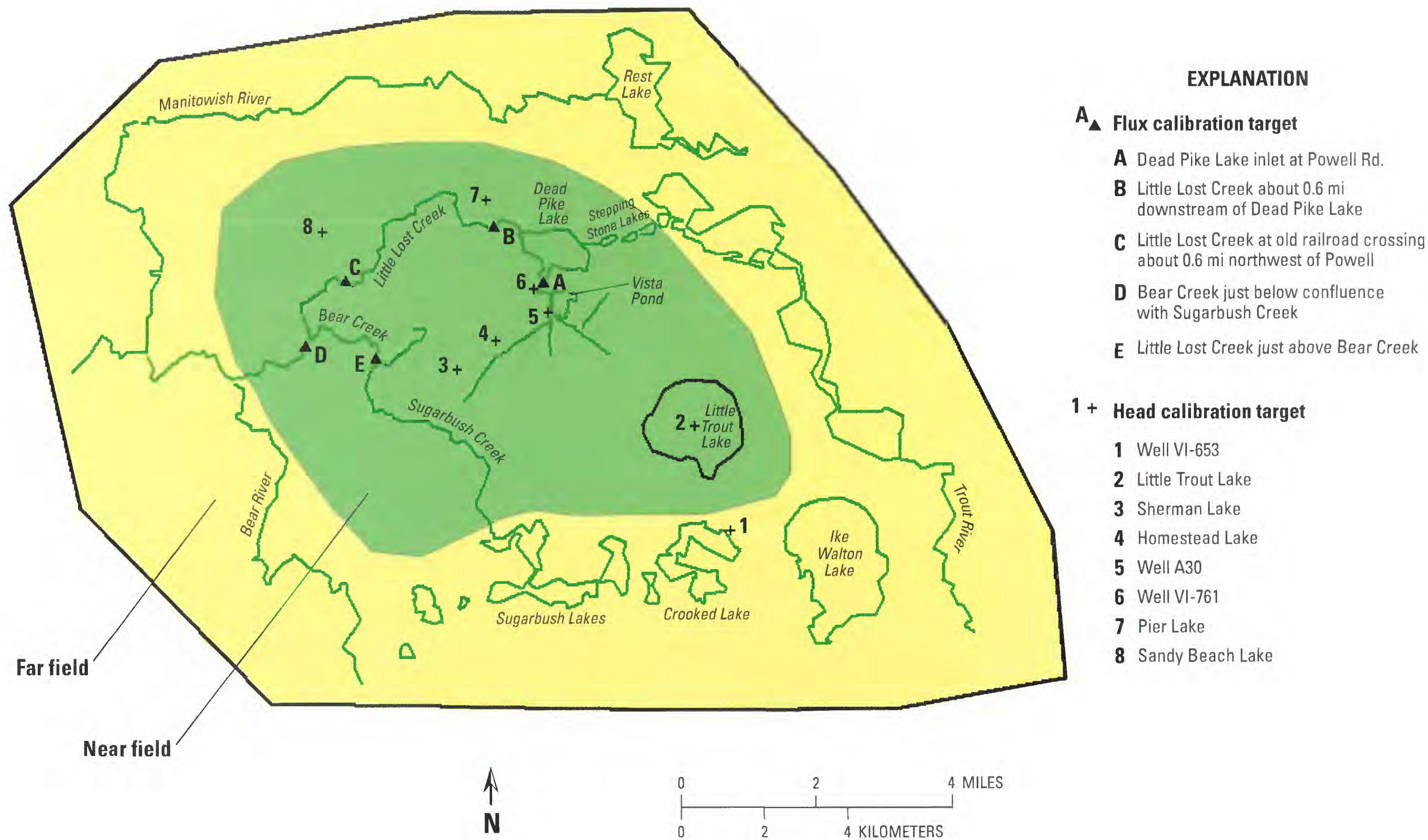

Figure 3. Simulated hydrologic features with analytic elements and location of calibration targets for the ground-water-flow model of Powell Marsh and Dead Pike Lakes, Wisconsin. (Global recharge is applied to the entire far field and near field.)

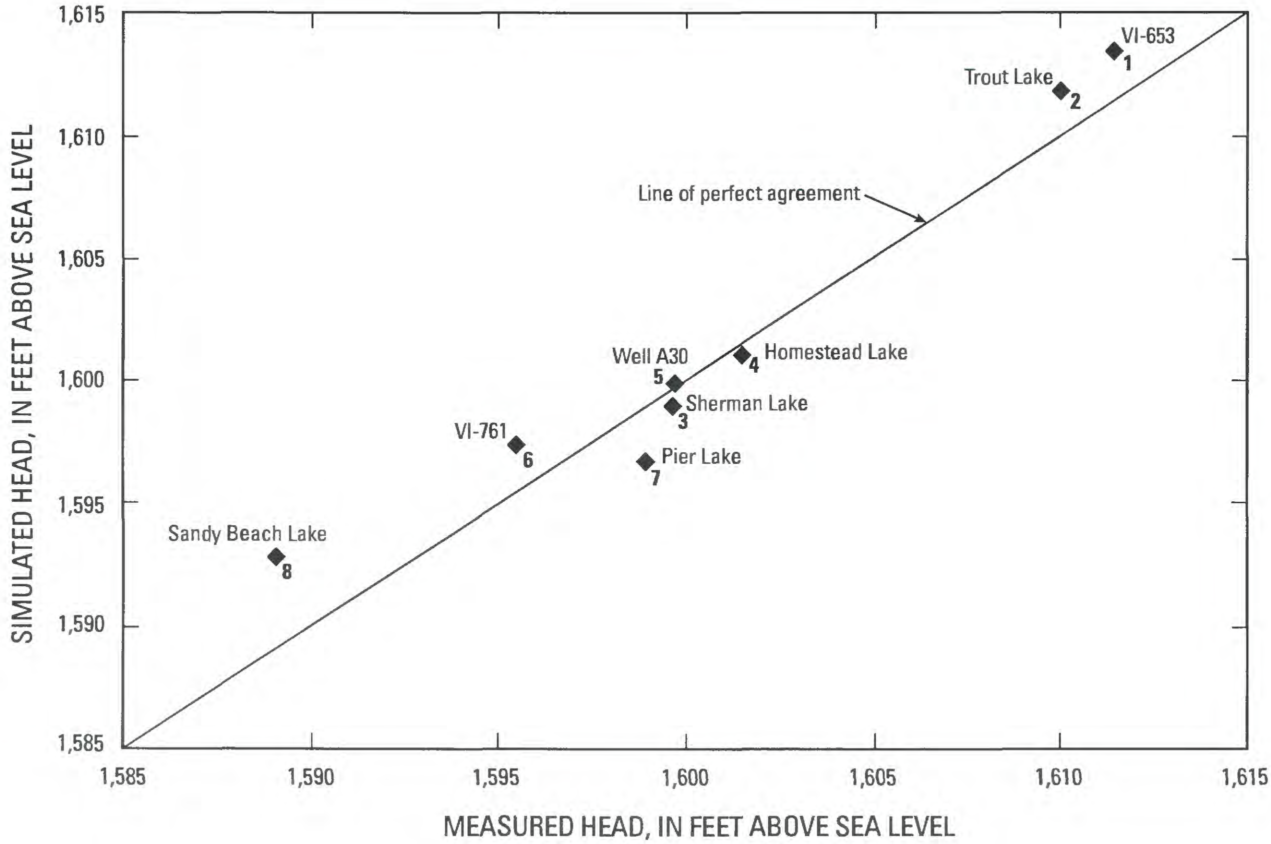

Figure 4. Measured and simulated head for the ground-water-flow model of Powell Marsh and Dead Pike Lake, Wisconsin. Location of head calibration targets are shown in figure 3. Head measurements were made on June 14 and 15, 2000 except for wells VI-761 and VI-653, which are from Batten and Lidwin, 1996.

or flux targets consisted of five sites in the near field where streamflow was measured during this study (fig. 3). These targets were used to constrain the simulated fluxes and associated regional recharge. The relation of the target to the model calibration is such that lower values of the streamflow target result in lower rates of recharge and lower corresponding horizontal hydraulic conductivity.

Using a recharge rate of 10 in/yr, an aquifer hydraulic conductivity of 100 ft/d, and a higher stream resistance for Bear and Sugarbush Creeks than other near-field streams, a reasonable match between measured and simulated head and flux was obtained. A stream resistance of 10, which results in a vertical hydraulic conductivity of 0.1 ft/d if the sediment thickness is 1 ft, was assigned to Bear and Sugarbush Creeks. All other near-field streams were assigned a resistance of 1. The effect of increasing stream resistance was to reduce the amount of ground water discharging to Bear and Sugarbush Creeks and to increase water-table elevation in the vicinity of Powell Marsh. No data were collected to verify a high streambed resistance in Bear and Sugarbush Creeks. However, field reconnaissance indicated that these streams are low gradient and contain large wetlands in their basins, which are typified by fine-grained streambeds and, therefore, yield high streambed resistance. Comparison between measured and simulated head is shown in figure 4. Calibration statistics based on eight head targets include the following differences between measured and simulated heads: a maximum of 3.8 ft, a minimum of -2.2 ft, an average of 0.8 ft, a median of 1.0 ft, a mean absolute of 1.6 ft and a root mean squared of 2.0 ft. These statistics are similar to those of other calibrated models (Hunt and others, 1996) and is considered a good steady-state model match.

The calibration to flux indicates that measured streamflow generally brackets simulated streamflow (fig. 5). Streamflow flux targets are based on only one measurement rather than the preferred method of having enough measurements over the range of high and low flows to determine flow duration (Krohelski and others, 2000). The calibration to flux is reasonable because most of the simulated flows are close to mea-

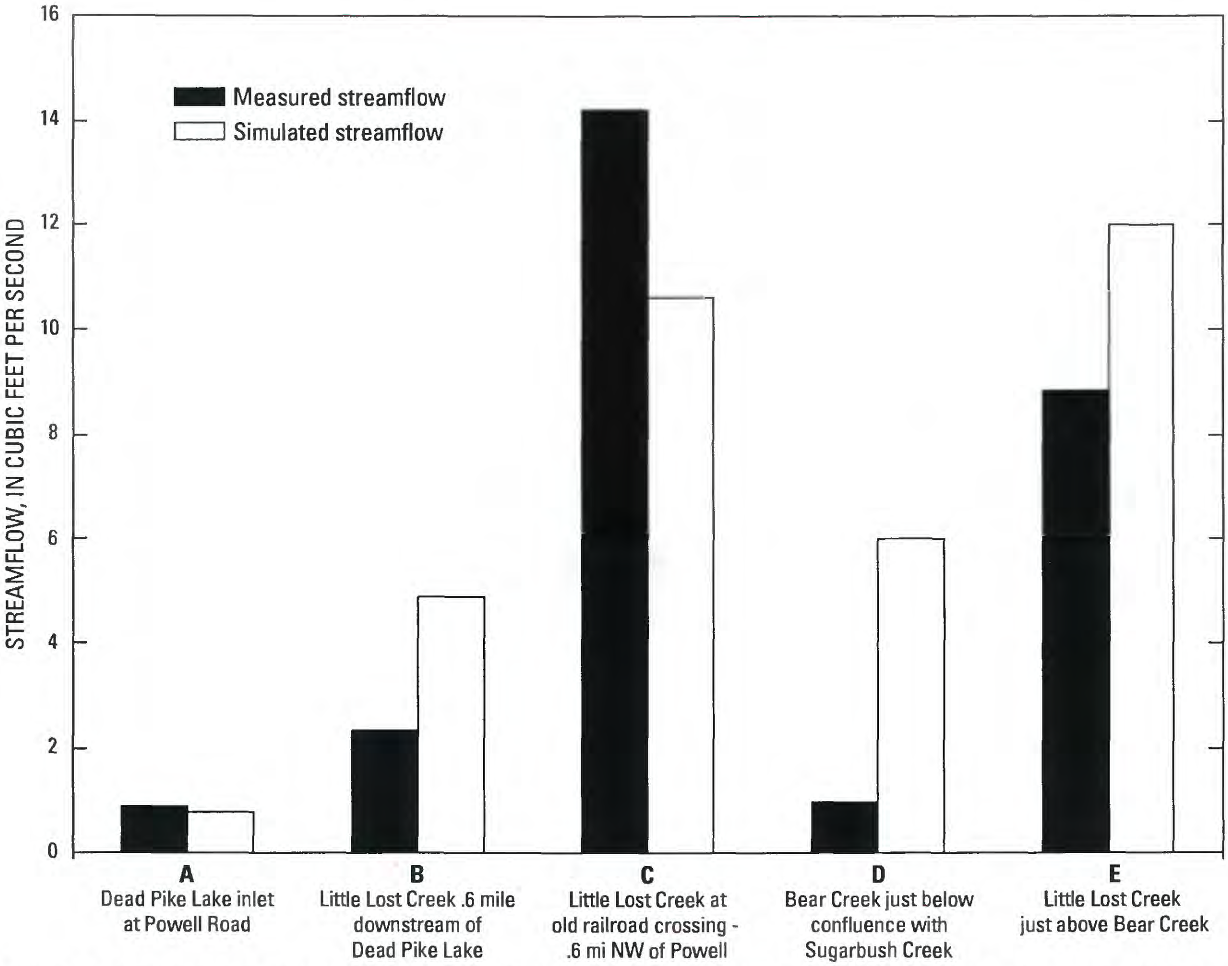

Figure 5. Measured and simulated flux (streamflow) for the ground-water-flow model of Powell Marsh and Dead Pike Lake, Wisconsin. Location of flux calibration targets are shown in figure 3. Streamflow measurements were made on June 14 and 15, 2000.

sured flows with some higher and some lower. Some difficulty in measuring equilibrium streamflow conditions was encountered because of beaver activity; modifications to beaver dams are common and can cause reductions or increases in streamflow that may not be representative of the site under equilibrium or steady-state conditions in model simulation.

MODEL RESULTS

Ground water flows from high to low elevation and generally at right angles to contour lines on a map. Therefore, the contour map (fig. 6A) of calibrated model results indicates that the highest near-field water-table elevation occurs just south of Little Trout Lake and from this point ground-water flow is roughly radial. In the vicinity of Powell Marsh, ground water flows to the northwest and west. As indicated by the pathlines (red lines on figure 6A), ground water recharging on Powell Marsh likely will discharge to a ditch. For example, the pathline labeled "1" on figure 6A represents a simulated particle of water that is recharged at the water table and is simulated discharging to the ditch. Using an estimated porosity of 0.2, the time of travel for this particle from the water table to the ditch is approximately 12 years. It also is interesting to note that in the vicinity of Dead Pike Lake, particles that are started at the water table on all sides of Dead Pike Lake eventually discharge to Dead Pike Lake (fig. 6A). The calibrated model indicates that Dead Pike Lake receives about 2.4 ft^3/s of ground-water inflow along with 1.0 ft^3/s of surface-water inflow from the south part of the Dead Pike Lake Basin (this part of the basin includes Powell Marsh) and about 0.9 ft^3/s of ground-water inflow from the north part for a total inflow to the lake of 4.3 ft^3/s.

In order to approximate the effect of the Powell Marsh ditches and Vista Pond on the hydrology of Dead Pike Lake, the calibrated model was modified by removing the analytic elements that represent the ditches and pond. The same particle locations and con-

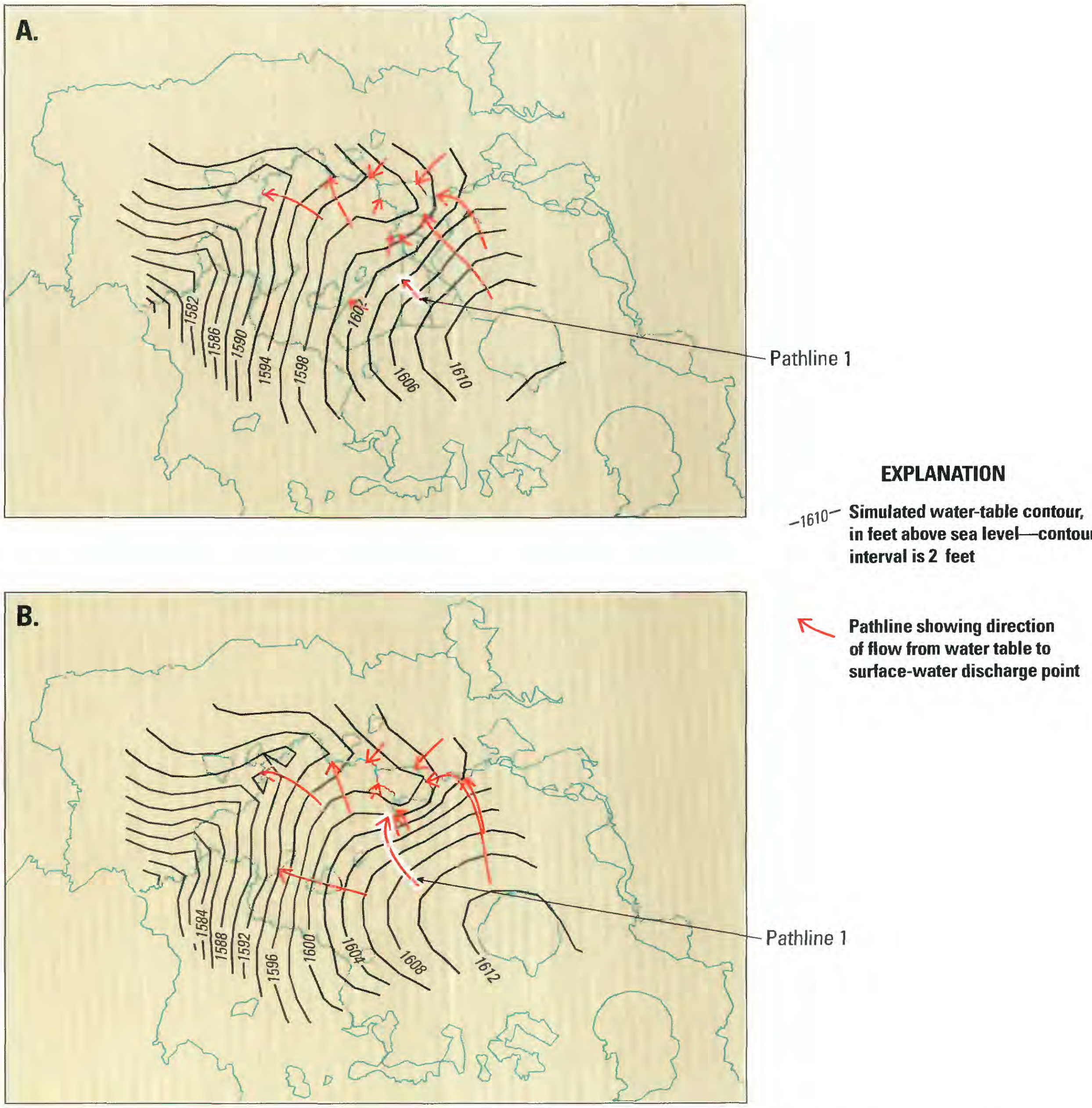

Figure 6. Simulated water-table elevation and selected path lines for (A) calibration and (B) without Powell Marsh structures (ditches and Vista Pond), Vilas County, Wisconsin.

tour interval used to present the calibrated model are presented for the case without the Powell Marsh features in figure 6B. Model results with the Powell Marsh features removed indicate a water-table elevation in the vicinity of Little Trout Lake would be about 2 ft higher than the simulated conditions in the calibrated model. Although the shape of the contours is approximately the same as the simulation with the features, indicating that the general direction of ground-water flow is the about the same, the gradient as indicated by the spacing of the contours (compare figure 6A to 6B) in the vicinity of Powell Marsh is slightly steeper. The travel time from recharge to discharge of the pathline labeled "1" is much longer (36 years compared to 12 years) because the simulated pathline does not discharge to the ditch but to the inlet stream of Dead Pike Lake, a longer distance from the site where the pathline was started (recharged). The model simulation without the Powell Marsh features also indicates that the amount of water entering Dead Pike Lake is approximately the same as the simulation when the Powell Marsh features were included. Ground-water inflow from the south is 3.0 ft^3/s and 0.5 ft^3/s from the inlet stream as compared to 2.4 ft^3/s of ground-water flow from the south and

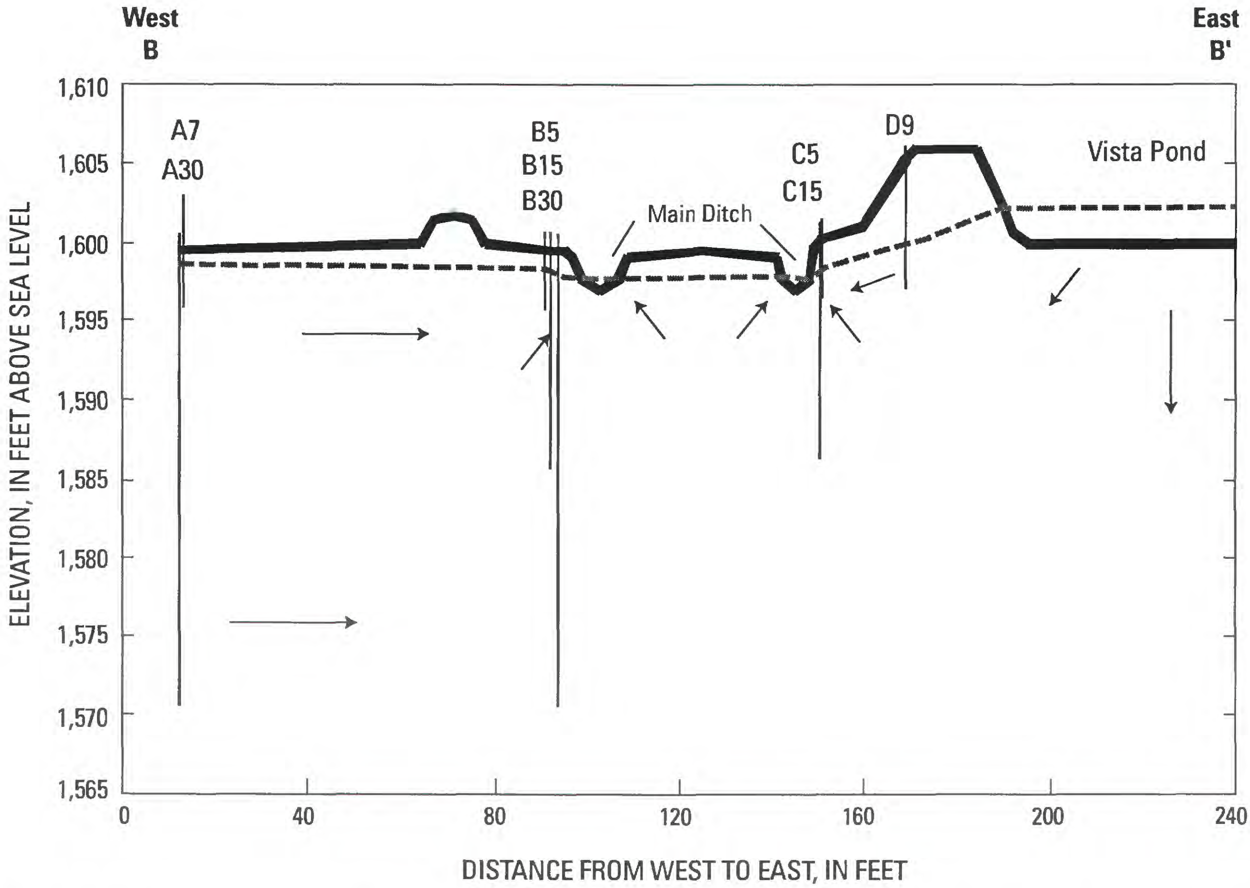

Figure 7. West to east section, B-B', showing the position of water table (dashed line) and direction of ground-water flow indicated by arrows, Vilas County, Wisconsin. Section trace is shown on figure 1. Piezometers locations are identified by letter ID and depth designation in feet.

1.0 ft^3/s from the inlet stream in the calibrated model. As in the calibrated model case, there is 0.9 ft^3/s from the north part of the basin. Total inflow to Dead Pike Lake is 4.4 ft^3/s in the simulation without the Powell Marsh features, compared to 4.3 ft^3/s for the model that includes the Powell Marsh features. This result indicates that the Powell Marsh features do not change the overall lake water budget, but rather redistributes the water budget components slightly.

RELATIONS BETWEEN THE GROUND-WATER AND SURFACE-WATER SYSTEMS

Field data were collected during the study to determine the hydrologic relation between the ground- and surface-water systems and to determine the geochemical process of iron and manganese transport. Piezometers made of 1-inch diameter PVC with 1-ft-long number 10 screens were installed along section B-B' (fig. 1). The section is about 200 ft long and was chosen to intersect Vista Pond and the Main Ditch, which is split into two channels along the section (fig. 7).

Hydrogeology

Piezometer nests are located at 4 sites along the section B-B' to determine vertical and horizontal gradients. The location of the piezometers in section and the direction of ground-water flow based on ground-water and surface-water level measurements are shown on figure 7. The deepest piezometers are finished 30 ft below land surface. A 12-ft sediment core was obtained close to piezometer site "A". The core consisted of a 2-ft peat layer underlain by medium to coarse sand. The surface elevation of Vista Pond and ground-water levels measured in the piezometer "D-9" indicate flow from Vista Pond to the west toward the ditches. The ground-water level in "D-9" was well below the level of Vista Pond but above levels in nest "C" indicating downward

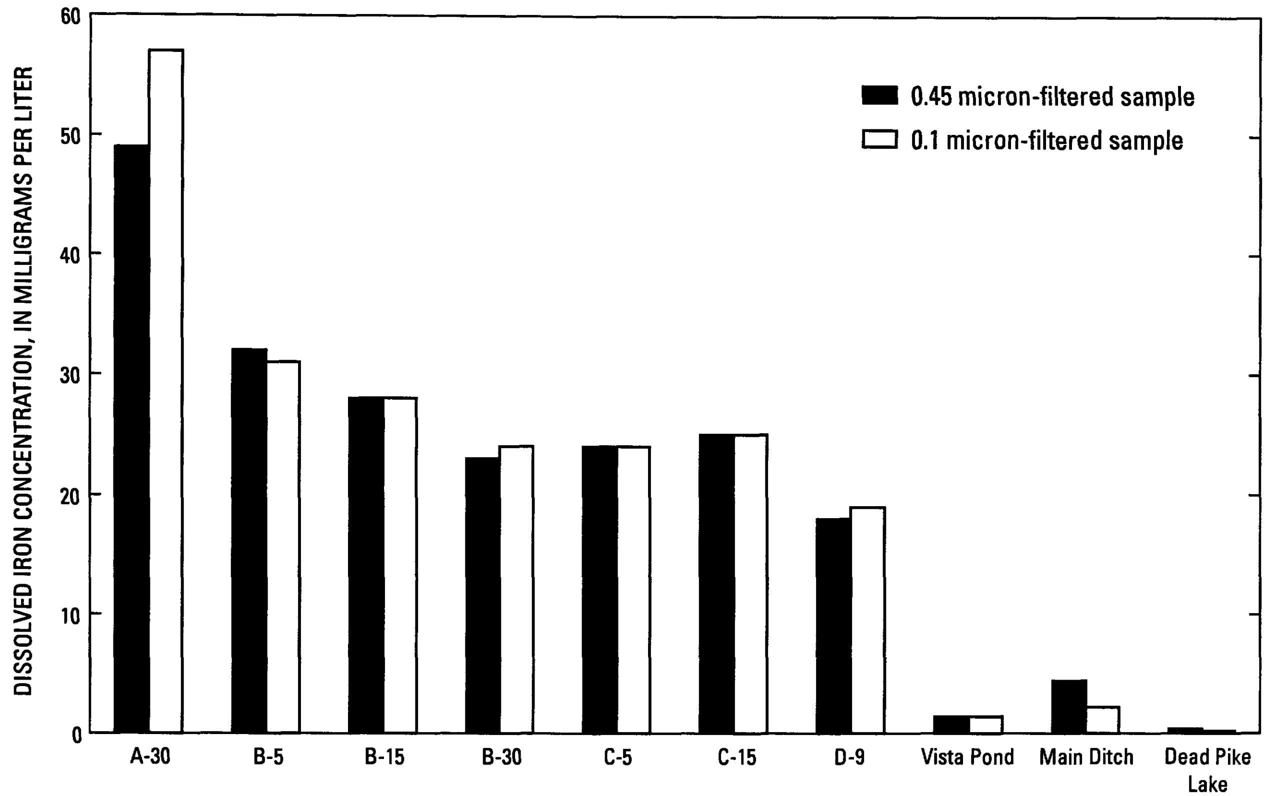

Figure 8. Comparison of iron concentrations in 0.45 micron-filtered water samples, Vilas County, Wisconsin. Location identifiers (for example, A–30) are those from the cross section shown in figure 7.

movement. Ground-water levels measured in nest "C" piezometers indicate upward movement and discharge into the eastern ditch. At nest "A", ground-water levels were identical in the "A-7" and "A-30" piezometers indicating only horizontal flow. Ground-water levels in piezometer nest "B" indicate horizontal movement from site "A" to "B" (west to east) and upward at "B" discharging to the western ditch.

Geochemistry

The form (dissolved and/or precipitated) and transport of iron and manganese in ground water is affected by environmental conditions, particularly in changes of oxidation or reduction. For brevity this discussion will focus on iron but it also applies to manganese. Reduction/oxidation state (or "redox") refers to the relative availability of electron donors or acceptors in aqueous systems (Stumm and Morgan, 1970). Systems with an appreciable concentration of "electron donors" are described as having reducing conditions with a negative Eh value; systems with an appreciable concentration of "electron acceptors" result in oxidizing conditions with a positive Eh value. Dissolved oxygen is an efficient electron acceptor; thus, the presence of dissolved oxygen is considered to be a strong indicator of oxidizing conditions. Generally, iron in a reduced state, Fe (II), is soluble and will travel along with ground water, but iron in an oxidized state, Fe (III), in the presence of oxygen may form a precipitate or oxyhydroxide floc; when in a floc form the iron is not transported with the water. Iron chemistry can be affected by additional complicating factors. For example, iron complexes can form with DOC (Hem, 1989). Fe (II) in complexes may be considerably more resistant to oxidation or the DOC can stabilize Fe (III), preventing or delaying the formation of iron floc. Iron solubility also is a function of pH, the amount of hydrogen ion in solution, but because all waters on Powell Marsh sampled during the study were similar (pH between 5.8 and 6.9, appendix 3), the discussion presented here will focus on the effects of redox and the presence or absence of oxygen.

To gain insight into the processes that lead to the formation of iron floc in the Powell Marsh ditch network, water samples were collected from both surface

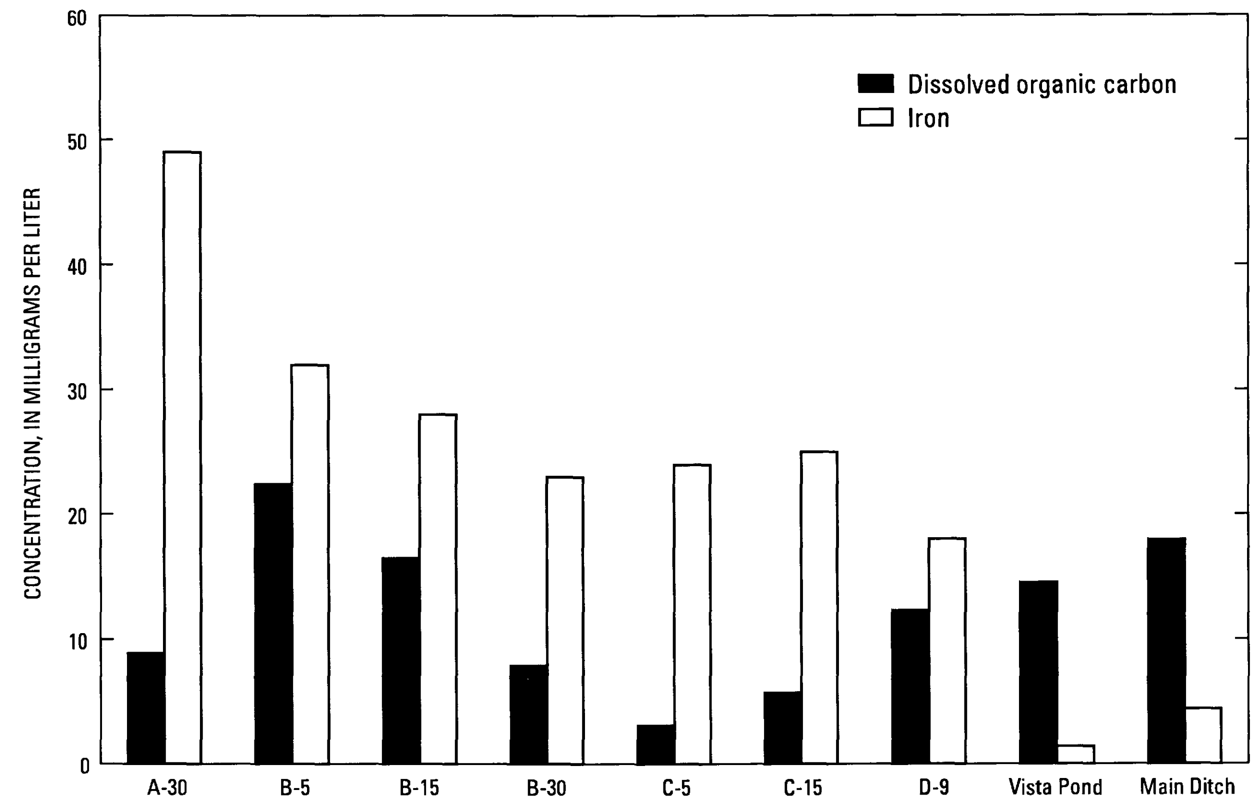

Figure 9. Comparison of dissolved organic carbon concentration to iron in 0.45 micron-filtered water samples, Vilas County, Wisconsin. Location identifiers (for example, A–30) are those from the cross section in figure 7.

and ground water. As previously discussed, the section B-B' is along a flow path that intersects typical Powell Marsh surface-water features (pond and ditch) and the ground-water system. Dissolved iron concentrations were found to be higher than what commonly is found in ground water in northern Wisconsin, a result of the high amounts of naturally occurring iron present in the aquifer. Moreover, the iron measured in the ground water was over ten times higher than concentrations measured in surface water, reflecting the change in the solubility of the iron when exposed to the dissolved oxygen present in the surface water.

The analyses gave near identical iron concentrations for the 0.45 and 0.1 micron-filtered samples (fig. 8) indicating that the iron nominally is "dissolved" or perhaps present as iron (III)-DOC complexes with less than 0.1-micron sizes. The latter transport mechanism has been noted in central Vilas County where high concentrations of iron in ground water were attributable to iron (III)-DOC complexes smaller than 0.1-micron (Krabbenhoft, 1984). The relative importance of DOC-facilitated transport of iron in ground water is not well understood because of the lack of information regarding the DOC quality and the low correlation between DOC and iron concentrations (fig. 9). Although a strong correlation may be expected between high concentrations of iron and DOC if organic molecules play an important factor, it is possible that other factors rather than DOC concentrations limit iron transport. Regardless of the exact iron transport mechanism, it is important to note that water sampling demonstrated that high iron concentrations transported by ground water are precipitated as iron floc when the ground water is discharged into a surface-water body. Thus, it appears that dissolved oxygen in the surface water is able to combine with the iron—whether dissolved or carried by DOC colloids—and form the oxyhydroxide floc.

Iron transport can be explained from a regional flow system perspective. The capacity of ground water to transport iron is related to the redox potential of the ground-water system. The redox potential, in turn, is related to the location in the ground-water-flow system. Infiltrating water from the land surface carries oxygen obtained from the atmosphere; this dissolved oxygen is carried with the infiltrating water as it recharges the ground-water system. The presence of dissolved oxy-

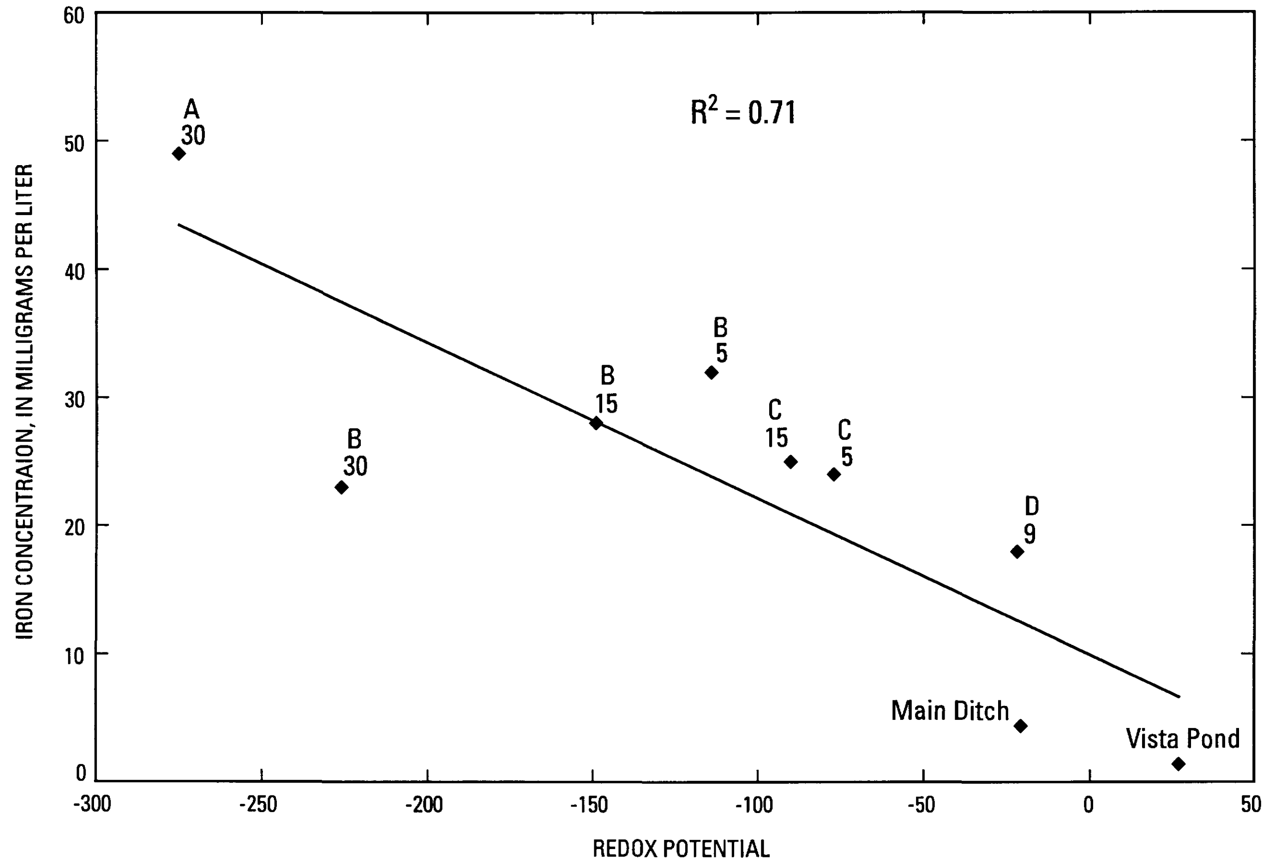

Figure 10. Relation of iron concentration in 0.45 micron-filtered samples to redox potential, Vilas County, Wisconsin. Location identifiers (for example (A–30) are those form the cross section shown in figure 7. [R^2, coefficient of determination, is an indicator that ranges from 0 to 1 and reveals how closely the estimated values for the trendline correspond to the actual data. A trendline is most reliable when its R^2 is at or near 1.]

gen in the recently recharged water causes the water to have a high oxidation potential; thus, iron is in the oxidized form and is not soluble. Along its subsurface flow path, the ground water encounters conditions that can consume the dissolved oxygen, most commonly microbial communities and organic matter (Freeze and Cherry, 1979). Thus, water that has traveled farther, and has had greater exposure to these conditions will contain less dissolved oxygen. Given enough distance the dissolved oxygen will be completely consumed and the ground water becomes reducing. When the ground water becomes sufficiently reducing, iron containing minerals in the aquifer can dissolve and the iron can be transported by the ground-water system.

As the ground water flows from the recharge area to the discharge area, additional water is added to the top of the saturated zone as the aquifer receives recharge from infiltrating water. Thus, deeper water (deeper than the infiltrating water) will have traveled further than shallower water. This result is demonstrated by the field data collected in this study; water samples from deeper piezometers represent longer ground-water-flow paths with more reducing conditions, and more dissolved iron (fig. 10). Water samples from shallower wells represent shorter flow paths with more oxidizing conditions, and lower concentrations of dissolved iron (fig. 10). Surface waters in the ditch and Vista Pool has a constant source of oxygen from the atmosphere, and thus, are always oxidizing. These sites have low dissolved iron, but higher amounts of particulate iron floc representing the change of iron from the dissolved to solid phase. Results from these surface-water samples can be considered to represent the end of the ground-water-flow path.

SUMMARY AND CONCLUSIONS

There is concern that iron floc from Powell Marsh ditches is damaging the aesthetic quality of Dead Pike Lake in western Vilas County, Wis. A study was initiated by the U.S. Geological Survey, in cooperation with Wisconsin Department of Natural Resources to evaluate the effect of Powell Marsh on the hydrology of Dead Pike Lake and to determine the source of iron floc and the potential for its transport from Powell Marsh to Dead Pike Lake.

A calibrated analytic element ground-water-flow model indicates ground water generally flowing from Powell Marsh to the northwest toward Dead Pike Lake and west toward Little Lost Creek. Simulation results indicate that, from the south part of its watershed, Dead Pike Lake receives about 2.4 ft^3/s of ground water and 1 ft^3/s of surface water. If the Powell Marsh structures were removed, Dead Pike Lake would receive about 3 ft^3/s of ground-water flow and 0.5 ft^3/s of surface water. These results show that Powell Marsh hydrologic structures change the distribution of the water budget components but not the overall water budget for Dead Pike Lake.

Water levels measured along a west to east flow path indicate that water moves from Vista Pond and the marsh and discharges to ditches. Analyses of ground and surface waters along the flow path indicate that dissolved iron is relatively high in ground water and low in surface water (the ditches and Vista Pond). Naturally occurring dissolved iron in ground water derived from surficial deposits is the source of iron floc in the Powell Marsh ditches and is coincident with iron floc observations. Iron and manganese precipitate and form a floc when the ground water discharges to the ditches. The transport and form of iron and manganese in the water of the Dead Pike Lake area can be explained by oxidation/reduction. If ditches were removed, floc forming in the ditches would no longer be available for transport because the environment that is suitable for floc formation would be removed. However, it is likely that the floc formation may be redirected to the near-shore environment in Dead Pike Lake where ground water discharges.

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APPENDIXES 1–3

TABLES

Table A1. Location of lake and stream-elevation measurements

[GPS, Global Positioning System, UTM, Universal Transverse Mercator]

UTM X (meters)	UTM Y (meters)	Wisconsin State Plane X (feet)	Wisconsin State Plane Y (feet)	Elevation (ft above sea level)	Site description as stored by GPS unit	
277220.164	5109501.046	1998266.352	342048.660	1602.177	OS10WSELSTEPPINGSTONE1	Stepping Stone Lake
277811.938	5109570.273	2000197.393	342348.821	1602.173	OS3STEPPINGSTONEWSEL	Stepping Stone Lake
277811.940	5109570.264	2000197.400	342348.792	1602.091	OS3STEPPINGSTONEWSEL	Stepping Stone Lake
279810.783	5110428.704	2006642.604	345409.935	1600.651	OS4WSELLITTLESTAR	Little Star Lake
266879.437	5106898.464	1964696.496	332238.745	1573.122	OS16BEARCRWSEL	Bear Cr. just below confluence with Sugarbush Cr.
267361.024	5112778.056	1965546.831	351568.521	1579.718	OS17WSELMANITOWISHRIVER	Manitowish River
269737.588	5107708.014	1973963.784	335245.707	1581.740	OS7LITTLELOSTCRATHWY47	Little Lost Creek at HWY 47
269826.063	5107395.008	1974292.505	334230.775	1581.866	OS14AND021WSELUP	Little Lost Cr. just above Bear Cr.
269840.285	5107382.666	1974340.646	334192.083	1579.243	OS14AND021WSELDN	Little Lost Cr. just above Bear Cr.
270521.432	5109420.954	1976320.765	340956.920	1589.061	OS13WSELSAYBEACH	Sandy Beach Lake
270746.324	5108557.393	1977164.765	338154.411	1583.210	0S8WSEL	Little Lost Cr. at old RR xing ~0.6 mi NW of Powell
275165.329	5113110.888	1991084.317	353625.917	1589.416	OS18WSEL	Manitowish River
272997.496	5106273.166	1984825.788	330946.327	1599.660	OS15WSELSHERMAN	Sherman Lake
273509.426	5104589.893	1986711.967	325492.603	1594.365	OS6SUGARBUSHONHWY47	Sugarbush Creek at HWY 47
274283.559	5109939.827	1988587.014	343123.276	1592.655	OS11WSEL	Little Lost Cr. ~0.6 mi. downstream of Dead Pike Lake
274295.455	5110390.505	1988570.197	344601.887	1598.922	OS12WSELPIERLAKE	Pier Lake
274383.279	5102411.882	1989845.528	318462.055	1597.613	OS5WSELUP	Lower Sugarbush Lake outlet
275455.109	5108314.956	1992628.050	337942.619	1596.229	OS1WSEL	Dead Pike Lake Inlet at Powell Rd.
276712.848	5108843.115	1996685.027	339829.404	1595.887	WSELDEADPIKE	Dead Pike Lake

Table A2. Locations of piezometers and Vista Pond along section B-B'
[GPS, Global Positioning System; UTM, Universal Transverse Mercator]

UTM X (meters)	UTM Y (meters)	Wisconsin State Plane X (feet)	Wisconsin State Plane Y (feet)	Elevation (ft above sea level)	Site description as stored by GPS unit	
275792.215	5107873.055	1993787.653	336535.960	1600.547	WELLA30	Piezometer A-30
275816.789	5107864.372	1993869.272	336510.543	1600.686	WELLB5	Piezometer B-5
275817.327	5107864.364	1993871.034	336510.583	1600.686	WELLB15	Piezometer B-15
275817.993	5107864.321	1993873.223	336510.523	1600.463	WELLB30	Piezometer B-30
275831.288	5107862.842	1993916.981	336507.321	1597.751	VISTAPONDDNWSEL	Vista Pond
275834.537	5107864.213	1993927.461	336512.219	1601.305	WELC15	Piezometer C-15
275834.585	5107863.701	1993927.681	336510.544	1601.546	WELLC5	Piezometer C-5
275840.267	5107860.934	1993946.646	336502.178	1606.114	WELLD9	Piezometer D-9
275847.110	5107863.396	1993968.771	336511.096	1602.154	VISTAPONDWSEL	Vista Pond

Table A3. Locations of water level measurements upstream and downstream of Powell Marsh structures
[GPS, Global Positioning System; UTM, Universal Transverse Mecator]

UTM X (meters)	UTM Y (meters)	Wisconsin State Plane X (feet)	Wisconsin State Plane Y (feet)	Elevation (ft above sea level)	Site description as stored by GPS unit
275834.007	5108254.793	1993877.372	337792.325	1602.170	008WSELUP
275823.753	5107796.328	1993900.519	336288.382	1597.794	009WSELDN
275826.451	5107784.989	1993910.765	336251.551	1603.271	009WSELUP
275816.945	5107625.388	1993899.365	335727.262	1603.234	010WSELUP
275807.278	5107622.181	1993868.080	335715.554	1602.212	010WSELDN
275802.468	5106643.838	1993973.412	332508.324	1603.206	011WSELUP
275803.275	5106651.756	1993975.077	332534.376	1603.255	011WSELDN
276577.150	5107279.865	1996433.790	334688.851	1604.861	012WSELDN
276577.602	5107273.447	1996436.066	334667.869	1605.266	012WSELUP
276488.424	5107352.898	1996133.939	334917.246	1603.182	013WSELDN
276492.231	5107334.801	1996148.658	334858.402	1603.538	013WSELDNWEST
276495.515	5107348.918	1996157.675	334905.079	1604.891	013WSELUP
276570.225	5107391.225	1996397.307	335052.990	1604.818	014WSELDN
276576.253	5107399.411	1996416.050	335080.568	1605.555	014WSELUP
277347.164	5106801.698	1999016.789	333216.883	1605.954	015WSELDN
277348.531	5106793.997	1999022.224	333191.811	1607.655	015WSELUP
277281.731	5106788.424	1998803.967	333165.277	1604.812	016WSELDN
277286.445	5106783.990	1998819.966	333151.328	1607.526	016WSELUP
277244.408	5108333.815	1998490.332	338225.898	1603.115	017WSELDN
277252.425	5108328.563	1998517.260	338209.678	1605.534	017WSELUP
274679.631	5106866.575	1990265.647	333099.424	1598.830	018WSELDN
274687.414	5106875.531	1990290.046	333129.740	1602.278	018WSELUP
275820.763	5108252.980	1993834.188	337784.741	1597.091	WSELDNDAMATSTRUCT

Appendix 2. Flow and ground-water level measurements

[UTM, Universal Transverse Mecator; ft^3/s, cubic feet per second; MP, measuring point; LS, land surface; ~, approximately; --, no data]

Site	UTM (meters)	Wisconsin State Plane (feet)	Date	Time	Flow (ft^3/s)
Dead Pike Lake Inlet at Powell Rd.	275455.109 5108314.956	1992628.050 337942.619	6/15/00	1204–1232	0.92
			7/20/00	2005–2020	3.35
Lower Sugarbush Lake outlet	274383.279 5102411.882	1989845.528 318462.055	6/14/00	0840–0852	2.99
			7/21/00	0849–0859	4.7
Bear Cr. Just below confluence with Sugarbush Cr.	266879.437 5106898.464	1964696.496 332238.745	6/14/00	0930–0945	.96
			7/21/00	0924	1.03
Little Lost Cr. Just above Bear Cr.	269826.063 5107395.008	1974292.505 334230.775	6/14/00	1035–1050	8.84
			7/21/00	0950–1013	7.69
Little Lost Cr. at old RR xing ~0.6 mi NW of Powell	270746.324 5108557.393	1977164.765 338154.411	6/14/00	1125–1145	14.2
			7/21/00	1043–1100	7.04
Little Lost Cr. ~0.6 mi. downstream of Dead Pike Lake	274283.559 5109939.827	1988587.014 343123.276	6/15/00	1393–1405	2.35
			7/21/00	1021–1141	8.12
Pool outlet of pool just south of Vista Pond			7/20/00	~1930	1.46
Vista Pool outlet			7/20/00	~1940	1.07
	UTM (meters)	**Wisconsin State Plane (feet)**	**MP Elevation (feet)**	**LS Elevation (feet)**	
Vista Pond	275847.110 5107863.396	1993968.771 336511.096	1602.154	--	
Piezometer A-7	275793.215 5107873.055	1993790.933 336535.960	1602.904	1599.719	
Piezometer A-30	275792.215 5107873.055	1993787.653 336535.960	1600.547	1599.717	
Piezometer B-5	275816.789 5107864.372	1993869.272 336510.543	1600.686	1599.476	
Piezometer B-15	275817.327 5107864.364	1993871.034 336510.583	1600.686	1599.606	
Piezometer B-30	275817.993 5107864.321	1993873.223 336510.523	1600.463	1599.573	
Piezometer C-5	275834.585 5107863.701	1993927.681 336510.544	1601.546	1599.626	
Piezometer C-15	275834.537 5107864.213	1993927.461 336512.219	1601.305	1600.075	
Piezometer D-9	275840.267 5107860.934	1993946.646 336502.178	1606.114	1600.554	

Appendix 3. Powell Marsh—Dead Pike Lake water analyses along section B-B'

[mg/L, milligrams per liter; °C, degrees Celsius; organic C, organic carbon; Mn, manganese; Fe, iron; --, no data]

Site	Date	Sample treatment	Organic C mg/L	Mn mg/L	Fe mg/L	Temperature °C	Specific conductance	Dissolved oxygen mg/L	pH	Redox
Piezometer A-30	6/14/00	Raw water	9.21	0.93	58	7.4	41	0.17	6.8	-275
		0.45 micron	8.88	.85	49					
		0.1 micron	8.62	.95	57					
Piezometer B-5	6/15/00	Raw water	23.39	.43	33	10.45	24	.2	6.2	-114
		0.45 micron	22.43	.44	32					
		0.1 micron	24.94	.43	31					
Piezometer B-15	6/15/00	Raw water	16.37	.59	29	9.15	26	.19	6.5	-149
		0.45 micron	16.49	.61	28					
		0.1 micron	15.91	.61	28					
Piezometer B-30	6/14/00	Raw water	8.56	1.2	61	9.83	40	.2	6.9	-226
		0.45 micron	7.89	.94	23					
		0.1 micron	8.74	.95	24					
Piezometer C-5	6/15/00	Raw water	3.25	.2	26	12.36	13	.29	6.2	-77
		0.45 micron	3.12	.2	24					
		0.1 micron	3.44	.19	23					
Piezometer C-15	6/15/00	Raw water	8.98	.31	27	11.3	17	.22	6.2	-90
		0.45 micron	5.72	.3	25					
		0.1 micron	5.26	.3	25					
Piezometer D-9	6/15/00	Raw water	9.79	.19	19	12.28	11	.24	5.8	-22
		0.45 micron	12.33	.19	18					
		0.1 micron	11.45	.2	19					
Vista Pool	6/15/00	Raw water	13.38	.01	2.4	17.5	21	7.94	6	27
		0.45 micron	14.55	.01	1.4					
		0.1 micron	18.55	.01	.71					
Main Ditch	6/15/00	Raw water	17.85	.07	10	17.23	80	6.35	6	-21
		0.45 micron	17.97	.06	4.4					
		0.1 micron	14.56	.05	2.2					
Dead Pike Lake	7/20/00	Raw water		.02	.98	22.6	76	8.82	7.3	--
		0.45 micron		.00	.37					
		0.1 micron		.00	.2					

Hydrologic Investigation of Powell Marsh and its Relation to Dead Pike Lake, Vilas County, Wisconsin

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