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HYDROLOGY OF WISCONSIN WETLANDS

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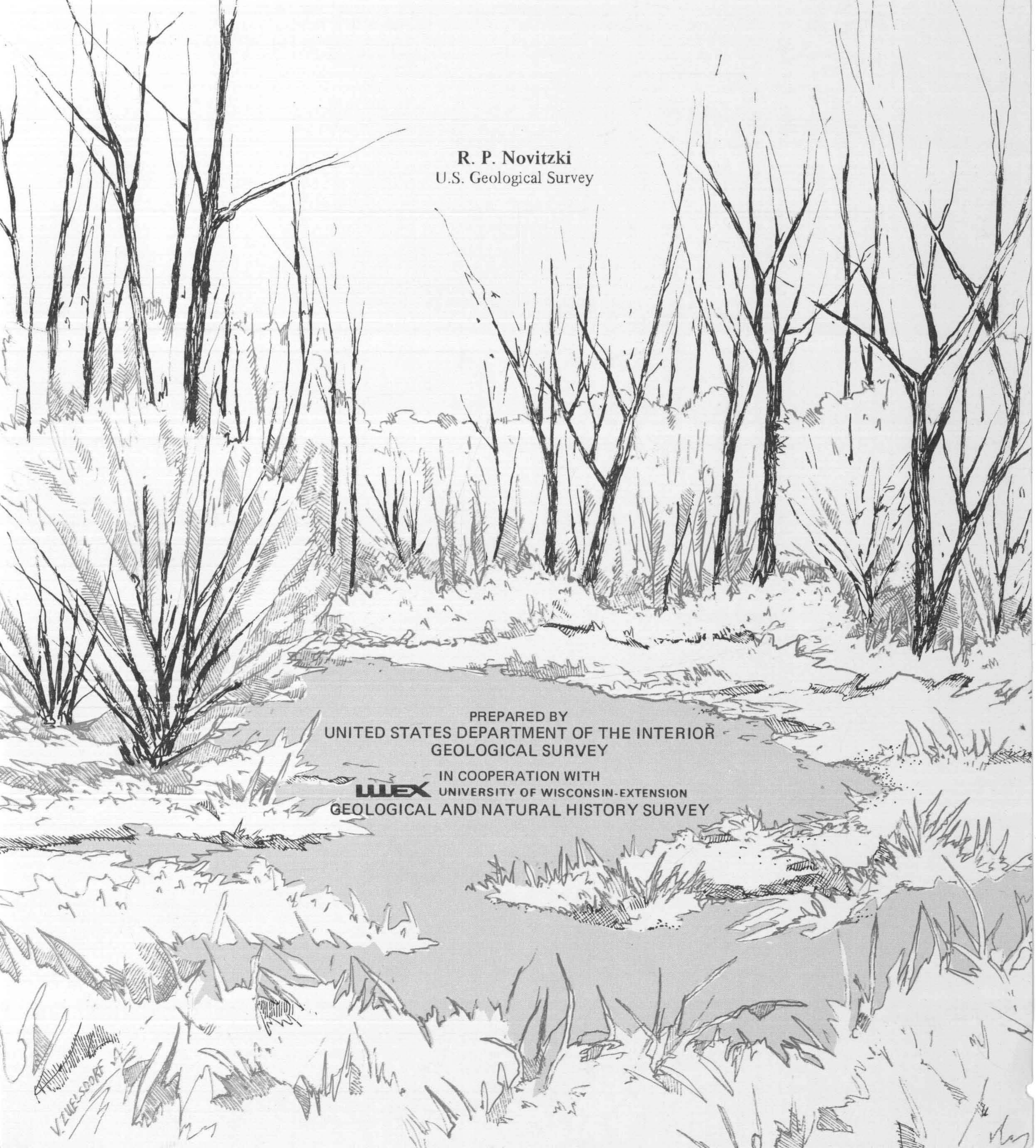

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This report is a product of the Geological and Natural History Survey Water Resources Program which includes: systematic collection, analysis, and cataloguing of basic water data; impartial research and investigation of Wisconsin's water resources and water problems; publication of technical and popular reports and maps; and public service and information. Most of the work of the Survey's Water Resources Program is accomplished through state-federal cooperative cost sharing with the U.S. Geological Survey, Water Resources Division.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
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UNIVERSITY OF WISCONSIN–EXTENSION
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To convert inch/pound units to SI (metric) units:

Multiply	By	To obtain
in (inch)	2.540×10^1	mm (millimeter)
ft (foot)	3.048	m (meter)

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ABSTRACT

Data from 15 wetland study sites, supplemented by data from reconnaissance visits to 219 additional wetlands, were used to describe the hydrologic characteristics of Wisconsin wetlands and to suggest a simple hydrologic classification system. Wisconsin's wetlands occur in depressions and on slopes. They may be in contact with ground water or totally surface-water supported. Hydrologically, wetlands may be classed as surface-water depression, surface-water slope, ground-water depression, or ground-water slope wetlands. Precipitation comprises more than half of the inflow to all but the ground-water slope wetlands, where ground water may provide as much as 90 percent of the inflow. Flood peaks may be as much as 80 percent lower in basins with much wetland area than in similar basins with little or no wetland area. Ground-water recharge appears to be less in basins with much wetland area than in basins with little or no wetland area. Wetlands retain sediment, and sediment loads in streams draining basins with much wetland area may be 90 percent lower than those in streams draining basins with little or no wetland area.

INTRODUCTION

"Can we save our wetlands?" ask legislators, scientists, students, farmers, and other concerned citizens in Wisconsin. "Estimated losses to drainage, filling, and grazing exceeds 20,000 acres each year," proclaims a pamphlet distributed by the Wisconsin Chapter of the Wildlife Society, College of Natural Resources, Stevens Point, Wis. These and numerous other such statements indicate a legitimate concern that wetlands are being converted to other uses without proper regard for values lost. However, efforts to justify wetland preservation are emotional and often based on a poor understanding of wetland characteristics, functions, and values. For example, during hearings on proposed wetland-protection legislation, legislators were told that wetlands are "worth $70,000 per acre for water supply alone," this was based on statements such as: "wetlands are an important water-supply resource ..." (Heeley, 1973, p. 46). Mr. Heeley modifies this statement in the following sentence saying that "... wetlands are commonly associated with areas of high ground-water favorability...", indicating that the ground-water reservoir, not the wetland, is the water-supply resource. Another popular misconception is that wetlands are major ground-water recharge areas. Carter and others (1979, p. 351-352) conclude that there is little evidence to suggest that significant recharge to ground water occurs in wetlands. Wetlands occupy about 74 million acres of the 48 contiguous states (Shaw and Fredine, 1956, table 6), or less than 4 percent of the approximately 3 million square miles (1.9 billion acres)(Webster, 1977, p. 1,252), so that it is unlikely that the majority of ground-water recharge occurs in such a small area. Wetlands also are known to reduce floods, improve water quality, and provide wildlife habitat, as demonstrated by previous studies. Many of these studies are described in summaries such as "Our Nation's Wetlands" (Horwitz, 1978) and "Wetland Functions and Values: The State of Our Understanding" (Greeson and others, 1979).

This report attempts to fill a few gaps in our understanding of wetlands. The emphasis is on the hydrologic characteristics of wetland sites because these are least understood. The study provides estimated water budgets at representative sites to identify the relation between wetlands and ground and surface waters. The study was too limited in scope and time to adequately quantify the influence

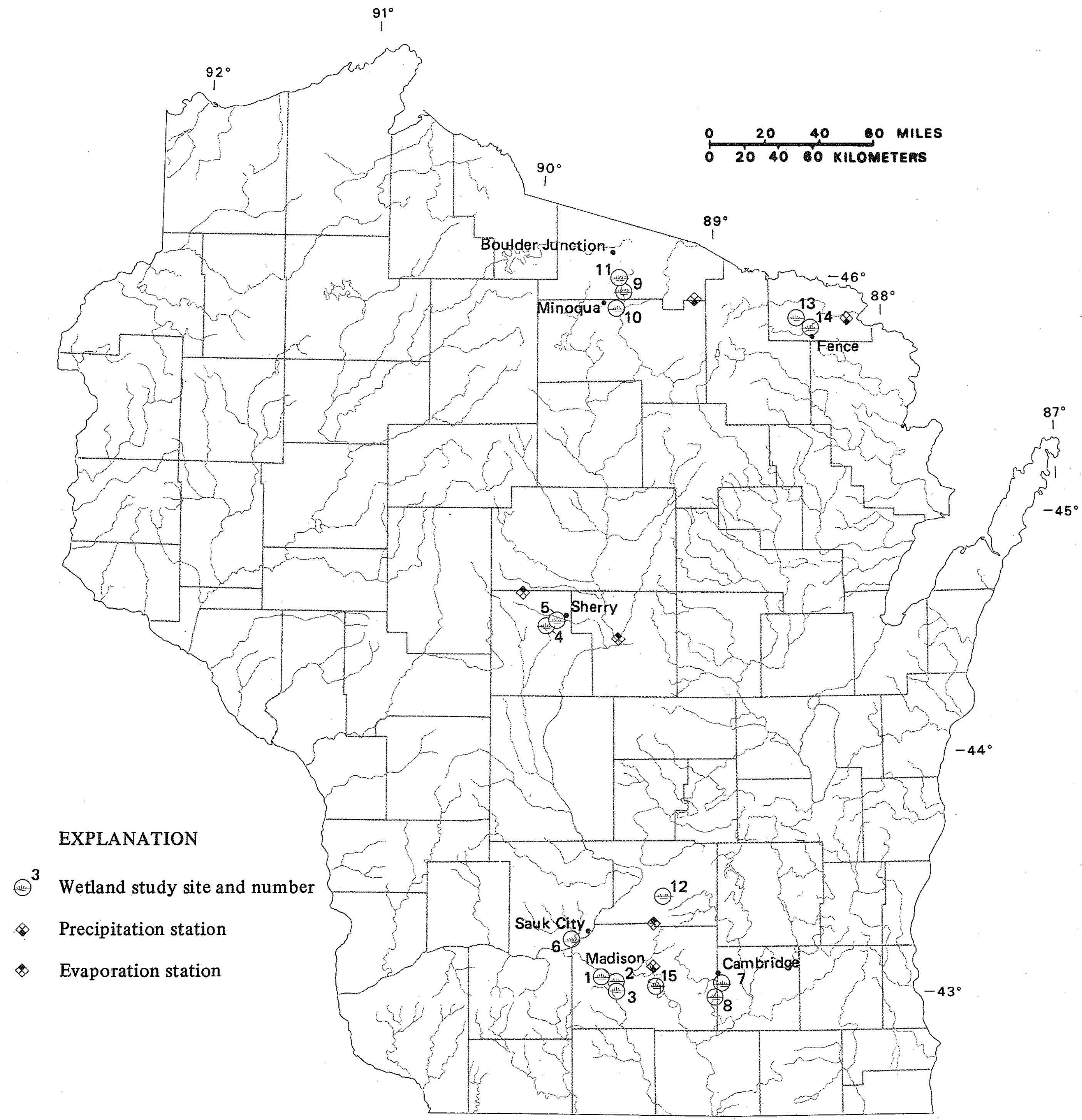


Figure 1. Location of wetland study sites and precipitation and pan evaporation stations.

of wetlands on floods, recharge, and sediment loads in streams, but these aspects were examined by analysis of information provided by earlier studies. A simple hydrologic classification was developed to suggest the relative importance of different components of the water budget in wetlands other than those included in this study. This information may assist other investigators in understanding the relation between hydrology and vegetation, soils, and other wetland characteristics.

This study was conducted by the U.S. Geological Survey in cooperation with the University of Wisconsin-Extension, Geological and Natural History Survey. Thanks are extended to those property owners and State personnel who allowed access to their wetlands, and to those many individuals who have taken the time to discuss wetland hydrology.

APPROACH

This report is based on data from 15 wetland sites, supplemented by data from reconnaissance visits to another 219 wetlands throughout the State. Figure 1 shows the location of the 15 study sites. These sites were visited monthly and water levels in observation wells and open water, streamflow, soil moisture, and water-quality parameters were measured. The thickness and nature of organic material and the type of underlying mineral soil were determined.

Additional hydrologic, geologic, and climatologic data were obtained from other sources. The Hydrologic Atlas series for Wisconsin, published by the U.S. Geological Survey (Cotter and others, 1969; Devaul and Green, 1971; Young and Hindall, 1972; Hindall and Borman, 1974; and Oakes and Cotter, 1975) provided information on surficial and bedrock geology and surface-water and ground-water characteristics. Data from seven weather stations (fig. 1) provided climatic data (four precipitation stations and three evaporation stations). Figure 2 shows the extent of glacial aquifers (from Devaul, 1975) and the distribution of wet soils (from a map by Frazier and Kiefer, 1974).

A water budget which includes estimates of inflows and outflows was developed for each wetland. The water budget is written as:

$$P + OF + SWI + GWI = ET + SWO + R$$

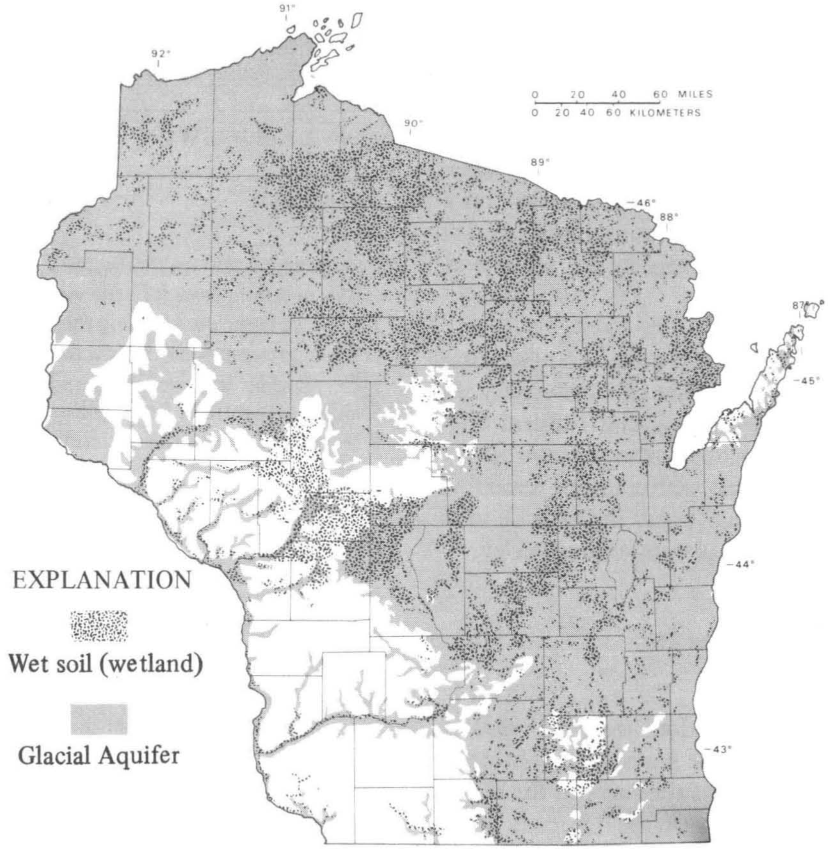
where:

P = precipitation on the wetland, in inches,
OF = overland flow into the wetland,
SWI = streamflow entering the wetland,
GWI = ground-water inflow to the wetland,
ET = evapotranspirative losses from the wetland,
SWO = streamflow leaving the wetland, and
R = recharge from the wetland to ground water.

The water-budget terms are converted to inches of water on the wetland surface. The water budget is defined for the period 1975 through 1977. Precipitation during this period averaged 29 in. per year, compared to a long-term statewide average of 32 in., so the study period should be representative of near-normal conditions.

Inflow to the wetland may include precipitation on the wetland, overland flow, streamflow, and ground-water inflow. Precipitation (P) is the annual average for 1975 through 1977, as reported by the precipitation station nearest the wetland. Overland flow (OF) is estimated by summing the precipitation that occurred from November through April and multiplying by a factor between 0 and 1. The factor is based on the author's judgment that considers the permeability of the upland soils, topographic characteristics such as slope and relief, and other characteristics that would influence runoff. The factors used ranged from 0.1 to 0.4 for the wetland sites. The streamflow into the wetland area (SWI) is based on streamflow measurements or available streamflow data for the period 1975 through 1977. Ground-water flow into the wetland (GWI) is estimated from water-table gradients, the cross section through which water can move into the wetland, and estimated aquifer characteristics.

Outflow from the wetland includes evaporation from open-water surfaces, plant transpiration,



Wet soils map by B.E. Frazier
and R.W. Kiefer, 1974.
Limit of glacial aquifer from
Devaul, 1975.

Figure 2. Distribution of glacial aquifer and wet soils.

streamflow leaving, and recharge to ground water. Evaporation estimates from open-water surfaces are based on reported pan evaporation for the nearest evaporation station times the standard conversion factor 0.7. Evaporation is estimated only for open-water areas associated with the wetland. Transpiration estimates consider the vegetative community and the availability of water. For those wetlands with no open water and no surplus water during the growing season, transpiration is assumed to equal "actual evapotranspiration" calculated using the Thornthwaite technique (1957). This number is the ET term published in the Hydrologic Atlases (Cotter and others, 1969; Devaul and Green, 1971; Young and Hindall, 1972; Hindall and Borman, 1974; and Oakes and Cotter, 1975). For those wetlands with dense vegetation and surplus water through most of the growing season, evaporation and transpiration are estimated together (ET) and ranged from 0.7 to 1.3 times measured pan evaporation. Streamflow away from the wetland (SWO) is based on streamflow measurements or available streamflow data for the period 1975 through 1977. Recharge, or infiltration losses occurring within the wetland area (R), are obtained by subtracting ET plus SWO from the total inflow, and the result is compared to ground-water flow computed using Darcy's Law to assure reasonable values.

The estimated inflows and outflows are crude, but provide a means to compare water budgets for different wetland types.

Temperature, conductance, pH, hardness, alkalinity, and dissolved oxygen were measured in the field in water from ponds, lakes, or streams associated with the wetland, from the wetland surface when standing water was present, and from wells within and near the wetland. Conductance was measured with meters having appropriate ranges (0 to 1,000 or 50 to 10,000 micromhos) for the different wetland sites. The pH values were determined principally with a colorcomparison kit having a range of 4.0 to 10.0 pH units and a sensitivity of 0.5 pH unit and a few readings were obtained with a pH meter. Hardness and alkalinity were determined by titration techniques with a sensitivity of 0.5 grain/gal [8.5 mg/L (milligrams per liter)]. Dissolved oxygen was determined by a titration technique with a sensitivity of 0.5 mg/L. Chloride concentrations in samples from wetlands in the northern half of the State were determined using a titration technique with a sensitivity of 0.1 mg/L chloride. Water samples also were obtained seasonally and analyzed in the USGS regional laboratory for the common cations and anions, the several nitrogen species, and dissolved organic carbon.

Soil moisture was determined within the wetland, at the transition from wetland to upland, and on the upland. The moisture content was determined using powdered carbide to convert moisture to gas pressure.

The thickness and nature of organic material was determined at the wetland sites. A 1-in.-diameter soil auger was used to determine the thickness of organic deposits and the type of mineral soil beneath the organics. A McCullough sampler was used to identify differences within the peat, muck, and marl deposits.

WETLAND CHARACTERISTICS

The occurrence and distribution of wetlands in Wisconsin are related to the extent of glaciation. Wetlands are common on glacial aquifers in the interior of the State and near the Great Lakes (see fig. 2). They are uncommon in the unglaciated part of the State except in stream valleys filled with glacial drift or alluvium. Their occurrence appears to be related to water supply, which is affected by climate. Surface-water supplies are more constant if rainfall is relatively uniform rather than seasonally concentrated. Ground-water supplies are not as sensitive to nonuniform precipitation. The difference between evapotranspiration and precipitation also affects wetland water supply. In the northern parts of the State, precipitation exceeds evaporation by a greater amount than in the southern and western parts, where they are approximately equal (fig. 3).

Proposed Hydrologic Classification System

Wetlands can be characterized in terms of hydrology, vegetation, and soils; each has an influence on the other two. Wetland classifications have traditionally grouped wetlands by similarities in water depth and duration of flooding, plant communities, and soil types (Martin and others, 1954; Stewart and Kantrud, 1971; Golet and Larson, 1974). The most recent classification, developed by the U.S. Fish and Wildlife Service (Cowardin and others, 1979) separates wetlands into classes and subclasses based on plant life form or substrate type, and provides descriptors for water regime, water chemistry, and soil type. These classification schemes do not stress the hydrologic similarities and differences among wetlands, so they do not allow extrapolation of hydrologic data to other sites. For this report, we have correlated the terminology used by these authors. The resultant 15 wetland types, and their equivalents, are shown on table 1.

Wisconsin's wetlands occur in depressions and on slopes; they all receive surface water but some also receive ground water. The wetland's relation to ground water and surface water, and its location either on a slope or in a depression, accounts for the major hydrologic differences. A simple hydrologic classification based on wetlands visited in this study includes four classes: *Surface-Water Depression, Surface-Water Slope, Ground-Water Depression,* and *Ground-Water Slope.* Wetland class, where mentioned in the remainder of the text, refers to these four classes except where otherwise noted.

Surface-Water Depression Wetlands

A surface-water depression wetland occurs where precipitation and overland flow collect in a depression (fig. 4). This wetland's distinguishing characteristic is that water leaves only by recharge or by evapotranspiration. Wetland conditions will be maintained if the depression bottom retards recharge. The bottom of the depression is above the local water table most of the time.

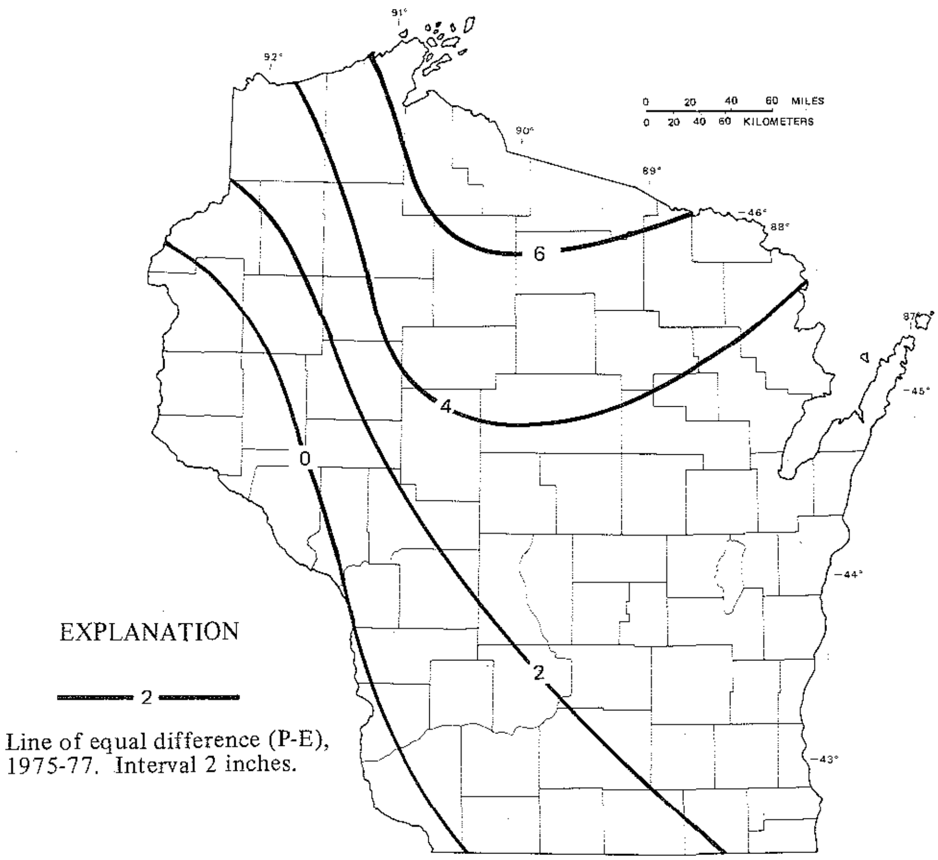


Figure 3. Annual precipitation (P) minus evaporation (E) in Wisconsin, 1975-77.

Three of the four surface-water depression wetlands studied in detail occur in closed depressions. Site 4 occurs in a shallow depression that easily overflows. All of the sites occur in glacial drift only a few feet thick that overlies sandstone. The water table is nearly 100 ft below land surface at wetland sites 1 and 2, but only a few feet below sites 3 and 4, where it may occasionally rise to the level of the wetland. In local terminology (which is used in this report), site 1 is a "seasonally flooded" basin, site 2 is a "shallow marsh", site 3 is a "pond", and site 4 is a "shrub swamp". (See table 1 for comparable terms).

Water budgets were estimated for the four surface-water depression wetlands (table 2). The annual average precipitation at all four sites was 29 in. Estimated overland inflow ranged from 1 to 58 in. Estimated ET ranged from 25 in. at site 4, which is dry for much of each growing season, to 39 in. at sites 2 and 3. Estimated typical recharge ranged from 0 to 34 in. Recharge at site 4 was estimated at zero because little water ponds there. The depression is so shallow that water quickly fills it and excess water flows away as streamflow. Holes were drilled through the wetland bottom and into the underlying sandstone to drain site 1, so the 55 in. of recharge is not typical. Normal recharge from site 1 may be comparable to the 3 in. of recharge from site 2.

Water levels in surface-water depression wetlands are typically high in spring and decline through the rest of the year (fig. 5); periodic rises may result from intense storms.

Water levels fluctuate widely in small wetlands that receive much overland flow. Water levels in surface-water depression wetlands decline as water is lost by ET and recharged to the ground. Re-

Table 1. Correlation of wetland types used in this report with those of other investigators.

Terminology used in this report	Terminology used by other investigators		
	Bedford and others, 1974, p. 53-67	Shaw and Fredine, 1956, p. 20-22	Cowardin and others, 1979, p. 4-26
1. Seasonally flooded basin	Sedge-grass meadow	Seasonally flooded basin	Palustrine persistent emergent wetland, seasonally flooded, fresh, alkaline, mineral soil
2. Shallow marsh	Shallow marsh	Inland shallow fresh marsh	Lacustrine littoral, unconsolidated mud bottom, semipermanently flooded, fresh, alkaline, mineral soil
3. Pond	Deep water marsh	Inland deep fresh marsh	Lacustrine littoral, unconsolidated mud bottom, intermittently exposed, fresh, circumneutral, mineral soil
4. Shrub swamp	Shrub carr	Shrub swamp	Palustrine scrub-shrub wetland, saturated, fresh, circumneutral, mineral soil
5. Seasonally flooded flat	Sedge-grass meadow	Seasonally flooded flat	Palustrine persistent emergent wetland, intermittently flooded, fresh, acid to alkaline, mineral soil
6. River flood-plain forest	River flood-plain forest	Wooded swamp	Palustrine broad-leaved deciduous forested wetland, temporarily flooded, fresh, alkaline, mineral soil
7. Shallow lake-edge marsh	Shallow marsh	Inland shallow fresh marsh	Palustrine persistent emergent wetland, intermittently exposed, fresh, alkaline, mineral soil
8&10. Forested bog	Bog	Wooded swamp	Palustrine needle-leaved deciduous forested wetland, saturated, fresh, acid, organic soil
9&11. Shrub bog	Bog	Shrub swamp	Palustrine scrub-shrub wetland, saturated fresh, acid, organic soil
12. Marsh	Deep water marsh	Inland deep fresh marsh	Palustrine persistent emergent wetland, saturated, fresh, circumneutral to alkaline, mineral soil
13. Hardwood swamp	(no term)	Wooded swamp	Palustrine broad-leaved deciduous forested wetland, semipermanently flooded, fresh, circumneutral to alkaline , organic soil
14. Cedar swamp	(no term)	Wooded swamp	Palustrine needle-leaved evergreen forested wetland, saturated, fresh, circumneutral to alkaline, organic soil
15. Wet meadow	Shrub carr	Inland fresh meadow	Palustrine persistent emergent wetland, saturated, fresh, alkaline, organic soil

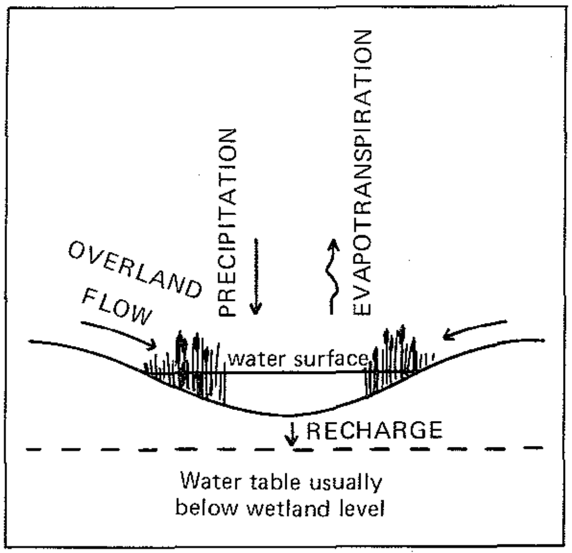


Figure 4. Flow components of surface-water depression wetlands.

charge occurs as long as water is present, but ET occurs largely during the growing season so that water-level declines are rapid in the growing season, but slower in the winter (fig. 5). Water-level declines also are rapid in wetlands where much recharge occurs, but slower in wetlands where little recharge occurs.

Surface-Water Slope Wetlands

A surface-water slope wetland occurs along the margins of lakes and streams (fig. 6). The wetland includes the shallow part of the lake or river and extends up the slope to a point that is flooded occasionally. This wetland's distinguishing characteristics are that it may receive lake or river floodwaters, it is usually above the local water table, and the water drains readily as stages fall.

Three surface-water slope wetlands were studied. Wetland site 5 occurs on the flood plain of a small, intermittent stream, and wetland site 6 occurs on the flood plain of a large river. A lake-edge wetland, site 7, was studied but data obtained were not adequate to define a water budget. Site 5 occurs on silty, clayey glacial deposits, less than 5 ft thick, that overlie sandstone. The water table in the sandstone aquifer is below the wetland. Site 6 occurs in river-valley outwash deposits that may be as much as 200 ft thick. The water table in the sandy outwash averages 2 ft below the wetland, but it ranges from several feet above land surface when the wetland is flooded, to 3 or 4 ft below land surface when river stages have been low for extended periods.

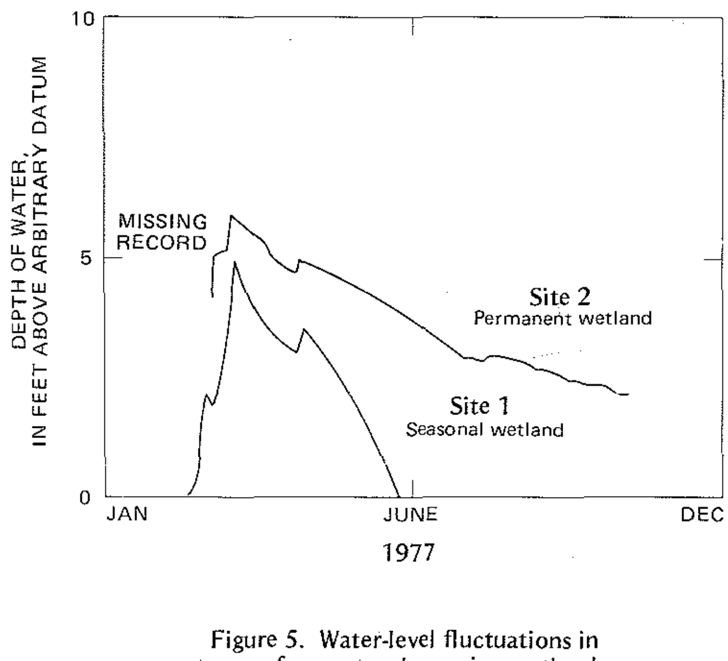


Figure 5. Water-level fluctuations in two surface-water depression wetlands.

Table 2. Average annual water budgets for four surface-water depression wetlands, 1975-77.

Wetland type	INFLOW (inches on wetland)		OUTFLOW (inches on wetland)		
	Precipitation	Overland flow	Evapotranspiration	Recharge	Streamflow out
1. Seasonally flooded basin	29 (33 percent)	58 (67 percent)	32 (37 percent)	*55 (63 percent)	----
2. Shallow marsh	29 (69 percent)	13 (31 percent)	39 (93 percent)	3 (7 percent)	----
3. Pond	29 (40 percent)	44 (60 percent)	39 (53 percent)	34 (47 percent)	----
4. Shrub swamp	29 (97 percent)	1 (3 percent)	25 (83 percent)	0	**5 (17 percent)

* Recharge from site 1 is atypical.

** There will only be streamflow away from shallow depressions that occasionally overflow.

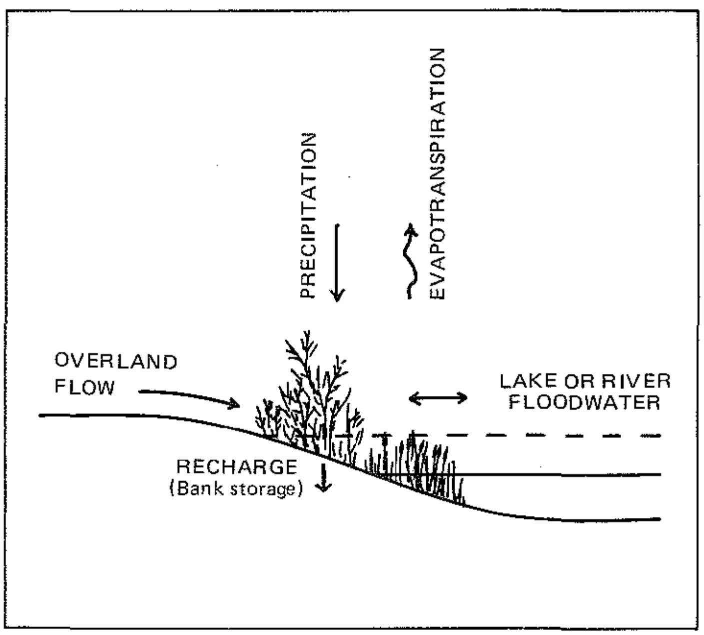


Figure 6. Flow components of surface-water slope wetlands.

In local terminology, wetland site 5 is a "seasonally flooded flat", wetland site 6 is a "river floodplain forest", and wetland site 7 is a "shallow lake-edge marsh". (See table 1 for comparable terms.)

Water budgets were estimated for two of the three surface-water slope wetlands (table 3). Estimated overland flow was 6 in. and 12 in. Streamflow in (floodwater) was 6 in. and 24 in. Estimated ET was 23 in. and 25 in. because these wetlands are seldom flooded and ET is assumed to be approximately equal to ET from upland areas. Streamflow out was high (16 in. and 24 in.) because much of the water entering the wetland during snowmelt drains readily from it. Recharge from site 5 is negligible; however, about 18 in. of local recharge occurred from site 6 because the water table is typically 2 to 4 ft below land surface before snowmelt, but the soil is saturated after flooding. This recharge water slowly drains to the river as stages fall, so it could be considered as bank storage rather than recharge.

Lake-edge wetlands differ from river-edge wetlands because lake levels fluctuate slowly compared to river stages (fig. 7). Lake-level fluctuations in Wisconsin are discussed by Novitzki and Devaul (1978). Lake levels are typically high in spring and decline through the remainder of the year. Some lakes fluctuate little, but do so each year. Other lakes fluctuate greatly, seasonally and on cycles that may span several years. In the permanently flooded area water is continuously available, so evaporation and plant transpiration occur at maximum rates and the water loss equals or exceeds the loss by evaporation alone (Sayles, 1977).

The major input to temporarily flooded areas may be precipitation and overland flow, rather than floodwater. The net contribution from floodwaters is only the increase in soil moisture in the wetland soils during flooding. The amount varies according to the duration of flooding, the porosity of the wetland soils, and antecedent soil moisture.

Ground-Water Depression Wetlands

A ground-water depression wetland occurs where a depression intercepts the water table (fig. 8). The wetland receives direct precipitation, overland flow, and ground-water inflow. The wetland's distinguishing characteristics are contact with the water table and, in most cases, lack of surface drainage away from the site. The inflow of ground water may be continuous, whereas inflow from precipitation and overland flow are sporadic. Ground-water inflow may not be a large term in the wetland's water budget, but because it may be available during drought periods, it is very important.

The wetland usually receives ground-water inflow, but it also may recharge the ground-water system. During spring, wetland water levels briefly may be above the water table, and during this period the wetland may recharge the ground-water system. Later in the summer, wetland water levels may be below the water table, and ground water may flow toward the wetland (fig. 8, A). This recharge/discharge situation is analagous to the bank storage associated with rivers. Ground water may move toward the wetland from all directions

Table 3. Average annual water budgets for three surface-water slope wetlands, 1975-77.

Wetland type	INFLOW (inches on wetland)			OUTFLOW (inches on wetland)		
	Precipitation	Overland flow	Streamflow in	Evapotranspiration	Streamflow out	Recharge
5. Seasonally flooded flat	29 (71 percent)	6 (15 percent)	6 (15 percent)	25 (61 percent)	16 (39 percent)	----
6. River flood-plain forest	29 (45 percent)	12 (18 percent)	24 (37 percent)	23 (35 percent)	24 (37 percent)	18 (28 percent)
7. Shallow lake-edge marsh	------- Insufficient data to define water budget -------					

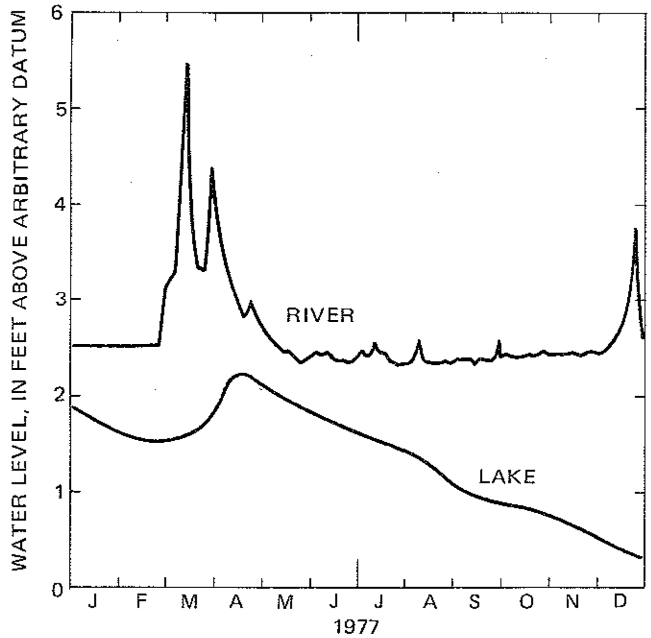


Figure 7. Water-level fluctuations in a river compared to those in a lake, 1977.

(fig. 8, B), or it may move toward the wetland from some directions, and away from it in others (fig. 8, C). A shallow depression also may overflow, allowing streamflow away from the site (fig. 8, D).

Four ground-water depression wetlands were chosen for detailed study. These four wetlands occur in closed depressions on thick deposits of sandy glacial drift. The water table is typically at, or slightly below, the level of water in the wetland. Wetland sites 8 and 10 are "forested bogs" and wetland sites 9 and 11 are "shrub bogs" in local terminology. (See table 1 for comparable terms.)

Water budgets were estimated for the four ground-water depression wetlands (table 4). Estimated ground-water inflow ranged from 0 to 3 in. Estimated ET ranged from 22 to 39 in. Because total inflow exceeded ET estimates, ground-water outflow is assumed to range from 7 to 15 in. However, this difference may reflect low ET estimates. Investigators have shown that organic soils retain water against drainage (Boelter, 1971), so significant recharge seems unlikely.

A ground-water depression wetland receives ground-water inflow as well as precipitation and overland flow. Most shallow aquifers in Wisconsin are recharged by snowmelt and spring rainfall, so ground-water levels (fig. 9) and wetland water levels are highest in spring and early summer. Water levels decline through summer and fall, although at a slower rate than they decline in surface-water depression wetlands because ground-water inflow replaces some of the water lost by ET. Because of continuing ground-water inflow, wetland water levels may rise at the end of the growing season when ET diminishes (fig. 10). In 1977, when runoff from snowmelt was less than normal, the water-level rise after the growing season resulted in the highest water levels for the year in both the ground-water system and in the wetland. Ground-water levels showed similar responses in 1949, 1951, 1959, and 1966 (fig. 9). Wetland water levels and ground-water levels typically decline through the winter, reaching their annual low just before snowmelt. Ground-water levels vary over periods of several years (fig. 9) and these long-term variations also affect wetland water levels.

Ground-Water Slope Wetlands

A ground-water slope wetland occurs where ground water discharges as springs or seeps at the land surface (fig. 11). This wetland's distinguishing characteristics are continuous ground-water inflow and drainage away from the site that eliminates

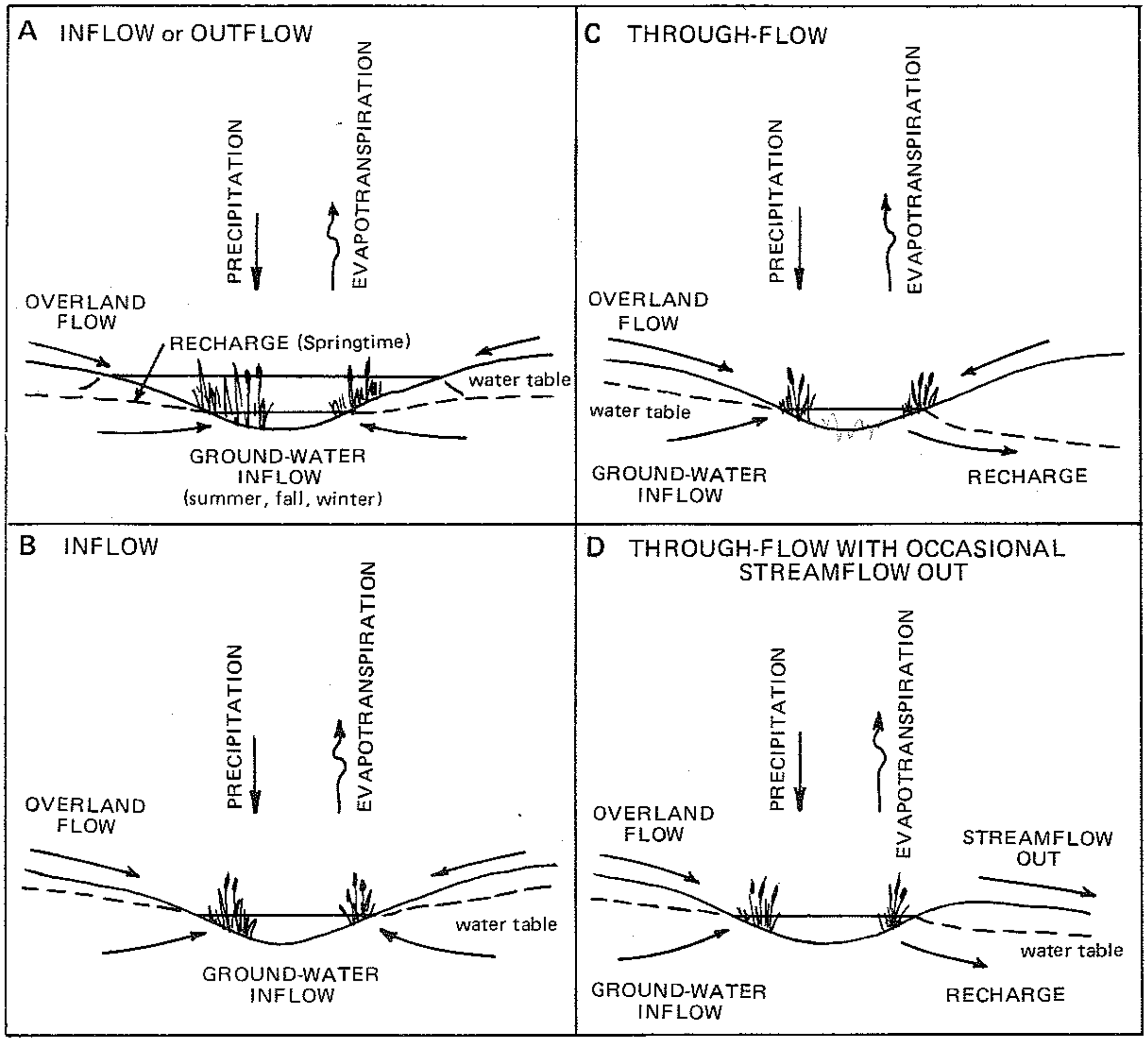


Figure 8. Flow components of ground-water depression wetlands.

permanent ponding, although temporary ponding may occur at some sites. These conditions are obvious where a wetland is the headwaters of a stream, but they may be difficult to recognize where discharge is by diffuse leakage along a streambank or lakeshore. These wetlands usually occur at the bottoms of hills, or on hillsides where ground water discharges to the land surface.

Four ground-water slope wetlands were chosen for intensive study. The four wetlands occur on nearly flat slopes at the base of hills or in broad valleys partly enclosed by hills. Each is the headwaters of a small stream. The water table slopes toward the wetland from the surrounding hills. In the wetland, the water table is typically at or above wetland water levels. In local terminology, wetland site 12 is a "marsh", wetland site 13 is a "hardwood swamp", wetland site 14 is a "cedar swamp", and wetland site 15 is a "wet meadow". (See table 1 for comparable terms.)

Water budgets were estimated for the four ground-water slope wetlands (table 5). A water budget for wetland site 15 for the period 1974-76 was available from an earlier study (Novitzki, 1978). Estimated overland flow ranged from 1 to 30 in. Estimated ground-water inflow ranged from 8 to 405 in. Estimated ET ranged from 32 to 43 in. Streamflow away from the sites ranged from 14 to 420 in. Where ground-water levels may be temporarily below the wetland water level, some ground

Table 4. Average annual water budgets for four ground-water depression wetlands, 1975-77.

Wetland type	INFLOW (inches on wetland)			OUTFLOW (inches on wetland)	
	Precipitation	Overland flow	Ground-water inflow	Evapotranspiration	Recharge
8. Forested bog	29 (63 percent)	14 (30 percent)	3 (7 percent)	39 (85 percent)	7 (15 percent)
9. Shrub bog	29 (91 percent)	3 (9 percent)	-----	23 (72 percent)	9 (28 percent)
10. Forested bog	29 (85 percent)	3 (9 percent)	2 (6 percent)	24 (71 percent)	10 (29 percent)
11. Shrub bog	29 (78 percent)	7 (19 percent)	1 (3 percent)	22 (59 percent)	15 (41 percent)

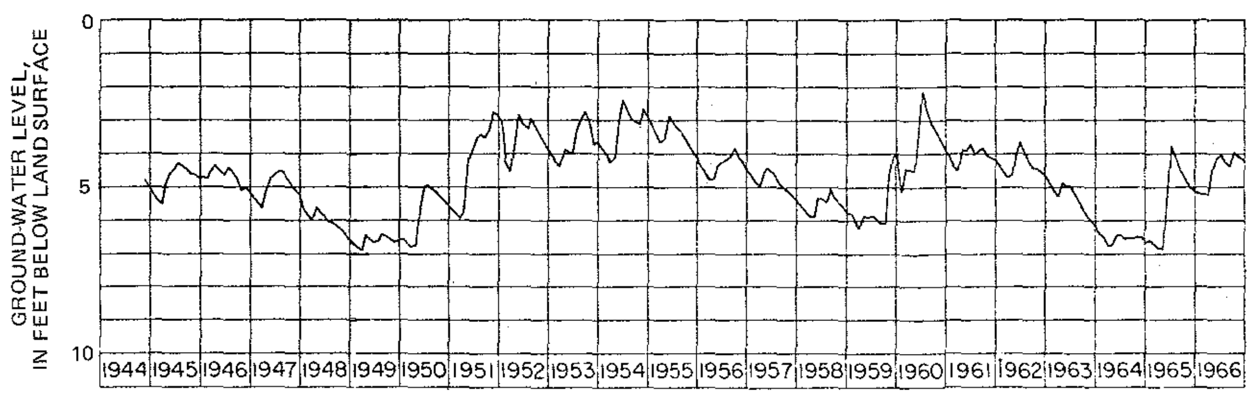


Figure 9. Typical ground-water-level fluctuations (Vilas County).

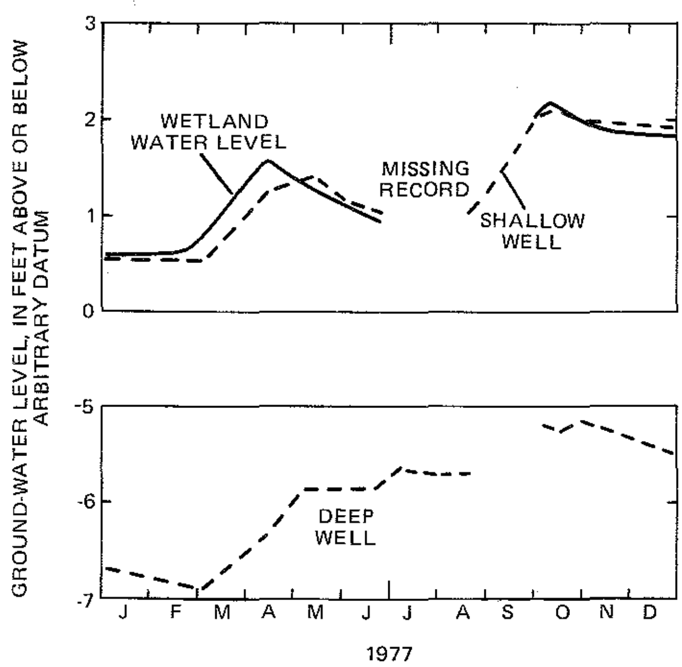


Figure 10. Water-level fluctuations in a ground-water depression wetland and in nearby wells.

water also may recharge from the site. Two sites (12 and 14) may provide some recharge: 6 and 4 in., respectively.

The ground-water slope wetland receives continuous ground-water inflow as well as sporadic inflow from precipitation and overland flow. The wetland soils may be saturated after snowmelt and excess water runs off the surface. The wetland is dryest in late summer when ET is greatest and ground-water inflow is relatively low. However, even when upland soils contain less than 5 percent water, the wetland soils may contain 25 percent or more water because of ground- water inflow.

WETLAND INFLUENCE ON STREAMFLOW

The influence that wetlands have on streamflow characteristics depends on whether water is retained in depression wetlands or only temporarily stored in slope wetlands. However, Wisconsin's wetlands have not been classified hydrologically, so the following analyses include all wetland types, as well as lakes.

Flood peaks may be as much as 80 percent lower in basins with much lake and wetland area than in similar basins with little or none. Regression equations developed by Conger (1971, p. 12-13) relate flood peaks of different frequencies to basin characteristics, including basin storage, a term that includes lake and wetland area. The regression equations show that flood peaks are only 20 percent as large in basins with 40 percent lake and wetland area as they are in similar basins with no lake or wetland area (fig. 12). (The basins included in Conger's analysis had from 0 to 40 percent basin storage.) In basins containing as little as 5 percent lakes and wetlands, flood peaks are only half as large as they are in basins with no lake or wetland area. This analysis was based on Conger's equation for floods with a 50-year recurrence interval. Conger presents five other intervals of 2, 5, 10, 25, and 100 years. However, the coefficient for the basin storage ranges only from -0.30 to -0.45, so figure 12 would not change materially if another equation were used for analysis. The negative exponents increase for the longer recurrence intervals, indicating that wetlands have greater influence on the larger floods.

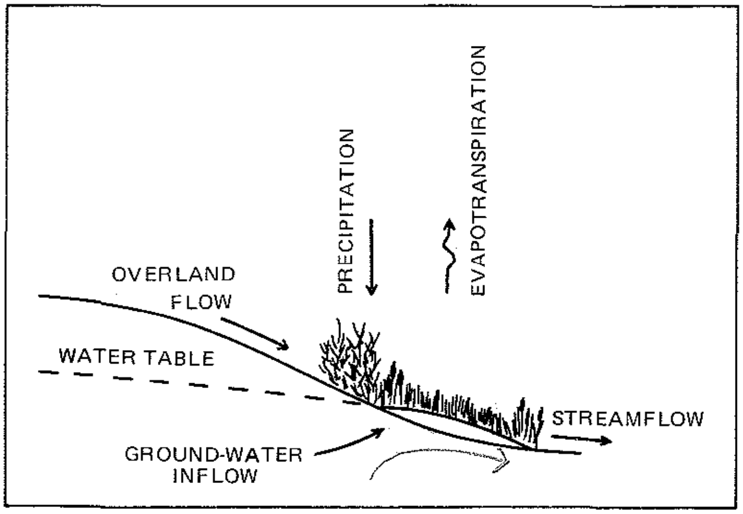


Figure 11. Flow components of ground-water slope wetlands.

Table 5. Average annual water budgets for four ground-water slope wetlands, 1975-77.

Wetland type	INFLOW (inches on wetland)			OUTFLOW (inches on wetland)		
	Precip-tation	Overland flow	Ground-water inflow	Evapotrans-piration	Streamflow	Recharge
12. Marsh	29 (43 percent)	30 (45 percent)	8 (12 percent)	43 (64 percent)	18 (57 percent)	6 (9 percent)
13. Hardwood swamp	29 (63 percent)	1 (2 percent)	16 (35 percent)	32 (70 percent)	14 (30 percent)	----
14. Cedar swamp	29 (29 percent)	6 (6 percent)	65 (65 percent)	32 (32 percent)	64 (64 percent)	4 (4 percent)
15. Wet meadow	29 (6 percent)	21 (5 percent)	405 (89 percent)	35 (8 percent)	420 (92 percent)	----

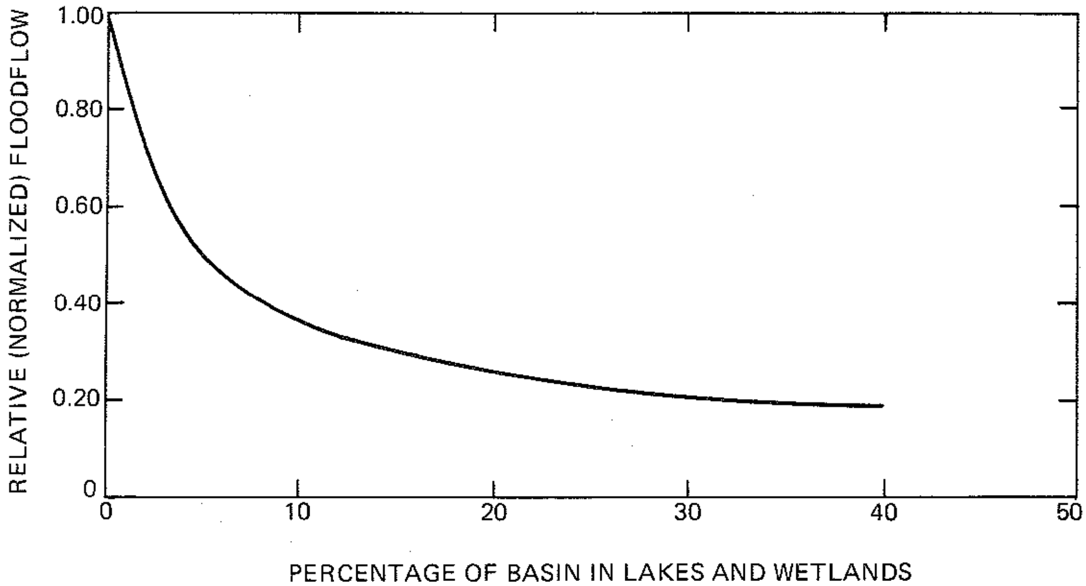


Figure 12. Relative (normalized) floodflows in basins with different percentages of lake and wetland area.

Although flood peaks are lower, runoff periods are extended, so total springtime streamflow is greater in basins with much lake and wetland area than in basins with no lake or wetland area. Regression equations developed by Campbell and Dreher (1970, table A-4) relate average monthly streamflow to basin characteristics, including basin storage. These equations show that streamflow in April and May is 40 percent greater in basins with 40 percent lake and wetland area than in basins with no lake or wetland areas (fig. 13).

Because springtime runoff is greater, recharge is less and fall and winter streamflow is lower in basins with much wetland area than in basins with no lake or wetland area. Discharge from the ground-water system (which is replenished primarily by springtime recharge) is the principal source of flow in Wisconsin streams in late fall and winter. The monthly flow equations developed by Campbell and Dreher (1970, table A-4) show that streamflow in August, September, January, and February is 40 percent lower in basins with 40 percent lake and wetland area than it is in basins with no lake or wetland area (fig. 13). (The basin-storage term is not included in the equations for October, November, and December.)

WETLAND INFLUENCE ON SEDIMENT AND WATER QUALITY

This study has shown that wetlands retain sediment. Depression wetlands retain all of the sediment entering them. Slope wetlands also retain sediment if water velocities decrease within the wetland area. A ground-water slope wetland retained approximately 80 percent of the sediment entering it (Novitzki, 1978, p.17).

Hindall (1975) analyzed sediment yields in Wisconsin streams. In the northcentral one-third of the State, lake and wetland area was the only significant basin characteristic in the equation used for predicting sediment yield (Hindall, 1975, table 3). This equation shows that sediment yields are approximately 90 percent lower from basins containing 40 percent lake and wetland area than in basins with no lake or wetland areas (fig. 14).

Dissolved minerals also may be retained in wetlands. Water is retained in depression wetlands, so retention of dissolved minerals is greater there than in slope wetlands, where water drains from the site and only limited retention occurs by sorption on deposited sediments.

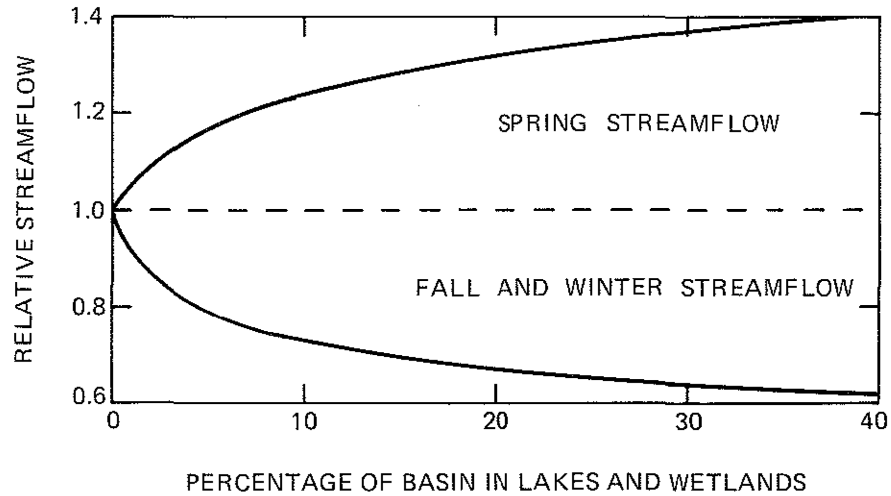


Figure 13. Relative seasonal streamflow in basins with different percentages of lake and wetland area.

Depression and slope wetlands that retain overland flow may improve water quality in downgradient streams and lakes. However, water draining from slope wetlands may be degraded if it picks up minerals previously deposited in the wetland, or those released by decomposition occurring in the wetland. Depression wetlands in which minerals accumulate may degrade the quality of water recharged to the ground-water table.

Depression Wetlands

In surface-water depression wetlands, water quality varies considerably between spring high water and fall low-water conditions as water is lost by evapotranspiration. Conductance, reflecting the concentration of dissolved minerals in the water, is low in spring but may be 10 times greater by fall (table 6). Hardness and alkalinity variations correspond to variations in conductance. The pH values are typically in the alkaline range, ranging from 6.5 to 10. The pH values are often lower in vegetated areas than in open-water areas. Dissolved-oxygen values vary considerably, reflecting respiratory and photosynthetic cycles of the wetland plants.

In ground-water depression wetlands, water-quality variation is less than in surface-water depression wetlands. Water quality in wetlands where ground-water inflow is a large part of the water budget is similar to that of the local ground water, with pH values near 7.0, conductance ranging from 200 to 500 μmhos, and hardness and alkalinity of 50 to 150 mg/L. Where thick organic deposits have isolated the wetland surface from ground-water inflow, precipitation is the chief source of water to the vegetation. Water ponded at the surface of these wetlands typically has pH less than 5.5, conductance less than 100 μmhos, and hardness and alkalinity less than 50 mg/L.

Slope Wetlands

Sediment is deposited in slope wetlands, but dissolved minerals are not so readily retained, although some may be sorbed on sediment deposits. Soluble minerals previously precipitated or freed by decomposition may be removed by floodwaters. A study by Novitzki (1978, p.17) indicated that 7 percent of the phosphorus and 21 percent of the nitrogen that entered a ground-water slope wetland was retained there. Slope wetlands where organic soils accumulate can be assumed to retain some dissolved minerals, but those where organic soils are lacking probably have minimal retention capabilities.

Water in a surface-water slope wetland is similar in quality to that in the associated surface-water body. In the vegetated shallows the water is similar to that in open-water areas except that pH values commonly are lower in the vegetated zones than in

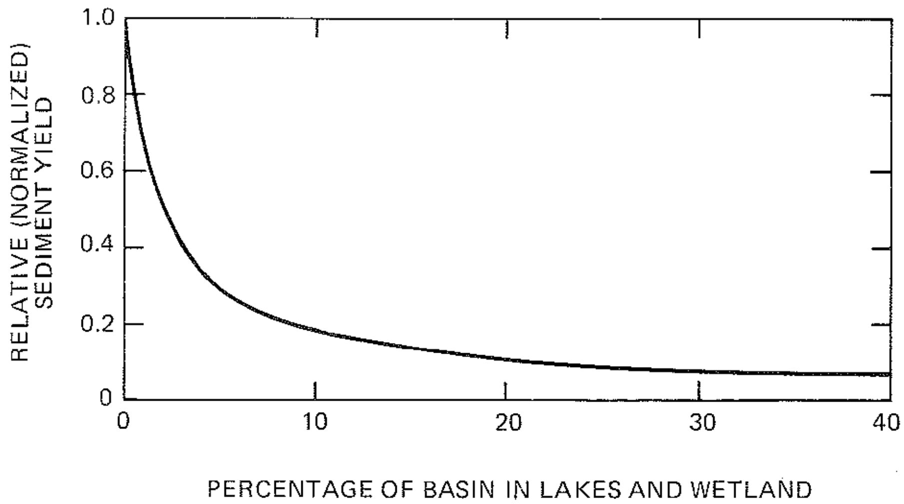


Figure 14. Relative (normalized) sediment yields in north-central Wisconsin basins with different percentages of lake and wetland area.

Table 6. Measured water-quality ranges in three surface-water depression wetlands.

(Analysis by field measurements)

Site	Conductance (μmhos)	pH	Hardness (mg/L)	Alkalinity (mg/L)	Dissolved oxygen (mg/L)
1	92-1,000	6.5-10.0	45-420	35-170	2.0-10.0
2	60- 474	6.5-10.0	45-160	60-160	5.6-14.0
3	55- 480	6.5-10.0	45-155	45-140	4.0-20.5

open-water areas. In areas that are dry for part of each year, the concentration of dissolved minerals may be higher when water first enters, dissolving minerals deposited by previous flooding and released by decomposition. Where organic material is accumulating, water exchange between the vegetated and open-water areas is apparently restricted and water characteristics may differ. In wetlands on river flood plains where organic soils are thin or lacking, pH is typically greater than 6, conductance greater than 100 μmhos, and hardness and alkalinity greater than 50 mg/L. Where thick organic soils, particularly peat, accumulate, pH is typically less than 6, conductance is less than 100 μmhos, and hardness and alkalinity are less than 50 mg/L (Boelter and Verry, 1978, p. 18).

In ground-water slope wetlands, water quality reflects local ground-water quality. Where ground-water inflow is continuous, water quality will be relatively stable. The pH will typically be in the range of 7 to 9, conductance from 150 to 500 μmhos, and hardness and alkalinity in the range of 100 to 200 mg/L.

SUMMARY AND CONCLUSIONS

Wisconsin's wetlands receive direct precipitation and overland flow, and some also are in contact with the ground-water system. They occur in depressions and near the bottom of slopes, particularly along lakeshores or streambanks. They also occur on large, flat areas that are poorly drained; the central part of these wetlands may function as a depression wetland, and the edges as a slope wetland. Wetlands whose inflow is precipitation plus limited surface-water inflow differ from those that also receive continuous ground-water inflow. Those in depressions where water is retained differ from those on slopes where water can drain away.

A wetland classification system based on hydrology and location includes four classes: surface-water depression, surface-water slope, ground-water depression, and ground-water slope.

A surface-water depression wetland receives precipitation and overland flow and loses water by evapotranspiration and recharge to the ground-water reservoir. Sample budgets showed that precipitation comprised from 33 to 97 percent of total inflow, and overland flow comprised from 3 to 67 percent. The major outflow was typically to evapotranspiration (37 to 93 percent) but one site, a very shallow depression, typically overflowed, losing water as streamflow (17 percent) and one lost much water to recharge (63 percent) because holes had been drilled in an attempt (partially successful) to drain the site. The wetland retains water and reduces flood peaks. It also retains sediment and dissolved minerals and may degrade the quality of recharge water.

A surface-water slope wetland receives precipitation, overland flow, and overflow from a lake or river and loses water by evapotranspiration, recharge, and drainage back to the lake or river. Although three sites were studied, the water budget for the lake-edge site was not adequately defined. At the two stream-side sites, precipitation comprised 71 and 45 percent of the total inflow, overland flow comprised 15 and 18 percent, and streamflow comprised 15 and 37 percent. The temporary flood storage may have been much greater than the streamflow component in the budget, but much of the stored water flows back to the stream before it is available for evapotranspiration or recharge. Outflow was comprised of evapotranspiration (35 to 61 percent), streamflow out (39 and 37 percent), and recharge (0 and 28 percent). Outflow to evapotranspiration was similar to that from upland areas because these sites are dry much of each year. The wetland provides temporary flood storage and reduces flood peaks. However, it does not retain water so it does not retain dissolved minerals, although it may retain sediment.

A ground-water depression wetland receives precipitation, overland flow, and ground-water inflow, and loses water by evapotranspiration and ground-water recharge. Sample budgets showed that precipitation was the major inflow, ranging from 63 to 91 percent, overland flow ranged from 9 to 30 percent, and ground-water inflow ranged from 0 to 7 percent. Continuous ground-water inflow may be significant during drought periods when precipitation and overland flow are deficient. Most water was lost to evapotranspiration (59 to 85 percent) and the rest to recharge (15 to 41 percent). The wetland retains water, thereby reducing flood peaks, and retains sediments and dissolved minerals. Some recharge occurs, but the wetland may degrade the quality of recharge water.

A ground-water slope wetland receives precipitation, overland flow, and ground-water inflow and loses water by evapotranspiration, stream discharge, and, occasionally, ground-water recharge. The inflow to four ground-water slope wetlands was comprised of precipitation (6 to 63 percent), overland flow (2 to 45 percent), and ground-water inflow (12 to 89 percent). The outflow was comprised of evapotranspiration (8 to 70 percent), stream discharge (30 to 92 percent), and ground-water recharge (0 to 9 percent). The wetland provides temporary flood storage and reduces flood peaks. It retains much of the sediment entering it, but little of the dissolved mineral load.

Water quality differs among the wetlands. Surface-water depression wetlands collect overland flow during snowmelt. When water is lost by evapotranspiration, the concentration of dissolved minerals may increase 10 times or more. Where these wetlands recharge ground water, they may degrade the quality of the recharge water (table 7). Ground-water depression wetlands receive ground-water inflow, but they also collect overland flow and the concentrations of dissolved minerals increases during low-water periods, but not as much as it does in surface-water depression wetlands. These wetlands, too, may degrade the quality of water recharged to the ground-water system (table 7). Water quality in surface-water slope wetlands is

Table 7. Wetland functions related to the hydrologic characteristics of the wetland site.

Wetland class	Wetland function						
	Reduces flood peaks	Increases springtime runoff	Increases base flows	Retains sediment	Retains dissolved material	Increases ET	Degrades recharge water quality
Surface-water depression	Yes	---	Some	Yes	Yes	Some	Yes
Surface-water slope	Yes	Yes	Some	Yes	---	----	Yes
Ground-water depression	Yes	---	----	Yes	Yes	Yes	Some
Ground-water slope	Yes	Yes	----	Yes	---	Yes	----

similar to that in the adjacent surface-water body. Ground-water slope wetlands occur where ground water is discharging, so the water there usually reflects ground-water-quality characteristics. Where thick organic soils develop, they may isolate the wetland surface from all water sources except precipitation, and the water quality there is similar to precipitation, having low pH and dissolved-mineral concentrations.

Flood peaks are lower, spring streamflow higher, and fall base flow lower in basins with much lake and wetland area (table 7). Flood peaks may be as much as 80 percent lower in basins with 40 percent lake and wetland area than in basins with no lake or wetland area. Floodwaters are retained in depression wetlands, but only temporarily stored in slope wetlands. Some of the water retained in depression wetlands may recharge ground water and increase base flow, but analysis of Wisconsin streamflow characteristics indicates that springtime streamflow is more and fall base flow is less in basins with much lake and wetland area. The difference in streamflow may be as much as 40 percent between basins with 40 percent lake and wetland area and basins with no lake or wetland area.

Sediment yield in the north-central one-third of Wisconsin is less in basins with much lake and wetland area than in basins with no lake or wetland area (table 7). Sediment yield may be as much as 90 percent lower in basins with 40 percent lake and wetland area than in basins with no lake and wetland area. Depression wetlands retain all of the sediment entering them; slope wetlands may retain as much as 80 percent.

This report briefly describes the interaction between wetlands and the hydrologic system and provides a hydrologic classification scheme useful for determining the relative importance of components of the hydrologic budget for different wetlands. More detailed studies are needed of water and nutrient budgets of selected wetland types, coupled with detailed biological studies. This type of detailed study will assist in the assessment of the benefits lost against the benefits gained when wetlands are converted to other uses.

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