Hydrology and Chemistry of Selected Prairie Wetlands in the Cottonwood Lake Area, Stutsman County, North Dakota, 1979–82

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CONVERSION FACTORS

For the convenience of those readers who prefer to use U.S. customary units rather than the International System of Units (SI), the conversion factors for terms used in this report are listed below:

Multiply SI unit	By	To obtain U.S. customary unit
centimeter (cm)	0.393	inch
meter (m)	3.281	feet
kilometer (km)	.621	mile

HYDROLOGY AND CHEMISTRY OF SELECTED PRAIRIE WETLANDS IN THE COTTONWOOD LAKE AREA, STUTSMAN COUNTY, NORTH DAKOTA, 1979–82

By J. W. LABAUGH, T. C. WINTER, V. A. ADOMAITIS,[1] and G. A. SWANSON[1]

ABSTRACT

The relation of hydrologic setting and temporal variability in hydrology to nutrient content and geochemical characteristics of a group of prairie wetlands and adjacent ground water was studied during the period 1979–82. Although data were collected from many wetlands and wells at the study site, emphasis in this report primarily is on four wetlands—two seasonal and two semipermanent–and four wells contiguous to them along a hydrologic section. The seasonal wetlands, T8 and T3, contained water only for a few weeks to months after filling in spring and early summer; both were completely dry by August. The semipermanent wetlands, P1 and P8, contained water throughout each year and were ice covered in winter. One wetland, T8, recharges ground water. Wetlands P1 and P8 are in areas of ground-water discharge. None of the wetlands received water by channelized surface-water inlets. Only wetland P8 had a channelized surface-water outlet. Ground-water-level data showed that high points of the water table did not always occur beneath land-surface highs. Reversals of ground-water flow occurred occasionally between two of the wetlands, T3 and P1.

Significant differences existed in the chemical composition of the wetlands based on their hydrologic setting. In general, the dominant cation and anion in the wetlands were potassium and bicarbonate in wetland T8, calcium and sulfate in wetland T3, magnesium and sulfate in wetland P1, and magnesium and bicarbonate in wetland P8. Significant seasonal differences existed in the water chemistry of the wetlands in ground-water discharge areas. Water in three of the wetlands, T3, P1, and P8, was most dilute while they filled in spring after icemelt. Concentration increased during the open-water period, and two of the wetlands, P1 and P8, became most concentrated under ice cover. Concentrations of total phosphorus and total nitrogen were greatest in wetlands in areas of ground-water recharge and least in wetlands in areas of ground-water discharge. Differences in the chemistry of water from wells in the adjacent ground water resulted primarily from the positions of the wells in the ground-water flow system. The chemical type of water from well 12, which was located in a ground-water recharge area, was calcium sodium bicarbonate. Water from well 4, located downgradient from wetland T8, and from well 16, located downgradient from wetland P1, typically was a calcium sulfate type. Water from well 13, located between wetlands T3 and P1 in an area of changing ground-water flow directions, was a magnesium sulfate type. Data from this study show that an understanding of hydrologic conditions is important in the interpretation of the water chemistry of wetlands in the study area.

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INTRODUCTION

Numerous studies published in the proceedings of symposia on the subject of wetlands have indicated that the relation between hydrologic processes and the function and structure of wetland ecosystems is poorly understood (Good and others, 1978; Greeson and others, 1979). Probably the principal reason for this lack of understanding is that comprehensive, multidiscipline studies of wetlands rarely have been done; hydrologic studies seldom include comprehensive analyses of chemical and ecological processes, and, conversely, few ecological studies of wetland ecosystems include comprehensive investigations of hydrologic processes.

Some ecological studies of wetlands have presented evidence that the structure of biological communities is affected by hydrologic processes. Gooselink and Turner (1978) indicated that plant communities change because the frequency of inundation of wetland soils affects the availability of oxygen in the root zone. Studies of wetland seed banks were used by van der Valk (1981) to show how changes in water level alter plant-community structure. The ability of seeds or propagules to become established in areas of either standing water or no standing water was attributed to water-level changes.

Hydrologic setting also can affect structure of plant communities in wetlands, through its relation to wetland water chemistry; for example, Stewart and Kantrud (1972) determined that the composition of plant communities in prairie wetlands is correlated with specific conductance of water in those wetlands. Wetland water chemistry is related to hydrologic processes because those processes are a major factor in controlling the movement of chemical constituents to and from wetlands. Hemond (1980) noted that information on the movement of water to and from wetlands is essential for biogeochemical studies.

The wetland-biogeochemical studies most dependent on investigation or measurement of hydrologic processes are those of chemical mass balance. Quantification of water inputs and outputs is an integral part of determining chemical inputs and outputs in mass-balance studies; for example, Valiela and Teal (1978) indicated that the quantification of water and nutrient inputs and outputs is important in understanding nu trient dynamics of wetlands. Yet, in only a few studies have nearly all relevant hydrologic processes been measured as a basis for understanding biogeochemical processes in wetlands (Crisp, 1966; Valiela and others, 1978; Mitsch and others, 1979; Hemond, 1980; Verry and Timmons, 1982). However, even in these studies, at least one hydrologic process that was a component of the water budget was measured some distance away from the study area or was calculated as the difference between measured inputs and outputs.

Ground water commonly is calculated as the difference between measured inputs and outputs in chemical mass-balance studies of lakes (Winter, 1981); this approach also commonly is used in the study of wetlands. A major problem with using the approach of calculating ground water as a residual in wetland studies is that hydrologic instrumentation usually is not optimal in either accuracy or placement relative to the wetland; the difference between measured inputs and measured outputs can have little hydrologic meaning because of errors in hydrologic measurement (Winter, 1981).

Conceptual models of ground-water flow systems near wetlands have been developed primarily by Canadian hydrologists; for example, Meyboom (1966, 1967) studied the interaction of ground water with several prairie wetlands and lakes in Saskatchewan. Many of Meyboom's study sites were of wetlands that received ground-water inflow because water-table highs underlaid land-surface highs. In some cases, the water table beneath hills would decline to the point where the wetland would have seepage from it to ground water for part of the year. Meyboom also conducted studies of open-water evaporation (1967) and of transpiration from phreatophytes near wetlands (1966, 1967). Lissey (1971) also studied ground-water flow near prairie wetlands in Canada; he proposed that most ground-water recharge and discharge in that environment takes place in land-surface depressions that commonly are occupied by wetlands.

A few studies of wetlands have attempted to relate wetland water chemistry to the hydrologic concepts of Meyboom (1966, 1967) or Lissey (1971). These few studies have been confined to prairie potholes in western Canada (Rozkowska and Rozkowski, 1969; Rozkowski, 1967, 1969; Sunde and Barica, 1975) and have indicated that a relation exists between the water chemistry of lakes and wetlands and nearby ground water. Hydrologic data were not available in those studies. Consequently, water chemistry was interpreted by using a conceptual model of hydrologic processes instead of in conjunction with directly measured hydrologic processes.

In most cases, wetlands have been studied individually rather than as a group within a hydrologic unit, such as a ground-water flow system. Many ecologists are unaware of ground-water flow systems and associated theory on the way ground water may effect the wetlands under investigation. This is manifested in studies of wetland biogeochemistry, where chemical mass-balance calculations include estimates of ground water by difference. Before chemical mass balances, including direct measurement of ground water, can be determined, wetlands need to be shown to be an integral part of ground-water flow systems. Such a system then can be used to begin to examine the relation between the water chemistry of wetlands and adjacent ground water.

Wetlands in the prairies of North America are ideal systems for such an investigation because many have no channelized surface-water inlet or outlet. Therefore, the hydrologic processes most likely to effect such ecosystems are those related to atmospheric exchange (rainfall-evaporation-evapotranspiration) and ground-water flow.

Hydrologic process research is being conducted in the Cottonwood Lake area of North Dakota (Winter and Carr, 1980). This area includes numerous wetlands within the same ground-water flow system. Concurrent investigation of ecological processes is part of the research program. For this report, the scarcity of interpretive studies of wetland water chemistry, based on comprehensive analysis of hydrologic processes, led us to ask the following questions: What is the hydrogeologic function of prairie wetlands? and what is the effect of hydrogeologic setting on wetland water chemistry?

PURPOSE AND SCOPE

The objective of this report is to examine the relation of ground-water flow and related hydrologic characteristics to differences in major ions, total phosphorus, and total nitrogen among prairie wetlands in the Cottonwood Lake area, Stutsman County in North Dakota. During the period of study, 1979–82, the area had a small climatic cycle that began with a wet year (1979), followed by two dry years (1980 and 1981), followed by another wet year (1982). The hydrologic setting of the study site is analyzed to show the important features affecting selected wetlands. The chemical composition of water in the wetlands then is placed in the context of hydrologic setting, climatic cycle of the study period, and chemical composition of ground water in the study area.

ENVIRONMENTAL SETTING OF THE STUDY AREA

Wetlands in the Cottonwood Lake area are being studied by the U.S. Geological Survey and the U.S. Fish and Wildlife Service because they are believed to be typical of the vast region of prairie wetlands in the Missouri Coteau region. Largely because of the wetlands, this region has long been recognized as a primary waterfowl breeding habitat in North America.

The Cottonwood Lake area is located in east-central North Dakota (fig. 1). It is situated in one of the higher parts, near the eastern edge, of the Coteau du Missouri (Winter and Carr, 1980). The coteau is a large glacial drift complex transecting north-south through North and South Dakota and consisting of end and stagnation moraine, ice contact, and outwash deposits (Colton and others, 1963). At the study site, the glacial drift is greater than 130 meters (m) thick. It consists largely of clayey, silty till, but a few thin lenses of sand of unknown lateral extent also were observed when test drilling for the water-table wells.

Local relief of the study area is about 30 m; the highest part is in the southeastern corner, and the lowest is in the northwestern corner (fig. 1). This magnitude of local relief is typical of the Coteau du Missouri. The higher part of the area, where wetlands T9, T8, and T5 are located, is separated from an intermediate level by a steep slope about 15 m high. The slope is most pronounced between wells 1 and 10. Wetlands T4, T3, P7, P6, P1, P2, P4, and T1 are situated at this intermediate level. The lowest part of the area has the appearance of a north-south-trending valley, which is separated from the intermediate level by a sharp slope about 10 to 15 m high. Wetlands T2, P8, and P9 are located in the valley.

Nearly all wetlands in the intermediate and high parts of the area do not have surface-water outlets. One exception is wetland T3, which occasionally overflows to wetland P1 for a week or two after snowmelt. Wetlands T2 and P8, in the valley along the west edge of the area, are connected by surface-water channels that contain water intermittently. Location and identification of wetlands, wells, and instruments in the Cottonwood Lake area are shown in figure 1.

Four wetlands were selected for the detailed study presented here. Two, T8 and T3, were seasonal, containing water for only part of the year. Two, P1 and P8, were semipermanent, containing water throughout the year. Although data were collected from many wetlands, these four wetlands were selected because they were representative of the variety of wetlands at the site. They also were along a line of water-table wells designed to determine the water-table configuration between the highest and lowest parts of the study area (Winter and Carr, 1980). Four of these wells (4, 12, 13, and 16) were chosen for detailed study because of their location with respect to the four wetlands selected for the study. Because of the location of these selected wetlands within this network of water-table wells, the position of these wetlands within the local ground-water flow system could be defined.

Vegetation in the general area consists of a variety of prairie herbs and grasses. A few small patches of aspen and chokecherry occur on north-facing slopes. A comprehensive report on the aquatic vegetation of the wetlands of the area is given by Stewart and Kantrud (1972). Because wetlands T8 and T3 are dry part of the year, they are dominanted by shallow-marsh plant species that occupy the central part of the wetlands. Slough sedge (*Carex atherodes*) and marsh smartweed (*Polygonum cuccineum*) are found in the shallow-marsh zone of wetland T8. Whitetop (*Scolochloa festucacea*) is a dominant plant species of the shallow-marsh vegetation in wetland T3. Wetlands P1 and P8 retain water year around; as a result, these two wetlands support deep-marsh plant species and submerged vascular plants in the central part of the wetland. Hardstem bulrush (*Scirpus acutus*) and cattail (*Typha latifolia* and *T. glauca*) usually dominate the deep-marsh zone of wetland P1. Cattail species are the dominant vegetation in the deep-marsh zone of wetland P8.

METHODS OF INVESTIGATION

Hydrologic characteristics of the wetlands and their watersheds that are important for this paper are precipitation, water depth of the wetlands, and ground-water flow. Precipitation was measured at the study site by using a recording tipping-bucket gage. A standard nonrecording gage was used as a backup instrument. Both gages, located between wetlands T3 and P1, were operated only during the open-water season. For the remainder of the year, precipitation data were obtained from a National Weather Service station in Woodworth, about 16 kilometers west-northwest of the study area. These latter data were used only to obtain general estimates of precipitation.

Water levels in wetlands were measured by using staff gages that were read weekly to biweekly. A recording stage gage was installed on wetland P1 in July 1980. Altitude of the water table, which is the upper surface of the ground-water system, was determined by measuring water levels in water-table wells. [Details of well construction were given by Winter and Carr (1980).] A steel tape was used to measure water level in wells weekly to biweekly during spring through fall and monthly during winter.

Water samples for chemical analysis were collected from the wetlands on approximately a biweekly basis from spring thaw to formation of ice cover for wetlands

P1 and P8 and from spring thaw to a condition of being completely dry for wetlands T3 and T8. In addition, water was collected occasionally from wetlands P1 and P8 when they were ice covered. During the period of open water, three samples of water were obtained from each wetland. The wetlands were divided by three transects into six zones of 60° each from the center of the wetland. The first transect always started at 158° with respect to magnetic north. In wetlands P1 and P8, water samples were collected along each of the three transects 1 m outside the deep-marsh zone (fig. 2). In wetlands T8 and T3, samples were collected along each transect at a point one-half the distance between shore and the center of the wetland.

The entire water column was sampled at each site, using a 65-centimeter (cm)-internal-diameter acrylic tube column sampler described by Swanson (1978). The contents then were transferred to acid-cleaned polyethylene bottles and brought to the chemical laboratory of the U.S. Fish and Wildlife Service Northern Prairie Wildlife Research Center Jamestown, N. Dak., for analysis.

Because of the low permeability of the glacial till at the study site, ground water for chemical analysis was collected by bailing the wells. Water standing in the wells was removed before sampling to assure that the sample collected was representative of ground water and that it had minimal contact with the well screen and casing. Water was collected in acid-cleaned polyethylene bottles before being brought to the chemical laboratory of the U.S. Fish and Wildlife Service Northern Prairie Wildlife Research Center for analysis.

Anions and Kjeldahl nitrogen were analyzed by using standard methods (American Public Health Association, 1980). Cations were determined by plasma

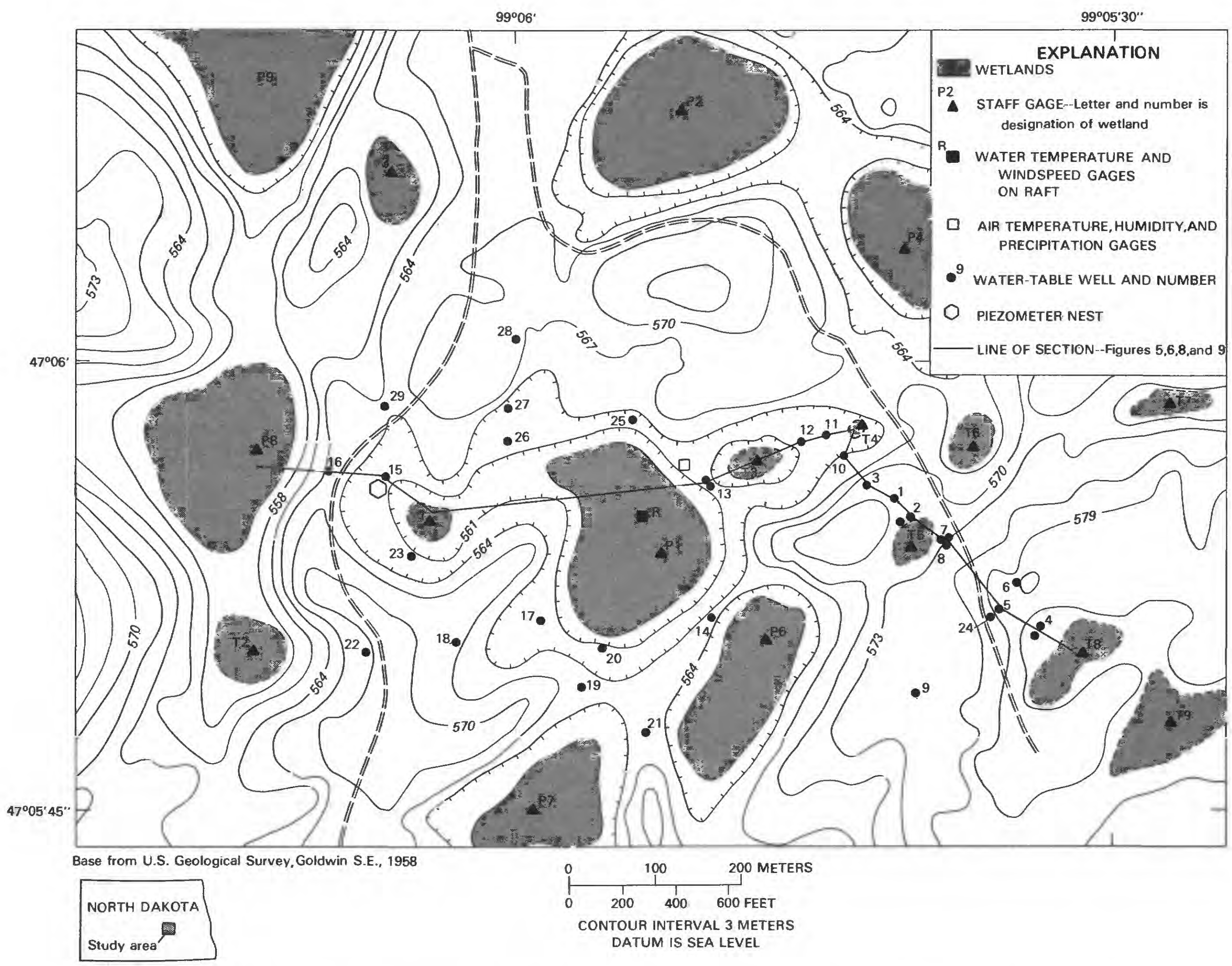


FIGURE 1.—Hydrologic instrumentation and location of wetlands and wells sampled for chemical analysis.

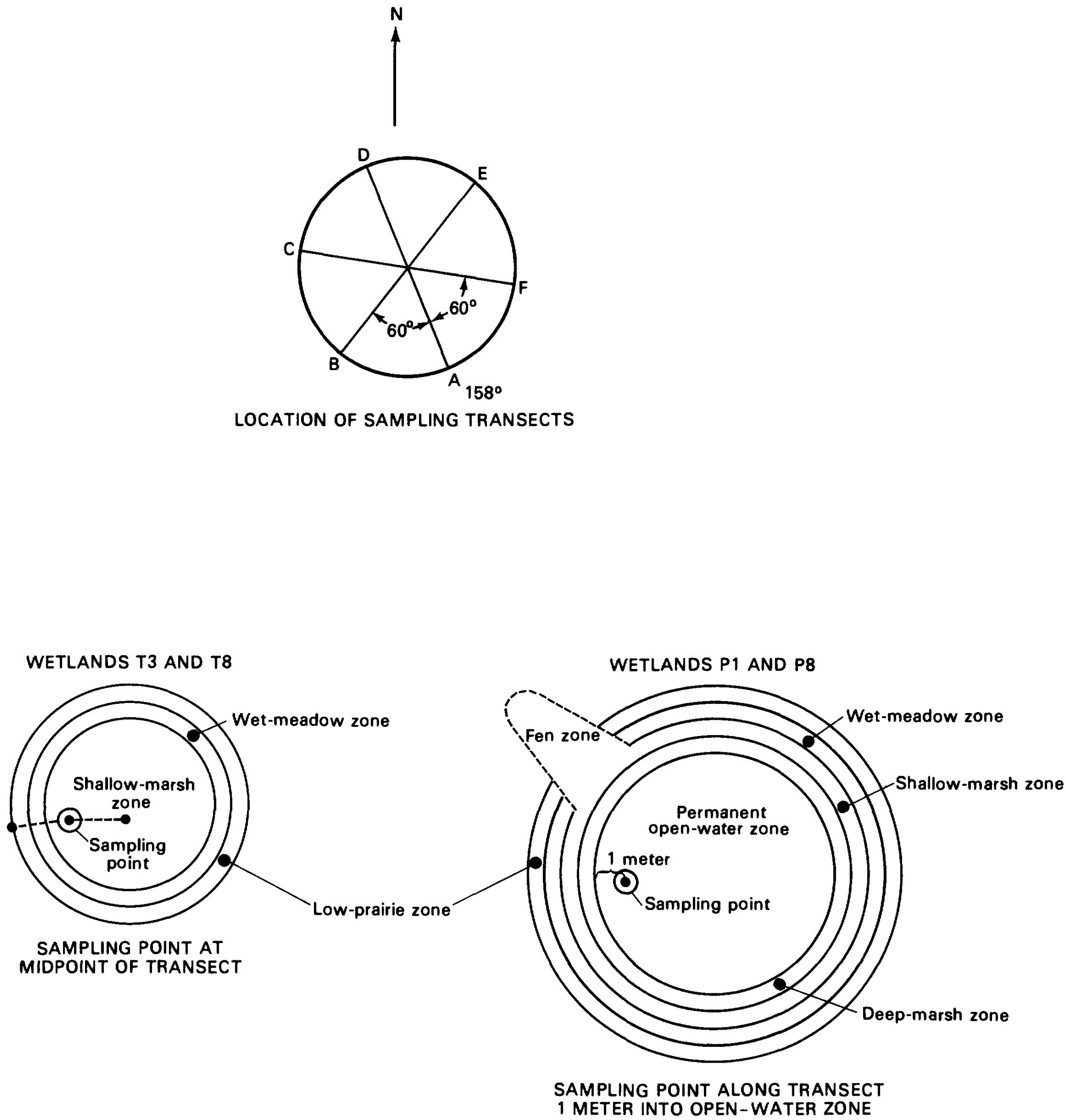


FIGURE 2.—Design for sampling water in wetlands.

emission spectrometry. Total phosphorus was determined from unfiltered samples by the method used for cations. Specific conductance and pH were determined electrometrically in the laboratory.

Statistical analyses used in the study were linear regression, analyses of covariance, and analysis of variance (Helwig and Council, 1979). A significance level of $P < 0.05$ was accepted in all analyses unless otherwise stated.

HYDROLOGIC CONDITIONS

The following detailed description of ground-water levels and wetland water levels is given to emphasize the great variability in the mechanisms that control direction of water flow between the ground-water system and the wetlands. The process changes annually and seasonally depending on the quantity of snow before snowmelt, timing of snowmelt, and quantity and timing of rainfall. Results show that it would be misleading to assume general processes exist, particularly if data are collected for only 1 or 2 years.

CALENDAR YEAR 1979

Winter 1978–79 had normal to greater-than-normal snowfall, resulting in an extensive snowpack that averaged 0.3-m depth before snowmelt in spring 1979. Melting of this snow resulted in high water levels in the wetlands (fig. 3). At wetland T8, which is at the highest

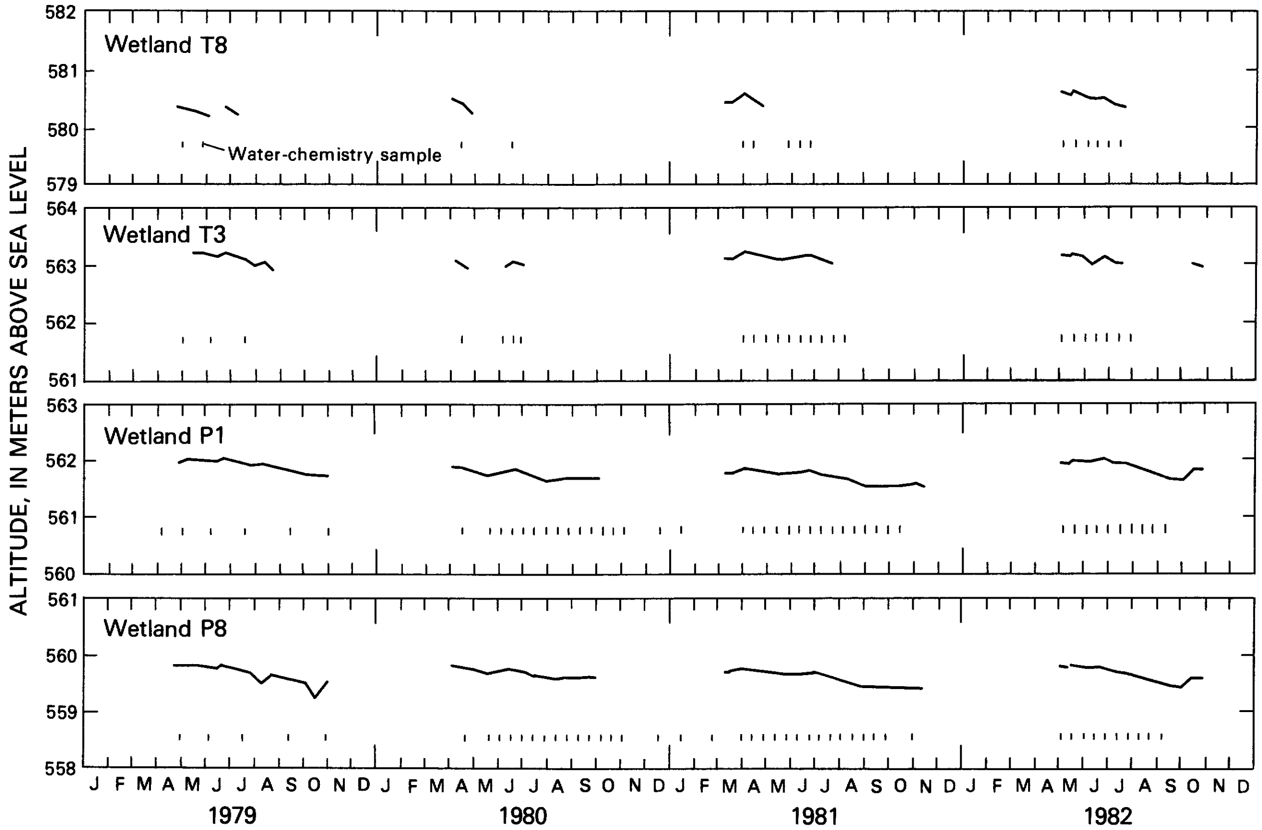


FIGURE 3.—Water levels in wetlands sampled for chemical analysis.

altitude of all the wetlands, the water level declined throughout May, and the wetland dried up in early June. A brief period of water-level decline in early June at all the wetlands was interrupted by intense rainfall June 19–22. As a result of this rainfall, water levels rose in all the wetlands, including wetland T8, which contained water until it again dried up near mid-July. After the June rainfall, water levels in all wetlands gradually receded throughout the summer. Wetland T3 dried up in late August. Water levels in the semipermanent wetlands, P1 and P8, receded to their lowest level in late October, at which time they froze.

All ground-water wells showed rapid response to spring recharge in 1979, as indicated in figure 4. After the spring water-table high in mid-May, the water table receded in altitude throughout the remainder of the year. A reversal in this water-level recession was caused by the intense rainfall in June and by another period of rainfall in early August.

To examine the interrelation of ground and surface water, it is useful to examine a hydrologic section (fig. 5) from the highest part of the study area to the lowest. The section transects the 15-m-high slope that occurs between wells 1 and 10. Wetland T5 is located at the top of the slope; wetlands T4 and T3 are at the base of it.

Starting at the topographically highest part along the hydrologic section, the water level in well 4 is always lower than that in wetland T8, indicating that this wetland has seepage from it on its downgradient side whenever it held water. Wetland T5 also shows a water-table gradient away from it on both sides for the entire period it held water. Water-level information from well 1 shows a depression in the water table similar to that near well 24 (fig. 5). These data indicate that, in the higher parts of the area, water-table highs do not underlie land-surface highs and that water-table highs are created by seepage from wetlands.

A mechanism to explain the mounds near wetlands and the water-table depressions beneath hills, which are controlled largely by the low permeability of the till, has been presented by Winter (1983), who used numerical simulation. These numerical simulations showed that, in porous media of low permeability, water-table lows are common beneath land-surface highs. Depending on the magnitude of recharge and permeability of the porous media, this condition can persist for considerable periods of time. Numerical simulation of unsaturated-saturated flow in porous media (Winter, 1983) also has shown that ground water is recharged quickest directly next to surface water.

The phenomenon of water-table lows underlying land-surface highs was observed in the Cottonwood Lake area, as shown by the very low position of the water table between wetlands T8 and T5. At first, it was believed that the water-table low was a result of poor well construction. However, four wells in place between wetlands T8 and T5 confirm this low position of the water table in this area. Again, numerical simulation of the interaction of lakes and ground water (Winter, 1976) indicates that, if an area is underlain by a more permeable unit, recharge to the lower unit significantly affects water movement in the upper unit and that it would tend to cause the water table to be lower. Sand was observed in the bottom of the test hole drilled for well 24, but the extent of the sand unit has not been mapped.

In the intermediate level of the study area, the water table slopes toward wetland T3 from wells 11 and 12 (upgradient side of wetland T3). Water-table levels on the side of wetland T3 toward wetland P1 (downgradient side) were always lower than the wetland level, indicating seepage from wetland T3 to the ground-water system. Thus, wetland T3 and probably wetland T4 are flow-through-type wetlands; ground water enters one area of the wetland and exits from another area of the wetland.

For a time during late winter and early spring, wetland P1 had seepage to ground water on its upgradient side, the side toward wetland T3 (fig. 5*A*). This appears to be a late-winter condition only because, as late as mid-October (fig. 5*D*), the water-table gradient was toward wetland P1, even after wetland T3 dried up.

On the downgradient side of wetland P1, the side toward wells 15 and 16, the water table had a mound higher than wetland P1 during the period of study at well 16. However, water-level information from well 15 shows a water table lower than in wetland P1 before spring recharge (fig. 5*A*) and after late August.

These data from 1979 show the wetlands selected for detailed study are in a ground-water flow system in which water moves from an area of recharge, wetland T8, through an intermediate area, wetland T3. Available 1979 data from wells in the vicinity of wetlands P1 and P8 were insufficient to clearly define their position in the flow system. A seasonal reversal in ground-water flow occurred between wetlands T3 and P1 at the location of well 13.

CALENDAR YEAR 1980

Winter 1979–80 had very little precipitation; by April 1, 1980, only a small quantity of snow was on the

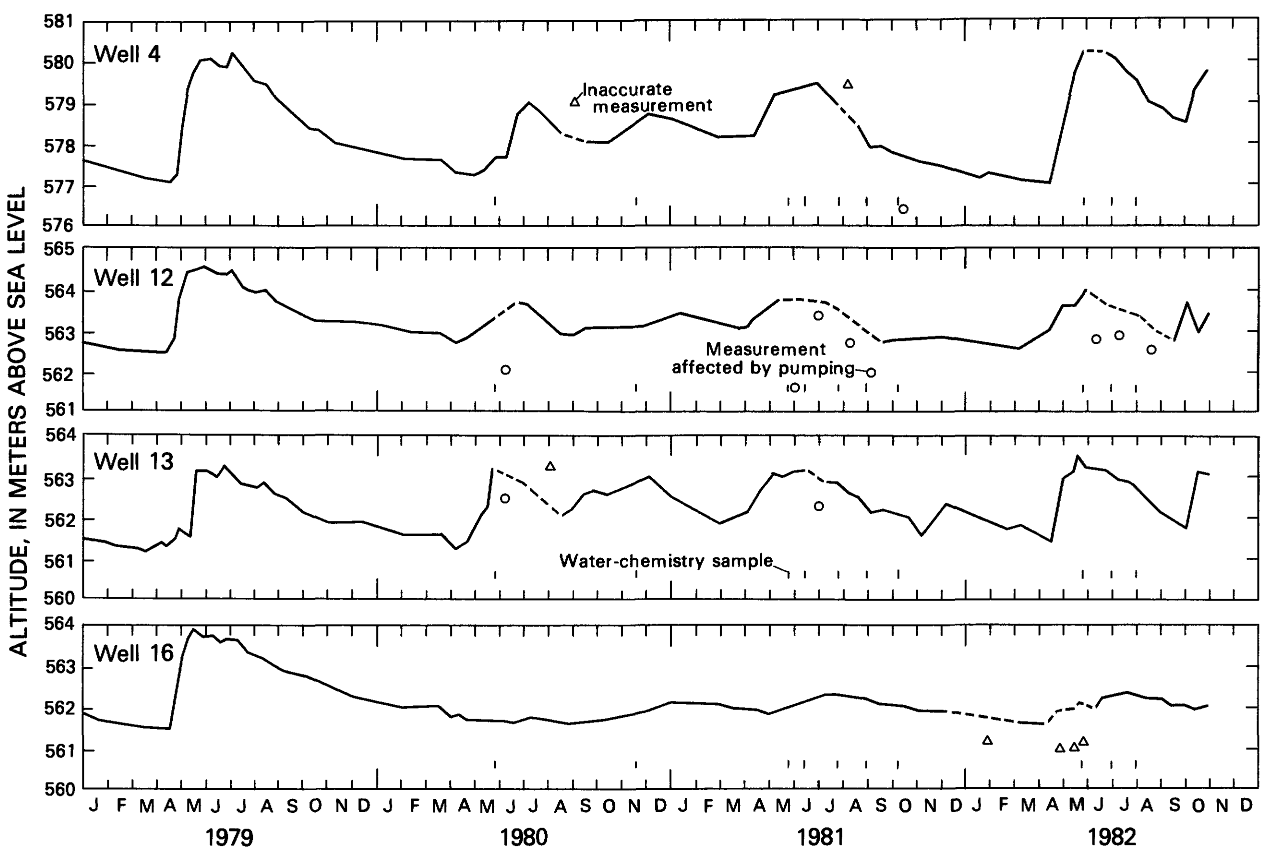


FIGURE 4.—Water levels in wells sampled for chemical analysis.

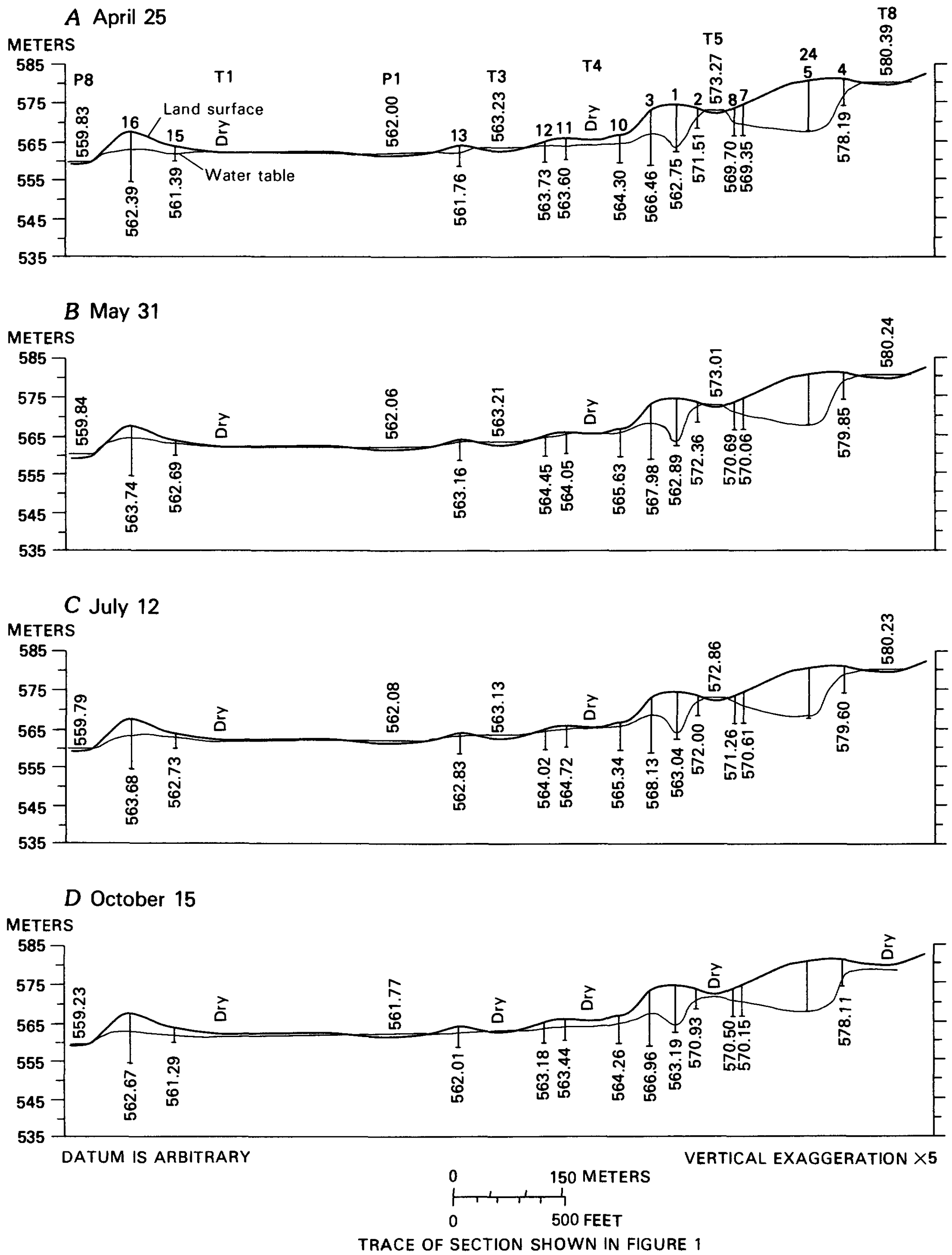


Figure 5.—Relation of wetland water levels to water-table levels for four dates in 1979 (modified from Winter and Carr, 1980). *A*, April 25. *B*, May 31. *C*, July 12. *D*, October 15.

ground. Because of minimal snowmelt in 1980, water levels in the wetlands generally were lower than in 1979, and the seasonal wetlands dried up by the end of April (fig. 3). As in 1979, however, more than 10 cm of rainfall in June resulted in water being present in the seasonal wetlands and in water-level peaks in the semipermanent wetlands. After the wet June, seasonal wetlands quickly dried up again, and water levels in semipermanent wetlands receded sharply through July. Greater-than-normal rainfall in August and September caused water levels in permanent wetlands to rise slightly and to remain stable into October when they froze. A late-summer rainfall did not cause water to be present in seasonal wetlands.

Recharge to ground water in 1980 began in April, but the water table reached a lower peak in 1980 than that of 1979 (fig. 4). The water level in well 16 showed no spring rise (fig. 4). Ground-water levels in most wells responded to the greater-than-normal late-summer rainfall. Well 13 showed particularly large rises in water level in contrast to the water level in well 16, which merely ceased to decline.

In the higher part of the area, ground-water flow directions between wetlands and ground water in 1980 were much like those determined for 1979 (fig. 6). In the immediate level of the area, water seeped from wetland P1 on the side toward wetland T3 during most of April (fig. 6*A*). At this time, wetland T3 also had seepage from it on its upgradient side, toward well 12, which is a relatively rare condition. By May 19 (fig. 6*B*), the water table between wetlands P1 and T3 (at well 13) was higher than the water level in wetland P1, thereby reversing the direction of ground-water flow in this area. The same is true of wetland T3 and well 12. This latter flow condition continued through the remainder of 1980 (fig. 6*C*-*E*).

Ground-water flow conditions between wetlands P1 and P8 in 1980 were considerably different from those in 1979. During 1979, the water level in well 16 was always higher than that in well 15. In the early part of 1980, the water level in well 16 was higher than that in well 15, but, by November, it was lower. In addition, the relation of the water level in well 16 to that in wetland P1 was much different in 1980 compared to 1979. In 1979, the water level in well 16 was always higher than the level of wetland P1; but, in 1980, it was lower from early spring to midfall. By November, water levels in wells 15 and 16 were higher than the water level in wetland P1. The significance of the 1980 data for wells 15 and 16 and wetland P1 is that the ground-water system in this area also had reversals of ground-water flow similar to, but not as short term as, that of the area between wetlands P1 and T3.

Construction of additional water-table wells (wells 17–29) in August 1980 made it possible for the first time to determine the areal configuration of the water table in the study area. Water-table maps for many dates were constructed; the general configuration was consistent for periods of high and low ground-water levels (fig. 7). The maps show that wetland P1 was principally in a ground-water discharge area and that the reversals of flow discussed for this 4-year period apply only to the low areas in the intermediate level along the hydrologic section.

As in the previous year, data from 1980 showed wetland T8 to be an area of ground-water recharge and wetland T3 to be intermediate, receiving ground-water discharge and, then, recharging ground water. Additional wells in the vicinity of wetlands P1 and P8 indicated that they were in areas of ground-water discharge. Reversals in ground-water flow again occurred between wetlands T3 and P1; however, these reversals were of shorter duration than those of 1979. Unlike 1979, reversals of flow also were determined between well 12 and wetland T3 and between wetlands P1 and P8. Reversals in flow between wetlands P1 and P8 were of longer duration than reversals between wetlands T3 and P1.

CALENDAR YEAR 1981

During winter 1980–81, only small quantities of snow fell in the study area; virtually no snow was on the ground before icemelt. Consequently, water levels in the wetlands in early spring 1981 were at low levels for the second consecutive year. Further, because of the warmer winter, ice in the wetlands melted in early March, which was at least 1 month earlier than in any other year of the study period.

Precipitation in late March caused rises in water levels in all wetlands (fig. 3). These rises were followed by declines of water levels through April, when wetland T8 dried up, and May, until a wet period in late May through June caused a second, but lower, water-level peak in June. After late June, water levels in the wetlands declined for the remainder of the open-water season. Wetland T3 dried up in late July.

The fluctuation pattern of ground water, indicated by the well data (fig. 4), was similar to that in 1980 with respect to magnitude and shape of spring peaks. The only exception was well 16, in which the water level rose to a peak in July, whereas, in 1980, no rise in water level occurred (fig. 4). Because no major rainfall occurred in late summer 1981, in contrast to 1980, no significant interruption of the summer-through-winter recession occurred.

Unlike the previous 2 years, because of the unusually low water levels in the wetlands, especially in wetland P1, no seepage occurred from wetland P1 on the side toward wetland T3 (fig. 8*A*). Thus, throughout the part of 1981 that wetland T3 held water, ground-water flow always was from wetland T3, past well 13, to wetland P1 (fig. 8*A*-*D*). Reversal of ground-water flow in the area between wells 15 and 16 again occurred in 1981, but that reversal was of a much longer duration than that of 1980. A reversal of ground-water flow from well 15 to wetland P1 also occurred in 1981; in 1980, however, no reversal occurred.

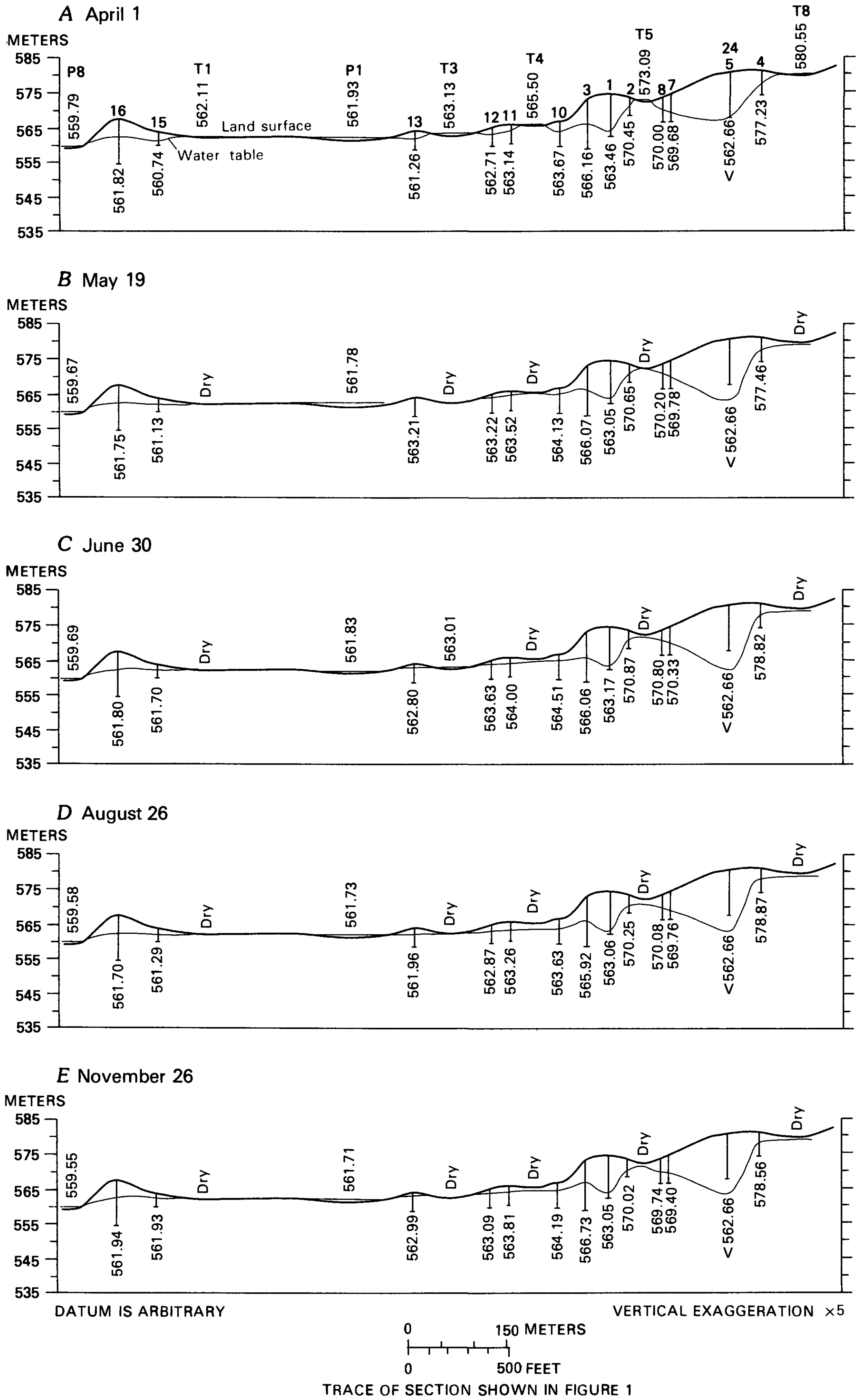


FIGURE 6.—Relation of wetland water levels to water-table levels for five dates in 1980. *A*, April 1. *B*, May 19. *C*, June 30. *D*, August 26. *E*, November 26.

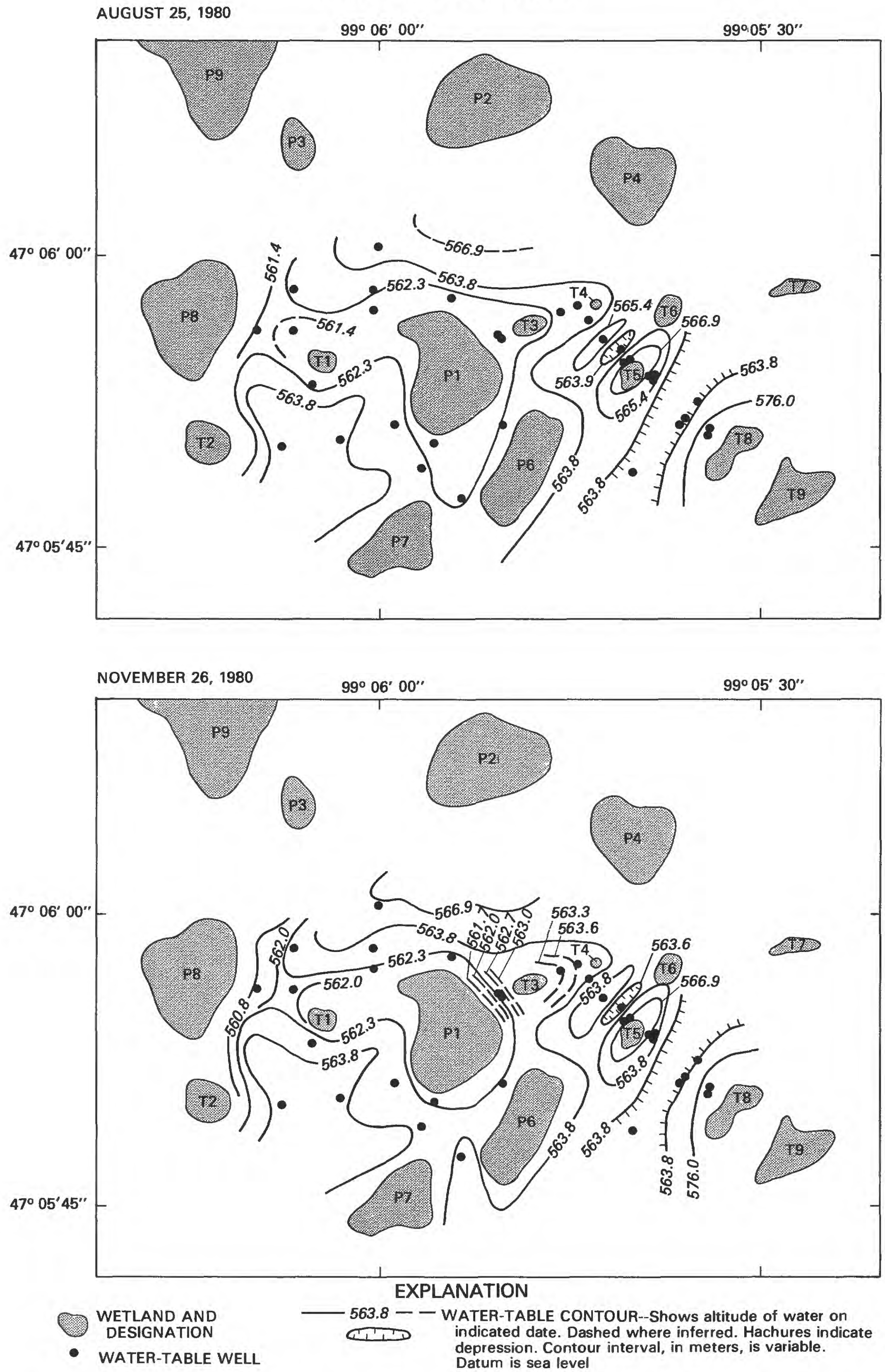
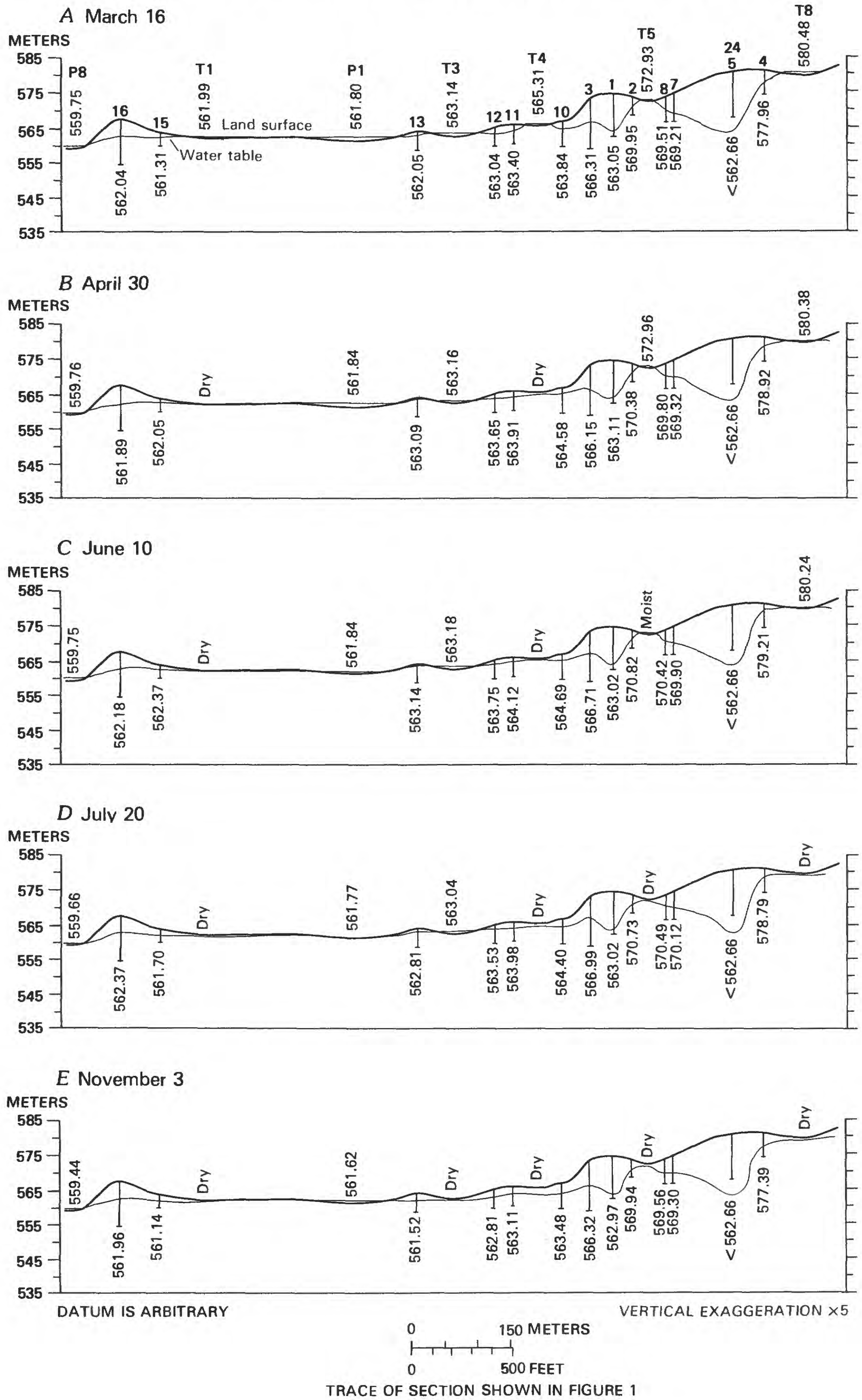


FIGURE 7.—Altitude and configuration of the water table for August 25 and November 26, 1980.


A March 16
METERS
585
575
565
555
545
535
P8
T1
P1
T3
T4
T5
T8
24
16
15
13
12 11
10
3
1
2
8 7
5
4
559.75
561.99
561.80
563.14
565.31
572.93
580.48
Land surface
Water table
562.04
561.31
562.05
563.04
563.40
563.84
566.31
563.05
569.95
569.51
569.21
<562.66
577.96
B April 30
559.76
Dry
561.84
563.16
Dry
572.96
580.38
561.89
562.05
563.09
563.65
563.91
564.58
566.15
563.11
570.38
569.80
569.32
<562.66
578.92
C June 10
559.75
Dry
561.84
563.18
Dry
Moist
580.24
562.18
562.37
563.14
563.75
564.12
564.69
566.71
563.02
570.82
570.42
569.90
<562.66
579.21
D July 20
559.66
Dry
561.77
563.04
Dry
Dry
Dry
562.37
561.70
562.81
563.53
563.98
564.40
566.99
563.02
570.73
570.49
570.12
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578.79
E November 3
559.44
Dry
561.62
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Dry
Dry
Dry
561.96
561.14
561.52
562.81
563.11
563.48
566.32
562.97
569.94
569.56
569.30
<562.66
577.39
DATUM IS ARBITRARY
VERTICAL EXAGGERATION ×5
0
150 METERS
0
500 FEET
TRACE OF SECTION SHOWN IN FIGURE 1

As in 1979 and 1980, wetland T8 was an area of ground-water recharge. Wetland T3 had ground water flowing through it. Wetlands P1 and P8 were in areas of ground-water discharge. No reversals of flow occurred between wetland T3 and well 12, between wetlands T3 and P1, or between wetlands P1 and P8. The only reversal in ground-water flow occurred between wetland P1 and well 15.

CALENDAR YEAR 1982

Although snowfall during winter 1981–82 was not as great as that of 1978–79, about 0.3 m of snow was on the ground in early March just before snowmelt. This accumulation resulted in early spring water levels in the wetlands being higher than they had been the two previous years; water levels were similar to those of spring 1979 (fig. 3).

Precipitation in May and June was sufficient either to maintain stable water levels in the wetlands or to cause them to have only minor declines, followed by a second, lower, peak in June. Steady water-level declines continued through the remainder of the summer and fall. Wetland T8 held water longer than at any time during the study period; then it dried up in mid-July. Wetland T3 also held water until mid-July.

In early October, an exceptionally large rainfall, about 13 cm, occurred, which is about two to five times greater than normal for October. This rainfall caused sharp water-level rises in wetlands P1 and P8; it also resulted in wetland T3 again holding water until the wetlands froze in late October.

Ground-water levels also responded to recharge from the large snowmelt in 1982 by showing sharp spring rises to peaks that were equivalent in some wells, such as 4 and 13, to the peaks of 1979 (fig. 4). In other wells, such as 12 and 16, the peaks were lower than in 1979. Ground-water levels receded throughout the remainder of summer and fall, but all wells showed a rise in water levels in response to the large October rainfall. The water-table rise in October was especially sharp in wells 4 and 13 (fig. 4).

Examination of the hydrologic section for 1982 (fig. 9) shows that wetlands T5 and T8 continued to have seepage to ground water on all sides, just as in the other 3 years of the study. In the area between wetlands T3 and P1, seepage from wetland P1 moved toward well 13 only during a brief period in April (which is not shown on sections in fig. 9). In the area between wetlands P8 and P1, reversals of ground-water flow again occurred. The pattern of reversals was similar to those of 1981, although 1982 had a much wetter spring.

Data from the 4 years show the wetlands selected for intensive study lie within a ground-water flow system that includes recharge and discharge areas. Wetland T8 is an area of recharge to the ground-water flow system. Between wetlands T8 and T3, configuration of the water table does not follow the topography of the land surface. Wetlands P1 and P8 are in areas of ground-water discharge. In the low areas between wetlands T3, P1, and P8, configuration of the water table is dynamic. Reversals of ground-water flow are common between wetlands T3 and P1 in the vicinity of well 13. Timing and duration of these reversals are affected by seasonal and annual fluctuations in snowpack recharge and by rainfall. Less pronounced or frequent reversals of flow occur between wetlands P1 and P8. Rare reversals in flow happen higher in the ground-water flow system.

WATER CHEMISTRY

GROUND WATER

Distinct quantitative and qualitative differences occur in the dissolved major ions of water from wells sampled during the study (fig. 10). With respect to major ions, water in well 12 is the least concentrated, and water in well 13 is the most concentrated. Geochemical types of water in the wells were calcium sodium bicarbonate in well 12, calcium sulfate in wells 4 and 16, and magnesium sulfate in well 13. Based on major-ion analysis, ground water at the study site is neither quantitatively nor qualitatively uniform.

To provide a ready means of comparing both water type and concentration, major ion data will be presented in the form of Schoeller diagrams (Schoeller, 1959). Although some seasonal variation occurred in the concentration of some of the major ions in water from each well, differences in average annual concentration were more pronounced (fig. 10). Despite these changes in concentration, with the exception of well 12, no difference was apparent in the geochemical type of water from year to year in the wells. Sodium replaced calcium as the most abundant cation only in 1981 in water from well 12.

Before examining differences in the geochemical type of water present in the wells, the positions of the wells in the ground-water system will be reviewed. Well 4 is downgradient along a ground-water flow path from a recharge area, wetland T8 (figs. 5-9). Well 12 is located in an area where ground-water was affected substantially by localized recharge to the ground-water system (figs. 5, 6, 8, 9). Although ground water in this vicinity would be expected to show evidence of dis-

FIGURE 8.—Relation of wetland water levels to water-table levels for five dates in 1981. *A*, March 16. *B*, April 30. *C*, June 10. *D*, July 20. *E*, November 3.

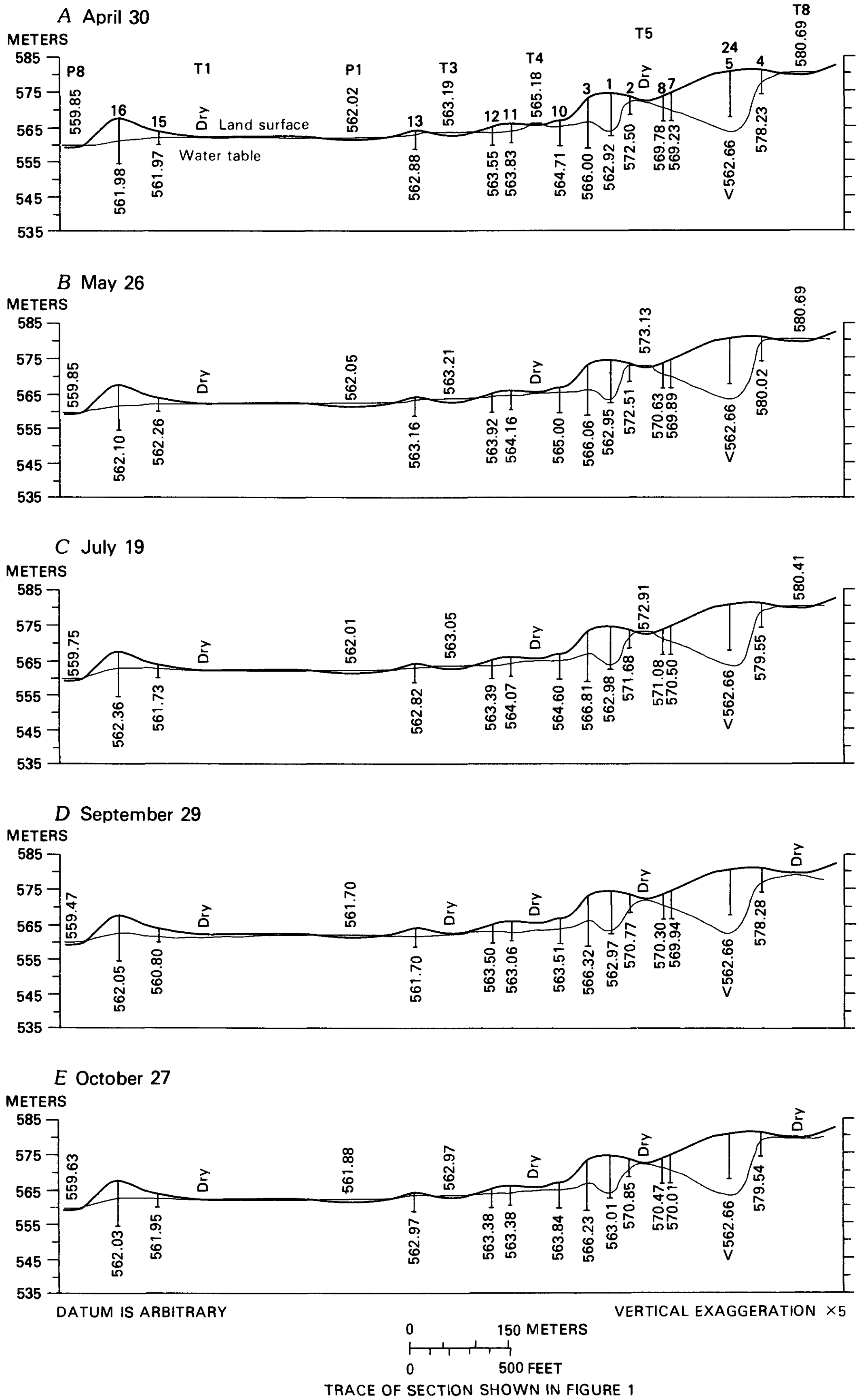
A April 30
METERS
585
575
565
555
545
535
P8
T1
P1
T3
T4
T5
T8
24
16
15
13
12 11
10
3
1
2
8 7
5
4
Dry
Land surface
Water table
559.85
561.98
561.97
562.02
562.88
563.19
563.55
563.83
565.18
564.71
566.00
562.92
572.50
569.78
569.23
<562.66
578.23
580.69
B May 26
METERS
559.85
562.10
562.26
Dry
562.05
563.16
563.21
563.92
564.16
Dry
565.00
566.06
562.95
572.51
573.13
570.63
569.89
<562.66
580.02
580.69
C July 19
METERS
559.75
562.36
561.73
Dry
562.01
562.82
563.05
563.39
564.07
Dry
564.60
566.81
562.98
571.68
572.91
571.08
570.50
<562.66
579.55
580.41
D September 29
METERS
559.47
562.05
560.80
Dry
561.70
561.70
Dry
563.50
563.06
Dry
563.51
566.32
562.97
570.77
Dry
570.30
569.94
<562.66
578.28
Dry
E October 27
METERS
559.63
562.03
561.95
Dry
561.88
562.97
562.97
563.38
563.38
Dry
563.84
566.23
563.01
570.85
Dry
570.47
570.01
<562.66
579.54
Dry
DATUM IS ARBITRARY
VERTICAL EXAGGERATION ×5
0
150 METERS
0
500 FEET
TRACE OF SECTION SHOWN IN FIGURE 1

FIGURE 9.—Relation of wetland water levels to water-table levels for five dates in 1982. *A*, April 30. *B*, May 26. *C*, July 19. *D*, September 29. *E*, October 27.

charge from adjacent ground-water highs (fig. 7), ground-water flow from these highs might be moving preferentially to wetlands rather than to the ground-water system between wetlands. The ground-water system in the vicinity of well 13 is in a discharge area for water moving from water-table highs in the adjacent valley walls (fig. 5). It also is in an area of alternating direction of ground-water flow between wetlands T3 and P1. Well 16 is in an area of ground-water discharge with some flow reversals between two wetlands that contained water throughout each year. Thus, each of the four wells was in a different position in the ground-water flow system.

If no chemical interaction occurs between water and the geologic material through which it moves along the ground-water flow path, then water in the four wells would be chemically identical and indistinguishable from water recharging the ground-water system. Data from the wells (fig. 10) and snowmelt recharge (fig. 11) show the water is neither chemically identical in the wells nor chemically indistinguishable from snowmelt at the Cottonwood Lake area.

The data shown in figures 10 and 11 indicate that some chemical interaction must occur between water and the geologic material through which it moves. It is assumed that, as water moves through geologic material along a ground-water flow path, interaction with that material takes place, as long as the ionic assemblage in the water is undersaturated with respect to the mineralogical composition of the geologic material. Thus, if water recharging the ground-water system was moving through gypsum, then the concentration of calcium and sulfate in the water would continue to increase until saturation for gypsum was achieved. Saturation could occur within a short distance along the ground-water flow path, if ground-water movement was slow, or within a longer distance along the flow path, if ground-water movement was fast. Consequently, composition of the water in a well is affected by geologic material in the flow path and by the position of the well in the ground-water flow system.

At the Cottonwood Lake area, geologic material in the area is assumed to be uniform. This assumption is based on results of drilling in the study area. The simplest explanation for the differences in the major-ion chemistry of the water in the wells then becomes one of a well's position in the ground-water system. Well 12 is in an area of ground-water recharge; therefore, water in well 12 has the least concentration of dissolved major ions (fig. 10) and is most similar qualitatively to snowmelt recharge of the wells sampled in this study (fig. 11). Well 13 is in an area of frequent flow reversals in a ground-water discharge area; so, water in well 13 is the most concentrated (fig. 10). Comparisons of data from wells 13 and 12 indicate that, as water moved from a recharge area to a discharge area, the water became more concentrated with respect to sulfate and major cations, particularly magnesium.

Water from wells 4 and 16 is more concentrated than snowmelt recharge (fig. 11) or than ground water in a

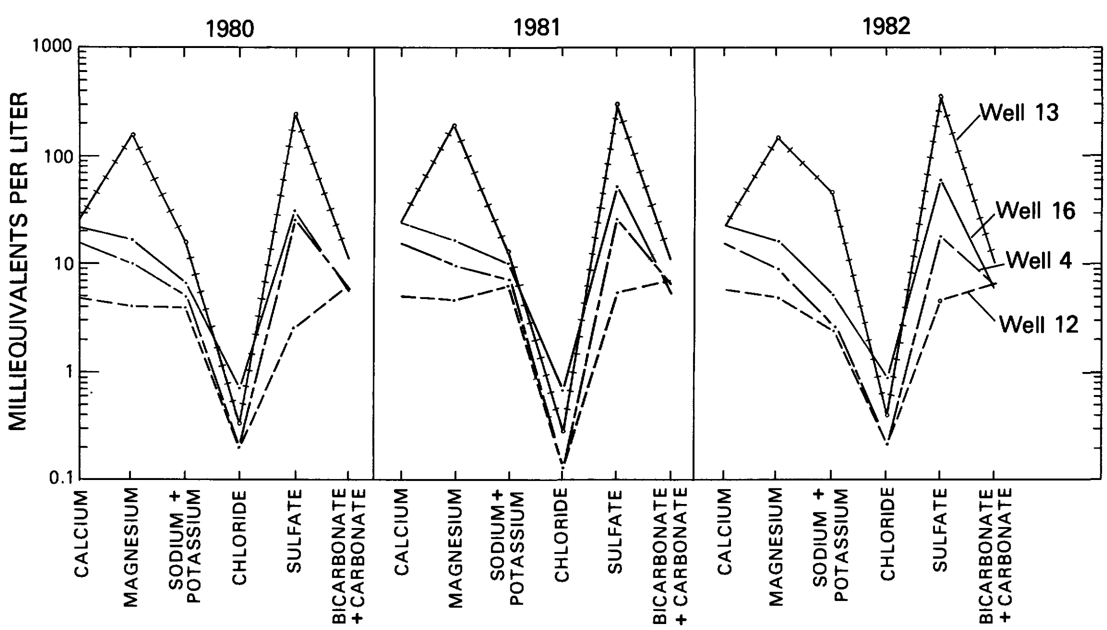

FIGURE 10.—Average annual major-ion composition of the water in wells.

recharge area, as represented by well 12 (fig. 10), particularly for calcium, magnesium, and sulfate. Because water in these wells is intermediate in concentration between a recharge area (well 12) and a discharge area (well 13), the wells must be along a flow path between recharge and discharge areas of the ground-water system. Although this is obvious for well 4 from the hydrologic sections and water-table contours presented in figures 5 through 9, the same is not true for well 16. Based on water-table configuration data, well 16 definitely is in an area of ground-water discharge with some flow reversals. Yet, the chemical composition of water in well 16 is distinctly different from that in well 13, which is in a similar position in the flow system, and statistically indistinguishable from water in well 4, which is in a very different part of the ground-water

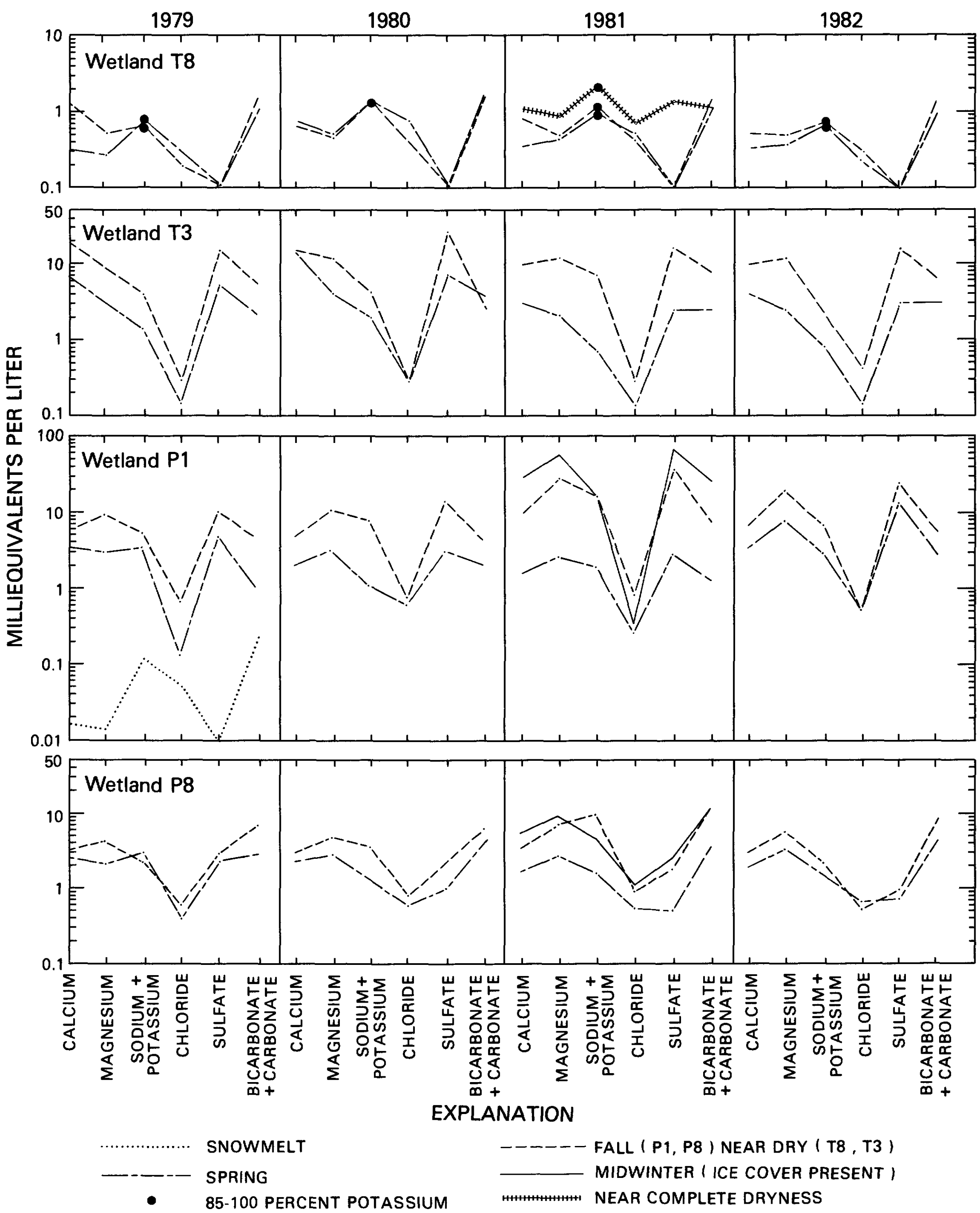

FIGURE 11.—Seasonal and annual changes in the major-ion composition of the water in wetlands.

system. These chemical data indicate that well 16 could be affected by localized recharge not evident from the available hydrologic information on the existing well network.

Chemical equilibrium analyses of water from the wells support the conceptual model used here to explain ground-water chemistry. These analyses were done using the computer program WATEQ (Truesdell and Jones, 1974). Water in the wells differed in the degree of saturation for certain minerals typically found in the till of the area. These analyses indicated that supersaturating conditions existed for calcite in the four wells. Supersaturation of the calcium sulfate mineral, gypsum, was evident in water from wells 13 and 16 throughout the study and in water from well 4 only in the driest year, 1981. Conditions of supersaturation did not exist for any magnesium sulfate minerals. These analyses indicated that the increase in calcium, magnesium, and sulfate in ground water may be a result of dissolution of calcium sulfate and magnesium sulfate minerals; for example, when water reaches a ground-water discharge area, as in the vicinity of well 13, magnesium increases relative to calcium because supersaturating conditions exist for calcium sulfate minerals but not for magnesium sulfate minerals.

In contrast to major-ion chemistry, no significant difference in concentrations of nitrite, nitrate, total Kjeldahl nitrogen, or total phosphorus occurred from year to year in water from each well. A statistically significant difference was shown to exist only in 1981 and 1982 between the ground water in each well on the basis of total Kjeldahl nitrogen alone; water from well 13 had the maximum concentration both years. Although total phosphorus concentration was least in water from well 4 and greatest in water from well 16 in the 3 years data were obtained from the wells, this difference in concentration statistically was significant only in 1981. Concentration of nitrite (when detected) was always equal to or greater than concentration of nitrate. This relation of nitrate to nitrite was most pronounced in water from well 13. These nitrogen and phosphorus data indicate the mechanisms controlling concentrations of nutrients along the ground-water flow path are different from those controlling major-ion concentrations at the site.

WETLANDS

As in the case of the wells previously discussed, distinctly different geochemical types of water existed in each of the wetlands (fig. 11). In general, the dominant cation and anion in waters of the wetlands were potassium and bicarbonate in wetland T8, calcium and sulfate in wetland T3, magnesium and sulfate in wetland P1, and magnesium and bicarbonate in wetland P8. Chloride was the least abundant major ion in the four wetlands. In contrast to the wetlands T3, P1, and P8, sodium and sulfate concentrations commonly were less than the detection limits in wetland T8.

Differences existed between the wetlands for major-ion concentration as well as water type (fig. 11). Based on these major-ion data, waters in the wetlands showed the following general relation with respect to concentration: wetland T8 is less than wetland P8 is less than wetland T3 is less than wetland P1. Water in wetland T8 consistently had the least specific conductance [110–600 microsiemens per centimeter (μS/cm)] of the wetlands. The greatest value of specific conductance (7,140 μS/cm) was measured under ice cover in wetland P1.

Very little seasonal change in concentration and water type occurred in wetland T8 when it contained water each year; similarity of concentration in early spring to concentration just before drying is shown in figure 11. A distinct change in water type occurred only when the wetland was almost dry, as in late May 1981. Sulfate was more abundant than bicarbonate.

Wetland T3 showed pronounced increases in concentration, particularly for calcium, magnesium, and sulfate, from the time it filled with water until it dried up in 1979, 1981, and 1982. The wide separation of points representing concentration in those years is shown in figure 11. Similar changes in concentration did not occur in 1980. A seasonal change in water type was measured only in 1980 and 1982, when magnesium increased slightly in abundance compared to calcium just before the wetland dried up.

Distinct seasonal patterns of changes in concentration of major ions were shown each year in wetland P1. Greatest concentrations were measured under ice cover; these concentrations were two to five times greater than the average concentration during the open-water season of 1981 (fig. 11). Water in the wetlands was most dilute during spring snowmelt; this was most evident at wetland P1 for the snowmelt period of 1979 (fig. 11) when concentrations of major ions were an order of magnitude less than during the rest of the year. Also, during snowmelt measured in 1979, water in wetland P1 was a sodium bicarbonate type, in contrast to other times of the year when the water typically was a magnesium sulfate type. Concentrations, particularly of the most abundant anions and cations, steadily increased from early April to ice cover in late fall. This increase was most distinct in 1981, particularly for wetland P1.

Concentrations of major ions in wetland P8 increased slightly from April to ice cover in late fall; the most marked increase was measured in 1981 (fig. 11). Greatest concentrations of calcium, magnesium, and bicarbonate were in samples collected under ice cover in 1981. Wetland P8 showed the most noticeable seasonal changes in major-ion type of all the wetlands; sodium became more abundant from spring to fall and was the dominant cation in October 1979 and 1981 (fig. 11). An example of the pronounced change in major-ion type in wetland P8, relative to the other wetlands, is shown by data from 1981 (fig. 12).

These data indicate that the wetlands differ qualitatively and quantitatively in the geochemical type of water present in each and that seasonal changes occurred in some wetlands. Hydrologic data presented in figures 5 through 9 show the wetlands are located in different positions in the ground-water flow system. Based on these data, the wetlands appear to be similar to the wells in that they differ chemically and in hydrogeologic setting. This study indicates that the chemical

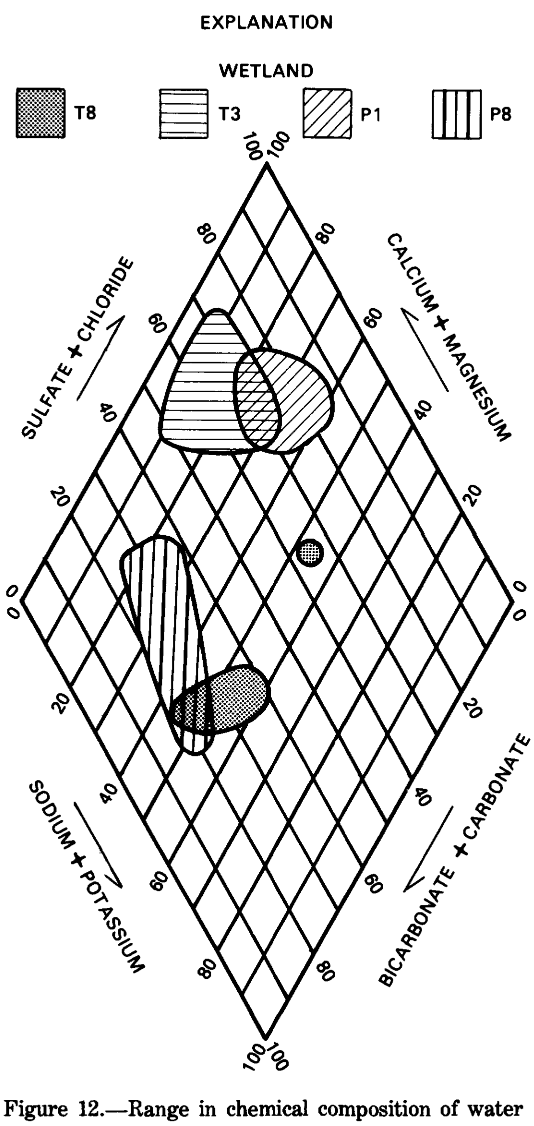

Figure 12.—Range in chemical composition of water in the wetlands, 1981.

composition of water in the wetlands is related to the position of the wetlands in the ground-water flow system, as was the case for the wells.

If the position of a wetland in the ground-water system does affect the geochemical type of water in the wetland, then water in wetlands in ground-water recharge areas would be similar to atmospheric deposition, and those in discharge areas would be similar to ground water in the discharge area. At the study site, wetland T8 was in a ground-water recharge area, and the water was a monovalent-cation bicarbonate type and relatively dilute, like snowmelt measured at wetland P1. Wetland P1 was in a ground-water discharge area, and the geochemical type of water in the wetland was magnesium sulfate like ground water in a discharge area (well 13). The geochemical type of water in wetland T3 was similar to that found in ground water in a position along a flow path between ground-water recharge and discharge areas, represented by well 4. Water in both was a calcium sulfate type. Although wetland P8 was in a ground-water discharge area, it was not characterized by a magnesium-sulfate-type water; instead, it was a magnesium-bicarbonate-type water. The dominant cation, magnesium, was typical of ground-water discharge in the flow system at the site, as represented by water in well 13 and wetland P1. Unlike wetland P1, wetland P8 has an intermittent surface-water outlet.

Other hydrological processes can affect the type of water found in each wetland, in addition to the wetlands' position in the ground-water flow system, as shown by geochemical data from wetland P8. Water and chemical elements were supplied to the wetlands by snowmelt, rainfall, overland runoff, and ground-water inflow. Water and chemical elements were lost from the wetlands by outflow to ground water and by evaporation. In addition, losses occurred by an intermittent channelized surface-water outlet from wetland P8. The quantitative importance of each of these processes in determining the chemical composition of water in each wetland is beyond the scope of this report.

However, it is possible to examine indirectly the effect of concentration by evaporation. Each of the wetlands had some seasonal changes in the concentration of major ions; these changes were most pronounced in wetland P1 and almost negligible in wetland T8 (fig. 11). Typically, water in the wetlands was most dilute during snowmelt and loss of ice cover. Water in the wetlands became more concentrated while they contained open water; it became most concentrated under ice cover in wetlands P1 and P8. Because water levels in the wetlands declined concurrently with the increase in concentration, change in water level and change in concentration appear to be correlated.

If concentration by evaporation alone was the process responsible for the seasonal changes measured in the major-ion composition of the water in the wetlands, then a significant statistical relation could exist between water level and concentration. Most of the variability in concentration then could be accounted for by changes in water level, providing evaporation alone resulted in water-level changes. Water-level changes were assumed to be an indirect estimate of changes in water volume of the wetlands because stage-volume data were unavailable. Results of regression analyses to examine the relation between changes in water level and in concentration are presented in figure 13.

Results of the regression analysis shown in figure 13 do not support the statement that concentration by evaporation alone is responsible for the seasonal changes in chemical composition shown in figure 11. These regressions, based on intercept, slope, and regression coefficient data, rarely were consistent from year to year. In many cases, water-level changes could account for only 60 to 70 percent of the variability in concentration. No significant regressions occurred for wetland T8, which was consistent with the fact that no statistically significant seasonal increase in concentration was determined for that wetland, in contrast to wetlands T3, P1, and P8. These statistical analyses indicate that processes other than concentration by evaporation were occurring in these wetlands. To confirm this, change-in-mass calculations would have to be performed to show changes in mass with time. Water-volume data necessary for such calculations were unavailable.

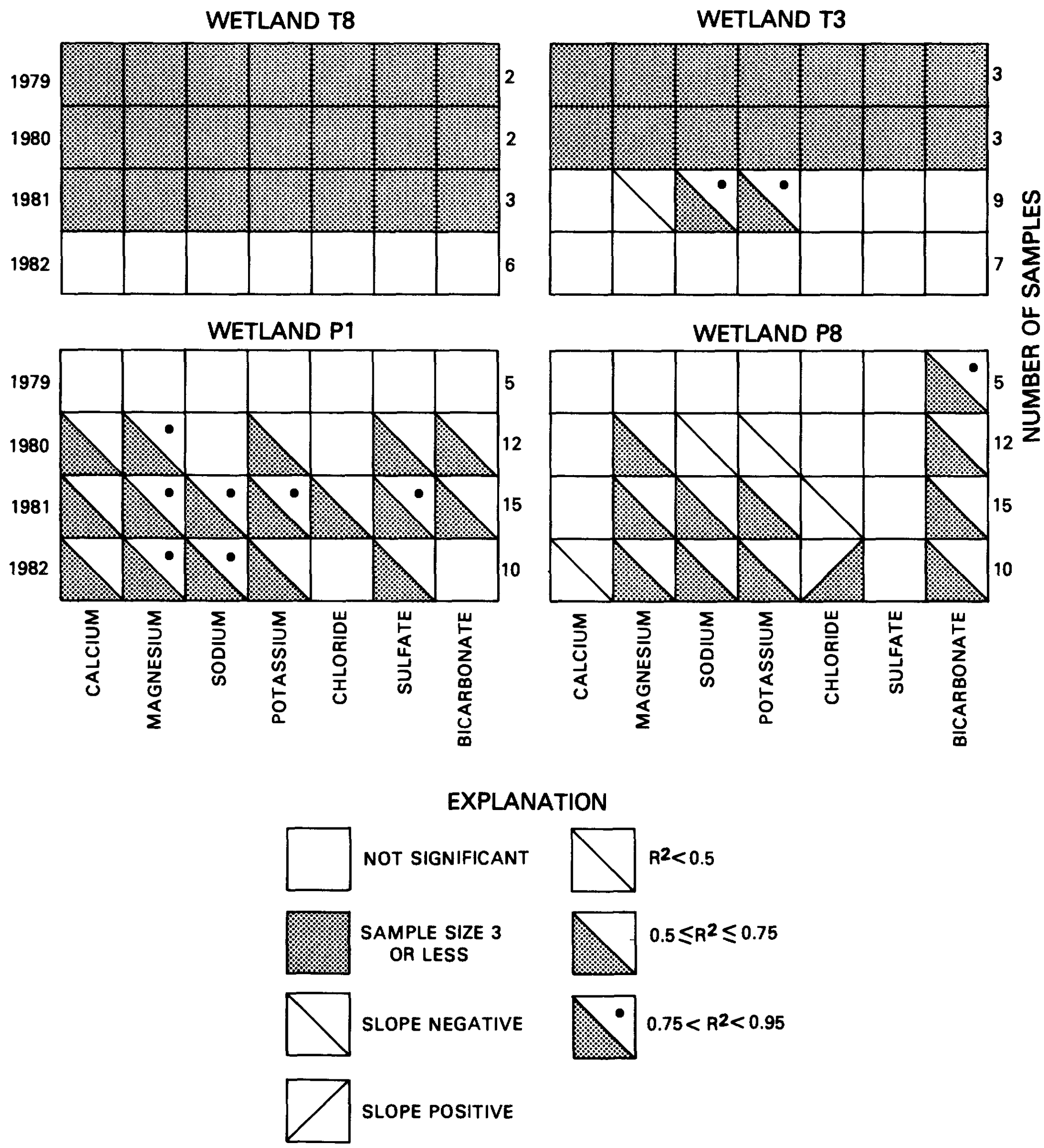

FIGURE 13.—Relation between water level and major-ion concentration in each wetland.

Comparison of data from wetlands T8, T3, P1, and P8 (fig. 13) indicated changes in water level were statistically related most often to changes in concentration for wetland P1, most likely because it was in a ground-water discharge area with no surface outlet and only a narrow area of outflow by ground water. No quantitatively significant hydrologic process exists that could transport ions out of the wetland, thereby affecting measured concentration in the water remaining in the wetland. Thus, concentration by evaporation would be expected to be an important mechanism controlling major-ion concentrations in wetland P1 in comparison to the other wetlands.

The relative importance of evaporation as a mechanism controlling major-ion concentrations in water within wetland P1 varied from year to year. In the driest year of the study, 1981, the effect of ground-water inflow-outflow on major-ion concentration would be less than in the other, wetter, years. In 1981, the most abundant ions in wetland P1 had nearly twice the increase per unit change in water level compared to any other year. Changes in water level accounted for greater than 85 percent of the variability in magnesium and sulfate, indicating that the effect of changes in water level on changes in concentration was most pronounced in a dry year.

To examine further statistical relations between changes in concentration and changes in water level between wet and dry years, analyses of covariance were used to compare regressions. Analyses showed differences between wet and dry years only in wetland P1 and only for specific conductance. A statistically identical relation existed between changes in water level and specific conductance for 1980 and 1981, based on comparison of regressions. This regression relation for 1980 and 1981 was different from regressions of water level and specific conductance in 1979 and 1982; changes in water level accounted for 72 to 74 percent of the variability in specific conductance in wetland P1 for 1980 and 1981, whereas, in 1979 and 1982, these changes accounted for 61 percent.

In contrast to the major ions, changes in the concentration of total phosphorus and total Kjeldahl nitrogen in the wetlands did not have a steady increase from ice-melt to the formation of ice cover. Wetland T3 had a marked increase in total phosphorus and total Kjeldahl nitrogen just before becoming completely dry only in 1981 and 1982. The concentration of total phosphorus just before complete dryness was more than double the concentration measured when wetland T3 contained substantial standing water. In 1980 and 1981, the concentrations of total phosphorus in wetland P1 were greatest just after loss of ice cover, and the concentrations decreased to one-third of those maxima from June to the formation of ice cover. This decrease did not occur in 1982. Patterns of change in concentration of phosphorus and nitrogen in wetlands T8 and P8 showed no similarity in any of the 4 years of the study.

With respect to concentration of phosphorus and nitrogen, based on analysis of variance, significant statistical differences occurred between the wetlands in each year of the study. The concentration of total phosphorus was greatest in wetland T8 and least in wetland P1 (fig. 14). The concentration of total phosphorus in wetland P1 was nearly an order of magnitude less than that in wetland T8. Wetlands T8 and T3 always had significantly greater concentrations of total Kjeldahl nitrogen than did wetlands P1 and P8.

These data for phosphorus and nitrogen for the wetlands indicate that mechanisms controlling concentrations of nutrients in the wetlands are different from mechanisms controlling major-ion concentrations. Phosphorus and nitrogen data do not show a steady increase in concentration with time beginning at snowmelt and loss of ice cover. Wetlands with the greatest phosphorus concentration had the least concentration of major ions. If the same mechanisms were controlling concentrations of major ions and nutrients, then concentrations of nutrients should have shown the same seasonal patterns and differences among wetlands as shown by the major-ion data.

RELATION TO AQUATIC VEGETATION

Plant communities of key wetlands examined in the Cottonwood Lake study area demonstrate the response of plant species to wetland hydrologic regimes, which determine the length of time water is present in the wetlands and chemical characteristics of the water. Wetlands in the study area were representative of different hydrologic regimes.

Wetland T8, located on a topographic high, receives precipitation and perhaps surface runoff as the dominant water sources; it functions as a recharge wetland that maintains a relatively small specific conductance. Indicators of water with relatively small specific conductance, slough sedge (*Carex atherodes*) and marsh smartweed (*Polygonum cuccineum*) (Stewart and Kantrud, 1972), are found in wetland T8.

Wetland T3 is located lower in the topographic profile; as a result, it receives ground water that increases the specific conductance of the water. Whitetop (*Scolochloa festucacea*), an indicator of increased specific conductance, is a dominant plant species of wetland T3.

Wetland P1 is a closed system to channelized surface-water outflow that establishes a dynamic hydrologic regime in response to changing climatic conditions.

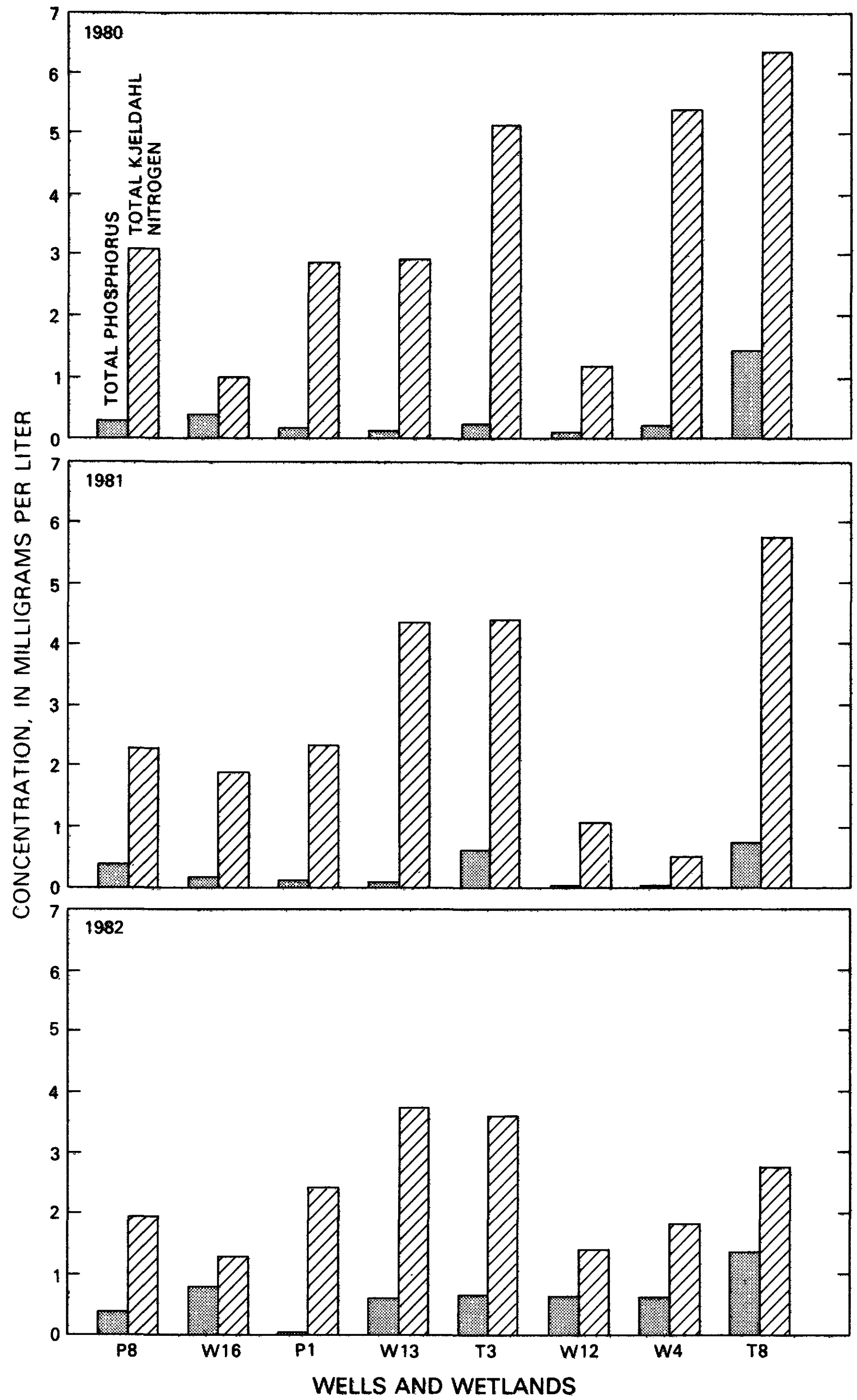

Figure 14.—Phosphorus and nitrogen data from wells and wetlands showing differences along the hydrologic section.

Changes in water level are followed by major changes in dissolved chemical constituents of the water. Wetland vegetation zones respond to changing water levels by constantly adjusting to drawdown and reflooding cycles that are accompanied by changes in specific conductance. The central part of wetland P1 has varied from open water dominated by submerged vascular plants during high-water conditions to shallow marsh dominated by whitetop during low-water conditions.

Wetland P8 is an open system to surface-water outflow that tends to stabilize water levels and to maintain a minimal specific conductance relative to its position in the ground-water flow system. This type of water regime provides conditions that support cattail dominance in the central part of the deep-marsh zone. Zonation tends to remain stable, and cattail has established a floating mat that is extending toward the central part of the wetland.

IMPLICATIONS OF THE INTERACTION OF PRAIRIE WETLANDS AND GROUND WATER

HYDROLOGIC RELATIONS

Results of this study indicate that the hydrologic interaction of wetlands and ground water in the glacial prairie environment is considerably more complicated than was indicated by some earlier studies (Meyboom, 1966; Eisenlohr, 1972; Sloan, 1972). The reason for these differing views of complexity is most likely the result of differences in project design. Some of the earlier studies were of individual wetlands that did not give the complete range of wetland–ground-water interactions, as do studies of wetland systems situated at different altitudes along a topographic (and groundwater) slope.

The concept of depression-focused ground-water recharge and discharge as proposed by Lissey (1971) is a natural outgrowth of studying a series of wetlands on a valley side. This concept is substantiated fairly well in this study of the Cottonwood Lake area. However, even the depression-focusing concept needs to be viewed with a perspective on the size of depressions needed to concentrate the surface water; for example, the water-table highs north and south of wetlands T1 and P1 (by wells 28 and 29 on the north and wells 18 and 22 on the south; fig. 7) did not show obvious depressions. Yet, water-table highs persisted in these areas. Although depressions for focusing recharge were not large, recharge to ground water apparently occurred in these uplands.

Study of the Cottonwood Lake area permitted synthesis of a number of concepts of the interaction of wetlands and ground water in the till-prairie environment. As stated before, Lissey's (1971) concept of depression-focused recharge and discharge was demonstrated clearly in the study area. Depression-focused recharge was particularly evident in the higher part of the area. Here, wetlands T8 and T5 served primarily as ground-water recharge pits. If either of these wetlands would be studied individually and if they were assumed to be representative of all prairie wetlands, then a serious misconception would result because they clearly represent only one possibility for the interaction of wetlands and ground water.

Wetlands in the intermediate and lower levels of the study area serve different functions with respect to ground water than wetlands in the higher area. Wetlands in these levels of the study area function either as areas of ground-water movement in and out of the wetland or as areas of ground-water discharge. The fact that the water chemistry from well 12 was so different from that of wetland T3 is an indication of depression-focused ground-water discharge. Wetland T3 was an excellent example of a flow-through wetland; that is, most of the time, ground water seeped into one side, and wetland water seeped out the other side. Wetlands P1 and P8 are good examples of ground-water discharge areas. Individual study of either of these wetlands and their contiguous ground-water system would result in the concept that water-table highs underlie land-surface highs and that the flow system is simply from these water-table highs to the adjacent lowland, which is occupied by a wetland. This concept, as seen in the Cottonwood Lake study area, also would be misleading if it were applied to all prairie wetlands. Results of studies in the Moose Mountain area of southern Saskatchewan (Rozkowska and Rozkowski, 1969; Rozkowski, 1967, 1969) need to be viewed from this perspective.

In addition to the implications of this study for understanding the interaction of wetlands and ground water, the results also add perspective to understanding ground-water flow in till of low permeability. Water-table lows underlying land-surface highs in the higher part of the study area provide onsite evidence for phenomena observed in theoretical modeling studies, as previously discussed in the section "Hydrologic Conditions."

Another aspect of theoretical numerical simulation studies with application to this study is the effect of water-table mounds between certain wetlands on ground-water flow and seepage. Studies of unsaturated-saturated porous media (Winter, 1983) also show that the depth of penetration into the ground-water system of local ground-water flow systems is related to water-table mounds of various heights. This relation is important to understanding the effect of ground-water recharge on seepage to and from surface water.

Finally, no discussion of ground-water flow in materials of low permeability is complete without mentioning flow in fractures. Clay-rich material commonly is fractured, particularly in the unsaturated zone. Grisak and others (1976) have discussed the hydrologic and geochemical properties of fractured till that is similar to till in the Cottonwood Lake area. Processes occurring in this till that affect water chemistry are described in the following section.

WATER-CHEMISTRY RELATIONS

MAJOR IONS

Geochemical interpretation by Rozkowski (1967, 1969) of wetland interactions with ground water was based on the simplest hydrologic concepts of recharge under land-surface highs and discharge to adjacent depressions. Consequently, in a series of papers on prairie wetlands in Canada, Rozkowski (1967, 1969) indicated that, in glacial moraine, ground water in recharge areas is a calcium magnesium sulfate type and that ground water in discharge areas is a magnesium sulfate type. Rozkowski (1967, 1969) also found calcium bicarbonate waters in sandy glacial deposits on slopes of hills. He did not interpret the calcium bicarbonate water type in the context of ground-water flow systems, as was done for calcium magnesium sulfate and magnesium sulfate water types.

Rozkowski's (1967, 1969) interpretation of the hydrogeochemical patterns of prairie wetlands in Canada was based on assumptions of the local hydrology, following Meyboom's (1966, 1967) concepts of ground-water movement, and not on actual concurrent investigation of the hydrology of his study area. The wetlands Rozkowski (1969) found to be a calcium bicarbonate type or a calcium magnesium bicarbonate type correspond to wetland T8 in the Cottonwood Lake area. The calcium magnesium sulfate waters of Rozkowski's "recharge" areas are similar to the waters found in wells 4 and 16 in the Cottonwood Lake area; both are some distance along the path of ground-water flow.

The increase in concentrations of magnesium, calcium, and sulfate along the ground-water flow path in the Cottonwood Lake area is similar to their occurrence in glacial till in other parts of the North American Prairie (Grisak and others, 1976). Based on calculations of saturation indices, Grisak and others (1976) suggested that the dissolution of soluble carbonates and sulfate minerals is the process responsible for the increase in these major ions as ground water moves through glacial till. This process occurs in the ground-water system at the Cottonwood Lake area, based on data from WATEQ chemical equilibrium analyses.

The effect of concentration under ice cover of the major ions followed by dilution of icemelt in wetlands P1 and P8 is similar to that reported by Barica (1975) for prairie-pothole lakes in Canada. Although the hydrology of their area was not studied by Barica, Sunde and Barica (1975) indicated that Lissey's (1971) model of depression-focused recharge and discharge was representative of ground-water conditions in their study area. Barica (1975) measured the chemical composition of water from local farm wells and indicated that a direct relation occurs between the composition of lake water and ground water.

Data from the Cottonwood Lake area provide some insight concerning the hydrogeological problem related to specific conductance and major-ion chemistry of lakes in the North-Central United States, as noted by Gorham and others (1983). In that study, they determined that lakes in the North-Central United States could be classified into five groups (I–V) on the basis of specific conductance. Of these five groups, only two (III and IV) occurred in the Cottonwood Lake area. According to the classification of Gorham and others (1983), Group III lakes had specific-conductance values between 141 and 501 μS/cm. The specific-conductance range for Group IV lakes was 501 to 7,079 μS/cm. A distinct geographical boundary existed between Group III and Group IV lakes. Bicarbonate is dominant in Group III lakes, whereas sulfate is dominant in Group IV lakes. Gorham and others (1983) stated the hydrogeological problem as not knowing (1) how much of the III–IV boundary could be explained by the effect of local versus regional ground-water flow and (2) how much of the III–IV boundary resulted from mineralogical and chemical differences in the glacial deposits.

Wetlands from the present study of the Cottonwood Lake area fell into two distinct groups, based on the classification of Gorham and others (1983)—wetland T8 into Group III and wetlands T3, P1, P8 into Group IV. However, based on seasonal changes, the four wetlands could be put into either group. During ice loss and snowmelt, wetlands T3, P1, and P8 would be classified as Group III. When nearly dry, wetland T8 would be classified as Group IV. Gorham and others (1983) pointed out that, in arid areas (North Dakota and western Minnesota), seasonal variability in concentration and composition of lakes would occur. Consequently, a lake could be classified as either Group III or IV depending on what time of year it was sampled for analysis. This variation in classification based on time of sampling also was verified in this study for wetlands in the Cottonwood Lake area.

Data from the Cottonwood Lake area indicate that position within local ground-water flow was the major determinant of concentration and chemical composition with respect to major ions of surface-water bodies and of ground water. These data indicate that the effect of local flow systems can be important in the interpretation of the Group III–IV boundary described by Gorham and others (1983).

PHOSPHORUS AND NITROGEN

During an investigation of the nutrient regime of prairie-pothole lakes in Manitoba, Barica (1975) also found considerable seasonal variation in nutrient concentrations in the lakes. Total phosphorus and total nitrogen were inversely related to specific conductance. A similar relation was found in wetlands of the Cottonwood Lake area. Total phosphorus and total Kjeldahl nitrogen varied on a seasonal basis in wetlands of the Cottonwood Lake area. Wetland T8 had the least specific conductance and the greatest phosphorus and nitrogen concentrations during the period 1979–82.

The fact that wetland T8 had the greatest concentrations of total phosphorus and total Kjeldahl nitrogen can be explained, in part, on the basis of its position in the local ground-water system and its seasonal hydrologic cycle; wetland T8 has one or more periods of filling and drying annually. Macrophytes in wetland T8 are subjected to a more rapid cycle of filling and drying than in the other wetlands. Standing dead macrophytes result from three conditions in wetland T8—flooding, drying, and freezing.

Ulehlova (1978) indicated phosphorus and nitrogen are leached rapidly from standing, dead, aquatic macrophytes. Rapid loss of phosphorus and nitrogen by leaching also has been measured by Davis and van der Valk (1978). They also noted that plant fragmentation accounts for the remainder of phosphorus and nitrogen losses from standing dead macrophytes. Because standing dead material would be produced more commonly in wetland T8 than in wetlands T3, P1, and P8, more frequent inputs of phosphorus and nitrogen to this wetland from the macrophytes would occur.

If the filling and drying of wetland T8 is responsible for greater concentrations of phosphorus and nitrogen, then other seasonal wetlands (for example, T3) should have greater concentrations of these elements than the semipermanent wetlands (P1, P8). Also, if the duration of standing water in seasonal wetlands is related to nitrogen and phosphorus concentrations, then wetland T3 should have lesser concentrations of these nutrients than does wetland T8. Both of these results actually occurred in the study area during the period 1979–82. The concentration of total Kjeldahl nitrogen was less in wetland T8 than that in wetland T3 only in 1982, when the duration of standing water was nearly equal for both wetlands.

Loss of elements from standing dead macrophytes in wetland T8, as suggested by phosphorus and nitrogen data, also might have been responsible for the relatively large concentration of potassium in that wetland. Potassium also is lost readily from dying or dead aquatic macrophytes (Chamie and Richardson, 1978; Davis and van der Valk, 1978; Ulehlova, 1978). The short cycle of filling and drying in wetland T8 would produce conditions favorable for the input of potassium from dead or dying macrophytes, thereby contributing to the potassium bicarbonate water characteristic of the wetland. This condition is indicated by the fact that, in the wet years (1979, 1982), the abundance of potassium relative to the other cations was less than that in the dry years (1980, 1981).

Being a recharge area to ground water explains why major ions do not show a pronounced increase with time due to concentration by evaporation in wetland T8 relative to the other wetlands. These elements are lost through the wetland sediments to the ground-water system or to plant uptake. In the latter case, the elements are not lost completely from the system, but this will affect concentration in the water of the wetland only through leaching or during decomposition of the macrophytes, as indicated by the data for potassium. It is probable that most of the phosphorus and, to a lesser extent, the nitrogen in water moving from the wetland through its sediments are taken up by the macrophytes, rather than by entering the ground water. This would account for phosphorus and nitrogen concentrations being much less in the nearby ground water represented by water in well 4.

Many studies of wetlands have been done to determine what percentage of nutrient input is retained in the wetland (Valiela and Teal, 1978; Kadlec and Kadlec, 1979; van der Valk and others, 1979). However, only a few nutrient budget studies have attempted to measure most components of the water budget (Crisp, 1966; Valiela and others, 1978; Mitsch and others, 1979; Hemond, 1980; Verry and Timmons, 1982). As noted by Richardson and others (1978), comprehensive nutrient budgets are essential to determine what fraction of input is not lost by output. Calculation of chemical budgets for the wetlands in the Cottonwood Lake area was not possible for the scope of this study. However, comparisons of a wetland (P8) with a surface-water outlet, a wetland (T8) recharging ground water, and wetlands with no surface-water outlet and in a ground-water discharge area indicate that retention of phosphorus, nitrogen, and major ions in those wetlands would be a function of their hydrologic settings.

CONCLUSIONS

This study has shown that, in the glacial prairie environment, the hydrologic interaction of wetlands and ground water is considerably more complex than previously conceived. Ground-water recharge and discharge are depression focused, but water-table highs were found under broad land-surface highs in parts of the system. Study of hydrologic interactions for several years has indicated that predictions based on shorter term studies would produce misleading information about the relation between wetlands and adjacent ground water. Reversals in ground-water flow between some wetlands were measured in this study, which indicate the need to study the adjacent ground water, as well as more than one wetland in a system of wetlands.

Position within the local ground-water flow system primarily was responsible for the chemical composition of wetlands and the adjacent ground water. Seasonal and annual changes in the hydrologic conditions of the wetlands in ground-water discharge areas resulted in seasonal and annual differences in major-ion chemistry within those wetlands. Changes in phosphorus and nitrogen in water of the wetlands were unrelated to seasonal changes in hydrologic conditions of the wetlands. Differences between the wetlands on the basis of phosphorus and nitrogen appeared to be related to the effect of hydrologic variability on aquatic macrophytes. These data indicate that comprehensive knowledge of hydrologic setting is essential for chemical flux studies of prairie wetlands.

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