THE INFLUENCE OF A NEW ENGLAND WETLAND ON WATER QUANTITY AND QUALITY

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and
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ABSTRACT

An investigation was undertaken to determine the influence of a wetland on water quantity and quality. An 11 acre pond-wetland in southeastern New Hampshire was selected as the study site. Hydrologic, meteorologic, and chemical data were collected from field instrumentation and laboratory tests. Water losses during June, July, and August, 1969 due mainly to evaporation and transpiration were equal to about 20 inches. Evapotranspiration from the vegetated area was 1.7 times as great as open water evaporation. Stream discharge was small. During June, July, and August, 1970 an evaporation retardant was used on the open water surface. Open water evaporation was reduced by about 32 percent. The only major difference in field conditions between the two summers was that precipitation was several inches less in 1970. The water chemistry changes somewhat during the summer and early fall, but the data display considerable scatter with time and spatially at a given time. The water appears to represent a mixture of atmospheric precipitation and soil water that has been modified by factors such as microorganisms and organic activity. Total dissolved solids, pH, silica, and alkalinity are relatively low whereas iron and organic coloring tend to be fairly high.

INTRODUCTION

Considerable concern is being expressed about the adequacy of present day freshwater supplies and the freshwater needs for the future. An added factor is an increasing public demand that future supplies be obtained economically and reasonably without significant adverse effects on the environment. A useful method of approach is by proper watershed management to at least maintain if not increase water yields. Since many watersheds in New Hampshire and the rest of New England contain substantial acreages of wetlands, they are worthy of detailed study. Before any feasible management practices can be developed or used, the role of wetlands in the hydrologic cycle must be understood. A survey of the literature shows that actual investigations of the wetland role have been limited although their general function has been postulated and fairly widely accepted.

The present investigation was undertaken as a preliminary project to study the hydrology of a wetland in order to determine the feasibility of developing and utilizing wetland management practices to increase water yield during the dry months of the year. The project was implemented under the title "The Influence of Wetlands on Quantity and Quality of Streamflow" by the University of New Hampshire, Water Resource Research Center in January, 1968. The objectives of the study were to:

1) Study the magnitude of water losses due to evapotranspiration from wetlands.

2) Determine the influence of wetlands on base flow of streams.

3) Study the effect of vegetation in wetlands on the chemical quality of water.

Because of the varying interests of available personnel and because of the soon apparent necessity of restricting the study to one wetland, the report title and the objectives have been modified somewhat. The major changes were a decision to determine whether water can be salvaged by suppressing evaporation through use of a monomolecular film and to do additional work to better quantify the role of vegetational transpiration. The results of the evaporation suppression study are reported herein, and the vegetative studies will be discussed in a separate report.

The introductory and background sections of this report are the joint responsibility of the authors. The section on water budget and evaporation suppression has been taken mainly from a M.S. Thesis by Rutherford (1971) and a paper by Rutherford and Byers (1972). The water chemistry is mainly from work of Hall. In order to save space and cut costs, most of the basic data are not included herein. However, a computer printout for chemical analyses is available on request to the Water Resource Research Center.

DESCRIPTION OF THE WETLAND

LOCATION

The site selected for study is a combination pond-wetland of 11 acres in extent located in Stratham, Rockingham County, about 8 miles south of Durham, the location of the University of New Hampshire. The wetland area, locally called Jewell Pond, is situated in southeastern New Hampshire about 8 miles west of the Atlantic Ocean and about 2 miles south of Great Bay, a large estuary (Figure 1).

TOPOGRAPHY, GEOLOGY, AND SOILS

The wetland is at an elevation of 150 feet above mean sea level in a group of low hills that stand some 100 to 200 feet above the gently rolling, surrounding lowlands which range from sea level to 100 feet in elevation (Figure 1).

The upland portions of the land surrounding Jewell Pond consist of poorly sorted glacial till in the form of drumlins with irregular shaped ice-contact deposits along some of their flanks (Bradley, 1964; Goldthwaite, et al., 1951). Both till and ice contact deposits reflect the lithology of the underlying bedrock except that calcareous material is absent or has been leached out in the soil and near surface zone in the vicinity of Jewell Pond. There is evidence of shore deposits formed by the reworking of the till or ice-contact deposits (Bradley, 1964). Further

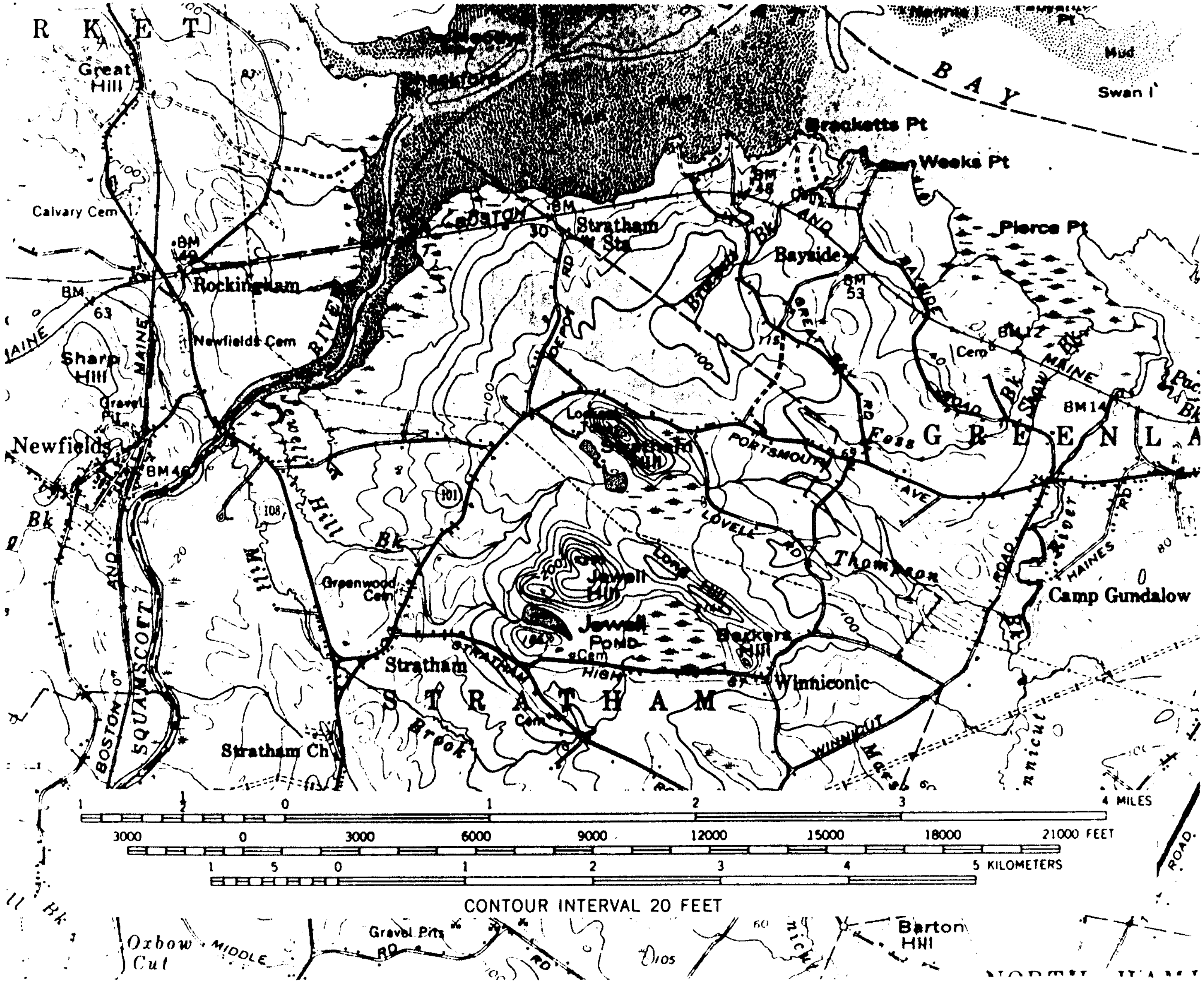

Figure 1. Map of the Jewell Pond Area

support for the presence of shore deposits is the fact that the hills in the area are greater in elevation than was the post glacial sea which covered large portions of coastal New England following the retreat of the glacial ice sheets. The lower elevations consist of marine deposited silts and clays and sandy stream deposits, nearly always underlain by marine sediments or with bedrock within a few feet of the surface.

The bedrock surface beneath the wetland area was eroded by Pleistocene glaciation, and presumably it is undulating with a range in elevations on the order of 40 to 100 feet and probably greater beneath the hills (Bradley and Peterson, 1962). The bedrock is the Eliot formation, which is a member of the Merrimack group and believed to be of Middle Silurian Age. In the Stratham area, the Eliot consists of: phyllite, commonly dolomitic; biotite schist; quartzite, in part feldspathic and in part dolomitic; and lime silicate rock (Billings, 1956).

The soils which tend to be fairly well drained are rocky, stony, sandy, or gravelly loams, and they closely reflect the character of the till and ice contact deposits (Van der Voet, 1959). The wetland areas including Jewell Pond are classified as Balch and Littlefield peats. The following description from Van der Voet, particularly for the Balch peat describes Jewell Pond very well.

"Balch and Littlefield peats -- These two soils were mapped together in Rockingham County as an undifferentiated soil group. Both occur in depressions where accumulated organic matter has remained wet enough so that some plant remains and cell structures were preserved. In most places this accumulation of organic matter is more than 3 feet deep, and in some places it is as much as 50 feet deep. These organic soils are associated with soils of the uplands and with soils of the glaciofluvial terraces."

"Balch peat, the dominant soil of the undifferentiated group, is dark brown, poorly decompoased, and acid. It consists principally of woody, fibrous, organic material formed mainly from decayed red maple, spruce, alder, and hemlock trees and from other woody plants. These same kinds of trees and woody plants now grow in the areas."

"Littlefield peat consists of the remains of sedges, rushes, and other herbaceous plants. It is acid, and trees rarely grow on this soil. In many places a shallow pond is in the center of an area."

CLIMATE

The climate of New Hampshire is mainly continental, but the wetland area undergoes some moderating effects from the nearby estuary and ocean. Mean annual precipitation is on the order of 42 inches, and precipitation tends to be evenly distributed throughout the year (Lautzenheiser, 1959). Evapotranspiration takes place mainly during the growing season period of mid May to late September, and it is on the order of 25 inches. The mean annual temperature is about 47°F with monthly means ranging from 70°F in July to 24°F in January.

VEGETATION

Jewell Pond is 11 acres in size but only 2.75 acres are left as open water (Figure 2). The remaining 8.25 acres has become filled with muck and peat which supports a dense growth of wetland vegetation consisting of buttonbush (Cephalanthus occidentalis) and leatherleaf (Chamaedaphne calculata). The open water areas have water lilies (Nuphar variegatum and others), pondweed (Potamogeten natans and Potamogetan berchtoldi), and bladderwort (Ultriculana vulgaris). Mixed hardwoods including red oak (Quercus borealus), black oak (Quercus velutina), white ash (Fraxinus americana), American beech (Fagus grandifolia), red maple (Acer rubrum), and paper birch (Betula papyrifera) along with eastern hemlock (Tsuga canadensis) and white pine (Pinus strobus) are found on the surrounding better drained soils. Grassland with sumac (Rhus typhina) is found at the western and eastern ends of the wetland.

GENERAL HYDROLOGY AND HYDROGEOLOGY

The group of low hills which contains several other ponds and wetlands in addition to Jewell Pond is drained by a more or less radial network of small streams that flow either to Great Bay or tributaries thereof (Figure 1). Discharge data are not available for these streams except for the tributary draining Jewell Pond during June, July,

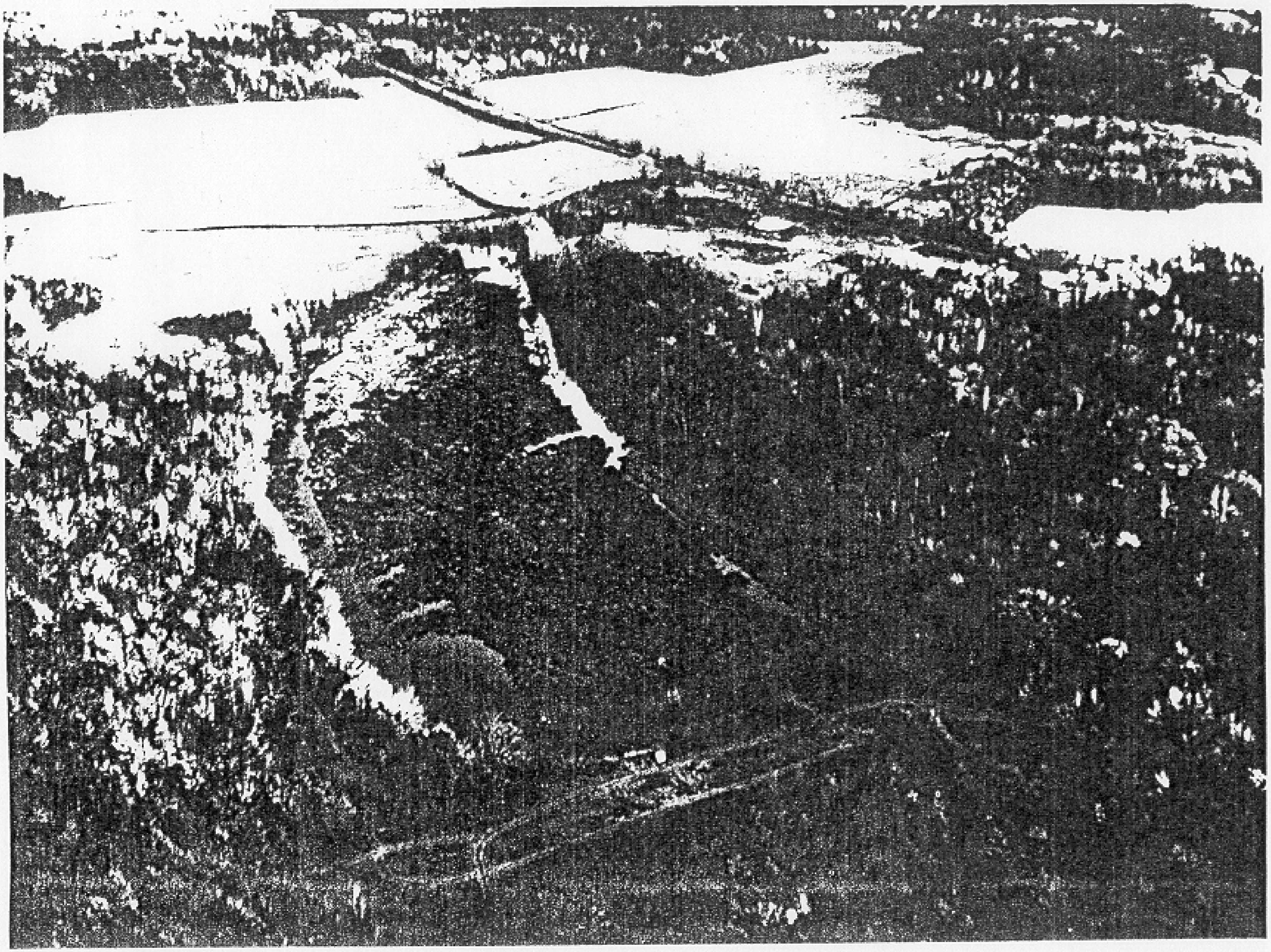

Figure 2. Aerial photograph of Jewell Pond showing the differentiation between the open water and vegetated areas.

and August of 1969 and 1970. The 11 acre wetland yielded about 1.6 inches each year. The drainage divide is hard to determine, but assuming a total area of 20 to 30 acres the areal runoff for these three months would be about 0.5 to 0.8 inches. Three nearby gauged streams with areas of 5 to 183 square miles had yields during the same period of 0.3 to 1.9 inches with the lower value being for the smallest basin. The data do not justify firm conclusions, but they do suggest that discharge from the wetland at least during the summer is within the regional range. Presumably the same holds for the rest of the hilly area.

A consideration of Figure 1 with regard to the similar elevations of the ponds and wetlands indicates that the group of hills represents a high or recharge area on the regional water table. However, the exact relationships of the ponds to the water table are not known with any certainty. Only a limited amount of hydrogeologic information is available (Bradley and Peterson, 1962; Bradley, 1964), but neither the hydraulic conductivity nor the specific yield of the till or underlying bedrock is likely to be very large.

Figure 3 is a generalized north-south cross section through Jewell Pond. The section is based on a few soil pits, peat probings within the pond, and the available soils and geologic data. The line of the section is shown on Figure 4. Although the section is not known in detail it does suggest that groundwater storage is not likely to be great.

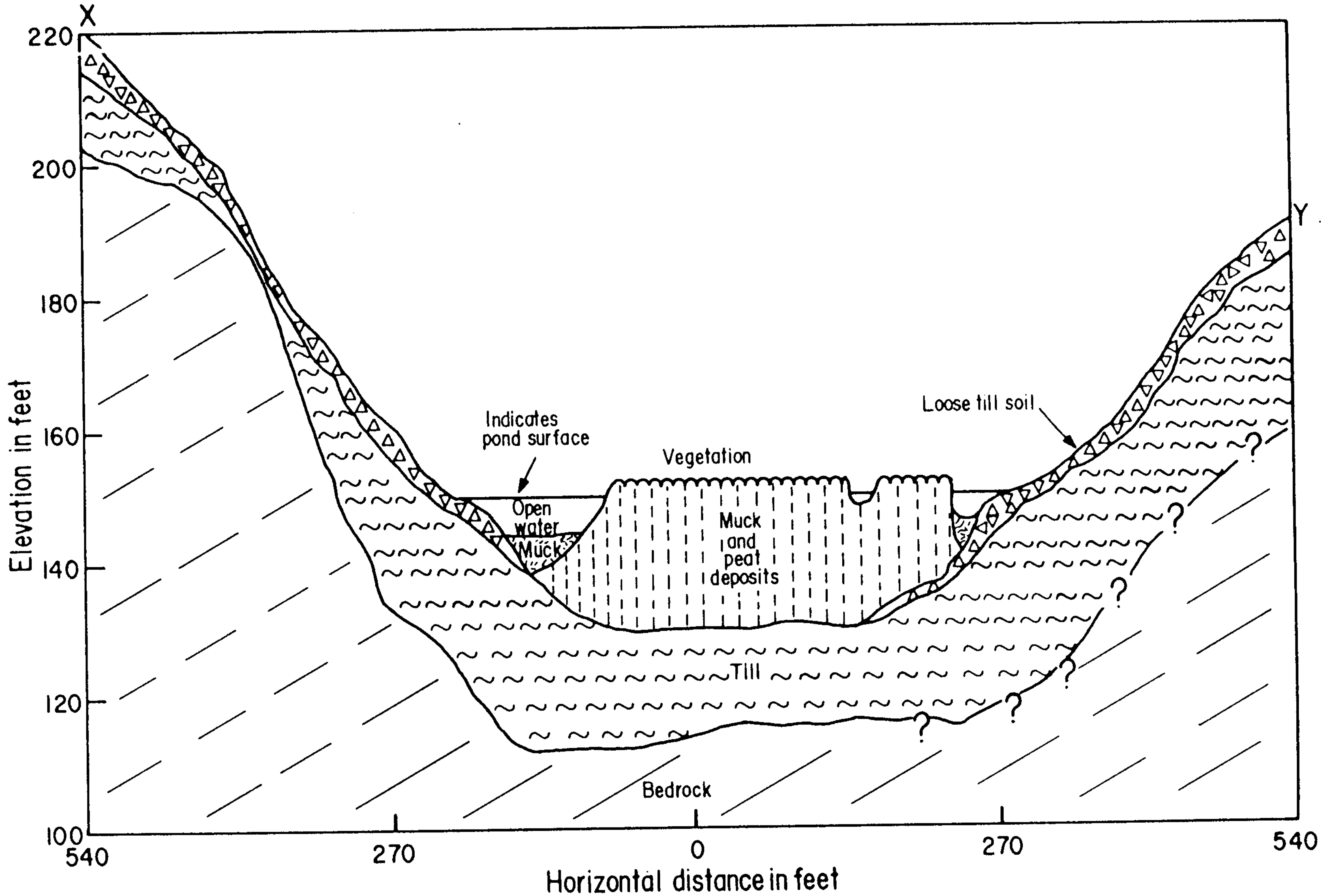

Figure 3. North-south cross sections through Jewell Pond.

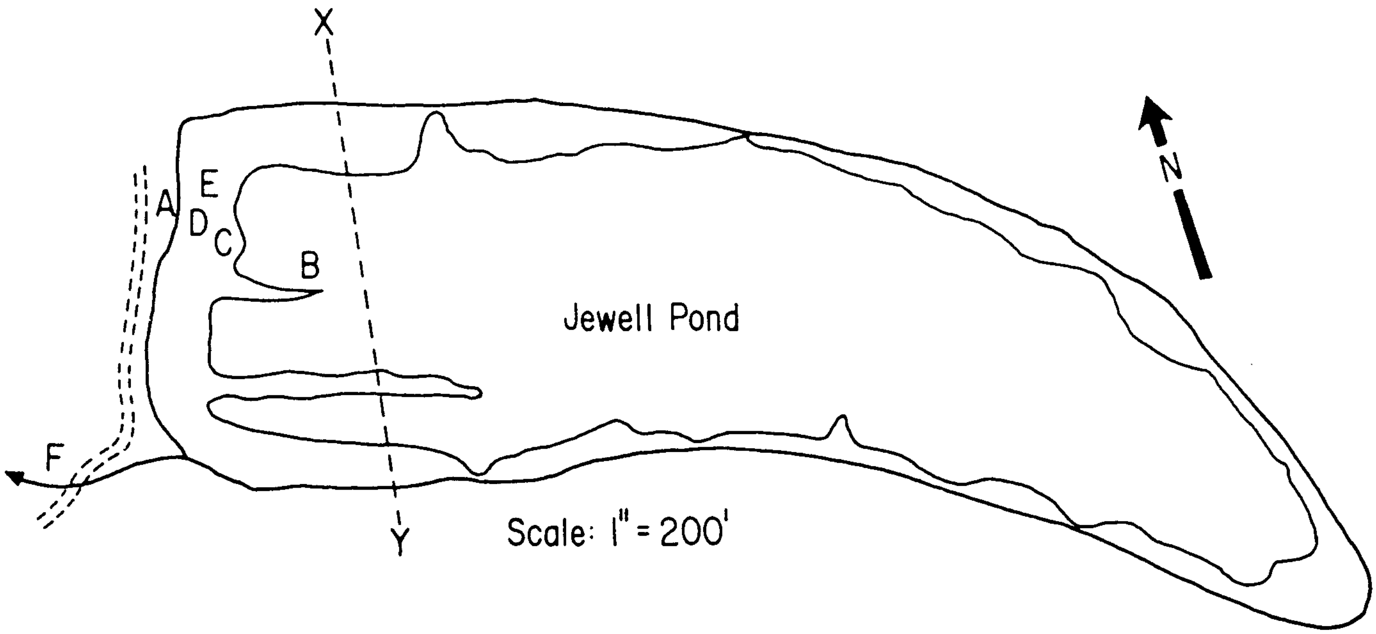

Figure 4. Instrument locations and chemical sample sites of Jewell Pond.

A. Location of recorders for net radiometer, integrating pyronometer, wind speed recorder, multi-point recorder and generator.

B. Location of the anenometer, air temperature and dew cell unit, and one of the net radiometers.

C. Location of the raingauge.

D. Location of the second net radiometer, the water temperature probe, and the regular surface and bottom water samples.

E. Location of the evaporation pan, the pond water level recorder, and the counting anenometer.

F. Location of the 90-degree V-notch weir and regular overflow samples.

XY. Position of the cross section depicted in Figure 3.

The pond is shallow with maximum depths of 7-9 feet at the western end. The pond level declines during the summer with reversals due to rainfall with a total lowering of about one foot to one and a half feet. The rather restricted area and shallow depths indicate that the pond does not undergo a seasonal overturn and this is also indicated by the water chemistry and lack of a distinct temperature profile. However, the pond water is kept fairly well mixed locally but not in its entirety, and aerated by the winds.

WATER BUDGETS FOR 1969 AND 1970

THE INSTRUMENTATION USED

Since both hydrologic and meteorologic data were needed for the study, appropriate instrumentation was required to collect both types of data. The meteorological data collected and the instruments used are listed in Table 1. Figure 4 shows the data collection sites. Additional hydrologic data collected consisted of (a) pond level fluctuations by the use of a water-level recorder; and (b) pond discharge by the construction of a 90-degree V-notch weir on the small stream that flows from the pond.

Table 1. Meteorological instruments employed in this study

Type of data collected	Instrument used
Precipitation	Weighing bucket and recording raingauge.
Air temperature and dew point depression	A motor-aspirated temperature and dew cell unit, recorded on a multi-point recorder.
Water temperature (at a 4" depth)	A temperature probe connected to the recorder.
Wind speed	A recording anemometer and an accumulating anemometer.
Incoming solar radiation	An integrating pyranometer.
Net radiation	Two miniature net radiometers: one over the vegetation and the other over the open water.
Water and vegetation surface temperature	An infrared thermometer.
Pan evaporation	A Weather Bureau "Class A" evaporation pan.

THE 1969 SUMMER WATER BUDGET

The first portion of the investigation was conducted during June through August, 1969. The evaporation and transpiration rates are high during these months in New England, and account for nearly one-half of the annual open water evaporation and about two-thirds of the annual transpiration from plants. To measure vapor transport from water surfaces, a "water budget" is usually developed in terms of outflow, inflow, and changes in storage in any given area. A water budget equation was used to determine the evapotranspirational water losses from the 8.25 acres of vegetated area within Jewell Pond. All values used in the equation were in terms of acre-inches of water, to account for the differences in the areas of open water and vegetation. The water budget equation used was:

$$ET = R - Q - E \pm \Delta S_W \pm \Delta S_p \qquad (1)$$

where:

ET = evapotranspiration;

R = rainfall;

Q = stream discharge;

E = open water evaporation;

ΔS_W = the change in storage for the open water body, and

ΔS_p = the change in storage for the area of peat.

The surface runoff from the surrounding land area into the pond was assumed to be insignificant, based on the following facts: (1) the normal rainfall intensity for the area during the months of June, July and August usually does not exceed the infiltration rate of the loose, sandy, glacial-till soils that surround the investigation site, (2) the consumption of water by both the hardwood forest that covers the hills and the grasses in the fields at the ends of the pond equals or exceeds the quantity of water received as rainfall during the summer. This high consumption of water by the plants tends to keep the soil relatively dry and increases the ability of the soil to hold and store water when rainfall occurs. Surface runoff during the summer has been found to be significant only when a storm of very high intensity or very long duration occurs (Pierce, 1966).

The flow of groundwater during the summer months was assumed to be negligible, therefore, any net flux would be absorbed in the evapotranspiration term (ET). The assumption was also made that the net groundwater flow would be constant from one year to the next.

During the 1969 investigation, the precipitation was 8 inches; the stream discharge was equivalent to 1.8 inches of water over the total pond area; the evaporation from the open water was about 8.25 inches; and the change in storage caused a decline in the pond water level of slightly over 14 inches.

Open water evaporation was calculated by the Penman evaporation equation (Appendix A). The ratio between the calculated Penman value and the evaporation pan data was 0.78, close to the anticipated ratio of 0.80 for a partially submerged evaporation pan to actual evaporation from an open water surface. The change in storage in the peat deposits was assumed to be 30 percent of the pond-level decline, determined from a limited number of measurements to obtain the water yield under gravitational drainage per foot of saturated peat. The 30 percent estimate is an arithmetic mean used during the investigation period and may vary by 10 or 15 percent. The evapotranspiration from the vegetated area, calculated by the water budget equation, was nearly 14.5 inches. This evapotranspiration value was 1.7 times the evaporation from the open water. The water budget analysis for each month and for the entire 1969 investigation is shown in Table 2.

Even though the data used in this investigation were collected during the summer when water losses are high, the results indicate that the yearly evapotranspiration loss from wetland vegetation may equal or exceed the yearly open water evaporation. The predicted annual evaporation for the Jewell Pond area is 25 inches, and the estimated evapotranspiration for wetland vegetation is about 27 inches, based on the values obtained in this investigation and the Thornthwaite evapotranspiration equation (Chow, 1964).

Table 2. The 1969 water budget analysis of Jewell Pond*

Time period	Evapotranspiration (ET) in:	
	acre-inches	inches
June	32.2	3.9
July	39.5	4.8
August	46.5	5.6
Summer season	118.3	14.3

*Based on the formula: $ET = R - Q - E \pm \Delta S_w \pm \Delta S_p$

The evapotranspiration from a mountain bog in the State of Wyoming was found to exceed evaporation pan losses by an average of 27 percent (Sturges, 1968). This average compares very closely with the 26+ percent value obtained in the present investigation. A study of two peatland waterhseds in Minnesota showed a relationship of evapotranspirational losses to potential evapotranspiration of from 87 to 121 percent, computed by the Thornthwaite equation (Bay, 1968). The relationships of water budget evapotranspiration to (potential) Thornthwaite evapotranspiration obtained in this investigation was from 92 to 116 percent, similar to the relation obtained in Minnesota. The Jewell Pond study and the Wyoming and Minnesota studies showed greater evapotranspiration losses than those measured in North Dakota prairie potholes, where the evapotranspiration losses were within 10 percent of the losses measured from open water surfaces (Eisenlohr, 1967). Probably more wetland studies have been made in the Soviet Union than any other place in the world, but it is rather difficult to utilize them since most of the Soviet work has been done in relation to draining wetlands for agriculture (Romanov, 1956).

EVAPORATION EQUATIONS AND WATER BUDGET COMPARISONS

After the water budget analysis for 1969 was completed, the values obtained for evapotranspirational water losses were compared to the values calculated by three of the most commonly used evapotranspiration equations, net radiation, and the Class A evaporation pan. The Penman, Thornthwaite, and Hamon equations were used (Appendix A). A ratio for each method was determined by dividing the calculated evapotranspiration value by the value obtained from the water budget. These ratios are shown in Table 3. The ratio obtained for the Thornthwaite equation (.99) was closest to unity, followed by the Hamon equation ratio (.86); the Penman equation ratio (.78); the class A evaporation pan ratio (.73); and the net-radiation ratio (.62). The net-radiation ratio appears to be low; however, there was no evidence during the investigation of trouble with these measurements. In addition, no measurements were made to determine the albedo of the vegetation. As a result, the net radiation is assumed to be correct. There are two other factors that may account for the lower ratio obtained from the Penman equation and the variations in the monthly values: advected energy load; and the vegetational characteristics such as plant growth, stomatal behavior, and the roughness of the vegetation surface. The ratios obtained compare reasonably well with the relations obtained in other investigations (Takhar and Rudge, 1970).

In order to overcome some of the problems encountered and to utilize another of the widely used evapotranspiration equations, consumptive-use coefficients for the Blaney-Criddle formula were calculated: they were 0.66, 0.69, 0.83 for the months of June, July, and August, respectively. Since these coefficients were calculated from the actual water budget values, they tend to compensate for the vegetation characteristics and the overall effect of the advected heat load. The coefficients therefore provide reasonably good results when used to calculate evapotranspirational losses for Jewell Pond and other areas with similar vegetational conditions, however, they cannot be used with confidence for wetlands that have different vegetational conditions.

Table 3. Evapotranspiration ratios obtained from the 1969 water budget.*

Time period	Basis for calculation: Class A evaporation pan	Net radiation	Penman equation	Thornthwaite equation	Hamon equation
June	.73	.66	.83	1.04	.92
July	.85	.60	.78	1.09	.98
August	.65	.61	.74	.86	.71
Summer season	.73	.62	.68	.99	.86

*Ratios were calculated by dividing the calculated evapotranspiration value by the value obtained from the water budget.

THE 1970 SUMMER WATER BUDGET

The second portion of the investigation was conducted during June through August, 1970. An evaporation retardant was used on the open water portion of Jewell Pond, to determine the impact of evaporation suppression on the wetland water budget and the suitability of its use in wetland management. The retardant was a mixture containing 59 percent hexadecanol, 34 percent octadecanol, and 7 percent impurities in the form of a dry powder. The retardant was sprinkled by hand from a boat at an average rate of 150 grams twice each week.

The 1969 water budget approach was used for calculating the results; however, evaporation loss was the term to be determined from the equation. The evapotranspiration was calculated using the Blaney-Criddle formula and the consumptive-use coefficients determined from the 1969 data. The Thornthwaite, Hamon, and Penman equations, and the Class A evaporation pan were also used to calculate the evapotranspiration loss for the entire investigation period. The seasonal rainfall was about 6.25 inches; the stream discharge was 1.73 inches; and the change in storage caused the water level to drop 16 inches. All values were converted to acre-inches for use in the water budget equation, in order to correct them for the differences in the areas involved in each term. The water budget calculations are in Table 4.

Table 4. The 1970 water budget analysis of Jewell Pond (entire summer season, June through August).*

Method of calculation	Evaporation (E) in:	
	acre-inches	inches
Blaney-Criddle formula	15.9	5.8
Thornthwaite equation	15.3	5.6
Penman equation	24.1	8.7
Hamon equation	19.8	7.2
Class A evaporation pan	22.8	8.3

*Based on the formula: $E = R - Q - ET \pm \Delta S_w \pm \Delta S_p$

EVAPORATION EQUATIONS AND WATER BUDGET COMPARISONS

After the evaporation losses were calculated by the water budget equation, they were compared to the corrected evaporation pan values to determine the effect of the use of the evaporation retardant. The evaporation pan correction was made by multiplying the pan loss by 0.78, the ratio obtained (between the Penman evaporation equation and pan evaporation) during the 1969 investigation period. The difference between the corrected pan loss and the water budget evaporation loss was divided by the corrected pan loss and reported as the percent evaporation reduction produced by the use of the retardant. The Penman evaporation equation was not used with the 1970 data because it was not known what effect the presence of the retardant had on the terms of the equation. It is evident that there was a significant effect on some of the terms, since the ratio between the Penman evaporation equation and the class A pan was 0.57 for the 1970 investigation period. The evaporation pan losses; corrected pan losses; water budget losses; the evaporation reduction; and the percent reduction are shown in Table 5. The evaporation reduction results indicate a significant reduction in water loss by using evaporation retardants. Using the average percent reduction (calculated from Table 5 as 32 percent), the quantity of water saved by reducing the evaporation was about 251,000 gallons.

Table 5. Evaporation reduction determined during the 1970 summer season at Jewell Pond.

Method of calculation in water budget	Calculated evaporation reduction:				
	Evaporation pan loss	Corrected pan loss (evap. pan x .78)	Water budget evaporation	Evaporation reduction (corrected pan loss-water budget evap.)	Reduction* (evap. reduction ÷ corrected pan loss)
	inches	inches	inches	inches	percent
Blaney-Criddle formula	13.5	10.5	5.8	4.7	45
Thornthwaite equation	13.5	10.5	5.6	4.9	47
Hamon equation	13.5	10.5	7.2	3.3	31
Penman equation	13.5	10.5	8.7	1.8	17
Class A evaporation pan	13.5	10.5	8.3	2.2	21

*Average percent reduction for all methods of calculation was 32 percent.

WATER CHEMISTRY

Water sampling for chemical analysis was begun in July 1968 and continued through September 1969. In addition, samples were taken only for conductivity measurements during June, July, and August, 1970.

ANALYTICAL ASPECTS

The analytical methods, constituents, or properties determined, and units are summarized in Table 6. An effort was made to obtain reasonable analytical results both by using standard procedures and by checking the cation-anion difference assuming that nitrate was a minor constituent. Also, an attempt was made to obtain a correlation between electrical conductivity and cation and anion totals in milliequivalents per liter (meq/l). However, the cation totals show a small but noticeable tendency of being a little large at lower concentrations and of being too small at higher concentrations with respect to the anion totals. The problem appears to lie partly with sodium and chloride but mainly with sulfate. The reasons for this difficulty are not obvious, but the generally unbuffered and highly colored character of the pond water may have affected the sulfate procedure.

Poor correlations were obtained between electrical conductivity and cation and anion totals. A reasonable explanation is that while the conductivity values covered a

Table 7. Analytical methods

Constituent or property & units	Method or instrument	Reference
Electrical conductivity in micromhos at 25°C	Industrial Instruments Model RC-16B2 and pipette cell with 0.10 cell constant	APHA (1965)
pH, pH units at 25°C	L&N pH Indicator Model 7401 with glass electrodes	APHA (1965)
Total iron and ferrous iron mg/l	Bathophenanthroline with ferric iron taken by difference	Shapiro (1966)
Silica, mg/l	Molybdate blue	APHA (1965)
Bicarbonate mg/l	Alkalinity titration using pH meter	APHA (1965)
Chloride, mg/l	Argentometric titration	APHA (1965)
Sulfate, mg/l	Thorin-Dioxane	Rainwater & Thatcher (1960)
Calcium, Magnesium Sodium, Potassium, mg/l	Techtron AA-3 Atomic Absorption spectrophotometer	Fishman & Downs (1966)*
Color, mg/l	Platinum-Cobalt	APHA (1965)

*Including slight modifications by UNH Engineering Experiment Station.

fairly narrow range there is a considerable variation in the amounts of the individual anions. Therefore, the pond water is not exactly equivalent to a homogeneous mixture undergoing dilution or concentration. The explanation is supported by the fact that with the minor exception of potassium poor correlations were obtained between electrical conductivity and individual constituents.

CLASSIFICATION AND CHEMICAL CHARACTER

The chemical data are shown on Figure 5, and the main sample sites are located on Figure 4. On two occassions in 1969 surface and bottom samples were taken at other open water sites. The results are plotted on Figure 5, but their locations are not given on Figure 4. In 1970, samples were taken two feet below the surface at the regular site, and the data are plotted on Figure 5. The surface samples were taken just below the water surface , and the bottom samples were taken just above the transition zone between water and mud. The overflow was sampled where it emerged from the ground or from the weir pond just downstream.

A number of graphical methods and regression analysis were tried in order to interpret the data. The statistical results were not very good probably because of the problems already discussed in regard to electrical conductivity and analytical balance and because the constituents showed considerable variations from one sample period to the next. These variations do not appear to be closely correlated with or completely random with time. In fact, some general trends

Figure 5. Graphs of constituents and properties versus day of year

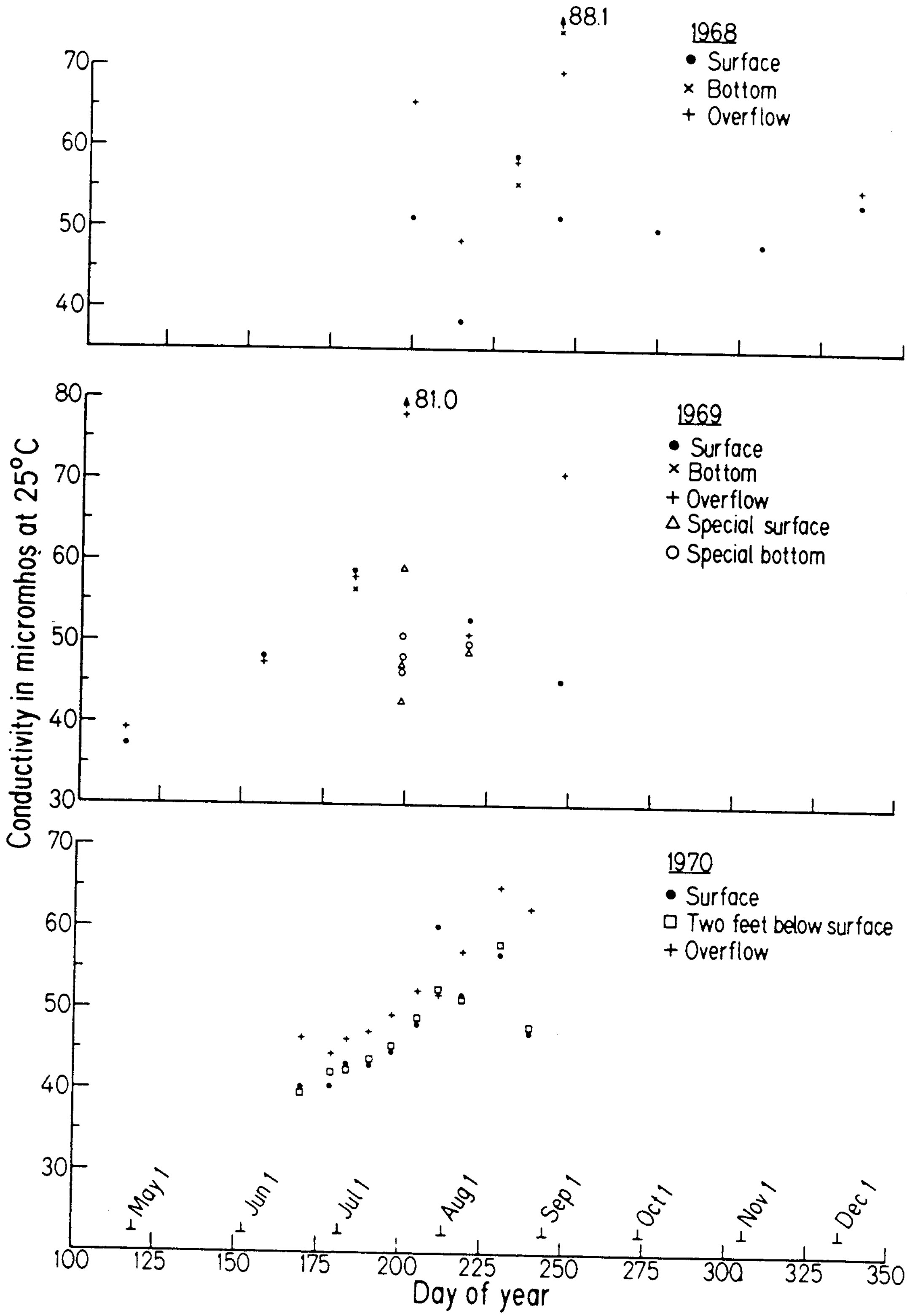

Figure 5a. Electrical conductivity in micromhos at 25°C

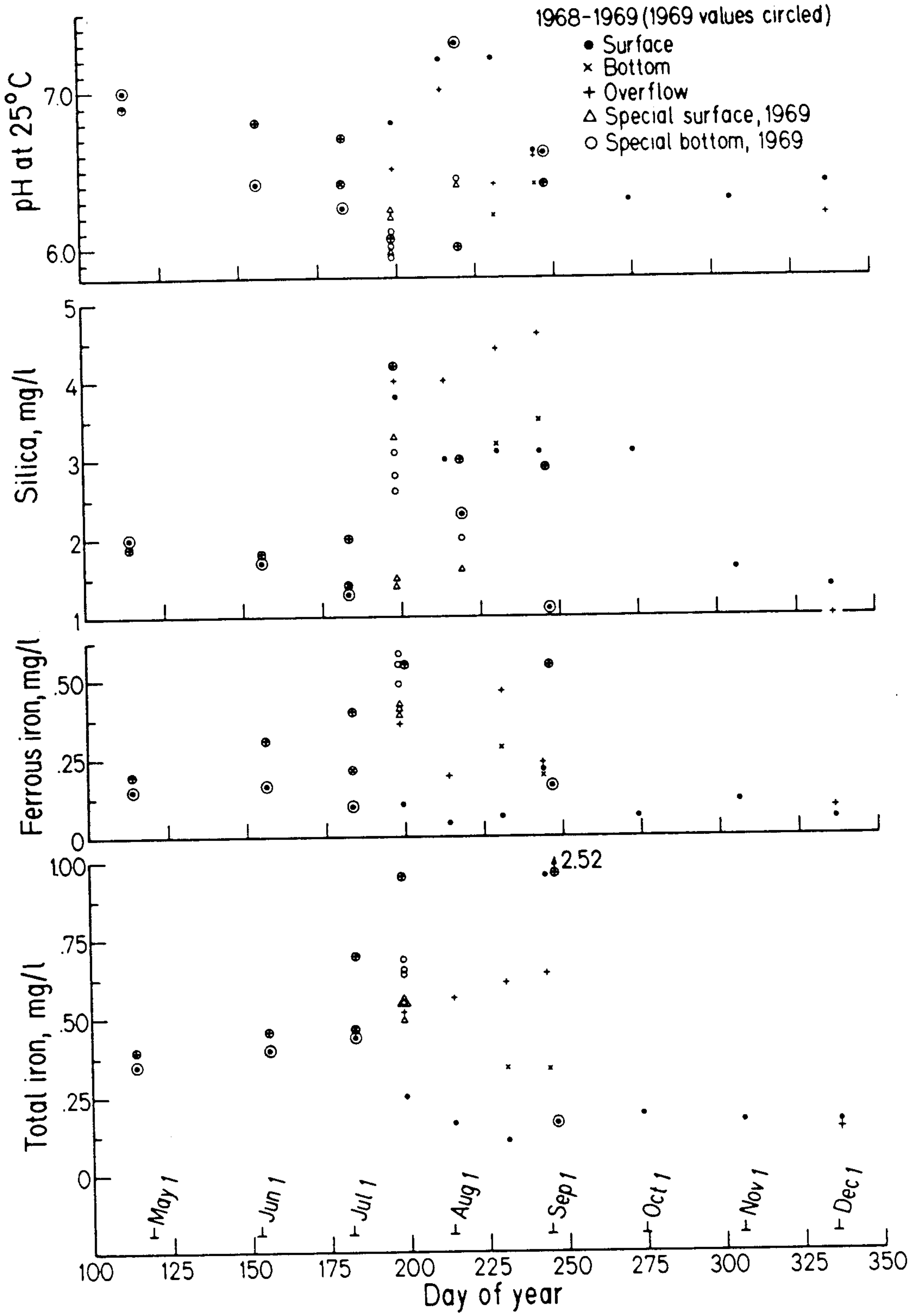

Figure 5b. pH at 25°C and silica, ferrous iron, and total iron in milligrams per liter.

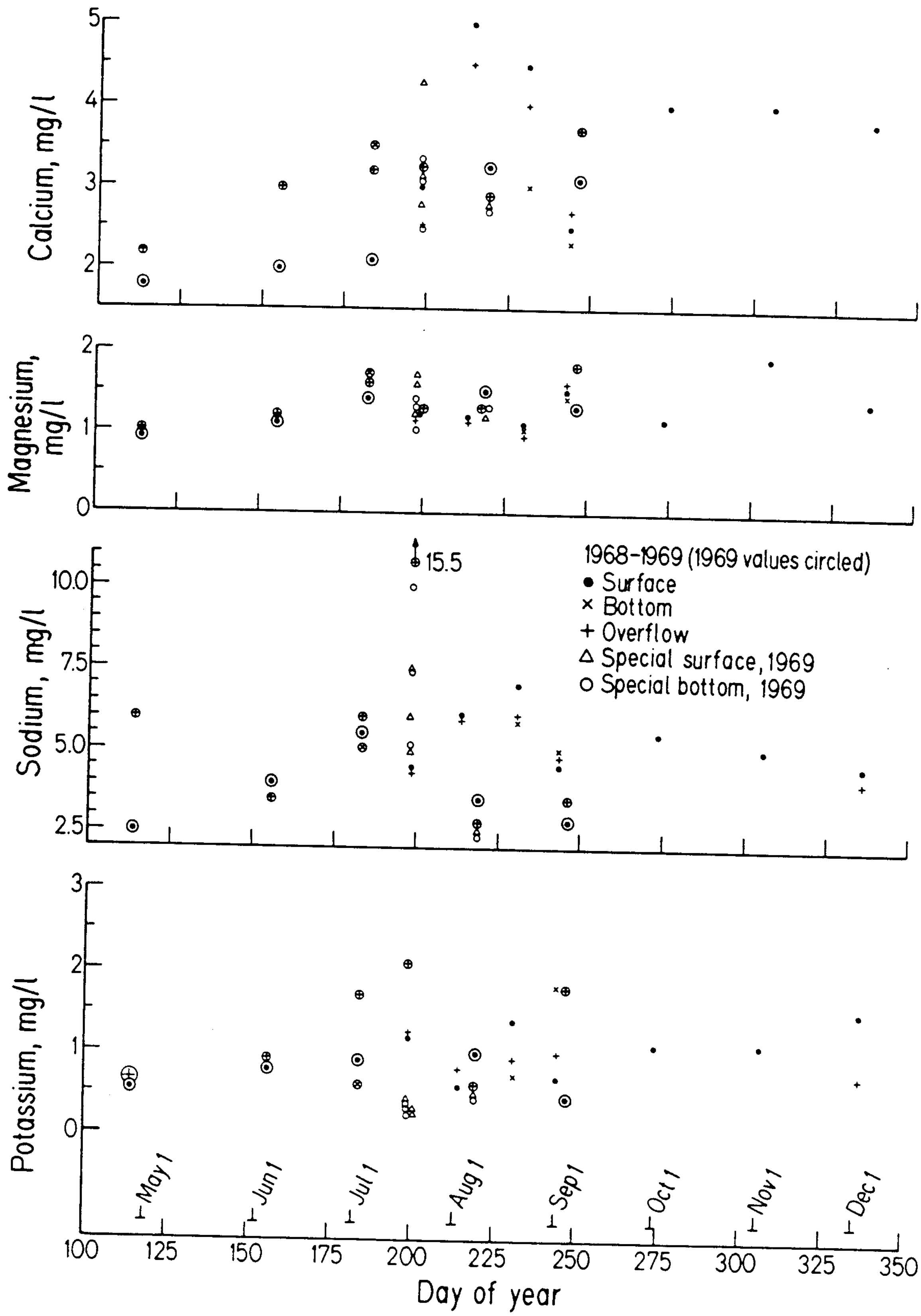

Figure 5c. Calcium, magnesium, sodium, and potassium in milligrams per liter

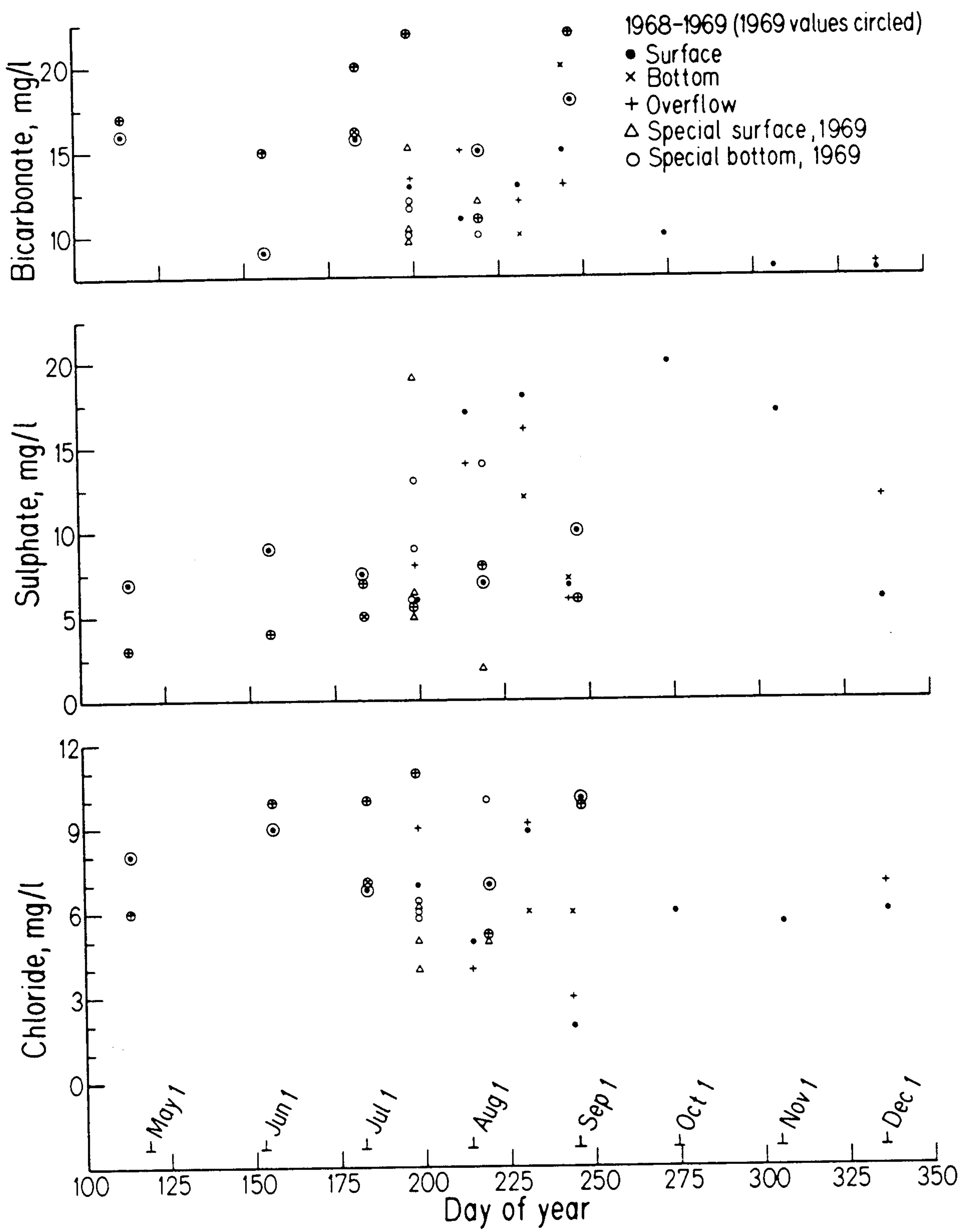

Figure 5d. Bicarbonate, sulfate, and chloride in milligrams per liter.

can be seen on Figure 5. For example, conductivity tends to increase during the spring and early summer, reach a peak in late July or August, and decrease in the fall.

A trilinear diagram (Hem, 1970) provides a reasonable basis for a qualitative discussion, and the range for Jewell Pond is shown on Figure 6. An analysis is plotted in all three fields as percent meq/l in terms of 100 percent cations and 100 percent anions. Individual analyses are not plotted on Figure 6, but in general the cations show a fair consistency with an Mg/Ca ratio on the order of 0.3. The anions and therefore the complete analyses in the central diamond show a much greater scatter. Nevertheless, the analyses as a whole are restricted to a rather small part of the diagram.

The central diamond of a trilinear graph is arranged so that water involved in chemical reactions with major rock types in the absence of modifying reactions or mixing with different waters will be found near the corners. In a sense, then the Jewell Pond analyses occur in a confusing part of the graph. Some insight can be obtained, however, from the other analyses plotted on the graph. The water at A is a so-called "standard" bicarbonate water utilized by limnologists (Hutchinson, 1957). Ground and surface waters in calcareous terrains would also be located in the same area. Waters involved in chemical reactions with sodium and potassium feldspars would fall in the vicinity of B (Garrels and Christ, 1965). If calcium bearing feldspars were also

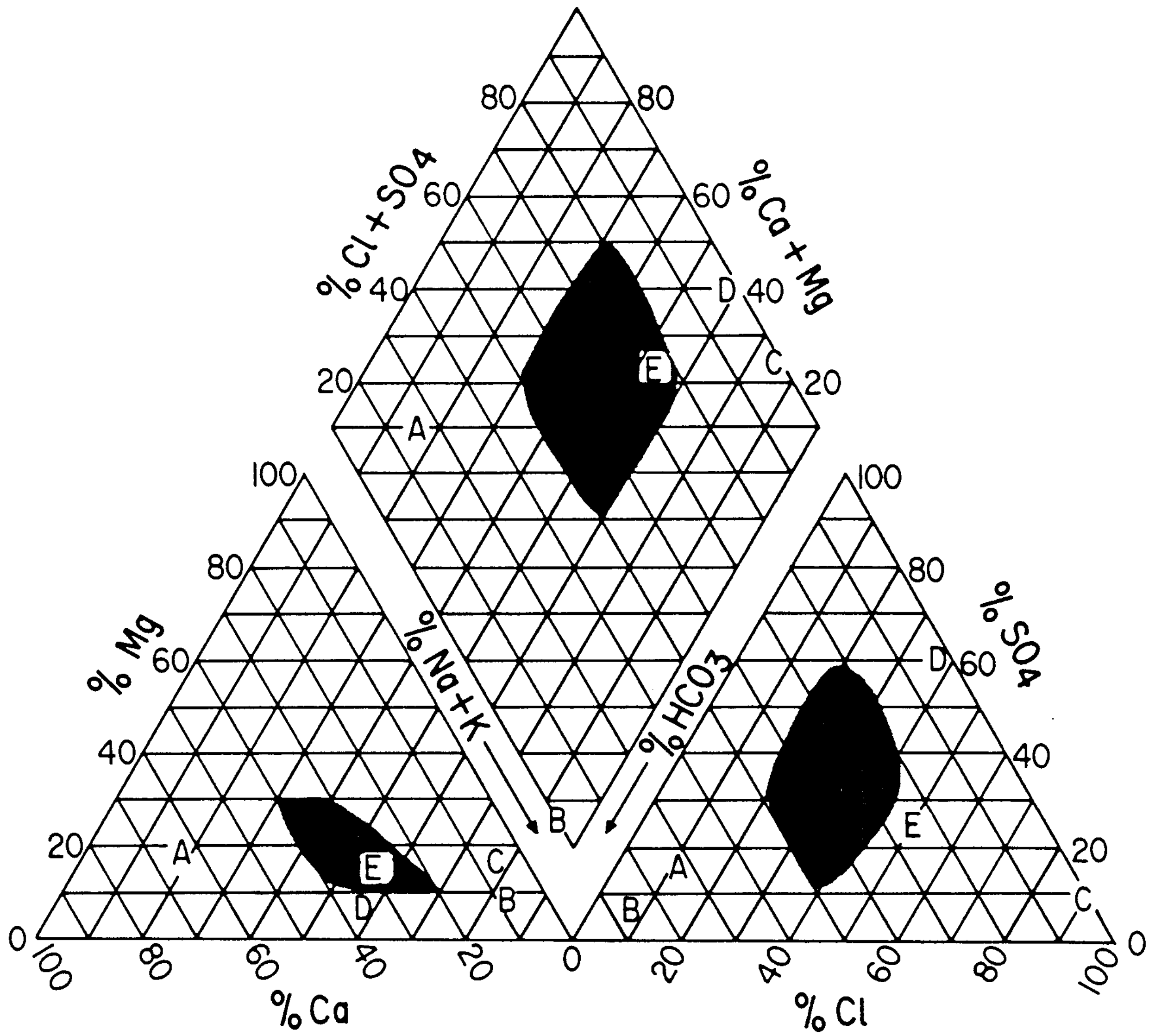

Figure 6. Trilinear diagram for Jewell Pond chemical data and other selected analyses.

A. Standard bicarbonate water (Hutchinson, 1957).

B. Water in contact with sodium and potassium feldspar (Garrels and Christ, 1965).

C. Average sea water (Hem, 1970).

D. Average coastal precipitation for northeastern New England (Pearson and Fisher, 1971).

E. Average for two streams in southeastern New Hampshire (unpublished data).

present then such waters would fall between A and B. Average seawater is plotted at C, and an approximate average coastal precipitation for New England is plotted at D (Pearson and Fisher, 1971). The approximation rises because hydrogen ion and ammonia make up 34 percent of the cations, but this cannot be shown on the trilinear graph. An average value for two local rivers is located at E (Hall, unpublished data).

The locations on Figure 6 of the Jewell Pond samples indicate that the water represents a mixing of atmospheric precipitation and water that has been in contact with feldspars and similar minerals in the soil and perhaps glacial till. The low values for calcium and bicarbonate indicate that carbonate minerals have been leached or are absent. Therefore, the main reactions have presumably been close to land surface.

The Jewell Pond chemical analyses do fall within the range for what Gorham (1967) has called minerotrophic peat deposits or fens where the peat surfaces are subject to some degree of silting or drainage from mineral soils. Fens are commonly dominated by reeds, sedges, grasses, and hypnoid mosses. The organic content is less than 80 percent. The pH and calcium ranges from noncalcareous conditions are 4.8-6.9 and 3-23 mg/l respectively. An implication is that Jewell Pond is on the way to but has not yet achieved full bog conditions where pH and calcium would be much lower.

GENERAL COMMENTS

The effects of possible modifying factors and other observation for Jewell Pond can be summarized as follows:

1. The water is undersaturated with respect to calcium carbonate (Garrels and Christ, 1965).

2. The water is poorly buffered (Weber and Stumm, 1963). That is, small additions of acid or base will cause considerable change in pH. Controls on pH, alkalinity, and buffering probably are exerted by atmospheric carbon dioxide augmented slightly by additional carbon dioxide in the soil atmosphere and from wetland respiration.

3. Total iron content is about what might be expected, but measured ferrous iron tends to be low and ferric iron taken by differences tends to be high with respect to a theoretical carbonate - hydroxide - water system (Stumm and Lee, 1960).

4. There is no chemical or other evidence for the reducing part of the sulfur cycle playing much of a role in the water chemistry (Stumm and Lee, 1960). Insufficient data are available to say whether this is true for the bottom mud.

5. Field pH measurements (data not reported herein due to uncertainties about field techniques) indicate a tendency for pH to decrease from the water surface down into the bottom mud.

6. There is neither chemical or visual evidence for algal blooms or similar phenomena. This is supported by

the pH measurements in Figure 5 and the unreported field measurements. Also, see discussion of silica below.

7. Silica content is lower than would be expected for water in contact with quartz and feldspar (Garrels and Christ, 1967). Microorganisms such as diatoms may exert some control, but there is little evidence for the kind of seasonal variation which would be expected from plant activity.

8. On July 16, 1969 (198th day of year) and August 6, 1969 (219th day of year) surface and bottom samples were taken at locations other than the regular ones. The results for many constituents and properties show nearly as much variation on these two days as did the regular sites during the season. These special sites are not shown on Figure 4 because there seems to be little relationship between location and constituents; however, one site was toward the eastern end of the north arm, one was a hundred feet east of the regular pond site, and one was at the southwest corner near the overflow.

9. Rainfall on the pond appears to lower or dilute surface water chemical content for a few days after the rain, but even a heavy rainfall does not appear to have much of a long term effect in comparison to evapotranspiration.

10. Sixteen color measurements during 1969 had in terms of a platinum-cobalt standard (APHA, 1965) a mean of 120 mg/l with a range of 80-150 mg/l. Trends are not noticeable although there is a tendency for bottom and overflow

values to be higher than surface water. The color will pass a 0.45 micron Millipore filter and is unaffected by centrifuging. Therefore, the color is not related to suspended matter and can be assumed to be in solution. No other work was done with color, but the range of values and the general character are typical of organic coloring due to the breakdown of plant material (Ghassemi and Christman, 1968).

SUMMARY AND CONCLUSIONS

1. The quantity of water lost to evapotranspiration in a muck and peat bog, covered with bushy vegetation, may easily equal or exceed the quantity of water lost by evaporation from an open water surface. This is supported by the fact that the evapotranspiration (per unit area) was more than 1.7 times the open water evaporation (per unit area) during the summer months of 1969.

2. Wetlands appear to be areas that can yield significant quantities of water for use during periods of water shortage through management practices. For example, the use of evaporation retardants as a wetland management practice will reduce evaporation from open water by significant amounts. This reduction appears to be a feasible practice on wetlands that contain some areas of open or nearly open water surfaces.

3. Wetlands can also be valuable with respect to flood control, in that they will act like a reservoir. The total water released from Jewell Pond during the 1969 investigation period was equivalent to about 20 inches of precipitation over the entire pond area. The precipitation received during the same period was nearly 8 inches. These data show that Jewell Pond stored over 12 inches of water and released it slowly, during the low flow period of the year. Although at Jewell Pond most of this water was

released in terms of evaporation and transpiration and not in streamflow, this need not be the case for wetlands with better connections to streams.

4. The pond water is characterized by a low dissolved solids content, relatively low pH and buffering ability, high organic coloring, and relatively high iron content. The water appears to be derived from a mixture of atmospheric precipitation and soil water that has undergone modifications by factors such as soil and plant carbon dioxide, micro-organisms, and organic activity.

5. There is little evidence for pond overturn or algal blooms although the wind appears to keep localized parts of the pond aerated and mixed.

6. The water chemistry shows some evidence for seasonal trends with a tendency for total dissolved solids to increase from the spring into early fall. The data show considerable scatter with time, and geographically at a given time; so there is little evidence for systematic or predictable trends.

RECOMMENDATIONS FOR FURTHER WORK

1. For any future study more emphasis should be placed on hydrogeology with particular regard to the relationship between pond water and groundwater. Also, an effort should be made to obtain an annual water balance in addition to a seasonal one.

2. A water chemical sampling program should be designed to cover a pond, spatially as well as with time. An attempt should be made to reduce the total number of analyses or where possible to minimize the number of determinations per individual sample. In addition to the measuremehts made at Jewell Pond, it would be advisable to obtain some values for phosphate, nitrate, and dissolved oxygen.

3. A similar study should be made for a wetland that is in much more intimate connection with a stream.

4. All freshwater ponds and wetlands in New Hampshire should be inventoried and given a preliminary hydrologic evaluation. This, in turn, could lead to more detailed knowledge of a valuable but neglected resource.

5. Studies should be made on the effects of filling in wetlands as this practice could deplete low flows of streams and enhance high flows.

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APPENDIX A: EVAPOTRANSPIRATION EQUATIONS

There have been many equations developed over the years to calculate or estimate evapotranspiration from various crops and under a wide variety of conditions. Most of the equations are of an empirical nature, based on and developed from years of experience. A few of them, such as the Penman equation, are based on the principles governing evaporation and plant transpiration.

The Penman, Thornthwaite, and Hamon equations were used in this study, as well as the Blaney-Criddle formula. These equations are designed to estimate potential evapotranspiration. Potential evapotranspiration is the potential, or possible, quantity of water that will be used by evapotranspiration when the supply of water is not a limiting factor. A description of each equation follows:

THE PENMAN EQUATION

$$ET = \frac{\delta/\gamma\ R_n + E_a}{\delta/\gamma + 1} (3.94 \times 10^{-2}) \qquad (2)$$

where:

$E_a = 0.35\ (e_a - e_d)\ (1.0 + 0.01W_2)$;

$W_2 = W_1\ (\log 6.6/\log h)$;

ET = potential evapotranspiration in inches of water per day;

δ = the slope of the saturation vapor pressure - temperature curve at the mean daily air temperature in millimeters of mercury per degree centigrade;

γ = a psychrometer constant in millimeters of water per degree centigrade;

R_n = the daily net radiation in millimeters of water;

E_a = the product of the wind function and the saturation vapor pressure gradient over the surface;

e_a = the saturation vapor pressure at the mean daily air temperature in millimeters of mercury;

e_d = the saturation vapor pressure at the mean daily dew point in millimeters of mercury;

W_2 = the horizontal wind speed in miles per day at a height of 2 meters above the surface;

W_1 = the wind speed in miles per day at a height h (in feet) above the surface;

0.335 = a constant that has the dimensions needed so that Ea will be in millimeters of water per day; and

3.94×10^{-2} = a constant to convert the results to inches (Tanner and Pelton, 1960).

The Penman equation requires more data measurements than do most other evapotranspiration equations and for this reason is not widely used. It does, however, offer potential for accurate estimates of daily as well as monthly and seasonal evapotranspiration when adequate data are available. Probably the largest source of error found in estimates made using the Penman equation is due to the use of incorrect surface roughness characteristics. The equation was developed for short grass vegetation and for any surface rougher than short grass it will underestimate the potential evapotranspiration (Takhar and Rudge, 1970).

THE THORNTHWAITE EQUATION

$$ET = 0.63\ (10\frac{t}{Tei})a$$

where:

$a = 6.75 \times 10^{-7}(Tei)^3 - 7.71 \times 10^{-5}(Tei)^2 + 0.01792Tei + 0.49239$;

ET = the potential evapotranspiration in inches per month;

t = the mean monthly temperature in degrees centigrade;

Tei = Thornthwaite's temperature-efficiency index (equal to the sum of 12 monthly values of the heat index $i = (t/5^{1.514})$; and

0.63 = a constant expressing the results in inches.

The Thornthwaite equation uses only temperature data and an adjustment factor to correct the equation for the number of 12-hour days per month at different latitudes. It was developed primarily from experience in the central and eastern United States (Chow, 1964).

THE HAMON EQUATION

$$ET = CD^2P_t \tag{4}$$

where:

ET = the potential evapotranspiration in inches per day;

D = daylength in units of 12 hours;

P_t = the absolute humidity (gm/m^3); and

C = constant = 0.0055 (Hamon, 1961).

Hamon's equation is relatively easy to use since it requires only temperature, humidity, and latitude converted to daylength (12-hour periods) for the evapotranspiration calculation.

THE BLANEY-CRIDDLE FORMULA

$$ET = KF \qquad (5)$$

where:

$$F = \sum_{1}^{m} Pt$$

ET = the potential evapotranspiration in inches per month;

m = the number of months in the calculation period;

P = the percent of daytime hours of the year occurring during the period, expressed in decimal form;

t = the mean monthly temperature in degrees fahrenheit; and

k = the consumptive-use coefficient (Chow, 1964).

The consumptive-use coefficient is determined by experimental methods for a particular vegetative cover, and then is adjusted for the month and location when being applied to situations with different times and locations than those where the original data was collected. Most of the established consumptive-use coefficients are for agricultural crops, in that the equation has been primarily used in agriculture work where irrigation practices are used. Once the consumptive-use coefficient for the particular vegetation under consideration is established, the Blaney-Criddle Formula is easy to use and gives reasonably good estimates of evapotranspiration for time periods of one month or more.