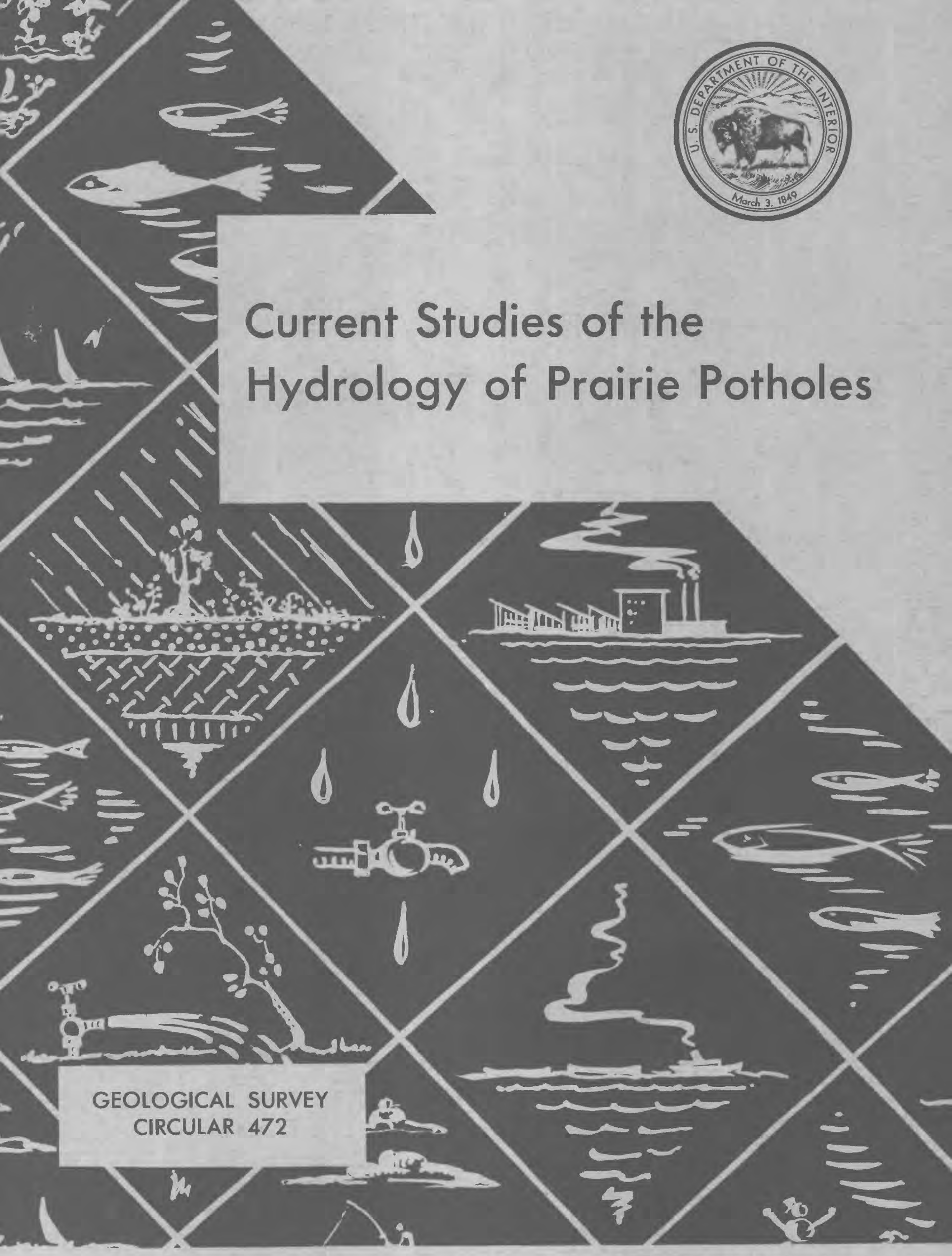

Current Studies of the Hydrology of Prairie Potholes

GEOLOGICAL SURVEY CIRCULAR 472

PREPARED AS PART OF A PROGRAM OF THE DEPARTMENT OF THE INTERIOR FOR DEVELOPMENT OF THE MISSOURI RIVER BASIN

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By J. B. Shjeflo and others

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Current Studies of the Hydrology of Prairie Potholes

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ABSTRACT

The prairie potholes in the North-Central States and in Canada are of glacial origin. Because many of them contain ponds or marshes, they are important in the prodnction of livestock and waterfowl. The objective of the present investigation is to determine the amonnt of water that accumulates in and is nsed in the potholes in their natural environment.

Two stndy areas were selected in North Dakota, and construction of gaging facilities was completed in 1960. Each stndy area contains four potholes. Three of the potholes for each area contain dense growths of aquatic vegetation, and one is clear of aquatic vegetation. The instruments to provide the basic data for compnting water losses include: water-stage recorder, water-temperature recorder, rain gage, anemometer, and hygrothermograph. Observations will also be made of ground-water levels, rate of growth and type of vegetation, and quality of water.

INTRODUCTION

Throughout great sections of the prairies of the northern States and of Canada are more than a million shallow depressions formed by the melting of glacial ice. They range in size from less than an acre to several hundred acres and are known in the region as potholes. Each pothole receives the drainage, if any, from the small closed basin of which it occupies the lowest part. Thus most potholes contain marshes, shallow ponds, or lakes, depending on the amount of drainage. Dense growths of aquatic vegetation emerge from most of these water bodies—an important factor in the water economy of potholes and their usefulness to wildlife.

The prairie pothole region is one of the greatest waterfowl production habitats on the continent; hence its preservation and possible improvement is of concern to wildlife interests. Already there has been considerable shallow flooding of lowlands by impoundments and dikes in some parts of the region, particularly in the Souris River basin, in connection with migratory waterfowl production and refuge areas. The demand for water for other needs is sometimes in competition with this usage. In areas where livestock grazing is practiced, potholes often provide the principal source of water. In some areas that are suitable for cultivation, agricultural interests encourage the draining of such potholes thus bringing new land into cultivation.

Irrigation projects that could eventually place more than 1.5 million acres under irrigation are being planned in the Dakotas. A large part of this area is in the prairie pothole region and thus many potholes would be eliminated by land leveling and the construction of drainage systems. Many of the lost potholes would be replaced by new marsh areas created by flooding certain lowlands through diversions and impoundments, and by construction of dikes and similar works.

The amount of water that would be required for these proposed undertakings is not known. Demands on the water available are made by seepage, evaporation, and transpiration from aquatic vegetation. Very little information is available for evaluating these demands so the present investigation was undertaken to measure the water losses at representative natural potholes. Such information should substantially aid in determining the feasibility of many of the proposed projects. The project is a part of a program of the Department of the Interior for development of the Missouri River basin.

Other questions raised by the drainage of potholes are: (a) What effect does it have on ground-water levels in the vicinity, (b) to what extent is the flood hazard to downstream areas increased, (c) how much runoff accrues to the stream receiving the drainage, and (d) what is the chemical quality of the drainage water. These questions however, are beyond the scope of the present investigation.

DESCRIPTION OF STUDY AREAS

LOCATIONS

The many types of observations needed in the investigations impose several requirements on the study areas to be selected. Each area should include several potholes. One should be clear of emergent aquatic vegetation, while the others should support a considerable amount of it. The ground under the potholes should be highly impervious in order to reduce seepage losses. The potholes should be unaffected by the activities of man, and the area should be accessible.

Two study areas were selected in North Dakota (fig. 1). One is in south-central Ward County about 80 miles south of the Canadian border, and the other is in the southwestern part of Dickey County, 2 miles north of the South Dakota State line. These areas are about 200 miles apart.

Preliminary selection of the areas was made from an airplane in regions preselected on geologic maps and aerial photographs. Final selection was made on the ground. Each study area comprises four potholes. Three of the potholes support various amounts and types of aquatic vegetation (fig. 2), while the fourth one is clear and almost entirely void of emergent vegetation (fig. 3). The potholes in the Ward County group were assigned numbers 1–4; pothole 3 is clear of emergent aquatic vegetation. Those in the Dickey County group were assigned numbers 5–8; pothole 5 is clear. The four potholes in each group are contained within a circle 8 miles in diameter, where soils and weather are expected to be very similar. The potholes generally are elliptical and range in size from 5 to 40 acres and in depth from 1 to 4 feet. All of these particular potholes hold water the year around except during extreme drought.

Many potholes do not hold water the year around. Some hold water for only a few days after the spring runoff or heavy rains. Others have never been known to go dry. It has been estimated that there are about a million potholes in North Dakota alone. The volume of water in each depends upon the amount of precipitation on its drainage basin.

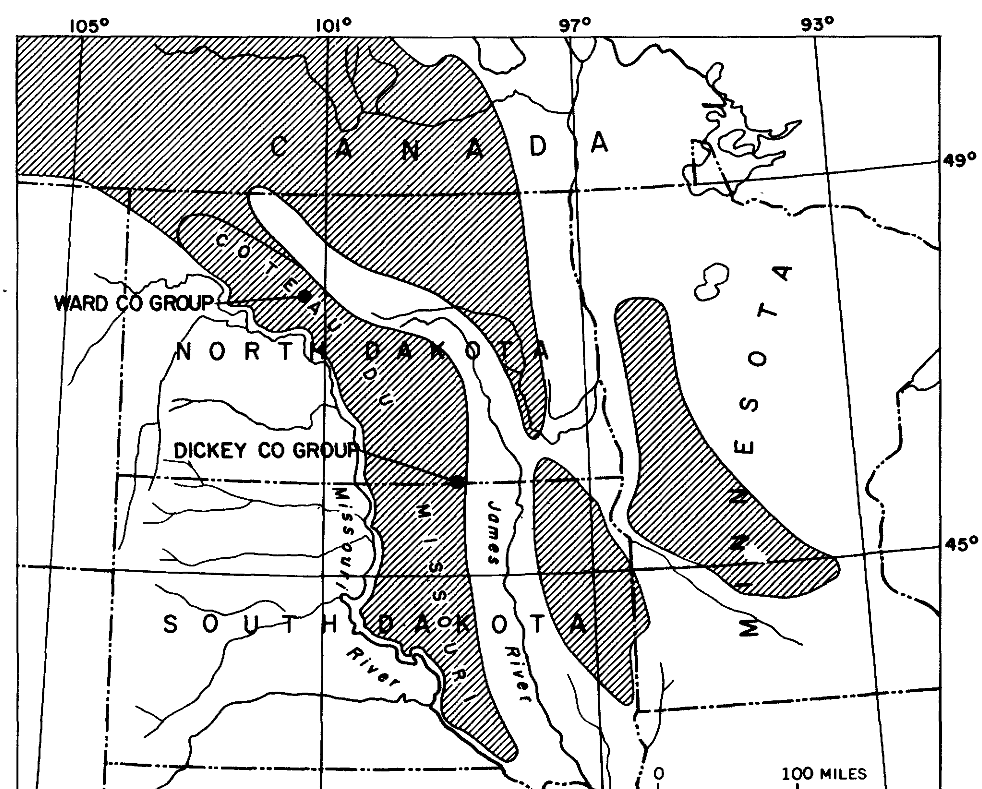

Figure 1.—Map of prairie pothole region (shown by ruling) in the United States showing location of study areas.

Figure 2.—Pothole with dense stand of emergent aquatic vegetation and vegetation gage.

The drought that has prevailed in much of the prairie pothole region between 1953 and 1961 probably aided in the selection of the study areas, for thousands of potholes were dry at the time of the reconnaissance for the selected study areas.

CLIMATE

Because of its midcontinental position and its location near the paths of many cyclonic storms, the general area has a markedly continental climate with extreme summer heat, extreme winter cold, and rapid fluctuation of temperature. The average July temperature is about 68°F for the Ward County group and 70°F for the Dickey County group, but daily maximum temperatures of 100°F or more are common.

The average annual precipitation in the vicinity of the Ward County group is about 16 inches, and at the Dickey County group it is about 19 inches. General rains can be expected in the spring until about the end of June. Summer rains are usually the result of thunderstorms, some of which are quite severe. Occasionally, several inches of rain may fall in a relatively short time on an area of only a few square miles. This is about the only type of rainstorm that will produce runoff in the prairie pothole region during the summer and fall.

Snowfall is probably the most significant factor in replenishing the water supply of potholes. Potholes, especially those with dense emergent vegetation, usually trap a great deal of snow. Also, deep snow drifts often develop on the periphery of some potholes while the surrounding hills may be bare. Normally about one-fourth of the precipitation in the study areas occurs as snow between October and March. Much of it reaches the potholes when melting occurs in the spring while the ground is still frozen.

The average wind velocity for the area is about 10 miles per hour with the highest velocities during April and May. The prevailing winds are northwest, but during the summer southeast winds are almost as common.

The area is generally thought of as being extremely dry, since it lies in a dry climatic region; but the relative humidity is not as low as some might expect. The long-term averages at noon during July show the relative humidity to be between 45 and 50 percent in the study areas.

According to the U.S. Weather Bureau, the greatest seasonal evaporation (April through September), as measured at an evaporation pan for the period 1907–1945 at the Dickinson Experiment Station (about 150 miles west of the study areas), was 51.43 inches in 1936. The rainfall was 3.49 inches during the same period. The lowest seasonal evaporation was 26.15 inches in 1942, when the total rainfall was 17.27 inches.

The potholes usually freeze over during the early part of November and remain frozen until the first or second week in April. The shallower ones (less than 3 feet deep) freeze to the bottom as will about half of those under study. No records will be collected during the period of ice cover.

Figure 3.—Pothole clear of emergent aquatic vegetation with water-stage recorder, anemometer, and rain gage.

TOPOGRAPHY AND DRAINAGE

Both study groups lie along the eastern edge of the high country known as the Coteau du Missouri; an area covered by glaciers in Pleistocene time. (Flint, 1955.) This is a region of many small lakes without outlets and of rolling prairies marked by ranges of rounded hills, some of them high.

The potholes in the Ward County group are in deep bowllike depressions where water would have to rise as much as 15 feet before it could flow into another pothole. Those in the Dickey County group are in an area where the water courses are better defined. The potholes in this area are in chains of saucer-like depressions, and in places, a rise of only 2 feet would cause water to flow from one pothole to another. However, since little or no runoff is expected except during early spring, the shallowness of these basins is not expected to detract from the study.

PROJECT PLAN

The plan is to determine the water budget for each of the potholes, and the seasonal variation of each of the items in the water budget. These include runoff, precipitation, seepage, and evapotranspiration. Changes in ground-water levels, chemical quality of water, and aquatic vegetation also will be observed.

The construction phase of the project was completed during the summer of 1960. For each pothole this included a stilling well and shelter for the water-stage recorder, supports for the anemometer and rain gage, water-temperature gage, outside staff gage, and a ground-water observation well. Vegetation gages were installed at each of the potholes having emergent aquatic vegetation to aid in determining the growth (fig. 2).

A shelter was erected near the center of each area to house a hygrothermograph used to serve the group of four potholes.

A detailed topographic survey was made of each pothole covering the expected range in stage, and stage-area curves, and stage-contents curves are being computed. The potholes will be resurveyed at the end of the field investigations to determine the rate of sediment accumulation. Transit-stadia traverses have been run to determine the drainage area of each pothole to determine unit runoff.

The operational plan is as follows:

1. Operate the water-stage recorder, anemometer, rain gage, water-temperature recorder, and hydrothermograph continuously throughout the open-water season. No attempt will be made to obtain records during the winter when the ponds are frozen, except to determine the elevation of the ice surface before the spring thaw.

2. Observe the ground-water level weekly at each observation well in the pothole group.

3. Determine the extent, density, and kinds of vegetation at each pothole at least three times each growing season (preferably in the late spring or early summer, midsummer, and shortly before the first frost) by measuring from the vegetation gages and by photographs. Aerial photographs will also be obtained to aid in determining the density and extent of emergent aquatic vegetation.

4. Obtain water samples at each pothole about once a month during the summer and once during the winter for chemical analysis.

5. The seepage-stage relation for each pothole will be determined. This will consist of measuring the net seepage at about four different reservoir stages.

The observations obtained will be used to compute the items in the water budget. Runoff can be obtained from stage records and area and capacity curves of the pothole. Evapotranspiration can be computed from the records of stage, precipitation, and computed seepage. The evaporation records from the clear pothole may be used to separate evaporation from the total evapotranspiration at the potholes having emergent aquatic vegetation. The records of ground-water levels will be used to determine what relation, if any, exists between ground-water fluctuation and water stages of potholes. The chemical analyses of water samples will be used to investigate trends in water quality and its possible effect on ground water and aquatic vegetation.

GEOLOGY AND GROUND-WATER CONDITIONS OF THE PROJECT AREAS

By H. M. JENSEN

The term "pothole" has great descriptive value and is a colloquial synonym for the geologic term "kettle." The pothole region is primarily in areas of morainal complexes—glacial drift deposited by ice advances in the Wisconsin stage of the Pleistocene epoch. The region is characterized by what geologists refer to as knob and kettle topography—small closely spaced hills and ridges with no integrated drainage pattern and local relief of from 20 to 100 feet.

The groups of potholes in this investigation are in the Missouri Plateau glaciated section of the Great Plains physiographic province, the northeastern strip of which is known as the Coteau du Missouri. (Simpson, 1929, p. 11.) (See fig. 1.) The border of the Coteau is a northeast-facing escarpment that rises 300 to 500 feet above the Central Lowland to the east and owes its prominence in part to topographically high bedrock. The high bedrock not only acted as a buttress to advancing ice sheets but it also influenced the distribution and landforms of the glacial drift deposited on the Coteau. Drift deposits of variable thickness were left on the Coteau, and, as the ice front retreated, isolated blocks of ice wholly or partly buried in the drift mass melted, leaving shallow saucer-shaped depressions or kettles. The morainic complex associated with the Coteau has been traced from northwestern North Dakota to southeastern South Dakota and has been called the Altamont end-moraine complex (Flint, 1947, p. 274).

The glacial drift in the areas of investigation is composed predominantly of till. Till is that part of the drift deposited by and underneath the ice mass, with little or no transportation by water. Till is a heterogeneous mixture of the rock fragments picked up by the advancing ice sheets, namely: clay, silt, sand, gravel, and boulders. In the study areas, a preliminary field reconnaissance showed that the till was composed predominantly of clay and could be expected to be impermeable. This fact was important in determining the suitability of the pothole areas to be studied.

Test wells were drilled in the immediate vicinity of the selected potholes as part of the investigation of ground water. Because no continuous sand and (or) gravel lenses were penetrated in drilling, and because the clayey till surrounding the potholes has relatively low permeability, it is inferred that there is little or no recharge or discharge of ground water in the immediate vicinity of the areas under investigation. To obtain additional ground-water information, one test hole at each pothole was converted to an observation well. The observation wells, consisting of $1\frac{1}{2}$-inch steel pipes, range in depth from 17 to 22 feet, and the bottom 6 to 10 feet of the pipe columns is slotted. When the pipes were installed, a gravel pack was placed outside the slotted part of the pipe. The remainder of the hole was packed with clay till to prevent the entrance of surface water.

The configuration of the water table in the vicinity of the potholes is uneven, reflecting to some extent the morainic topography. Water-level measurements in observation wells will be influenced by the topographic location of the observation well, the distance of the well from the pothole, and the type and amount of vegetative cover near the well. The period of record now (1961) is too short to form definite conclusions as to the effectiveness of measurements of the ground-water levels.

ECOLOGY

By R. S. ARO AND F. A. BRANSON

The ecologic phase of this investigation will involve the measurement and description of the vegetation associated with the evapotranspiration rate obtained for each pothole and an appraisal of the importance of the physical and biological factors at work in the existing plant communities. Water depth and quality, soil chemistry, and weight of emergent vegetation will be measured for each pothole, while less important factors, such as waterfowl and submersed plantlife, may be described in qualitative terms. Until the quantitative data are assembled, only a sketchy ecological picture of the eight potholes can be given. The following descriptions were prepared as the result of a brief visit to each pothole in October 1960.

The prairie pothole region is an extensive glaciated area stretching from the hardwood forests of Minnesota across the tallgrass and mixed prairie associations of North and South Dakota into the aspen parkland of Canada. All potholes being studied in the current project are located in the mixed prairie association, and are mostly surrounded by native grass hayfields or pastures, dominated by such species as needle-and-thread (*Stipa comata*), blue grama (*Bouteloua gracilis*), western wheat grass (*Agropyron smithii*), and little bluestem (*Andropogon scoparius*).

Cultivated fields that border parts of potholes 2, 3, 6, and 8 may constitute a source of salt and sediment in the ponds; but these possible small additions should be negligible. Mechanical harvesting of vegetation within the margins of potholes 1 and 8, and heavy grazing of plants in pothole 7 probably reduced 1960 gross transpiration below natural losses from these sites. Such land uses, which remove live pothole vegetation, must be recognized and evaluated along with estimates of subducted plant material when evapotranspiration rates are compared with the qualities and quantities of vegetation in affected ponds.

Typical of aquatic habitats, the pothole vegetation discussed here involves only a few dominant species and notably simple community structure. The following table indicates the presence and relative abundance of the major emergent plant species found, roughly in decreasing order of their tolerance to deep water.

Deep-water species dominate the appearance of all the containing potholes covered with emergent vegetation and the margin of one of the clear ponds. An exception, prairie bulrush (*Scirpus paludosus*), occurs twice as a codominant in relatively shallow water and saline soil. Species present on intermittently flooded or continually moist shorelines occur in zones coincident or parallel to pothole water levels and indicate, in part, fluctuations and gradations in soil moisture and salinity.

The emergent vegetation of pothole 1 consists mainly of hollowstem (*Scolochloa festucacea*), a tall rhizomatous grass occurring in the deeper water as round colonies, which merge into a nearly continuous belt around the margin of the pond. Just outside the hollowstem is a narrow band of broad-leaved cattail (*Typha latifolia*), with a scattering

Plant species and their relative abundance, observed in three ecologic niches at eight prairie potholes in North Dakota, listed approximately in decreasing order of their tolerances to deep water

[Relative abundance indicate by: R, rare; O, occasional; F, frequent; A, abundant; V, very abundant]

Ecological niches and their associated species		Species abundance in given pothole number							
		1	2	3	4	5	6	7	8
Deep water:									
Common bulrush	*Scirpus validus*		V		V	O		V	A
Hollowstem	*Scolochloa festucacea*	A					A	A	V
Broad-leaved cattail	*Typha latifolia*	A	A			R			O
Shallow water:									
Prairie bulrush	*Scirpus paludosus*				A		A		
Intermittently flooded or moist shorelines:									
Willow	*Salix* sp.						F		R
Northern reedgrass	*Calamagrostis inexpansa*	F							
Sedge	*Carex* sp.	O							
Prairie cordgrass	*Spartina pectinata*		R						
Desert saltgrass	*Distichlis stricta*				F			F	
Rayless aster	*Aster brachyactis*				F				
Foxtail barley	*Hordeum jubatum*				F			F	
Alkali sacaton	*Sporogolus airoides*				F				
Cottonwood	*Populus deltoides*						O		R
Aspen	*P, tremuloides*	O							

of northern reedgrass (*Calamogrostis inexpansa*) and sedge (*Carex* sp.) along its outside edge. On the south and east banks, aspen (*Populus tremuloides*) groves form a discontinuous community.

The dominant vegetation of pothole 2 is common bulrush (*Scirpus validus*), which occupies about two-fifths of the pond in one pure, dense stand at its southeast end. The remaining part is mostly open water containing water milfoil (*Myriophyllum exalbesceus*) and pondweed (*Potamogeton* sp.). In the shallower water, a fringe of broad-leaved cattail completely encircles the pothole, and on drier ground at the north edge prairie cordgrass (*Spartina pectinata*) is present.

Pothole 3 is free of all but submersed plants, such as water milfoil and pondweeds.

Common bulrush is the most important plant species throughout pothole 4, occurring in dense, scattered colonies; yet at least 25 percent of the pond is open water. All along the shallow saline margin prairie bulrush forms a distinct community; and above it, on the moist saline shoreline, a zone containing alkali sacaton (*Sporogolus airoides*), foxtail barley (*Hordeum jubatum*), desert saltgrass (*Distichlis stricta*), and rayless aster (*Aster brachyactis*) separates the aquatic vegetation from the mixed prairie.

Pothole 5, in the Dickey County group, is virtually free of vegetation, except at the water's edge, where common bulrush and a few patches of cattail form a continuous, narrow belt around the pond.

The plant communities of pothole 6, from the center to the shore, are a contrast between irregular patches of hollowstem, covering about half the deep-water area, and the narrow, ordered ranks of prairie bulrush. Mixed cottonwood and willow saplings mark their respective zones of water-level tolerance around the perimeter. Above these rows of young growth are scattered a few large willow trees.

Pothole 7 exhibits typical aquatic community zonation from its dense stand of common bulrush, which dominates the central 80 percent of the pond, to the prairie grasses at its rim. Hollowstem occurs mixed with the outer fringe of bulrushes, then as almost a pure belt about 30 feet wide. Next outside is a 20-foot band of foxtail barley and desert saltgrass bounded by a similarly mixed zone of foxtail and midgrasses, and finally by a belt of little bluestem.

Common bulrush and hollowstem express simple communities in pothole 8. The deepest one-third of the marsh contains a dense growth of bulrush and occasional clumps of cattail. Hollowstem forms a complete cover over the remainder of the pothole, extending outward to the surrounding native grassland.

Detailed investigations during the 1961 growing season will help to define and relate all of the principal components operating in these potholes, but even now several causative factors are apparent. For example, water depth seems to be controlling not only the ratio of vegetation-covered to open-water areas, but also species zonation and community structure. The presence of aspen and willow trees along several pothole margins suggests stable water levels in such ponds; and relatively high salinity and shallow water probably account for the two perimeter bands of prairie bulrush noted above. Observation of these study areas and comparisons of their ecological characteristics with other pothole communities over a period of years should reveal useful information on aquatic plant succession. Knowledge of these and other ecologic agents, processes, and changes will be essential to sound water and wildlife management of prairie potholes.

CHEMICAL QUALITY OF WATER AND SEDIMENTATION

By D. M. CULBERTSON

The ecology of the vegetation in the pothole area is affected by the chemical quality of the water. Although the effects are mostly indirect, information on chemical quality of water will aid in understanding the water requirements and the physicochemical relationship between the environment and the vegetation. In closed lakes, evapotranspiration and re-solution of deposited salts cause considerable fluctuation in water quality with time. Although the dissolved-solids content of the water directly retards evaporation by reducing the vapor pressure of the water, the effect on evaporation is not significant. The dissolved solids, however, may influence considerably the type of plants that will thrive in the lakes and thereby indirectly affect the rate of transpiration from the vegetation in the lakes.

The investigation provides for determination of the chemical quality of water in each of the potholes during the field seasons. These determinations will be made approximately every month. A comparison of the 1960 pothole survey with later surveys will provide the information for determining whether any significant deposition of sediment occurs. These data will be analyzed to relate changes in water quality to changes in depth of water, volume of water, and water temperature associated with the evapotranspiration rate computed for each pothole. Also, some correlations may be found between the change in water quality and the ecology in the potholes.

Prelinimary data for potholes 1–4 indicate that the chemical composition of the water differs considerably from one pothole to another. For example, in April 1960 water from pothole 3 had 237 parts per million (ppm) of dissolved solids, which was mostly calcium, magnesium, and bicarbonate; water from pothole 4 had 1,380 ppm of dissolved solids, which was mostly magnesium, sodium, and sulfate. Probably the inflow to each of the potholes contains principally calcium and bicarbonate, and the differences in chemical composition are partly the result of differences in the depth of water in the potholes. Although, as evaporation takes place, calcium and bicarbonate tend to precipitate, the other constituents tend to remain in solution until the potholes become nearly dry; consequently, the relative proportions of the more soluble constituents increase. In potholes that dry up occasionally, precipitates of even the most soluble constituents may have little chance to accumulate because they are susceptible to removal by wind. The data also indicate that the chemical composition of water in a pothole may differ considerably from time to time.

From April to October 1960, the dissolved solids in water from potholes 1, 2, and 4 more than doubled; however, the dissolved solids in water from pothole 3, which is clear of vegetation, increased only about 10 percent.

The deposited sediment, represented by a few samples obtained in 1960 from each lake, ranged from mainly sand to mainly silt and clay. The deposited sediment from pothole 3 was nearly all sand and was very low in organic matter, that from pothole 4 was predominantly sand and was low in organic matter; and that from the other potholes was predominantly silt and clay and was high in organic matter.

The deposited sediment from pothole 5 contained abundant mollusk (gastropod) shells, generally less than one-eighth inch in diameter. The sediment from potholes 3, 6, 7, and 8 contained less abundant shells, and the sediment from potholes 1, 2, and 4 contained very few or no shells. The relations among the kind and abundance of invertebrate forms, the chemical quality of the water, the type of suspended and deposited sediment, and the aquatic vegetation have not been established for these potholes.

INSTRUMENTATION

To provide the necessary data for computing water losses it is necessary to install instruments that will measure the following variables: water-surface elevation, wind movement, rainfall, water temperature just below the surface, air temperature, and humidity.

The change in water-surface elevation is measured by a continuous water-stage recorder in a shelter mounted on a 24-inch pipe stilling well near the edge of each pond (fig. 3). A 10:12 gage height ratio (1 foot per width of chart) and 4.8 inches per day time scale is used to produce the accuracy required. Auxiliary pen attachments were added near the right and left margins of the recorder chart to record the wind movement and rainfall. The chart is usually removed near the end of each month.

Wind movement is obtained by a three-cup totalizing anemometer with a dial showing linear movement to one-tenth mile. The anemometer is placed on an adjustable standard and set at about the 4-meter level above the water surface. An electrical connection between the anemometer and one of the auxiliary pens on the recorder permits the recording of each 10 miles of wind movement.

Rainfall is measured in a tipping-bucket rain gage (fig. 3). An electrical connection between the rain gage and the other auxiliary pen on the recorder permits the recording of each 0.10-inch of rain collected. After the rain actuates the tipping bucket mechanism it flows into a standard rain-gage can. The total collected is measured by means of a standard tube and graduated stick at the time of each weekly inspection.

The water-surface temperature is recorded on the chart of a weekly recorder with 10-foot capillary tube and sensing element. The sensing element is adjusted weekly when the chart is changed, to keep it below but as close to the water surface as possible.

Air temperature and relative humidity are recorded on a single chart of a hygrothermograph. This is a weekly, vertical drum, 2-pen recorder with a hair element for humidity and a bimetal element for temperature. A sling-psychrometer is used in checking and setting this instrument. One hygrothermograph is used for each pothole group and is as centrally located as possible with respect to the four potholes.

Two vegetation gages are located in each pothole where emergent aquatic vegetation is significant, to aid in determining the rate of growth. They are 1-inch by 6-inch boards, painted alternately black and white at 1-foot intervals, and set to gage datum (fig. 2).

Other measurements made on a weekly basis are the determinations of the water surface in each observation well, and photographs in the vicinity of the vegetation gages. Aerial photographs will also be obtained once or twice during the summer to aid in determining density of vegetation and percent of coverage.

During the first season of operation, 1960, only the Ward County group was fully instrumented and ready for operation. All instruments performed satisfactorily during the entire season except for a few days when the the water level dropped below the lowest intake holes in the stilling wells or the sensing element of the water-temperature recorder became exposed to the air.

Two areas of improvement in the records during the next season concern the humidity recorder and the rain gage. At times during the past season the humidity would be off several percent when checked by the sling-psychrometer. Accurate results will require repeated and careful checking and resetting, preferably during that part of the day when there is little or no change. The amount of rainfall was rather uncertain at times during intense storms, as the jogs on the chart were not sufficiently distinct and their total as counted did not check very closely with the amount in the standard rain gage. It is suspected that at times the tipping-bucket may have bounced and showed 0.2 or 0.3 inch of rain instead of 0.1 as it should have. Evaporation from the standard rain gage can further complicate the situation. Some sort of a maximum depth indicator placed inside the 8-inch rain-gage can may aid in determining more closely the actual amount of rainfall.

During the summer of 1960 the water-surface of pothole 1 (Ward County group) declined 31 inches with 7 inches of rainfall; during the same period the water surface in pothole 2 dropped 20 inches with 11 inches of rainfall, and the water surface in pothole 3 fell 22 inches with 12 inches of rainfall. The remainder of the gages were either under construction or awaiting delivery of instruments so no further results are available. Construction was completed, however, and data gathering began on all eight potholes by the spring of 1961.

SEEPAGE AND EVAPORATION COMPUTATIONS

By G. EARL HARBECK JR.

The basic objective of the prairie pothole project is to determine the water requirements of marsh and pothole areas. The volume of water in a pothole decreases gradually during the periods of no inflow because of seepage, evaporation, and transpiration losses. One of the criteria for selecting the two groups of potholes was that seepage losses should be small. Although the geology of both areas, and the test drilling indicate that is probably true, the seepage losses must be measured. The clear potholes have little or no emergent vegetation so that transpiration losses are negligible and only evaporation need be measured. It would be desirable to measure separately the evaporation and transpiration losses from the potholes containing aquatic vegetation, but adequate techniques are not now available, and it is necessary to measure the sum of the two, or the evapotranspiration loss. The potholes in each group, however, do not differ greatly in their physical characteristics and it appears reasonable to assume that annual evaporation rates would be approximately the same for all ponds in each group if none had vegetation. Differences in evapotranspiration rates between ponds are due partly to differences in transpiration rates and partly to differences in evaporation. The turbulent transport of water vapor away from the water surface is doubtless decreased by the emergent vegetation, so that evaporation from a pond covered with dormant or dead vegetation (no transpiration) presumably is less than evaporation from a clear pond.

The technique to be used in this study for measuring seepage and evapotranspiration losses was first suggested by Langbein, Hains, and Culler (1951) and has been successfully applied in other studies, among them being the measurement of seepage gains and losses from Lake Washington, Miss., (Harbeck and others, 1961). The basic assumption is given in the following equation:

$$E = N\,u(e_0 - e_a) \qquad (1)$$

in which E = evaporation

u = wind speed

e_0 = saturation vapor pressure corresponding to the water-surface temperature

e_a = vapor pressure of the air

The value of the coefficient N is of no consequence. Many mass-transfer equations have been proposed for the computation of evaporation, and the coefficient N is usually an extremely complicated mathematical expression. Nearly all the mass-transfer equations are similar in two respects: evaporation is directly proportional to the wind speed, u, and to the vertical humidity gradient, as represented by the vapor pressure difference, $(e_0 - e_a)$.

Using the equation developed by Yamamoto (1950), it was shown by Marciano and Harbeck (1954) that evaporation into still air was extremely small, even with free convection resulting from appreciable air-water temperature differences. If the vapor-pressure difference, $(e_0 - e_a)$ is zero, evaporation is zero regardless of the wind speed. In the technique described by Langbein and others (1951), it is assumed merely that evaporation is negligible when the product $u(e_0 - e_a)$ is zero.

In the absence of surface inflow or outflow, the measured fall in stage in any of the potholes may be considered to have two components, seepage and evaporation. The seepage component is outseepage minus inseepage, and the difference may have either a positive or negative sign. Lake Washington, for example, has a seepage gain in spring when the stage of the nearby Mississippi River is high and a seepage loss in fall when the Mississippi River is low.

To determine the seepage loss or gain, the fall in stage, ΔH, and the average values of the product $u(e_0 - e_a)$ are computed for selected periods during which neither surface inflow (including precipitation) nor surface outflow occurred, and the data plotted as shown in figure 4. The net seepage loss is the intercept on the y-axis. If the net seepage loss were zero, the best-fitting line should go through the origin, for then the fall in stage, ΔH, would be evaporation only, which is zero when the product $u(e_0 - e_a)$ is zero.

If there is a substantial seasonal change in stage in any pond, this type of analysis should be made for periods of high, low, and medium-pond stage, so that the relation between pond stage and seepage loss or gain may be defined. In this manner the daily seepage loss or gain from each pond can be determined.

During periods of no surface inflow or outflow, evaporation or evapotranspiration can

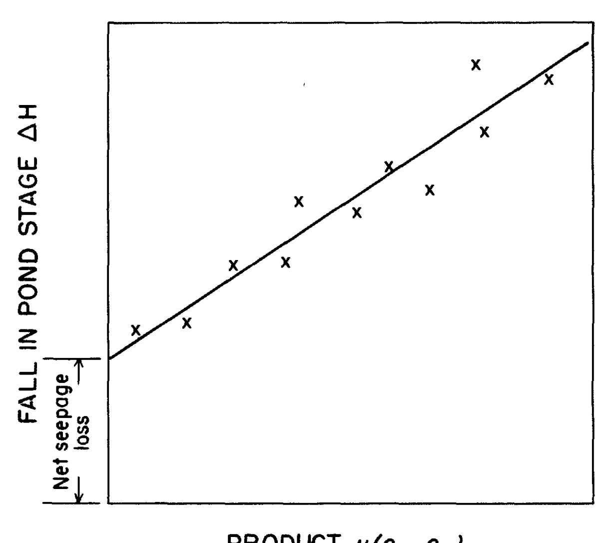

Figure 4.—Net seepage loss as determined from relation between fall in pond stage and product $u(e_0 - e_a)$.

be computed from the fall in reservoir stage minus the net seepage loss. During both inflow and noninflow periods, evaporation can also be computed using equation 1, with the value of N being the slope of the best-fitting straight line of figure 4.

The technique thus provides a means of computing the net seepage loss (or gain) from each pond, including the seasonal variation therein if significant, and the evapotranspiration losses from each pond. By continuing observation over a period of years it will be possible to determine the effect of variations in water levels on the consumptive use by different kinds and amounts of aquatic vegetation.

FUTURE PROJECT PLANS

Observations described in the previous sections are scheduled to continue until 1965. If climatic conditions vary widely during the 5-year period, there will be provided an opportunity to explore fully the relations between pothole water levels and rainfall, runoff, evaporation and evapotranspiration, ecology, ground-water levels, and water quality.

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