Water-Level Fluctuation in Wetlands as a Function of Landscape Condition in the Prairie Pothole Region

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Abstract
We evaluated water-level fluctuation (maximum water depth - minimum water depth/catchment size) in 12 temporary, 12 seasonal, and 12 semipermanent wetlands equally distributed among landscapes dominated by tilled agricultural lands and landscapes dominated by grassland. Water levels fluctuated an average of 14.14 cm in wetlands within tilled agricultural landscapes, while water levels in wetlands within grassland landscapes fluctuated an average of only 4.27 cm. Tillage reduces the natural capacity of catchments to mitigate surface flow into wetland basins during precipitation events, resulting in greater water level fluctuations in wetlands with tilled catchments. In addition, water levels in temporary and seasonal wetlands fluctuated an average of 13.74 cm and 11.82 cm, respectively, while water levels in semipermanent wetlands fluctuated only 2.77 cm. Semipermanent wetlands receive a larger proportion of their water as input from ground water than do either temporary or seasonal wetlands. This input of water from the ground has a stabilizing effect on water-levels of semipermanent wetlands. Increases in water-level fluctuation due to tillage or due to alteration of ground-water hydrology may ultimately affect the composition of a wetland's flora and fauna. In this paper, we also describe an inexpensive device for determining absolute maximum and minimum water levels in wetlands.

Key Words: agricultural impacts, landscape condition, prairie potholes, tillage, water-level fluctuations, water-level recorder, wetlands, wetland condition, wetland degradation, wetland monitoring

Introduction

Wetlands in the Prairie Pothole Region (PPR) of North America are severely altered by agricultural practices, including wetland drainage, physical manipulation of upland and wetland soils, sedimentation, and the application of agricultural pesticides and fertilizers. Sixty-five percent of the original wetland area in the PPR has been drained (National Research Council 1982, Tiner 1984, Dahl 1990). Remaining wetlands receive sediments (Martin and Hartman 1987) and chemical drift from adjacent fields (Grue et al. 1989). Moreover, wetland drainage and intensive management of agricultural fields alter the natural hydrologic cycles of many remaining wetlands. Removal of grasses and other native vegetation from catchment areas alters surface runoff dynamics and hence exacerbates impacts associated with sedimentation and agricultural chemicals absorbed on soil particles. Nonvegetated catchments have less capacity to mitigate excessive surface runoff, resulting in wetland water levels that are more variable than those in landscapes dominated by grasses and forbs. In addition to direct changes in hydrology, excessive runoff from major precipitation events can dilute salts in wetlands (LaBaugh et al. 1996). Due in part to the many problems associated with osmoregulation in fresh water (Potts and Parry 1964, Hutchinson 1967, Wetzel 1983), many organisms have developed specific tolerances to concentrations and species of salts present in wetlands (Moyle 1945, Macan 1961). Thus, excessive fluctuation in salinity resulting from unnatural dilution due to altered catchments may affect the natural composition of wetland flora and fauna. In this study, we tested the hypothesis that water levels fluctuate more in wetlands within landscapes dominated by tilled agriculture than in wetlands within landscapes dominated by grasslands. Despite the obvious and critical role of hydrology to the structure and function of wetlands, few ecological studies in the PPR have considered hydrology. One reason for the lack of hydrologic data in many studies of prairie wetlands is the high cost associated with required equipment. To obtain hydrology data for this study, we designed an inexpensive device that records maximum and minimum water levels in wetlands.

Study Area

We conducted this study using water-level data collected from 36 wetlands located throughout the PPR of North and South Dakota. Overall characteristics of wetlands in the PPR have been described in detail by van der Valk (1989). The selected wetlands were equally distributed among cropland and grassland dominated landscapes. In addition, we stratified our sample by wetland class (temporary, seasonal, and semipermanent)(Stewart and Kantrud 1971, Cowardin et al. 1988) because each class responds differently to surface and ground-water hydrology (Winter and Carr 1980). We drew sample wetlands at random from populations within a sample of 10.4 km^2 plots (Fellows and Buhl 1995) that are used to provide data for a mallard simulation model (Cowardin et al. 1988). In total, we sampled 12 temporary, 12 seasonal, and 12 semipermanent wetlands from 10, 10.4 km^2 plots (Figure 1). Wetlands in each 10.4 km^2 plot were mapped by the National Wetlands Inventory according to the classification of Cowardin et al. (1979), and the upland areas were classified as grassland or cropland as described by Cowardin et al. (1988). We adopted the same ratio of cropland to grassland that was used to index wetland condition in the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP-Wetlands) for the PPR (Cowardin and Peterson 1995). Due to the availability of detailed water level data, we tested the accuracy of prototype water-level recording devices in 2 semipermanent wetlands (wetlands P7 and P8) located at the Cottonwood Lake Study Area (CLSA), a long-term study area near Jamestown, North Dakota (Swanson 1987).

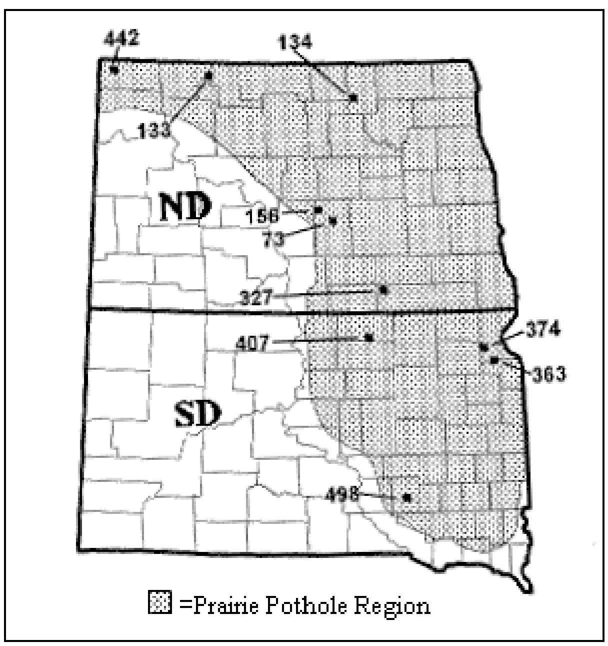

Figure 1. The Prairie Pothole Region of North and South Dakota showing the location of 10.4 km^2 plots used in this study.

Methods

We installed water-level recording devices (construction details described below) in the center of each of the 36 study wetlands. We defined a wetland's center as the lowest elevation within a basin as determined with a laser level. We wired each recording device to a steel t-post driven into the wetland's substrate and installed the devices so the top of the lower indicator was flush with the wetland substrate when the indicator was at its lowest position. We installed the devices between 21 April and 13 May 1993 and removed them between 25 August and 16 September 1993. At time of removal, we measured the distance between the two slides and later used this measurement as our estimate of water-level fluctuation in a wetland during the time period each device was in place.

We restricted our analyses to wetlands that contained water at some point during the study period and to wetlands where our devices were not destroyed by livestock (n = 27 wetlands). We used two-way analysis of variance (ANOVA) techniques to assess the effects of land use (tilled versus grassland), wetland class (semipermanent, temporary, and seasonal), and the condition-by-class interaction. The response variable was the difference between the absolute maximum and minimum depth measurements divided by the total area of the catchment to correct for differences in catchment size. We used the catchment sizes determined by Freeland and Richardson (1995) for each wetland. Briefly, they measured the distance from the wetland to the catchment divide along a minimum of 4 transects and computed an area based on those measurements. We used the General Linear Models procedure of SAS (SAS Institute Inc. 1989) to perform ANOVAs. If an effect was significant, we used Fisher's Least Significant Differences (LSD) test (Milliken and Johnson 1984) to isolate differences. We used a logarithmic transformation of the response variable plus 1 to stabilize the variance prior to statistical analysis (Steele and Torrie 1980). For descriptive purposes, we calculated 68% upper (UCL) and lower (LCL) confidence limits (approximates 1 standard error above and below the mean) for our back-transformed least squares means.

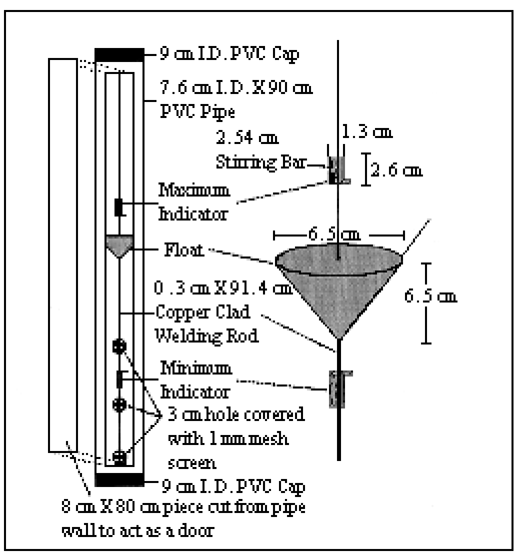

Figure 2. A water-level recording device designed to record maximum and minimum water levels of wetlands over discrete periods of time. Three, 3-cm diameter holes covered with 1-mm-mesh screen attached with silicon caulk allow water to enter the device and exclude debris. An access door cut from the wall of the pipe is held in place with plastic tie strips.

The device we designed to record the absolute maximum and minimum water levels in wetlands over discrete time periods is similar to the device designed by Bragg et al. (1994) to monitor below-ground water tables in mires. However, our device measures absolute water levels above the bottom substrates of wetlands. Richter (1995) also designed a device for recording maximum and minimum water levels. However, his device will not record minimum water levels less than 12 cm and was not designed to withstand the harsh environment of the Northern Great Plains. Our water level recorder (Figure 2) consists of a commercially available, copper-coated steel rod (length 91 cm) that guides a large float up and down as water levels fluctuate. Indicators above and below the float mark the extent of the maximum and minimum water levels. The guide rod and float are completely enclosed in a section of 7.6-cm inside diameter (I.D.) PVC pipe that is capped at both ends. The float is a piece of 0.2-mm brass shim stock formed into a 6.5 cm diameter cone. Cones are filled with buoyant foam and a circular cap of shim stock is soldered to the base. A 6.5-cm-long piece of 0.4-cm-I.D. brass tubing is inserted through the center of the float. Two slides, one above and one below the float, are pushed by the float. Slides consist of a 2.54-cm, teflon-coated, magnetic stirring bar with in a brass housing (Figure 3). The magnets hold the slides at their last positions, so the distance between the slides minus the height of the float is the distance the water level fluctuates during the time period between installation and the final recording (Figure 4). The device can be easily reset by sliding the magnetic indicators back to positions directly above and below the current level of the float.

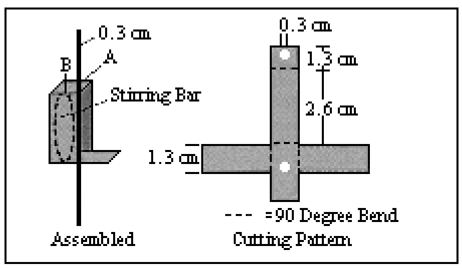

Figure 3. Maximum and minimum water-level indicators are constructed by cutting a piece of 0.2-mm brass shim stock into the above shape. The shim stock is then bent into a rectangular box and soldered along joints A and B. A teflon coated stirring bar (e.g., VWR Scientific # 58948-138; use of brand names does not constitute endorsement by the U.S. Government) is inserted into the housing thus created and the indicator positioned on the guide rod (one above and one below the float).

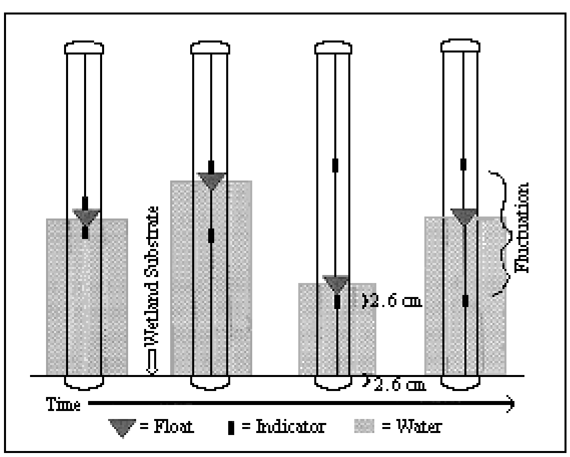

Figure 4. Diagram of a prototype water-level recording device showing how changes in water levels move the float and thus the indicator, providing a measurement of water-level fluctuation.

To test our prototype devices, we installed them in the 2 semipermanent CLSA wetlands in May 1992. We recorded the maximum and minimum water levels of the devices in September 1992 and reset them for the 1993 field season. In April 1993, we examined the devices for signs of wear and winter damage. We found some corrosion on the copper-coated steel guide rods, replaced them with new rods, and reset the water level indicators. We recorded water levels again in September 1993 and then removed the devices from the wetlands. After disassembly, we examined the devices for corrosion and other obvious problems that would limit their ability to function properly over extended time periods.

For the same May 1992 to September 1993 period, we also equipped the 2 CLSA wetlands with Telog (model WLS-2109) water-level monitoring systems (use of brand names does not constitute endorsement by the U.S. Government). These recorded water levels continuously throughout the study period. We housed the transducers inside a steel pipe sunk into the wetland sediment approximately 1 m below the water/sediment interface. Both units were standardized to read zero at this depth according to manufacturer's specifications. At the end of each year, we compared the water-level fluctuation (absolute maximum depth - absolute minimum depth) recorded by our prototype devices to the water-level fluctuation data collected by the Telog systems.

Results

Our analysis of water-level fluctuations, corrected for catchment size (Table 1), identified water-level fluctuation as a function of wetland condition (Figure 5). We observed both a wetland condition effect (F = 7.08, 1,21 df, *P* = 0.0146) and a wetland class effect (F = 4.88, 2,21 df, *P* = 0.0182). Further, there was no condition-by-class interaction (F = 0.86, 2,21 df, *P* = 0.4376) to complicate the interpretation. In proportion to catchment size, wetlands in agricultural landscapes had greater water-level fluctuations (14.14 cm, UCL = 19.73, LCL = 10.05) than wetlands in landscapes dominated by grassland (4.27 cm, UCL = 5.71, LCL = 3.14). As expected, due to their greater reliance on surface runoff as a water source, seasonal wetlands and temporary wetlands had greater water level fluctuations (11.82 cm and 13.74 cm, respectively) than semipermanent wetlands (2.77 cm, *P* = 0.0220 and *P* = 0.0090, respectively). We found no difference in water-level fluctuation between seasonal and temporary wetlands (P = 0.7775).

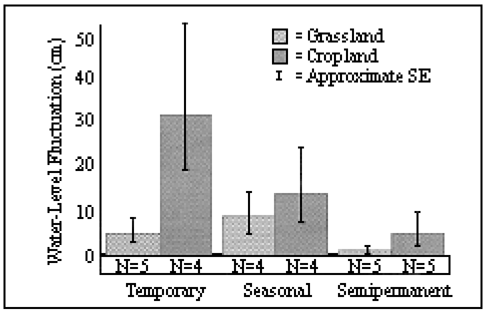

Figure 5. Mean (black-transformed LSM ± approximate standard error) 1993 water-level fluctuations of temporary, seasonal, and semipermanent wetlands located in areas dominated by agricultural lands and grasslands.

Table 1. Water-depth fluctuations (corrected for catchment size) of temporary, seasonal, and semipermanent wetlands from grassland & cropland dominated landscapes in the Prairie Pothole Region of N. & S. Dakota, 1993.

				Water depth (cm)		**Catchment**	**Corrected**
Plot	**Wetland**	**Landscape**	**Class**	**Maximum**	**Minimum**	**Size(ha)**	**Fluctuation**
73	86	Grass	Temp	gauge destroyed by cattle			
156	26	Grass	Temp	11.0	0.0	2.6	4.2
363	58	Grass	Temp	34.0	18.0	6.8	2.4
374	65	Grass	Temp	16.5	0.0	9.9	1.7
407	109	Grass	Temp	31.0	0.0	0.9	34.4
498	227	Grass	Temp	17.0	0.0	3.3	5.2
156	24	Grass	Seas	contained no water in 1993			
156	42	Grass	Seas	71.0	0.0	5.9	12.0
374	225	Grass	Seas	76.0	62.0	5.5	2.5
374	272	Grass	Seas	77.0	74.0	2.0	1.5
407	67	Grass	Seas	gauge destroyed by cattle			
498	277	Grass	Seas	37.0	18.0	5.8	3.3
73	29	Grass	Semi	75.0	22.0	26.1	2.0
156	22	Grass	Semi	gauge destroyed by cattle			
363	22	Grass	Semi	56.0	50.5	5.6	1.0
374	100	Grass	Semi	81.0	77.5	5.7	0.6
407	168	Grass	Semi	44.0	0.0	170.5	0.3
498	146	Grass	Semi	50.0	26.0	9.8	2.4
133	370	Crop	Temp	contained no water in 1993			
134	270	Crop	Temp	26.0	0.0	0.8	32.5
134	432	Crop	Temp	contained no water in 1993			
327	72	Crop	Temp	34.0	0.0	2.2	15.5
442	260	Crop	Temp	34.0	0.0	0.5	68.0
442	261	Crop	Temp	39.0	0.0	1.0	39.0
133	386	Crop	Seas	contained no water in 1993			
134	158	Crop	Seas	21.5	0.0	1.2	17.9
134	406	Crop	Seas	50.5	20.0	2.7	11.3
327	147	Crop	Seas	gauge malfunctioned			
442	93	Crop	Seas	68.0	0.0	0.3	226.7
442	281	Crop	Seas	85.0	0.0	5.2	16.3
133	380	Crop	Semi	contained no water in 1993			
134	140	Crop	Semi	40.5	31.0	1.0	9.5
134	165	Crop	Semi	27.5	0.0	5.4	5.1
327	117	Crop	Semi	88.0	39.0	15.6	3.1
442	295	Crop	Semi	41.5	0.0	46.5	0.9
442	301	Crop	Semi	47.5	0.0	18.8	2.5

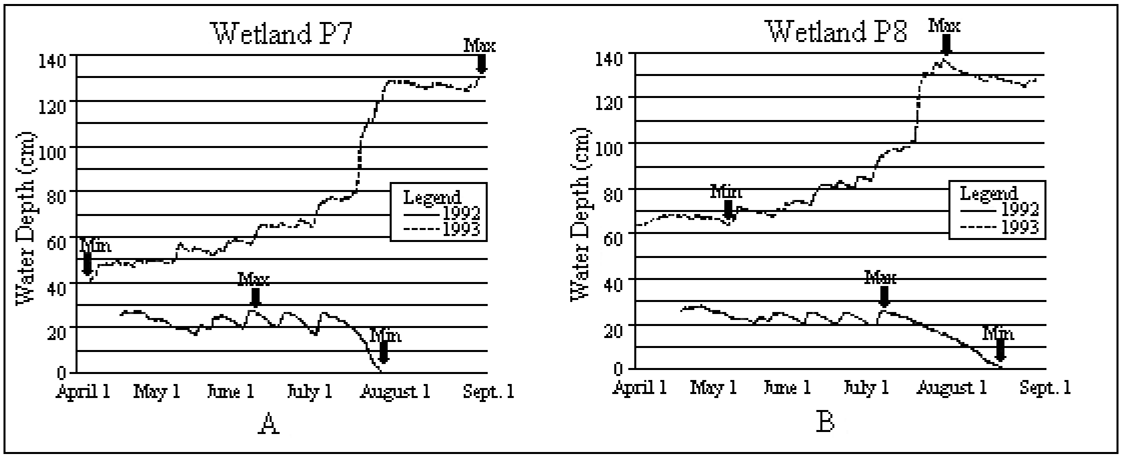

Figure 6. Water levels of wetlands P7 and P8, Cottonwood Lake Study Area, Stutsman County, ND as recorded by Telog water-level monitoring systems.

As determined by the Telog water-level monitoring systems installed at CLSA, water levels of wetland P7 (Figure 6a) reached a maximum depth of 28.2 cm on June 6 in 1992, after which levels steadily fell until the wetland went dry on July 23. In 1993, due to record high rainfall, the trends were reversed, with wetland P7 steadily gaining water through most of the summer. In 1993, depths of wetland P7 were minimum (39.6 cm) on April 5 and maximum (131.3 cm) on August 31. Water levels of wetland P8 (Figure 6b) followed the same general trends, reaching a maximum depth of 25.9 cm on July 2 in 1992 and steadily falling to dryness on August 18. Wetland P8 gained water throughout most of the summer of 1993, increasing from a minimum depth of 63.6 cm on May 6 to a maximum of 136.7 cm on July 25.

Table 2. Maximum and minimun water levels (cm) of wetland P7 and P8 at the Cottonwood Lake Study Area, Stutsman County, North Dakota, as recorded by prototype water-level recorders.

	1992		1993	
Wetland	Maximum	Minimum	Maximum	Minimum
P7	27.9	0.0	*	39.4
P8	25.4	0.0	*	65.0

*= Maximum water depth > capacity of gauge.

Throughout the study period, our prototype water-level recorders recorded the maximum and minimum water levels of wetlands P7 and P8 at CLSA, providing data within 1.4 cm of the readings provided by the Telog water-level monitoring systems. The only exception was in 1993 when record rainfall caused water levels to exceed the capacity of our recorders (Table2); the rods on the prototype devices were too short to record the increases. A frigid winter (lows to -40°C) did not damage our devices, but we noted that the copper-coated steel guide rods were corroded. Their copper coatings had either been scratched or were plated too thinly. We replaced the guide rods when the devices were checked in the spring of 1993 so the corrosion would not affect readings for this study.

Discussion

Our study demonstrates that water-level fluctuations are greater in wetlands located in areas of intensive agricultural activity relative to those in more natural grassland settings. The extent to which these increased fluctuations affect the plant, invertebrate, and ultimately the vertebrate communities of these wetlands is unknown. However, impacts are likely substantial if the increased fluctuations in a wetland are sufficient to alter the concentrations and species of salts present. In addition, increased fluctuations were directly related to increased runoff from adjacent uplands. How sediments and agricultural chemicals transported to wetlands in runoff affect plant, invertebrate, and vertebrate communities is poorly understood. Future studies should concentrate on determining how agricultural alteration of the natural hydrology of prairie wetlands affects their water chemistry and biota.

The differences observed in water-level fluctuations among the 3 wetland classes are related to the unique hydrology of each wetland class in the semiarid Prairie Pothole Region. In addition to surface runoff, semipermanent wetlands receive a large proportion of their water as input from ground water. This input of ground water has a stabilizing effect on water levels of semipermanent wetlands and results in wetlands of this class typically retaining water throughout the year. By contrast, seasonal, and to an even greater extent, temporary wetlands are dependent upon surface runoff for the majority of their water input. In addition, water loss in semipermanent wetlands is largely from evapotranspiration; whereas water loss in temporary wetlands is primarily from recharge to ground-water tables. Water loss in seasonal wetlands may be attributable to ground-water recharge and evapotranspiration, depending upon the wetland's hydrologic function and position in the landscape (Winter and Rosenberry 1995). The greater influence of surface runoff in the maintenance of water levels in temporary and seasonal wetlands highlights the critical role of vegetation in mitigating impacts from precipitation events.

While it would be highly desirable to use continuous water-level monitoring systems to monitor water-level fluctuations, the high cost of these devices precludes their use except on a very limited scale. The low cost devices we designed and tested in this study performed well despite being exposed to a severe winter and a spring thaw. The only major problem we encountered with the devices installed at CLSA occurred in 1993, when we received record rainfall that flooded area wetlands to depths beyond the capacity of our devices. The reason our prototype water-level recorders failed was because the guide rods were too short. We recommend that the lengths of the devices exceed maximum anticipated water depths. Of the 36 recorders placed in our study wetlands, 1 malfunctioned due to corrosion of its guide rod and 3 were destroyed by cattle. To avoid corrosion problems, we recommend that guide rods be made with a thicker copper plating. The thinly plated welding rods used in this study often had scratches and other imperfections that facilitated corrosion. Also, we suggest that the PVC casings of the devices be constructed out of 10.2-cm I.D. pipe instead of the 7.6-cm I.D. pipe we used. This would allow use of a larger, more buoyant float whose mass would overcome any friction associated with minor corrosion and fouling of the guide rod. Finally, if water-level recorders are installed in wetlands where cattle may be present, efforts should be made to exclude the cattle from the area immediately surrounding the recorders.

Acknowledgments

We thank P. W. Shaffer and R. D. Nelson for review of this manuscript, B. A. Hanson and R. A. Gleason for contributing to the design of the water-level recorder, and J. A. Beiser for conducting the statistical analysis. This research was cosponsored by the U.S. Environmental Protection Agency through Interagency Agreement Reference Number DW14935541-01 and the U.S. Fish and Wildlife Service Reference Number 14-48-0009-92-1929.

Literature Cited

Bragg, O.M., P.D. Hulme, H.A.P. Ingram, J.P. Johnston, and A.I.A. Wilson. 1994. A maximum-minimum recorder for shallow water tables, developed for ecohydrological studies on mires. Journal Applied Ecology 31:589-592.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, DC, USA. FWS/OBS-79/31.

Cowardin, L.M., D.H. Johnson, T.L. Shaffer, and D.W. Sparling. 1988. Applications of a simulation model to decisions in mallard management. U.S. Fish and Wildlife Service, Washington, DC, USA. Technological Report 17.

Cowardin, L.M. and S.R. Peterson. 1995. Objectives of EMAP program. p. 2-10. In Final Report on pilot test of indicators of wetland condition. U.S. Environmental Protection Agency, Washington, DC, USA. (in press)

Dahl, T.E. 1990. Wetland losses in the United States 1780's to 1980's. U.S. Fish and Wildlife Service, Washington, DC, USA.

Fellows, D.P. and T.K. Buhl. 1995. Research access to privately owned wetland basins in the Prairie Pothole Region of the United States. Wetlands 15:330-335.

Freeland A.F. and J.L. Richardson. 1995. Soils and sediments as indicators of agricultural impacts on northern prairie wetlands. p. 159-197. In Final Report on pilot test of indicators of wetland condition. U.S. Environmental Protection Agency, Washington, DC, USA. (in press)

Grue, C.E., M.W. Tome, T.A. Messmer, D.B. Henry, G.A. Swanson, and L.R. DeWeese. 1989. Agricultural chemicals and prairie wetlands: meeting the needs of the resource and the farmer--U. S. perspective. Transactions North American Wildlife Natural Resources Conference 54:43-58.

Hutchinson, G.E. 1967. A Treatise on Limnology. Volume II. Introduction to Lake Biology and the Limnoplankton. John Wiley and Sons, New York, NY, USA.

LaBaugh, J.W., T.C. Winters, G.A. Swanson, D.O. Rosenberry, R.D. Nelson, and N.H. Euliss, Jr. 1996. Changes in atmosphere circulation patterns affect mid-continent wetlands sensitive to climate. Limnology and Oceanography 41:864-870.

Macan, T.T. 1961. Factors that limit the range of freshwater animal communities. Biological Revue 52:45-70.

Martin, D.B. and W.A. Hartman. 1987. The effect of cultivation on sediment and deposition in prairie pothole wetlands. Water, Air, and Soil Pollution 34:45-53.

Milliken, G.A. and D.E. Johnson. 1984. Analysis of Messy Data. Volume I. Designed Experiments. Van Nostrand Reinhold Company, New York, NY, USA.

Moyle, J.B. 1945. Some chemical factors influencing the distribution of aquatic plants in Minnesota. American Midland Naturalist 34:402-420.

National Research Council. 1982. Impacts of emerging agricultural trends on fish and wildlife habitat. National Academy Press, Washington, DC, USA.

Potts, W.T.W. and G. Parry. 1964. Osmotic and Ionic Regulation in Animals. Pergamon Press, Oxford, England.

Richter K.O. 1995. A manual water level fluctuation gage to monitor wetland hydroperiod. Insert. In C. Botha (ed.) Society of Wetland Scientists Pacific Northwest Chapter Newsletter, December Kirkland, WA, USA.

SAS Institute, Inc. 1989. SAS/STAT User's Guide. Version 6. Cary, NC, USA.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics, a Biometrical Approach, second edition. McGraw-Hill Book Company, New York, NY, USA.

Stewart, R.E. and H.A. Kantrud. 1971. Classification of natural ponds and lakes in the glaciated prairie region. U.S. Fish and Wildlife Service Professional Paper 585-D.

Swanson, G.A. 1987. An introduction to the Cottonwood Lake area. Proceedings, North Dakota Academy of Science 41:25.

Tiner, R.W. 1984. Wetlands of the United States: current status and recent trends. U.S. Fish and Wildlife Service, Washington, DC, USA.

van der Valk, A. (ed.). 1989. Northern Prairie Wetlands. Iowa State University Press, Ames, IA, USA.

Wetzel, R.G. 1983. Limnology, second edition. Saunders College Publishing, New York, NY, USA.

Winter, T.C. and M.R. Carr. 1980. Hydrologic setting of wetlands in the Cottonwood Lake area, Stutsman County, North Dakota. U.S. Geological Survey Water Resources Investigation 80-99.

Winter, T.C. and D.O. Rosenberry. 1995. The interaction of ground water with prairie pothole wetlands in the Cottonwood Lake area, east-central North Dakota, 1979-1990. Wetlands 15:193-211.

Manuscript received 2 October 1995; revision received 3 June 1996; accepted 25 June 1996.