Canadian Water Resources Journal / Revue canadienne des ressources hydriques

ISSN: 0701-1784 (Print) 1918-1817 (Online) Journal homepage: http://www.tandfonline.com/loi/tcwr20

WATER LEVEL REGIMES IN PRAIRIE SLOUGHS

Jonathan S. Price

WATER LEVEL REGIMES IN PRAIRIE SLOUGHS

ResearchContributions/Recherches en cours
Submitted July 1992; accepted January 1993

Jonathan S. Price[1]

Abstract
Prairie sloughs from Saskatchewan were grouped according to their characteristic hydrological regime by examining data from 26 sloughs for the period between 1964 and 1974. Snowmelt was the dominant water input, after which water levels generally declined, some sloughs drying completely. Sloughs that dried <1% of the time were mostly from the northern parkland region, especially Melfort, or sloughs which had a low perimeter to volume ratio (<0.1 m/m^3), and an average depth exceeding 0.65 m. These sloughs either experience a very favourable water balance (*e.g.* Melfort), or are deep enough to withstand large water losses. Sloughs which were dry 1-25% of the time had a perimeter to volume ratio <0.4 m/m^3, and average depths >0.25 m. These sloughs only dried for short periods during exceptionally dry years. Sloughs dry 26-50%, and >50% of the time had a perimeter to volume ratio >0.4 m/m^3, and averaged <0.25 m deep, and consistently experienced dry periods every year. Sloughs dry >50% of the time contained no measurable water during dry years. Only sloughs from the climatically drier southern prairie region were dry >50% of the time, and these were typically the smallest and shallowest. Thus, while depth and perimeter to volume ratio are good indicators of the likelihood of drying, these measures themselves are linked to the climate, since the volume of water stored is largely controlled by the balance of climatically driven inputs and losses.

Résumé
Dans cette étude, nous avons examiné les données pour la période 1964 à 1974 de 26 marais de plaine au Saskatchewan. Nous les avons rassemblés selon un régime hydrologue typique. Il s'avère que la fonte de neige est la plus grande cause pour l'entrée d'eau dans le terrain marécageux. Suivant celle-ci, on remarque qu'en général, le niveau d'eau diminue et que parfois, quelques marais se sèchement complètement. Les marais qui sèchement <1% du temps proviennent, pour la plupart, de la région nordique des parcs, surtout celle de Melfort. Ou alors, ces marais se trouvent dans un rapport de périmètre à volume très bas (<0.1 m/m^3) et ils ont une profondeur qui dépasse 0.65 m. Ces marais-ci connaissent ou bien un bilan hydrologique très favorable (*e.g.* Melfort), ou bien ils sont assez profonds qu'ils puissent résister aux grandes pertes d'eau. Les marais qui sont secs de 1 à 25% du temps se trouvent dans un rapport de périmètre contre volume de <0.4 m/m^3, et révèlent des profondeurs moyennes de moins de >0.25m. Ce n'est seulement que pour de très courtes périodes lors des années exceptionnellement sèches que les terrains marécageux se sèchement. Les marais secs de 26 à 50% du temps sont dans un rapport de périmètre contre volume de >0.4 m/m^3, ils ont une profondeur moyenne de <0.25 m et ils connaissent régulièrement des périodes sèches chaque année. Lors des années sèches, les marais secs >50% du temps ne démontrent aucun niveau d'eau mesurable. Ce n'est que les marais qui se trouvent dans la région sud de la plaine, au climat plus sec, qui sont secs >50% du temps. Ces derniers sont typiquement les marais les plus petits et les

1. Geography Department, Queen's University, Kingston, ON

moins profonds. Ainsi, en dépit de l'importance de la profondeur du marais et son rapport de périmètre contre volume dans la détermination de la probabilité de séchage, ces indicateurs sont en eux-mêmes reliés au climat, puisque le volume d'eau accumulé dans le marais est largement contrôlé par la balance de l'échange climatique.

Introduction

Wetlands occur in areas where water inputs exceed water losses for a sufficient length of time to produce aquatic conditions and hydric soils. In the Prairie region precipitation is generally low, and highly variable in nature, but small topographic depressions collect sufficient surface runoff in spring to maintain a water surplus into the summer, and sometimes beyond. Millions of such wetlands, called "sloughs" or "pothole wetlands" exist in the semi-arid interior plains region of North America, and provide important habitat for migratory waterfowl (Millar, 1971). Such wetlands, which occupy the dry limit of wetland occurrence, are most susceptible to changes in climate and climate variability (Woo, 1992).

The hydrological role of prairie wetlands has been the subject of a number of scientific investigations, most of which have focused on groundwater interactions in one, or several linked wetland systems (*e.g.* Meyboom 1966; LaBaugh *et al.*,1987; Winter, 1988), reporting that seasonal reversals of groundwater flow affect the groundwater recharge function. Woo and Rowsell (in press) have recently completed a more thorough investigation of other water balance components, and thus quantified the seasonal water balance.

Water input to sloughs is typically dominated by snowmelt (Woo and Rowsell, submitted manuscript, Labaugh *et al.*, 1987). In a slough near Saskatoon, Woo and Rowsell (in press) found snowmelt and overland flow from upland snowmelt to be the most important input (159 mm), followed by rain (140 mm). Rain in spring can raise the slough water level significantly, but during drier summer conditions the water level may recede beneath the slough, and remain there even during heavy rain (Labaugh *et al.*, 1987). Water losses are from groundwater seepage, which may be 250-300 mm/y (Zebarth *et al.*, 1989), and from evaporation. Woo and Rowsell, submitted manuscript) found evaporation losses (213 mm) exceeded groundwater seepage losses (141 mm). Millar (1971) demonstrated that the rate of water loss in sloughs is related to the length of shoreline relative to the size of the pond (perimeter to volume ratio), where smaller ponds have proportionally greater shorelines in relation to the volume of water they contain. Thus, smaller sloughs experience relatively greater seepage losses, and higher evaporative losses by phreatophytic vegetation on the shore, and are therefore more likely to become dry during summer. The persistence, or duration of the water level in the slough, therefore, is usually seasonal, because summer rainfall is normally inadequate to offset the losses (Millar, 1976).

Meyboom (1966) noted that in sloughs, recharge conditions prevail in winter and spring, but a groundwater inversion in the phreatic zone develops in summer which induces groundwater inflow. Zebarth *et al.* (1989) estimated the regional recharge to the underlying aquifer provided by a Saskatchewan slough in hummocky terrain was 35 mm/y. This represents the seepage loss through the slough, expressed as a function of its drainage area. The concept of "slough focused recharge" was introduced by Lissey (1971), and studies of individual systems apparently support this. However, such studies do not account for the regional variability in soils, topography or climate on wetland function. For example, topographic position can cause distinct differences in the hydrology of a set of sloughs. LaBaugh *et al.* (1987), demonstrated that sloughs in the upper part of a catchment were most likely to be recharge wetlands, whereas mid-slope sloughs were "flow-through" wetlands, receiving groundwater on the upslope side, and losing it on the downslope side. They also noted that sloughs in low-lying areas were often discharge wetlands.

Currently, understanding of the nature and range of hydrological responses of sloughs in different physical settings, to climate variability, is inadequate. It is the objective of this report to examine water level fluctuations on a large number prairie sloughs to determine the nature of seasonal variations, and to characterize the frequency and magnitude of water depths, in the context of their physical setting and climate.

Study Area

As part of the Canadian contribution to the International Hydrological Decade, a series of 125 sloughs were monitored between 1964-1975, for water level, adjacent groundwater table elevation, and meteorological variables. The work was a co-operative venture between the Saskatchewan Research Council, and the Canadian Wildlife Service, which published the data for 26 sloughs located in five different areas (Lakshman, 1971, and Gillies and Lakshman, 1978). The sloughs were located near Saskatoon (5), Wilkie (5), and Melfort (6), Fort Qu'Appelle (5) and Swift Current (5) (Fig. 1).

The Saskatoon, Wilkie and Melfort area are in the Parkland district (Richards and Fung 1969) (Table 1). At Saskatoon and Wilkie the surficial deposits are hummocky disintegration moraine, with local kettled lacustrine deposits forming sloughs. The lithology is characterized by lacustrine, silt and sand deposits, forming low yield drift aquifers. Dark brown soils have developed at both sites (Richards and Fung 1969). The sloughs near Saskatoon exist in relatively small groups on localized lacustrine deposits, and sloughs are generally moderate in size, typically one to two hectares in area. At Wilkie slough occurrence is low to moderate, and many are large (20 to 50 ha). At the Melfort site the lithology is characterized by very hummocky moraine mantled with heavy clay of

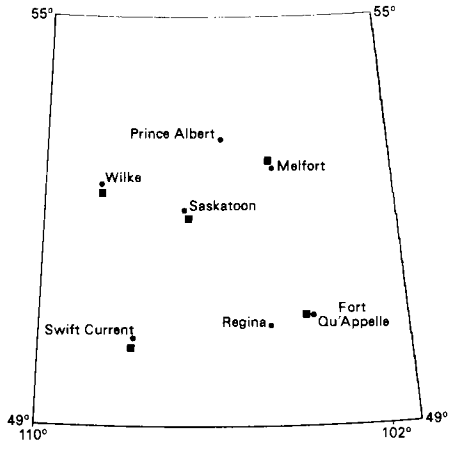

Figure 1: Location of Study Sites in Saskatchewan

lacustrine origin. These soils are noted for their poor drainage. Sloughs are moderate in size (typically 5 ha), and very numerous.

Swift Current and Fort Qu'Appelle are in the mid-grass and short grass prairie region respectively (Richards and Fung 1969). Sloughs at Swift Current are situated on a level upland plateau, set among a large concentration of predominantly small sloughs, indicating poor local drainage. The lithology is typified by till moraine and boulder clay, with localized kettled lacustrine deposits. At Fort Qu'Appelle sloughs exist on a level upland plateau within a very dense belt of small to moderately sized sloughs (typically < 1 ha), indicating very poor local drainage. The lithology is characterized by lacustrine deposits.

The general topography of all areas ranges from level to gently rolling, and even hilly in the Swift Current area. However, sloughs are distributed on locally level topography, with a slope less than 1%. The exception is at Melfort, where slough exist in hollows of the hummocky terrain. The average depth and area of sloughs chosen for this study are listed in Table 2. The slough sizes are typical of those shown on 1:50 000 NTS. However, sloughs were not selected randomly in the original study, and may inadequately rep-

Table 1. Physical and Climatic Features of the Study Areas

Location	Topography[1]	Lithology[1]	Soil[1]	Vegetation[1]	Precip.[2] (mm)		Mean Temp.[2] (°C)		Lake Evap.[3] (mm)	
					Annual	May-Sept	Annual	May-Sept	Annua;	May-Oct
Saskatoon	level to gently rolling	lacustrine silt and sand	dark brown	Southern Parkland	349	223	1.6	14.7	815	658
Wilke	level to gently rolling	lacustrine silt and sand	dark brown	Southern Parkland	354	234	1.0	13.7	-	-
Melfort	level to gently rolling	lacustrine clay	transitional black-grey	Northern Parkland	410	271	0.6	14.0	564	536
Swift Current	mod. rolling to hilly	till moraine boulder clay	brown	Mid-grass Prairie	380	240	3.2	14.6	1041	859
Ft. Qu'Appelle	level to gently rolling	lacustrine silt and clay	dark brown	Short-grass Prairie	366	245	2.2	15.0	-	-

1. Richards and Fung (1969)
2. 30 year normals (Environment Canada, 1982)
3. After Millar (1971); 1964-1969 (Saskatoon), 1966-1969 (Melfort), and 1962-1969 (Swift Current).

Table 2: Average Depth and Standard Deviation (m), Minimum, Average, and Maximum Area (m^2), Perimeter to Volume Ratio (P/A) (m/m^3), and Recharge/Discharge Function of the Sloughs in this Study

	Average Depth ±Std. Dev. (m)	Minimum Area (m^2)	Average Area (m^2)	Maximum Area (m^2)	P/V Ratio (m/m^3)	Recharge Discharge Function[1]
Melfort	0.73±0.19	13.2	16.7	20.2	0.011	R
G1	0.22±0.23	0	0.5	1.0	0.28	R
G2	1.60±0.26	1.9	4.2	7.3	0.04	R/D
G12	0.20±0.31	0	0.2	1.6	0.37	R/D
G15	0.27±0.26	0.4	1.2	1.8	0.15	R
G17[2]	? ±0.12	-	-	-	-	
Saskatoon						
G1	1.50±0.78	9.1	12.0	19.4	0.007	R
G11	0.93±0.38	0	2.0	2.4	0.027	R
G12	0.31±0.28	0	0.7	1.1	0.17	R/D
G13	0.65±0.44	0.4	0.8	1.0	0.03	R
G16	0.19±0.31	0	0.1	0.2	0.56	-
Wilkie						
G1	0.21±0.24	0	1.3	1.7	0.35	R
G5	0.37±0.20	0	0.9	1.0	0.13	R*
G6	0.11±0.17	0	0.5	0.9	0.58	R*
G9	1.21±0.93	0	12.1	15.8	0.01	D
G12	0.23±0.30	0	0.1	0.2	0.11	R*
Fort Qu'Appelle						
G1	0.18±0.33	0	0.4	0.8	0.34	R/D
G2	0.25±0.31	0	0.5	0.9	0.21	R/D
G17	0.33±0.29	0	0.3	0.7	0.19	R/D
G19	0.06±0.09	0	0.3	0.7	1.17	R*
G20	0.03±0.12	0	0.04	0.5	6.9	R*
Swift Current						
G1	0.71±0.44	1.1	4.1	5.0	0.02	R
G9	0.18±0.23	0	0.6	1.7	0.50	R*
G10	0.21±0.16	0	0.2	0.4	0.38	R*
G12	0.25±0.24	0	0.4	1.3	0.27	R
G20	0.85±0.31	0	0.7	0.9	0.06	R

1. R and D indicate predominantly recharge or discharge conditions, respectively. R/D indicates one or two wells are typically higher or lower than the water surface in the slough. * indicates two or more wells typically have a water level at least 0.5 m different from the water surface in the slough.
2. Slough geometry not available.

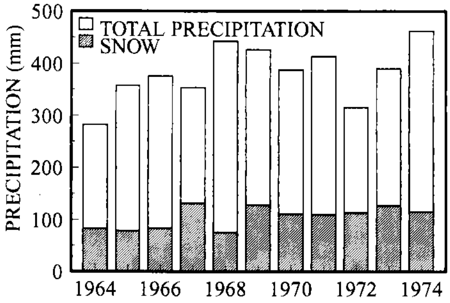

Figure 2: Annual Total Precipitation at Saskatoon during the Study Period, Including the Contribution by Snow

resent the numerous small sloughs (Millar, pers. comm.). The drainage area for each slough is not available from the data set, and in any case may not be particularly relevant, since much of the water is derived from blowing snow, with little or no surface inflow occurring during summer (Woo and Rowsell, submitted manuscript).

Annual precipitation ranges from 349 to 380 mm, except at Melfort, which receives 410 mm/yr. Lake evaporation ranges from a 564 mm/yr at Melfort in the north, to 1041 mm/a at Swift Current in the south (Table 1).

Methods

Rainfall , stage and groundwater elevation data from 1964 to 1975 were obtained from Lakshman (1971) and Gillies and Lakshman (1978). The measurement period varied from year to year between late April and late October, but the data are generally complete between May to September inclusive. The measurement interval was normally one week. All water level surface measurements were made relative to an arbitrary datum (h_a) at each slough, originally set at 100.00 ft. All elevations were converted to metres. The annual time series were plotted relative to the arbitrary datum (reduced to 30.5 m). To facilitate inter-comparison of data in the stage-duration analysis, water surface elevation was reduced to mean deviation (h_{md}):

$$h_{md} = h - h_a \tag{1}$$

where h_a is the mean stage for the period of record, and h is the measured stage. Thus, the mean elevation has a value of zero, elevations greater than the mean are positive values, and those less than the mean are negative. The data (h_{md}) were ranked to determine the percent of the total time that given values of h_{md} were exceeded (T_{EX}). h_{md} was plotted against "percent of time h_{md} less than the value indicated" ($1\text{-}T_{EX}$). The relationships between slough water level, perimeter length, area and storage volume are from data given by Lakshman (1971) and Gillies and Lakshman (1978), as are groundwater data and rainfall.

Results

The study period encompasses a wide range of climatic conditions, ranging from very dry years in the mid 1960's, to wet years in the early 1970's. For example, during the study period, precipitation at Saskatoon ranged from 282 mm in 1964, to 462 mm in 1974 (Fig. 2), with the average precipitation during this period being 382 mm, approximately 104 mm falling as snow. The 30 year average (1951-1980) precipitation for Saskatoon SRC is 371 mm, with 118 mm falling as snow.

Five distinct hydrological regimes can be distinguished by the nature of their seasonal and long term water level fluctuations (Fig. 3). Those which retained water at all times during the period of record are typified by the hydrological regime of Melfort G1. Other wetlands experienced drying late in the summer in some years (*e.g.* Saskatoon G12). A third group of sloughs always contained water during the early summer, but dried up later on (*e.g.* Wilkie G6), and another group remained completely dry in some years, and dried up at the end of all years (*e.g.* Fort Qu'Appelle G19). The fifth group (*e.g.* Wilkie G9) were characterized by extreme variations in storage, caused more by inter-annual variations in inputs, rather than extreme seasonal losses. The seasonal regime of all sloughs have one feature in common. They are dominated by snowmelt inputs,

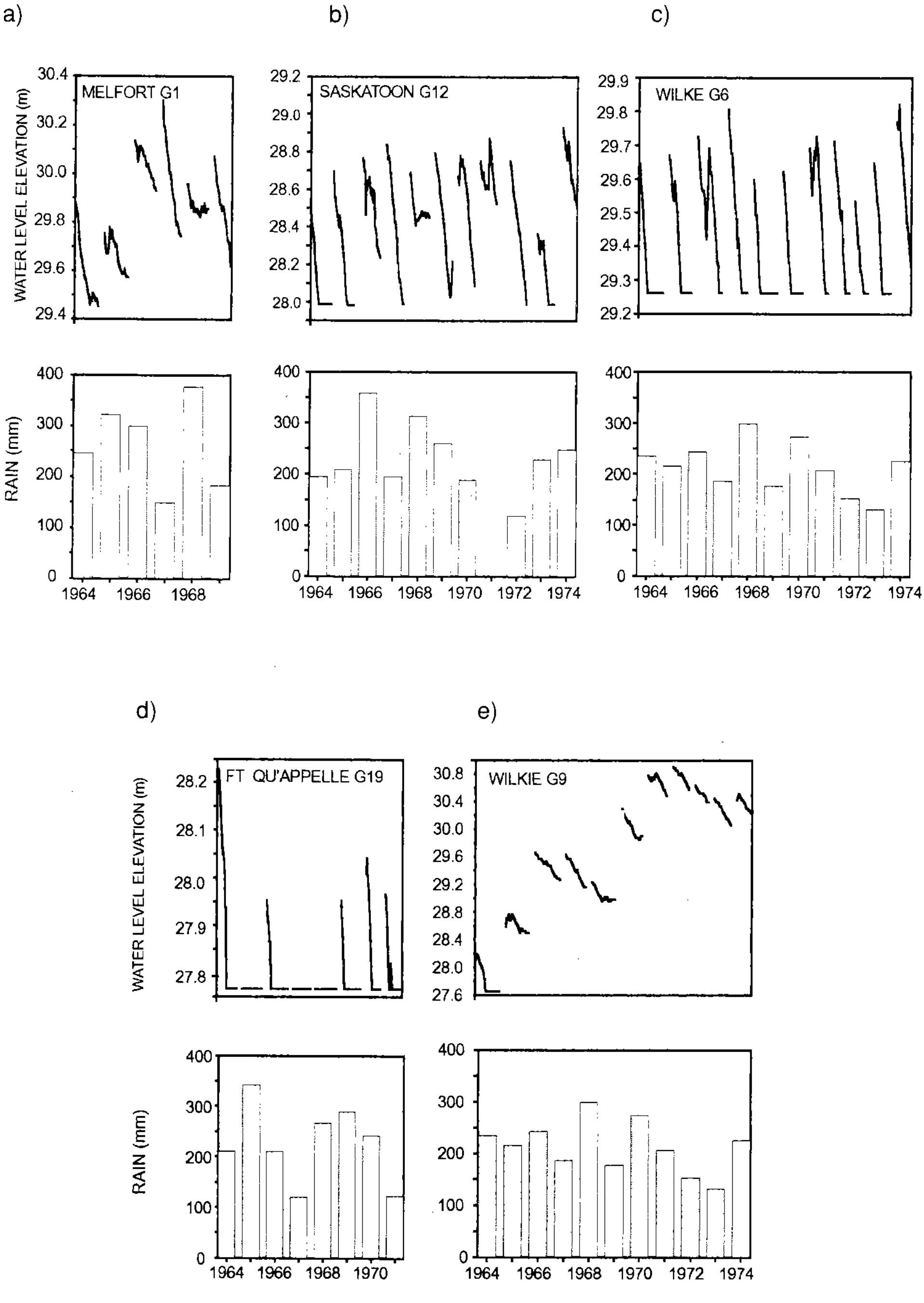

Figure 3: May to September Water Levels and Rainfall for Selected Sloughs. From left to right a) Melfort G1, b) Saskatoon G12, c) Wilkie G6, d) Fort Qu'Appelle G19, and e) Wilkie G9

which recharge the water level to the annual maxima, or close to it. The exception is for the fourth group which sometimes remained dry following years with low snowfall. The dominance of snowmelt inputs can also be seen by comparing the poor relationship between rain (May-September) and water level (Fig. 3). For example, the highest water levels in Wilkie G9 were in 1971-73, corresponding to the years with lowest summer rainfall. Furthermore, the highest water levels at Melfort G1, Saskatoon G12 and Wilkie G6 were achieved in 1967 when summer rain was low, but when snow accumulation (measured at Saskatoon) was high (Fig. 2). In most years, water level fluctuations due to rain occur primarily early in the season. Later, the water levels typically experience monotonic declines, and exhibit no recovery when dry.

Most sloughs had a network of four wells placed around the outside of the wetland. Only one of the sloughs (Wilkie G9) had a distinct groundwater discharge regime, as indicated by higher water table elevations in all wells, compared to the elevation of the slough water surface, for most of the study period (Table 2). Five of the sloughs had alternating periods of recharge or discharge, but more typically indicated recharge to one side of the slough, and discharge from the other (Table 2). These are flow-through wetlands (LaBaugh *et al.*, 1987). The 14 remaining sloughs exhibited distinct recharge regimes (Table 2). Of these, seven had "strong" recharge, where the water in the slough was up to several meters higher than the water table in the surrounding area, and typically 0.5 m higher. It should be noted that this is indicative only of the groundwater potential gradient, and that actual recharge rates are also governed by the hydraulic conductivity of the substrate.

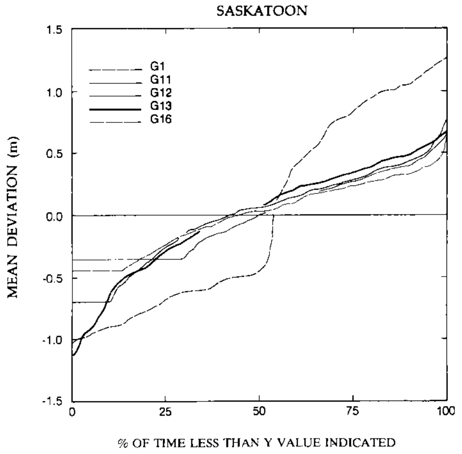

Figure 5: Stage Duration Curves for Sloughs in the Saskatoon Area

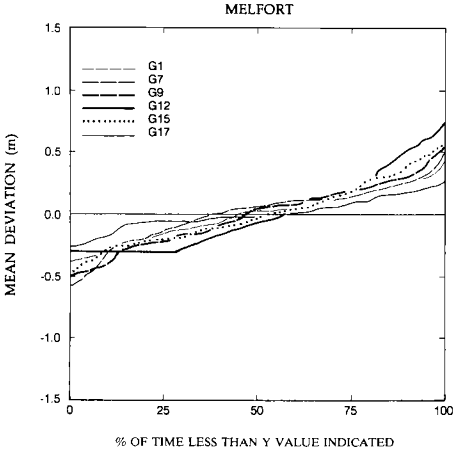

Figure 4: Stage Duration Curves for Sloughs in the Melfort Area

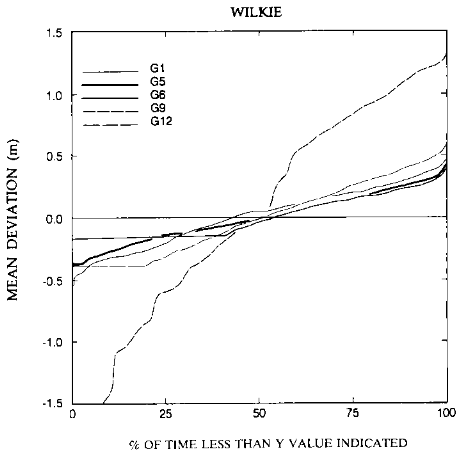

Figure 6: Stage Duration Curves for Sloughs in the Wilkie Area

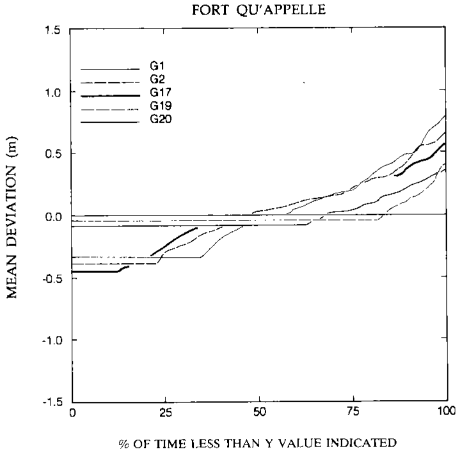

Figure 7: Stage Duration Curves for Sloughs in the Fort Qu'Appelle Area

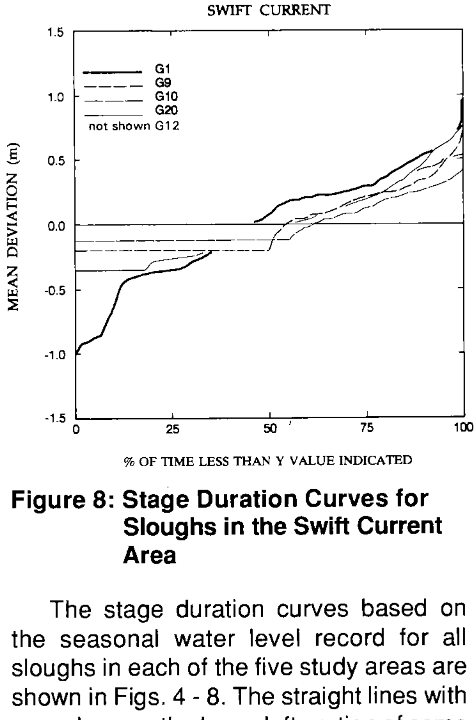

Figure 8: Stage Duration Curves for Sloughs in the Swift Current Area

The stage duration curves based on the seasonal water level record for all sloughs in each of the five study areas are shown in Figs. 4 - 8. The straight lines with zero slope on the lower left portion of some curves represent a water level which was at or below the lowest point at the base of the slough (i.e. dry). Gently sloping curves indicate the least water level variability, and steeply sloping curves represent high variability. Sloughs from the Melfort area (Fig. 4) exhibited the least water level variability, and were generally resistant to drying; only one slough dried completely. Three Saskatoon sloughs and two from Wilkie (Figs. 5&6) also had some dry periods, but their duration was relatively short. The sloughs from the southern group (Fort Qu'Appelle and Swift Current; Figs. 7&8) had a distinct tendency to dry up, some for up to 80% of the time. This included all of those at Fort Qu'Appelle, and three at Swift Current. The tendency for the southern prairie sloughs to dry may be related to the less favourable water balance (Table 1).

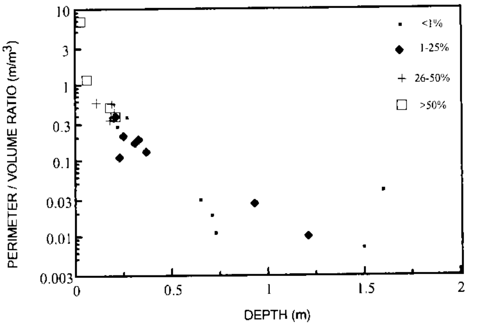

Figure 9: Average Depth vs. Perimeter to Volume Ratio, for Sloughs in all Classes

The stage duration curves were grouped to correspond to the period of dry time experienced over the duration of the study. Class intervals were arbitrarily set at <1%, 1-25%, 26-50%, >50% of the time (Table 3).

The relationships between perimeter length and storage volume was calculated at the average water depth for each slough (Table 2). In particular, the large sloughs (greater than 2 ha), and sloughs with an average depth greater than 0.65 m, had a perimeter to volume ratio of less than 0.1 m/m^3. These sloughs held a large amount of water relative to their area and perimeter length, and they all fell into the first category above (dry <1% of time), except Saskatoon G11 and Swift Current G20, which fall into the next category (dry 1-25% of time). As expected, the small and shallow sloughs, with a high perimeter to volume ratio (>0.4), fell into the last ca-

Table 3: Percent of Time Individual Sloughs Were Dry (by class)

% time dry	<1	1-25	26-50	>50
Melfort	G1,G7, G9, G15, G17	G12		
Saskatoon	G1,G13	G11,G12	G16	
Wilkie	G1,G9	G5,G12	G6	
Swift Current	G1, G9, G20 G10,G12			
Fort Qu'Appelle		G2,G17	G1	G19,G20

tegory (dry 50% of time). Fig. 9 shows that sloughs with a perimeter to volume ratio less than 0.4 m/m^3 were never dry more than 25% of the time, even for sloughs with comparatively shallow depths (0.25 m). Sloughs with a perimeter to volume ratio more than 0.4 m/m^3 were dry ≥26% of the time.

Discussion

There are two trends apparent in this data: i) Sloughs from the northern parkland region were less likely to dry than those from the southern prairie region, and ii) Sloughs with a small perimeter relative to their storage volume (i.e. <0.4 m/m^3) were least likely to dry. However, since sloughs in all classes (<1%, 1-25%, 26-50% and >50% of time dry) can be found in both northern and southern regions, and since adjacent sloughs may have very different regimes, the storage relationships offer a more reliable indicator of slough behaviour than location. It must be recognized, however, that the storage volume of sloughs is controlled not just by local morphometry, but also by climate. The resulting water balance produces distinct hydrological regimes which can be characterized by the stage duration curves. Melfort G1, Saskatoon G12, Wilkie G6, and Fort Qu'Appelle G19 (Fig. 3) are representative of <1%, 1-25%, 26-50%, and >50% of time dry classes, respectively.

Sloughs with gently sloping stage duration curves were mostly from Melfort (northern area), indicating a stable water level. The sloughs of this area have larger and more regulated inputs and especially less severe outputs (evaporative demand and seepage loses), so that large storage changes do not occur over the summer. At Melfort, rainfall inputs are higher, evaporation is lower (Table 1), and the lacustrine soils are of low permeability so that even though these are recharge wetlands, seepage losses are minimized, resulting in less seasonal variation in the water level. This is also evident in the annual hydrographs for the Melfort sloughs (Fig. 3), which responded readily to short term rainfall input, and exhibited recession curves much less steep than sloughs in other areas. Due to the more limited water sinks, water level fluctuations in a given year were frequently less than inter-annual variations, which were more closely tied to snowmelt input (Fig. 3). The same processes which limit water level variability in this area, minimizes the risk of the sloughs drying up. Sloughs in the Melfort area were least likely to dry, and dominate the "<1% time dry" class (Table 3).

Steeply sloping stage duration curves such as for Saskatoon (G1 and G13), Swift Current (G1), and Wilkie (G9) represent sloughs with highly variable water levels. This extreme variation occurs where large changes in storage arise from short or long term surpluses or deficits in the water balance, or where seepage, surface drainage and/or evaporation loses are high. Except for Wilkie G9, these are recharge sloughs, which consistently lose water to groundwater seepage. Groundwater losses are conceptually more consistent with extreme variations in water level, since they exacerbate losses by evaporation. However, it is likely that the morphometric character of individual sloughs within a locality, rather than differences in climate or lithology, produce the more extreme variations in water level. Examination of Fig. 3e shows that storage changes within seasons at Wilkie G9 are very small compared to changes from year to year, which reflect long term precipitation trends (Fig. 2). This type of slough demonstrates a high degree of persistence with respect to the previous years condition, because its large storage capacity enables it to hold a large volume of water (Table 2) when inputs are available. These sloughs with steeply sloping stage duration curves are all relatively deep, with an average depth of 0.65 m or more. As a consequence, they are also unlikely to dry completely, and all fall into the "<1% time dry" category. Therefore, two very different groups of sloughs end up in the same category (<1% time dry), for very different reasons. The first group because of the more favourable balance of inputs and outputs (*e.g.* in the Melfort area), and the second because of the sheer size and storage volume.

The remaining sloughs in this study have intermediately sloping stage duration curves, all indicating some significant period of time in the dry condition (i.e. 1-25%, 26-50%, and >50% of the time). These sloughs are mostly outside the Melfort area, therefore have less favourable climate, and a higher seepage loss. Typical of sloughs in these classes, they are small and shallow (Table 2), and the "% of time dry" increases with decreasing area and depth. Fig. 9 indicates that the "% of time dry" classes fall into two distinct groups (dry ≤25% of the time, or dry ≥26% of the time). The sloughs most likely to dry (i.e. ≥26% of the time) have a relatively large perimeter to volume ratio (>0.4 m/m^3), and are shallow (<0.25 m). These sloughs have less water to lose, and a larger surface and basal area (relative to their volume) across which losses occur (Millar 1971). When these morphometric thresholds are met, they can prevail over even the most favourable climate conditions of the study area (*e.g.* Melfort G12). Therefore, these sloughs dry completely when annual inputs, especially snowmelt, are insufficient to meet seasonal water demand. The sloughs which were dry ≥26% of the time do not show that storage deficits incurred in the antecedent year govern the behaviour during the current year, although there is necessarily some affect (Woo and Rowsell, in press).

Conclusions

While most sloughs have little or no hydrological record whatsoever, identifying groups of sloughs by hydrological criteria is useful and necessary if hydrological models of slough water levels can be used to simulate climatic 'variations' or global climatic warming (eg. Woo, 1992). Such models are capable of simulating many years of record, which could be easily categorized by the stage duration method. The stage-duration method has identified distinct hydrological regimes which were categorized by the % of time they were dry (<1%, 1-25%, 26-50% and >50%). Sloughs which experienced no significant drying during the study period (<1% of time) tended to be relatively deep (>0.65 m), and have a small perimeter to volume ratio (< 0.1 m/m^3). With respect to climate, the Melfort area has the greatest water surplus, because of higher precipitation inputs, and lower evaporative losses. Coupled with low seepage losses near Melfort, these conditions favour "permanent" sloughs.

Those sloughs which have been dry less than 25% of the time typically contain water in all but the driest years, so at least for the period of record can be considered "semi-permanent". They had intermediate storage volumes with average depth ≥0.25 m, and perimeter to volume ratio 0.4 m/m^3. These sloughs were only likely to dry when inadequate snowmelt failed to fully recharge them (Fig. 3b).

Sloughs which were dry 26-50% of the time are generally those which remain flooded in wet years, but typically experience a period of seasonal drying late in the summer (Fig. 3c). This typical behaviour may be referred to as "seasonal". These sloughs were shallow (0.1-0.2 m), and had a perimeter to volume ratio 0.4-0.6 m/m^3. As such, these sloughs were strongly dependent on snowmelt inputs, but in some years received sufficient rain to minimize the seasonal dry period.

Sloughs which were dry >50% of the time commonly experienced years with no free water surface at all (Fig. 3d), displaying a regime which can be called "ephemeral". These sloughs were very shallow (0.03 - 0.2 m), and had a high perimeter to volume ratio (0.4 - 1.17 m/m^3), indicating that they have little capacity to withstand normal seasonal water losses, regardless of the quantity of snowmelt input.

The results of this study indicate that the stability of water levels in sloughs is strongly affected by the size and shape of the slough, which controls the volume of water it contains, and the area across which losses occur. However, the influence of climate is implicit in this analysis, since the balance of regional inputs and losses affect the distribution of slough sizes across the study area. Indeed, northern sloughs, especially those near Melfort, most frequently had the requisite storage characteristics to minimize drying. Sloughs from the southern region were typically smaller, perhaps because of the less favourable water balance. The relationship between slough size and geographic location requires further study.

Acknowledgements

This study was funded by a contract with the Atmospheric Environment Service. Thanks also to R. Bouvier of the Saskatchewan Research Council for assistance in retrieving data.

References

Environment Canada. 1982. "Canadian Climatic Normals, 1951-1980: Temperature and Precipitation, Prairie Provinces." Ottawa.

Gillies, R. and G. Lakshman. 1978. *The Water Budget of Shallow, Permanent, or Intermittent Natural Reservoirs as it Affects Economy and Wildlife: A Compilation of Hydrometeorlogical Data Collected from Sloughs from 1971 to 1975.* Progress Report No. 8, Saskatchewan Research Council, Saskatoon, 51p.

LaBaugh, J.W., T.C. Winter, V.A. Adamaitis, and G.A. Swanson. 1987. "Hydrology and Chemistry of Selected Prairie Wetlands in the Cottonwood Lake Area, Stutsman County, North Dakota, 1979-1982, U.S." Geol. Surv. Prof. Paper 1431, 26p.

Lakshman, G. 1971. *The Water Budget of Shallow, Permanent, or Intermittent Natural Reservoirs as it Affects Economy and Wildlife: A Compilation of Hydrometeorlogical Data Collected from Sloughs from 1964 to 1970.* Progress Report No. 7, Saskatchewan Research Council, Saskatoon, 176p.

Lissey, A. 1971. "Depression Focused Transient Groundwater Flow Patterns in Manitoba." Geol. Assoc. Canada, Special Paper No. 9, 333-341.

Meyboom, P. 1966. "Unsteady Groundwater Flow Near a Willow Ring in Hummocky Moraine." *Journal of Hydrology*, 4: 38-62.

Millar, J.B. 1976. *Wetland Classification in Western Canada.* Canadian Wildlife Service Report Series Number 37, 38 p.

Millar, J.B. 1971. "Shoreline-Area Ratio as a Factor in Rate of Water Loss from Small Sloughs." *Journal of Hydrology*, 14: 259-284.

Richards, J.H. and K.I. Fung. 1969. *Atlas of Saskatchewan*, University of Saskatchewan, Saskatoon.

Winter, T.C. 1988. A Conceptual Framework for Assessing Cumulative Impacts on the Hydrology of Non-Tidal Wetlands. Environmental Management 5: 605-620.

Woo, M.K. 1992. "Impacts of Climate Variability and Change on Canadian Wetlands." *Canadian Water Resources Journal*, 17: 63-69.

Woo, M.K. and R.D. Rowsell. 1993. "Hydrology of a Prairie Slough." *Journal of Hydrology*, in press

Zebarth, B.J., E. deJong, and J.L. Henry. 1989. "Water Flow in Hummocky Landscape in Central Saskatchewan, Canada, II. Saturated Flow and Groundwater Recharge." *Journal of Hydrology*, 110: 181-198.