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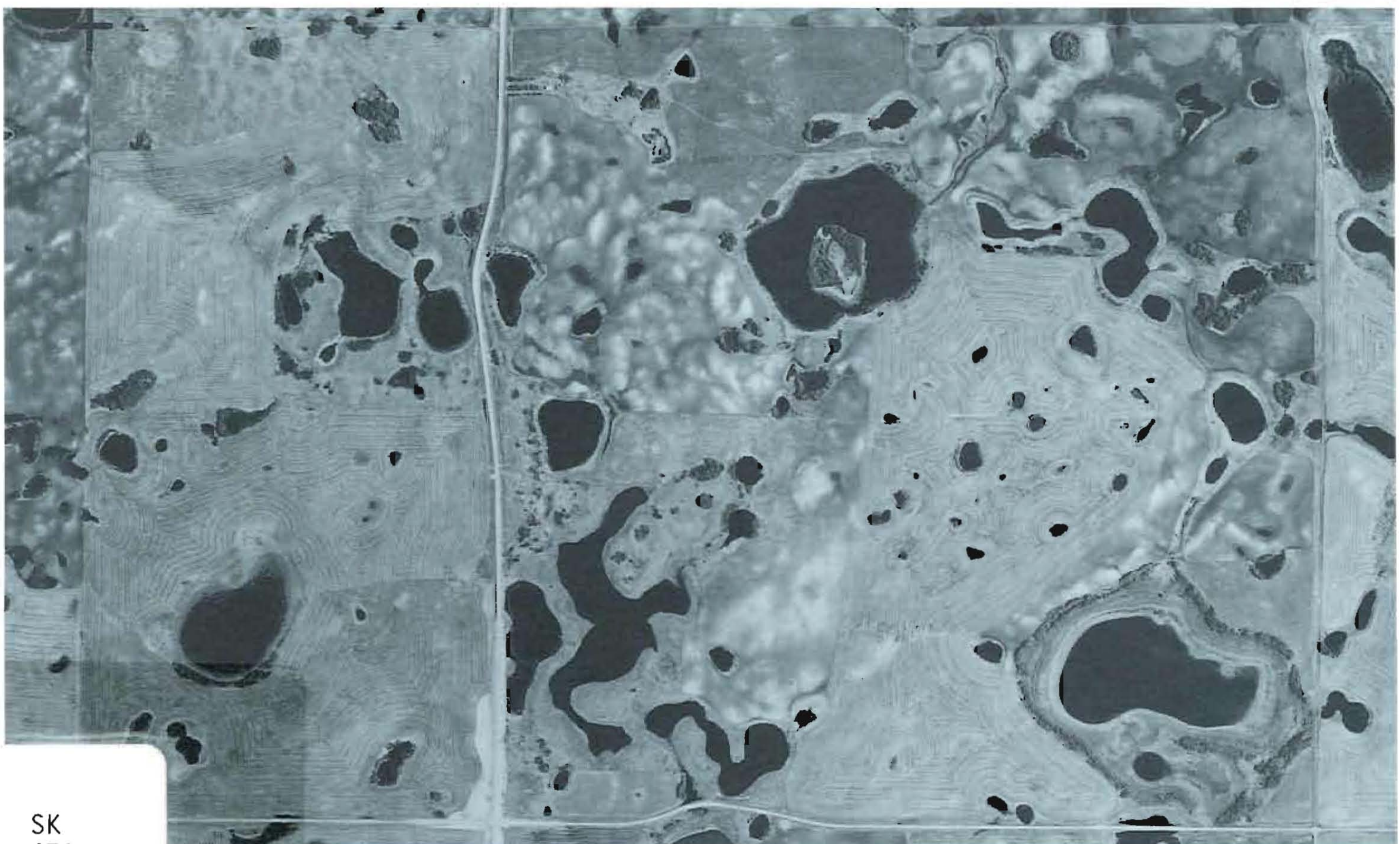

Ducks Unlimited Canada

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Cover photo: Aerial view of St. Denis National Wildlife Area, 1983

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Abstract

Several wetland classification schemes have been devised to facilitate waterfowl management in North America. These schemes were developed primarily from vegetational, not hydrological, characteristics of wetlands and so do not consider annual changes in slough responses to climatic variability. Here we provide a hydrological scheme that proves to be consistent with Millar's (1976) ecological classification scheme.

Based on information collected at the St. Denis National Wildlife Area from 1980 to 1990, four groups of wetlands were distinguished; temporal variation in wetland inundation created a continuum between groups. *Ephemeral wetlands*, equivalent to Millar's wet meadow wetlands, have 0.5 probability of being inundated for one month or less in each year. *Intermittent wetlands* (Millar's shallow marshes) have 0.5 probability of inundation for at least one month each year. These wetlands are fed largely by snow melt-water, although some intermittent wetlands may also benefit from groundwater discharge from the local groundwater system or, during wetter years, even the regional groundwater flow. *Semipermanent wetlands*, with 0.5 probability of being inundated for at least two months each year, correspond to Millar's emergent deep marshes. *Permanent wetlands* consist of shallow open water wetlands and open alkali wetlands. They have 0.6 probability of being inundated for at least seven months each year. These wetlands are fed mainly by regional groundwater, which responds, slowly, to annual water balance changes.

In late summer, flooding of permanent and some intermittent wetlands can be determined by fluctuations in the regional water table. Fractions of ephemeral and intermittent wetlands inundated during spring and early summer were predicted with near certainty using snowfall of current and past winters. Early (in May) predictions of wetland abundance may be useful for waterfowl managers who need to forecast breeding effort of waterfowl and fall waterfowl population size, although further information is needed regarding summer wetland abundance and quality and their relationships to survival of both adult and growing ducks.

Résumé

Plusieurs systèmes de classification des terres humides ont été conçus en vue de favoriser la gestion de la sauvagine en Amérique du Nord. Ces systèmes ont été élaborés en fonction principalement des caractéristiques végétales et non hydrologiques des terres humides; ils ne tiennent pas compte des changements annuels constatés dans les réactions des dépressions aux variations climatiques. Nous introduisons donc un système de classification hydrologique qui est compatible avec le système de classification écologique de Millar (1976).

Compte tenu des renseignements recueillis à la réserve nationale de faune de St-Denis de 1980 à 1990, on a relevé quatre groupes de terres humides; les variations temporelles au chapitre de l'inondation des terres humides ont créé un continuum entre les groupes. Il y a une probabilité de 0,5 que les *terres humides éphémères*, l'équivalent des prairies humides de Millar, soient inondées chaque année pendant au plus un mois et les *terres humides intermittentes*, marais de faible profondeur selon Millar, pendant au moins un mois. Ces terres humides intermittentes sont alimentées en grande partie par l'eau de fonte des neiges, même si certaines bénéficient aussi de l'évacuation du réseau local d'eaux souterraines ou, durant les années plus humides, de l'écoulement de la nappe d'eau souterraine régionale. Les *terres humides semi-permanentes*, dont le taux de probabilité d'inondation s'élève à 0,5 pendant au moins deux mois par an, correspondent aux marais profonds émergents de Millar. Les *terres humides permanentes* se composent d'eaux libres peu profondes et d'eaux libres alcalines. Leur taux de probabilité d'êtres inondées pendant au moins sept mois par année est de 0,6. Ces terres humides sont alimentées principalement par les eaux souterraines régionales qui réagissent lentement aux changements annuels du bilan hydrologique.

À la fin de l'été, les probabilités d'inondation des terres humides permanentes et de quelques terres humides intermittentes peuvent être déterminées en fonction des fluctuations de la nappe phréatique régionale. On a pu prédire quasiment avec certitude que certaines parcelles de terres humides éphémères et intermittentes allaient être inondées au printemps et au début de l'été grâce aux données sur les chutes de neige enregistrées pendant l'hiver courant et les hivers précédents. Si elle est effectuée tôt (en mai), la prévision de l'abondance des terres humides peut permettre aux gestionnaires de la sauvagine de prévoir le taux de reproduction des espèces de sauvagine et la taille des populations de sauvagine à l'automne, mais il faudra disposer de plus amples informations sur l'abondance et la qualité des terres humides en été, ainsi que sur leurs liens avec la survivance des canards jeunes et adultes.

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Introduction

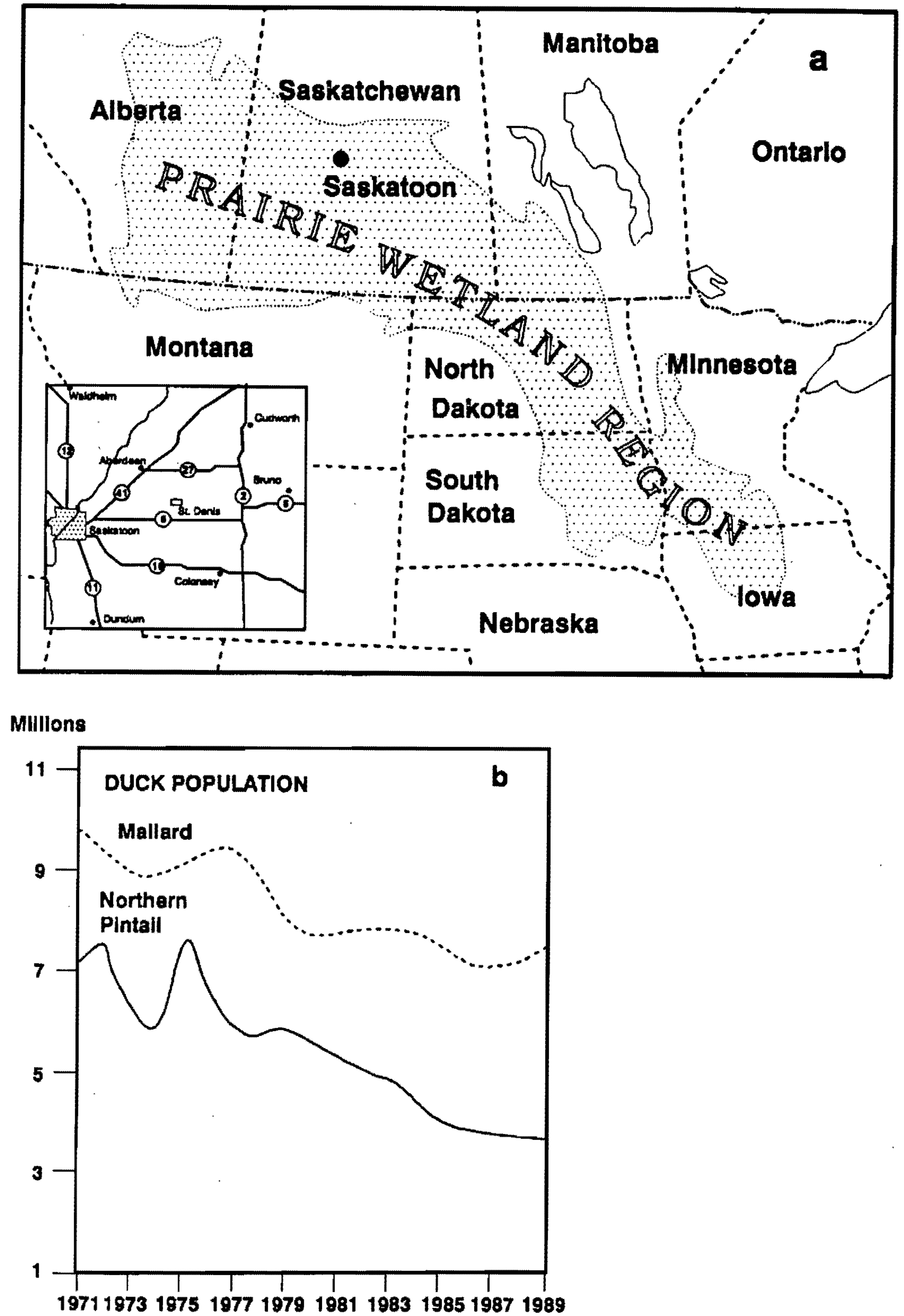
Several wetland classification systems based on vegetational criteria have been developed to meet the regional and national needs of wetland managers and researchers in Canada (e.g., Millar 1976; Adams 1988) and the United States (e.g., Martin et al. 1953; Stewart and Kantrud 1971; Cowardin et al. 1979). In the prairie region, numerous small wetlands (known as *sloughs* in Canada and *potholes* in the United States) can be found. Various classification systems have been devised for such wetlands. For example, vegetation and the extent of flooding have been used as the basis of slough classification because of their influence on waterfowl use of wetlands. Vegetation serves as an indicator of hydrological conditions, and slough vegetation may undergo dramatic changes in response to the drought and wet cycles (Coupland 1961). Because the formation and maintenance of wetlands are dictated by the hydrological regime of the land, hydrological consideration is fundamental to wetland classification. This is particularly germane in light of possible changes in prairie weather patterns predicted by global warming models (e.g., Schlesinger and Mitchell 1987; Wall 1990) and their expected negative impacts on prairie wetlands.

Apart from the implications of climatic change for human use of water resources, there is serious concern for wildlife, particularly those species that are strongly reliant on wetlands. The grassland and parkland regions of prairie Canada contain much suitable breeding habitat for waterfowl (Fig. 1a) and other wetland birds (Kantrud and Stewart 1984). However, recent changes in agricultural land use practices have heightened concerns regarding the well-being of duck populations (Sugden and Beyersbergen 1984; Boyd 1985; Johnson and Shaffer 1987) (Fig. 1b). Wetland drainage and degradation have been made easier by long periods of prairie-wide drought and have seriously reduced the availability of habitat suitable to breeding ducks. Various forms of wetland degradation affect ducks in different ways, owing to the diversity of ducks' spatial and nutritional requirements (e.g., Batt et al. 1989; Anderson and Titman 1992), but wetlands provide most of the foods eaten by laying and incubating female ducks and their young (reviewed thoroughly by Krapu and Reinecke 1992; Sedinger 1992). Reproductive effort and success of Mallards *Anas platyrhynchos* are reduced during drought (e.g., Krapu et al. 1983; Rotella and Ratti 1992a).

Stewart and Kantrud (1973) found that 42% of all breeding ducks in the pothole regions of North Dakota used seasonal wetlands (depressions with their central areas dominated by shallow marsh), which comprised only 33% of the total wetland area. Similarly, 27% of ducks used semipermanent wetlands (with deep marsh occupying the central zones of the wetland depressions), which comprised only 18% of the total wetland area. Dwyer et al. (1979) found that, in North Dakota, radio-marked female Mallards used as many as 7–22 different wetlands during the breeding season. In Manitoba, Rotella and Ratti (1992b) found that most of the available wetlands received some use by Mallard broods. Numbers of duck broods are often positively correlated with summer wetland conditions (e.g., Bellrose 1979; Leitch and Kaminski 1985; but see Trauger and Stoudt 1978), likely reflecting the availability of suitable wetlands for breeding pairs and brood rearing. Thus, complexes of wetlands are essential to provide resources to accommodate the spatial and nutritional needs of a diverse waterfowl community. Prediction in late winter of spring wetland conditions may give some indication of the size and success of breeding duck populations later in the year. The ability to forecast wetland conditions and future duck populations more reliably than by present methods could improve the annual setting of hunting regulations, particularly in Canada, where decisions on regulations have to be made early in June.

Our study has three main objectives. First, we briefly review existing wetland classification systems and comment on their relationships with hydrological regimes of prairie wetlands. Second, we examine hydrological regimes of wetlands at the St. Denis National Wildlife Area (NWA), Saskatchewan, recorded from 1980 to 1990, and relate these to Millar's (1976) wetland classification scheme. Third, we explore the relationships among snowfall, tree growth patterns, and wetland inundation at the St. Denis NWA. The last objective enabled us to develop and test a predictive model of seasonal wetland inundation in response to snowfall patterns that may prove useful in forecasting: (1) the likelihood of successful breeding by prairie ducks; and (2) the impact of future, predicted snowfall patterns on wetland abundance and permanence.

Figure 1
(a) Distribution of prairie wetlands in Canada and the United States (after Winter 1989), and the location of the St. Denis NWA study site. (b) Annual variation of Mallard and Northern Pintail populations in the prairies (after Environment Canada 1990).



Definitions and existing slough classification systems

A wetland is defined as "land that has the water table at, near, or above the land surface or which is saturated for a long enough period to promote wetland or aquatic processes as indicated by hydric soils, hydrophytic vegetation, and various kinds of biological activity that are adapted to the wet environment" (Tarnocai 1980; see also Cowardin et al. 1979). A slough (or pothole) commonly comprises an inundated zone and a noninundated zone, the extent of which may vary during different months and from year to year (Millar 1973). Hereafter, a slough refers to a combination of these two elements, generally found in a depression or basin.

Considering the continuum from wetland to lakes, Stewart and Kantrud (1971) distinguished eight categories of sloughs according to conditions at the centre of the sloughs (the principal vegetative or water-covered zones are given in parentheses):

- ephemeral potholes (low prairie),
- temporary potholes (wet meadow),
- seasonal potholes (shallow marsh),
- semipermanent potholes (deep marsh),
- tillage potholes (cultivated),
- permanent lakes (open water),
- intermittent saline lakes (saline water), and
- alkaline bogs or fens (alkaline wetland).

Improving upon Stewart and Kantrud's (1971) system, Millar (1976) produced a similar scheme of slough classification. Adams (1988) modified Millar's scheme and placed it in the context of the Canadian wetland classification system (Wetlands Working Group 1981), noting that Millar's slough categories fall within the marsh and shallow water wetland groups. All these classifications recognize the frequent occurrence of several vegetation zones that change from the edge to the centre of a slough. Their identification of slough type is made according to the predominant vegetation at the slough centre. In addition to artificial wetlands that contained dugouts, seven other types of sloughs were distinguished. Using Millar's (1976) scheme, these are:

- wet meadow,
- shallow marsh,
- emergent deep marsh,
- transitional open water wetland,
- open water marsh,
- shallow open water wetland,
- open alkali wetland, and
- disturbed wetland (Table 1).

Sloan (1972) provided some hydrological support to the first four categories of Stewart and Kantrud's (1971) classification scheme. He noted that for the sloughs in the Mount Moriah area of North Dakota, average water depths on 8 June 1967 for the ephemeral, temporary, seasonal, and semipermanent potholes were: dry, 0.23, 0.5, and 0.79 m, respectively (the corresponding average specific conductances were unknown for the ephemeral potholes, 270, 590, and 1320 µS for the other three categories). This work, like other prairie wetland classifications, suggests a positive link between the hydrological information and the vegetation-based classification schemes.

Table 1
Comparison of Millar's (1976) and Adams' (1988) slough classification systems with the hydrological classification developed in this study

Hydrological (this study)	Millar	Adams	Description
Ephemeral	Wet meadow	Wet meadow	Grasses, sedges, or willow, flooded only in spring
Intermittent	Shallow marsh	Shallow marsh	Grasses, sedges, and forbs of intermediate height; some floating, submerged plants
Semipermanent	Emergent deep marsh	Deep marsh	Shallow water with tall emergents such as reeds, rushes, and tall grasses
Permanent	Transitional open water wetland	Intermittent open water	Lacks submerged, shallow, open water plants
	Open water marsh	Permanent open water	Intermittent growth of emergents alternating with open water conditions
	Shallow open water wetland		Open water with some submerged plants
	Open alkali wetland	Intermittent saline lake	Open water of high salinity
(No equivalence)	Disturbed wetland		Cultivated, grazed (margin)

Hydrological basis of Millar's classification scheme

Millar's (1976) classification has several attributes. First, it allows extensive areas of wetlands to be mapped easily into different wetland types. Second, it is a comprehensive classification system that has been applied successfully to wetlands of the Canadian prairies. Third, it assists the inventory and management of waterfowl habitats, which parallels one of the objectives of the present study. Although Millar's system indicates what type of wetland occupies the depression at a particular time, many sloughs change their characteristics as hydrological conditions vary from year to year. This study examines the hydrological basis of Millar's system and provides a time dimension to his scheme.

Methods

The St. Denis NWA is located about 50 km east of Saskatoon, Saskatchewan. The 385-ha NWA is composed of annually cropped farmland, tame grasses, small wooded areas, and natural prairie vegetation (Sugden and Beyersbergen 1985) and contains more than 100 sloughs of different sizes and permanencies (details below).

Wetland measurements at the St. Denis NWA

From 1982 to 1990, NWA wetlands were visited every two to three weeks to determine water conditions (flooded or dry); in 1980 and 1981, visits were made only in early May, in July, and in October (J. Millar, pers. commun.). These data provide the quantitative basis to determine seasonal patterns of slough inundation. For each slough, the probability that it contained water for at least x months each year was calculated (Gringorten 1963):

$$\text{Prob (flood duration} \geq x \text{ months)} = (r - 0.25)/(n + 0.25) \quad (1)$$

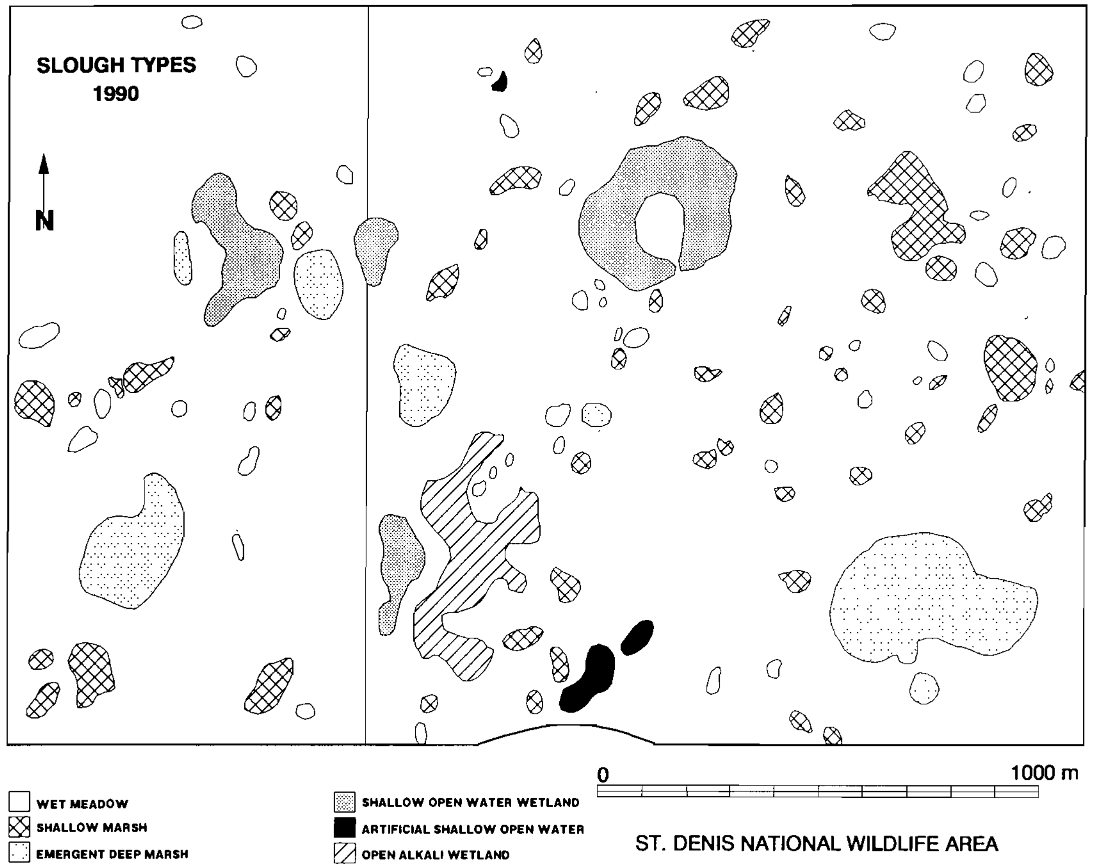
where n = 10 years (i.e., length of record) and r is the rank of the flood duration sorted in descending order.

In 1990, the sloughs were mapped (Fig. 2) and classified following Millar's system (J.B. Millar, pers. commun.): wet meadow, shallow marsh, emergent deep marsh, shallow open water wetland, and open alkali wetland. The water depths of 97 NWA sloughs were measured every two weeks.

Growth of trees, snowfall, and temperature

In 1989, 18 tree cores were collected from large trembling aspens *Populus tremuloides* growing in several wet meadows and shallow marshes on the St. Denis NWA. Only one tree dated back to 1926. After 1935, at least 10 trees were available to provide average values of annual growth increments. The growth trends for these trees were fitted, and the tree ring index was calculated as a ratio between the observed tree ring for a given year and the growth trend value for that year. These indices were compared with temperature and snowfall records obtained from the Saskatoon Airport.

Figure 2
Distribution of various types of sloughs in the St. Denis NWA in 1990 following Millar's (1976) classification



Prediction of slough response to climatic variability

Information from the NWA enabled us to predict slough inundation. For ephemeral and intermittent sloughs, snowfall is an obvious predictor. For permanent and semi-permanent sloughs, the regional groundwater system is the primary factor controlling flooding of basins (discussed below). Different prediction procedures should therefore be used for these groups of sloughs.

To predict the percentage of sloughs inundated during the breeding season, we used snowfall records, because these are readily obtained, continuous data that can be used for comparisons with wetland inundation information at a broad spatial scale. The ephemeral and intermittent wetland groups were lumped, as their inundation was strongly influenced by snowmelt. Using the 1982–90 slough inundation data from the St. Denis NWA and the winter snowfall record from Saskatoon Airport, the fraction of ephemeral and intermittent sloughs that are flooded (F) in spring was estimated from least squares regression:

$$F(t) = [b_o + b_1S(t) + b_2S(t-1)]^2 \qquad (2)$$

where S(t) refers to snowfall (in cm) of the current year, S(t − 1) is snowfall for the previous year, and b_o, b_1, and b_2 are regression coefficients.

We tested this model by comparing observed and predicted levels of slough inundation for two air–ground waterfowl transects (Benning 1986), one at Hanley and one at St. Gregor, which are, respectively, 60 km southeast and 120 km east of Saskatoon. Surveys of these transects were conducted annually in May and provided pond count data for the period 1979–90. The Hanley transect traversed terrain more similar to that of the St. Denis NWA, whereas the terrain of St. Gregor was flatter and its wetlands were subjected to substantial modification by agriculture during the study period (J.B. Millar, pers. commun.). Snowfall data for Saskatoon (Hanley) and the average of Saskatoon and Humboldt (St. Gregor) were used to predict wetland inundation. To be comparable with data collected at the St. Denis NWA, the total number of ephemeral and intermittent ponds for each transect was estimated from the sum of dry, class I, and class III wetlands recorded during the wettest year. Class I and class III wetlands correspond to ephemeral and intermittent wetland categories (class II does not exist). The number of class I and class III wetlands observed each year was then expressed as a fraction of the total population of wetlands and compared with values predicted from snowfall data using Eq. 2.

Results and discussion

Wetland classification

Of the 111 sloughs surveyed on the St. Denis NWA in 1990, 46 were classified as wet meadows, 51 were shallow marshes, seven were emergent deep marshes, and one was an open alkali wetland. There were seven shallow open water wetlands, three of which were considered artificial because they contained a dugout (Fig. 2). In general, large sloughs occupied relatively lower topographical positions and were more likely to be the emergent deep marsh, shallow open water wetland, or open alkali wetland types. Artificial shallow open water wetlands tended to be deep, whereas wet meadows often occupied small, shallow basins on higher ground.

Seasonal water level fluctuations in 1990

When seasonal changes in water depth (1990) were examined, four groups of sloughs were distinguished (Fig. 3). Only two of the 46 wet meadows remained flooded in mid-May, and 40 were dry from April to October. These are considered to be ephemeral sloughs. In contrast, most shallow marshes tended to dry out by late June, although their rate of water level decline was slower than that of the wet meadow, or ephemeral, sloughs. These marshes may be described hydrologically as intermittent sloughs. The emergent deep marshes were inundated up to at least early June, and three of them were flooded at least until July. These sloughs may be considered as semipermanent. The other types of sloughs, including the shallow open water wetland and open alkali wetland, remained flooded until September. Except in artificial shallow open water wetlands, pond levels dropped slowly during the summer. As these sloughs retained water for a protracted period in the thawed season, and because of their high probability of inundation even in the drier years (see next section), they are classified as permanent sloughs.

Fluctuations in level of inundation were related to the position of the water table. In the absence of an extensive network of observation wells throughout the St. Denis NWA, only the pond levels could be measured easily. Isolines of slough bed elevations and water surface were used to show the spatial relationship of three groups of sloughs, including the shallow marsh, the emergent deep marsh, and the shallow open water and open alkali wetland (Fig. 4). In early May, most of the sloughs contained water, and the water surface indicated by the isolines was highly uneven (Fig. 5). Several water level mounds were associated with flooded ephemeral and intermittent sloughs. By mid-June, these mounds dissipated as the ephemeral and then the intermittent sloughs became dry. Eventually, a simpler pattern, defined by the water levels of the semi-permanent and permanent sloughs, emerged in July and persisted in August. This pattern suggests a northwest to southeast regional gradient. The relatively high electrical conductivity values for some of the semipermanent and permanent sloughs (Fig. 5) are in agreement with the observations made in North Dakota by Sloan (1972).

Duration of flooding in sloughs

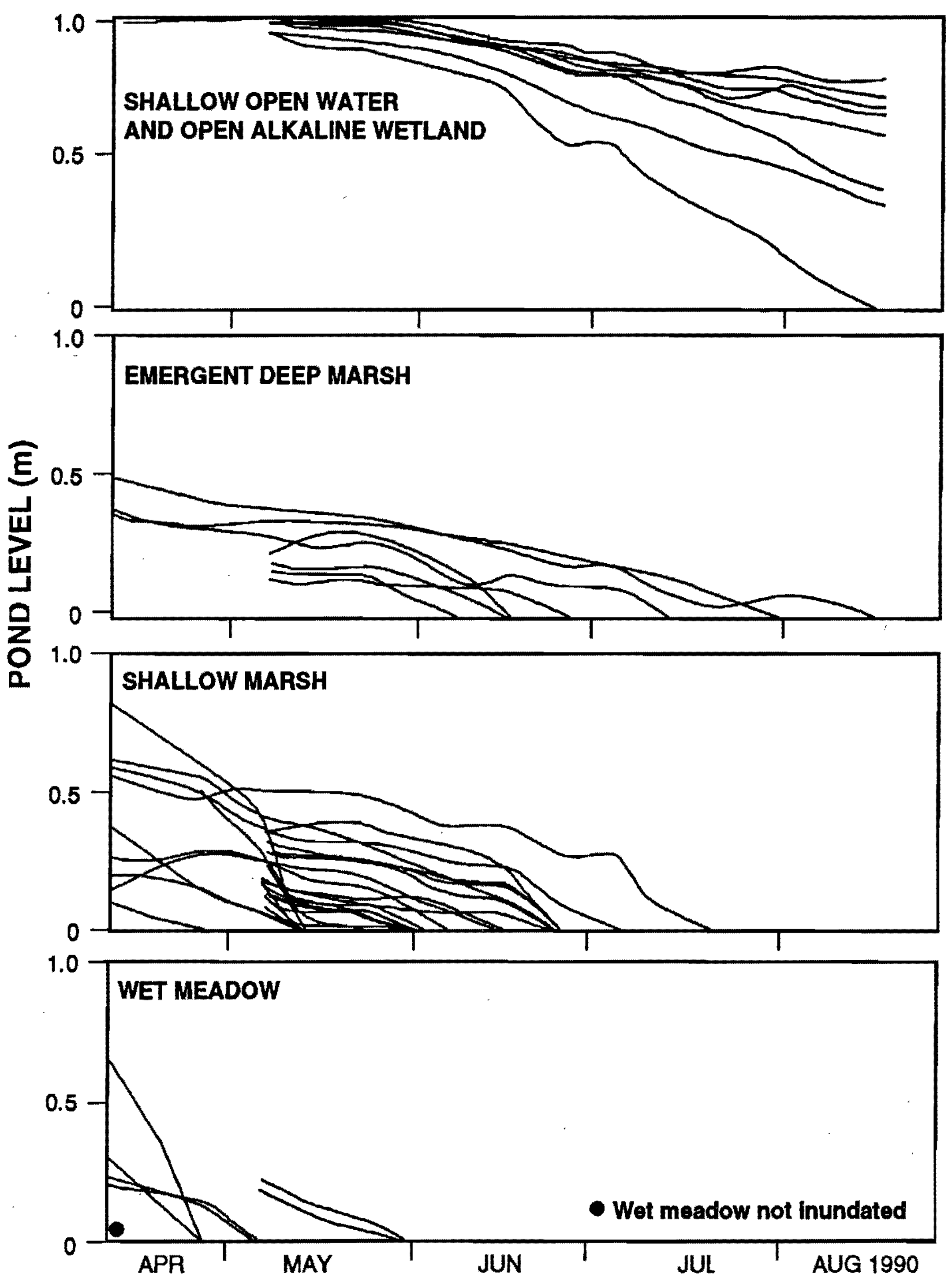
Each year, different sloughs have varying durations of flooding. The 11 years (1980–90) when slough inundation data were collected spanned a range of climatic conditions, yielding useful information on how the sloughs responded to the variability of the present climate.

The clustering of the plots of probability distributions of duration of flooding allowed the sloughs to be separated into four groups that correspond to Millar's (1976) classification. Wet meadow (ephemeral) sloughs formed a group that has 0.5 probability of being inundated for one month or less during each year. There are several extreme cases in which either the sloughs were not flooded at all or most held no water during the drier years. This group of ephemeral wetlands is highly vulnerable to drought.

The shallow marshes constituted a second group, which had 0.5 probability of being inundated for at least one month during each year. These wetlands are considered to be intermittent sloughs. Typically, those that are flooded for five to seven months in the wetter years are likely to remain flooded for two months in the drier years, whereas those that are flooded for up to three months in the wet years may lose their ponds in years of drought. The emergent deep marshes are considered to be semipermanent sloughs, with 0.5 probability of being flooded for at least two months. The shallow open water wetlands and open alkali wetlands have 0.6 probability of being flooded for at least seven months each year and are considered to be permanent sloughs.

When the upper and lower bounds of inundation probability distributions for the four groups of sloughs are plotted on the same graph, there are overlaps (Fig. 6). This

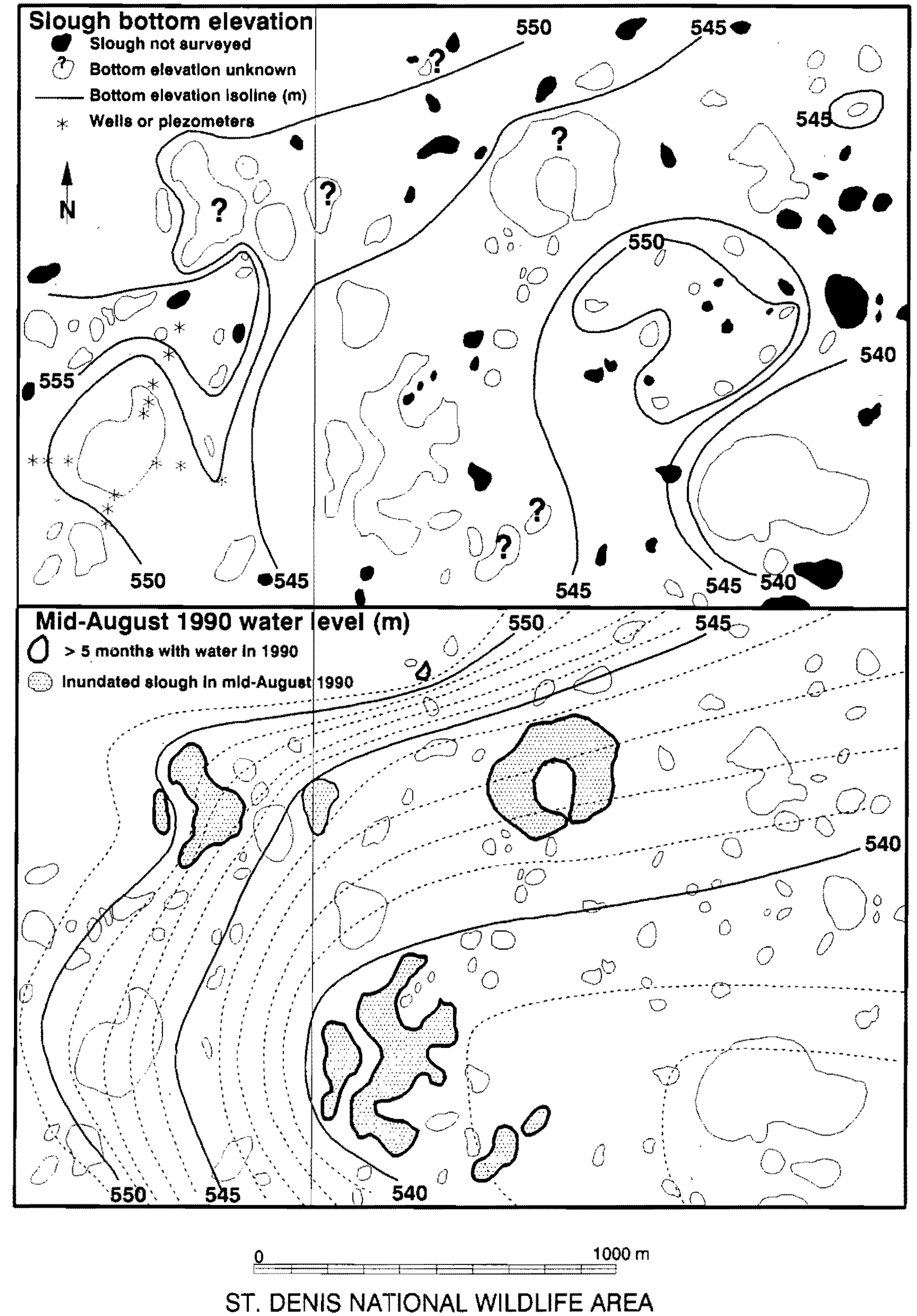
Figure 3
Fluctuations of pond levels in four groups of sloughs during spring and summer 1990, St. Denis NWA. For shallow open water and open alkali wetland, the spring water levels were referenced to some arbitrary elevation. For the other three groups, zero elevation refers to the slough bottom.



is expected, because some sloughs that are marginal between groups may change their vegetational characteristics as the years become wetter or drier (Millar 1973). In addition, hydrological conditions leading to the division of sloughs into the above groups tend to be a continuum rather than having abrupt thresholds, and one group of sloughs will grade into the next group.

Duration of ponding for the St. Denis NWA sloughs from 1980 to 1990 is presented in Figure 7. During wet years, such as 1985, all the semipermanent, all the permanent, and some of the intermittent sloughs were inundated for five or more months, whereas only a few ephemeral sloughs remained dry throughout the season. As conditions became drier (1986–89), only the permanent sloughs retained water for a long period, and many of the intermittent ones were inundated for two or fewer months. In a very dry year, such as 1989, even the semipermanent sloughs had six or fewer months of ponding, whereas the ephemeral sloughs were hardly flooded. These patterns

Figure 4
(*top*) Contours of elevations at the bottom of the sloughs in the St. Denis NWA. (*bottom*) Isolines of slough water level elevation in mid-August 1990.



illustrate the relative sensitivity of different groups of sloughs to the variability of the prairie climate.

Our data were collected from 1980 to 1990, one of the driest decades recorded for the prairies in this century. Although two of these years (1983 and 1985) provided excellent spring wetland conditions and ample summer precipitation, we recognize that the probability distributions for these groups of sloughs would be different if the study had spanned a longer (wetter) period. Specifically, sloughs other than permanent ones would remain inundated longer than suggested by Figure 6. On the other hand, we also observed the consequences of a severe, continuous drought,

Figure 5
Isolines of slough water level elevations during summer 1990, St. Denis NWA, and the electrical conductivities of water in selected sloughs, measured in July 1990

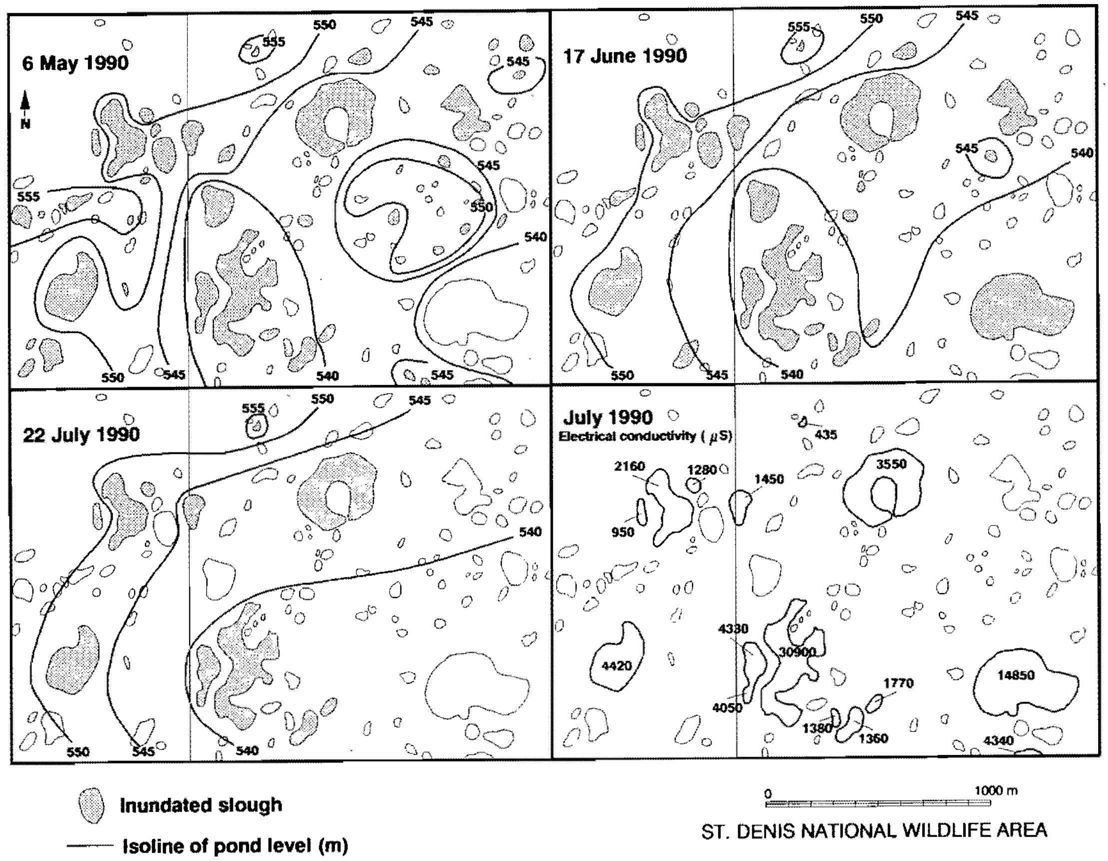


Figure 6
Classification of sloughs into ephemeral, intermittent, semipermanent, and permanent categories according to the probabilities that the sloughs are inundated for various durations in a year

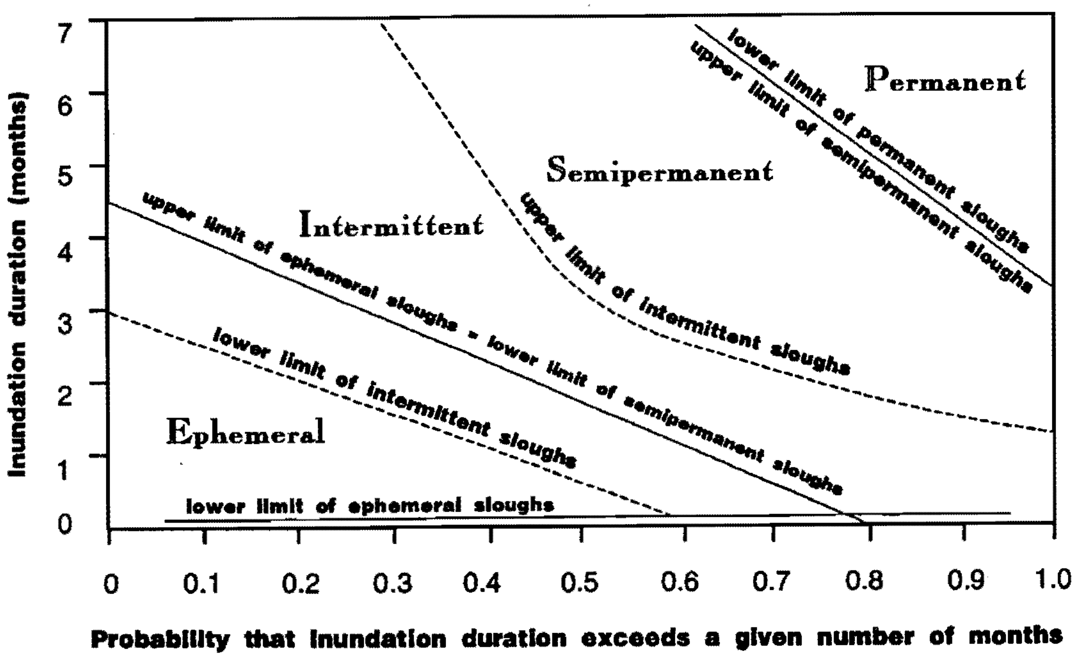
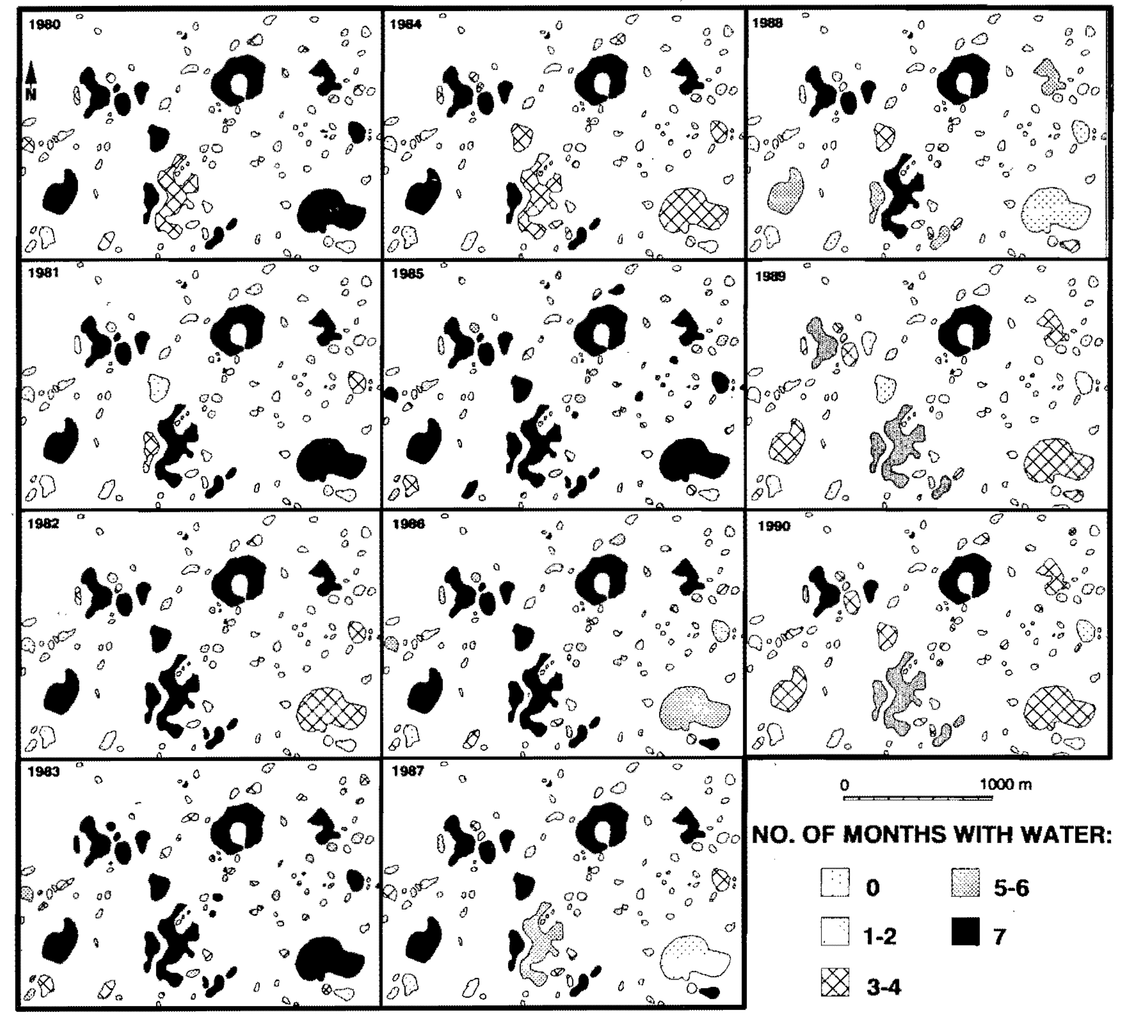


Figure 7
Durations of inundation for various sloughs in the St. Denis NWA, 1980–90



providing a clear indication of which sloughs at the St. Denis NWA may be considered permanent.

Prairie groundwater system and slough levels

In terms of the interaction between groundwater and prairie sloughs, Sloan (1972) recognized inflow, outflow, and throughflow relationships, depending upon whether groundwater moves towards (discharge), moves away from (recharge), or is transitory through the sloughs. Groundwater circulation may involve local, intermediate, and regional flow systems (Toth 1963), each having different flow and chemical properties. The three systems are of different spatial scales, with the local system superimposed on the intermediate, which lies above the regional flow. The local system may experience inflow during spring, as some flooded depressions produce local groundwater mounds. As summer progresses, consumptive water use by phreatophytes may reduce the moisture beneath and around the depressions faster than in the areas between depressions, leading to a reversal of flow direction (Meyboom 1966, 1967; Mills and Zwarich 1986). This flow reversal is unlikely to sustain flooding of the sloughs. Indeed, the local flow system continues to deteriorate in summer (Meyboom 1966), and the water table becomes less irregular as the groundwater mounds are depleted. Intermediate and regional flow systems are recharged largely by depressions located at relatively higher elevations, and such groundwater is discharged to depressions in lower topographical positions. This groundwater movement pattern emphasizes the depressions, rather than the interfluves, as the major points of groundwater inflow or outflow and is described as depression-focused recharge or discharge (Lissey 1971).

Mills and Zwarich (1986), using computer simulation, demonstrated that seepage is not as efficient as evaporation in dissipating the groundwater mound. Thus, the spring meltwater does not move deeply, and many of the seasonal exchanges are confined to the local groundwater zone. Stratigraphic heterogeneity can further reduce interactions between shallow and deep groundwaters. Zebarth et al. (1989) noted that with materials of high hydraulic conductivity overlying an impervious layer, there was rapid horizontal flow at shallow depth, but vertical flow was strongly impeded. The presence of an impervious substrate retains a saturated zone below the slough to buffer slough water level fluctuations. Seasonal frost beneath a slough has an effect similar to that of an impervious layer and greatly reduces meltwater seepage in the spring (Woo and Winter 1993).

Snowfall and slough recharge

Wetting and drying of ephemeral and intermittent sloughs appear to be more susceptible to climatic variations than wetting and drying of semipermanent and permanent sloughs, indicating that these two latter types of sloughs are linked to the regional groundwater, which is less dynamic than the local system. Without the buffer of regional groundwater discharge, the moisture status of ephemeral and intermittent sloughs should fluctuate in accordance with the climate. Most hydrographs show high slough levels in spring, produced by snowmelt. Summer evapotranspiration far exceeds seepage as the chief mechanism of water loss (Shjeflo 1968). These hydrological variables reflect the varying climatic conditions in the prairies. Long-term hydrological records are scarce, but tree rings offer a biological record of the degree of wetness of the sloughs. Mean daily temperatures reflect the potential for evaporation, but they did not correlate strongly ($r = 0.26$, $df = 60$, $P = 0.05$) with the growth rate of trees in the wetlands. In contrast, snowfall was highly correlated ($r = 0.83$, $df = 60$, $P < 0.001$) with the tree ring index (Fig. 8). This suggests that the amount of snow meltwater that recharges the rooting zone is the major factor influencing tree growth and hence serves indirectly as an indicator of the moisture conditions of the ephemeral and intermittent sloughs in which the trees grow.

Groundwater configuration and slough levels

Based on the above discussion and field observations, Figure 9 depicts the hydrological connection between slough recharge and discharge and the prairie groundwater system. This is a simplified version of Lissey's (1971) concept, retaining the salient features of depression-focused recharge or discharge, but with three modifications:

(1) Distinction is not made between intermediate and regional groundwater systems, because such a subdivision is scale dependent and does not affect the relationship between groundwater discharge and its recipient sloughs.

(2) Variation of the regional water table between wet and dry years is considered to be responsible for the fluctuations of water level in discharging sloughs.

(3) A group of recharging sloughs is recognized to be perched above the regional system because of separation by some tills of low hydraulic conductivity or because of considerable distance separating the meltwater source and the regional water table. For these sloughs, recharge is likely to be by downward seepage from the slough bottoms, rather than as saturated groundwater flows.

Seasonal frost is not represented in the diagram, although recharge from sloughs will be much retarded until the frost disappears.

This configuration shows that ephemeral sloughs occupy recharge locations and are fed entirely by precipitation, drying out as water drains from their depressions. Intermittent sloughs receive their water from precipitation but may also be fed by throughflow from the local groundwater system. The presence of an impervious substrate may reduce downward seepage to prolong the period of flooding. The shallow marshes on the east-central uplands of the St. Denis NWA are underlain by unweathered Floral till clay with a hydraulic conductivity of 10^{-8} mm/s (Miller et al. 1985), which may have caused a perched saturated zone to persist, thus extending the annual duration of slough inundation. Both groups of sloughs occupy topographically higher locations. Their water is fresh to slightly brackish, owing to dilution by snow meltwater.

Semipermanent and permanent sloughs are usually located in lower topographical positions or are deep enough (such as the excavated sloughs) to tap the regional groundwater reservoir, which provides a reliable source of discharge. Water of such an origin may be highly alkaline and unsuitable for animal consumption (e.g., Mitcham and Wobeser 1988).

Prediction of slough response to climatic variability

The annual setting of Canadian waterfowl hunting regulations in June relies on assumptions about the number of young ducks that will enter the fall flight, sometime later in the summer. Therefore, the number of sloughs inundated at a particular time of the year is of concern to waterfowl managers, because duckling survival is contingent, at least in part, on the availability of suitable wetlands during summer.

The predicted values using different snowfalls are graphed as Figure 10, and the computed fractions of inundated sloughs are also compared with the observed fractions for the 10 years of record. Regression coefficients and coefficients of determination were calculated for late April, early May, early June, and early July (Table 2). The ability to predict slough inundation improved until early June but diminished in early July, likely because variations in summer rainfall and temperature began to overshadow effects of winter snowfall.

The predictive model (Eq. 2) developed for the St. Denis NWA was applied to independent data collected from wetlands near Hanley and St. Gregor. The fractions of ephemeral and intermittent wetlands that were inundated in May were computed and compared with observed data for the two sites (Fig. 11). For Hanley, predicted fractions fell within 20% of the 1:1 line in 10 of 12 years. For St. Gregor, the agreement between predicted and observed fractions was poorer (eight of 12 years fell within 20% of the 1:1 line). One plausible explanation for the poorer predictions at St. Gregor is its flatter terrain, higher incidence of wetland drainage for agriculture, and different pattern of snow accumulation. On the whole, however, t-tests indicate that the predicted and the observed data were not statistically different.

Large variations in wetland inundation were observed in 1991, resulting from two counteracting phenomena. First, 89 cm of snowfall were recorded at Saskatoon for the winter 1990–91. According to Eq. 2, about half of the ephemeral and intermittent wetlands at the St. Denis NWA would be flooded in mid-May following snowmelt, and about one-quarter would persist until early June. However, the observed percentages were only 4% and 8%, respectively. The most plausible explanation for this was that soil in the NWA was dry during freeze-up in fall 1990 because of a long period without rain (unpubl. data). As a result, meltwaters easily infiltrated desiccation cracks and air pores in

Figure 8
Variations in snowfall at Saskatoon Airport and tree ring indices obtained from trembling aspen *Populus tremuloides* growing in ephemeral and intermittent sloughs of the St. Denis NWA

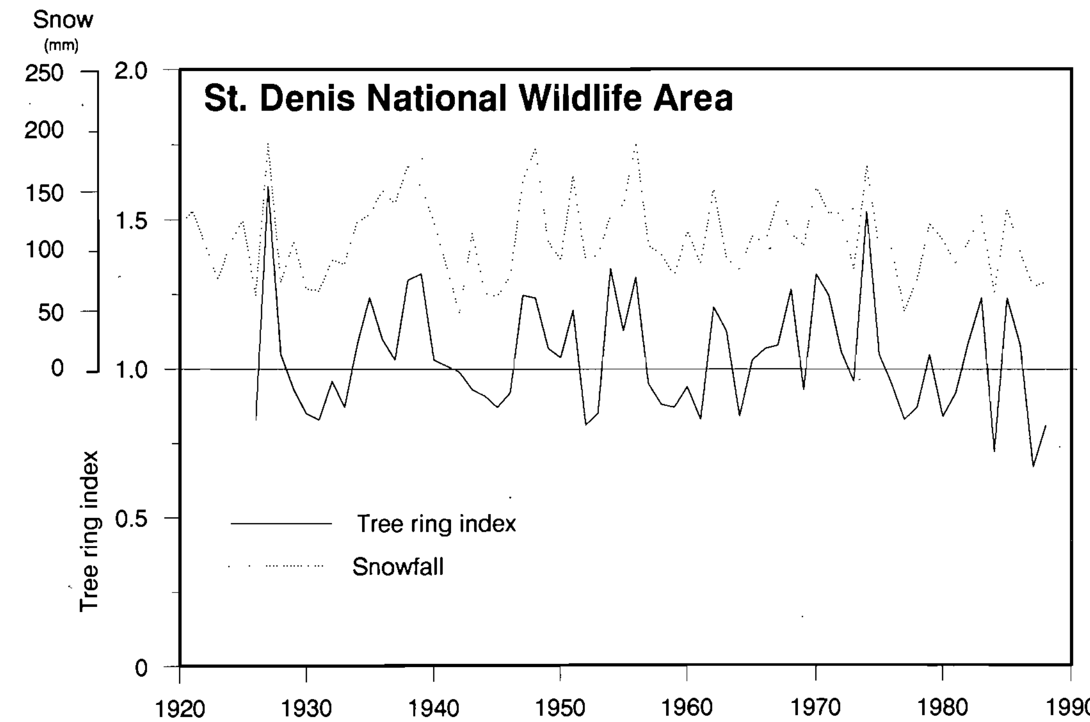
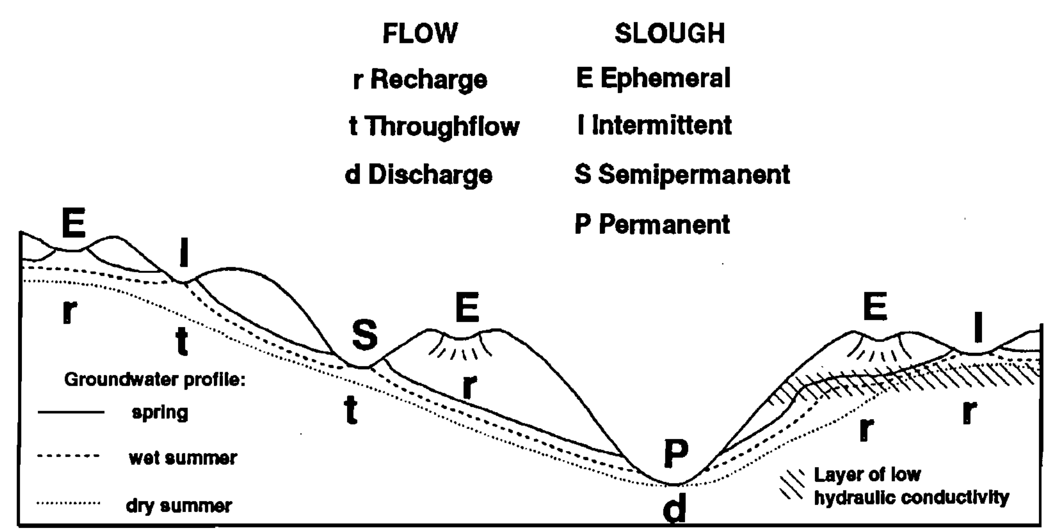


Figure 9
Conceptual representation of slough types and their relationship to the groundwater system during spring and wet and dry summers



dry frozen soils in spring instead of being forced overland by concrete frost to flood wetlands. Similarly, variations in fall precipitation may have contributed to differences between wetland inundation patterns predicted from St. Denis data and patterns observed at Hanley and St. Gregor (Fig. 11).

A second explanation is that, after the spring melt in 1991, exceptional storms deposited large quantities of rain on the St. Denis NWA. Rainfall on 30 June and 1 July totalled 21 mm, causing many dry wetlands to flood. Minor rain events in July maintained flooded wetlands, and an intense storm on 29 July, which deposited over 27 mm of rain in two hours, revived several more dry wetlands. These rainfall events are exceptional for the region and created inundation patterns that were not observed in the previous decade.

The semipermanent, permanent, and, to some extent, wetter sloughs of the intermittent group are usually inundated until mid-July. After that, the presence of water depends upon whether the slough bed is lower than the regional water table. It is deduced that during a series of dry years there is a continual withdrawal of water from the regional groundwater system without adequate replenishment, so that the water table will be lowered. Conversely, a series of wet years will raise the regional water table above the normal level. The shape of this water table will remain

Figure 10
Nomographs for the prediction of fractions of ephemeral and intermittent sloughs being inundated on selected dates. The families of curves depict snowfall of the previous winter for amounts of snowfall in the current year (x-axis).

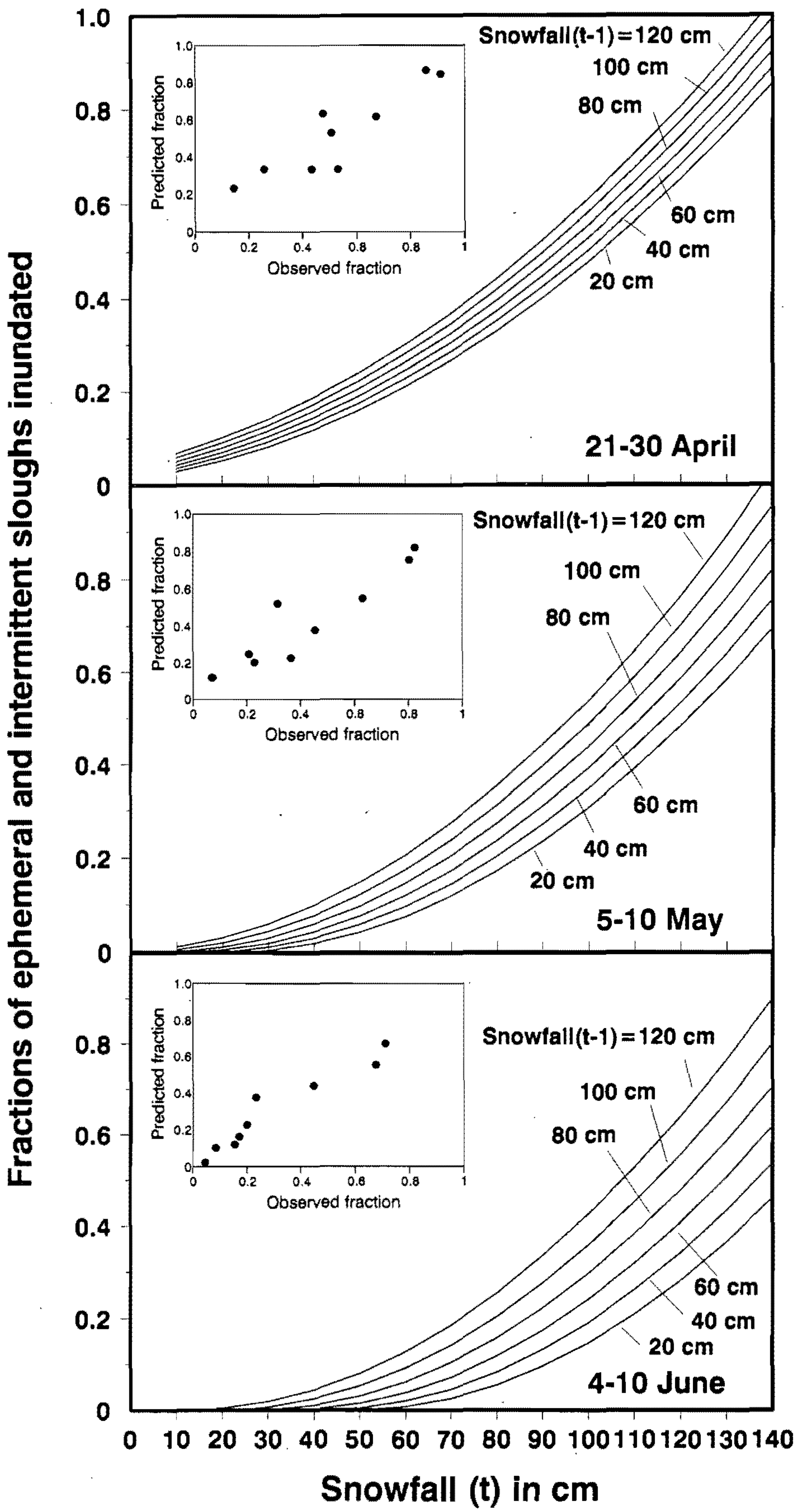
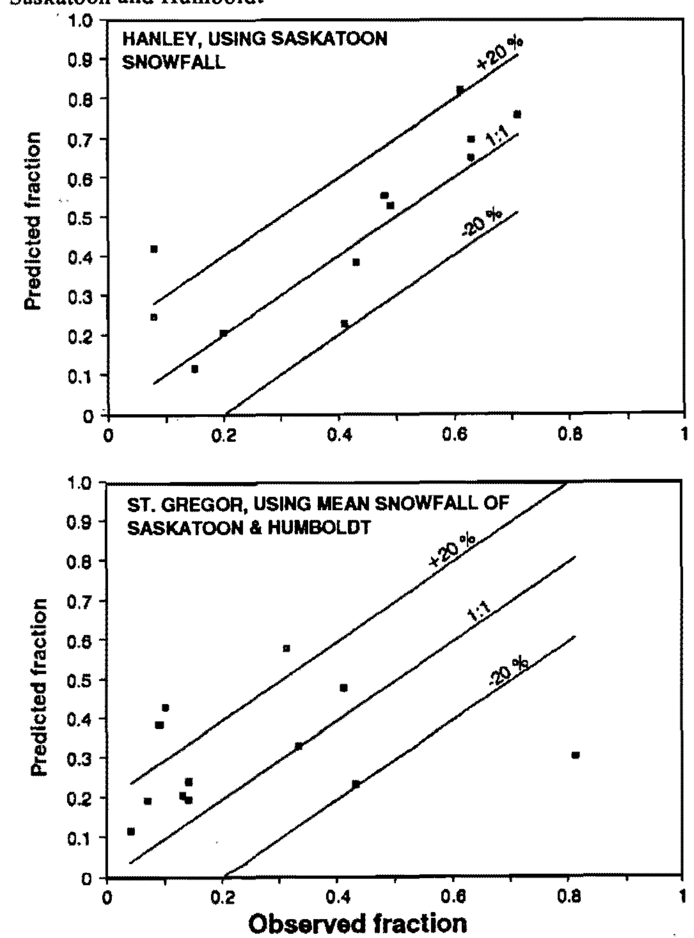


Table 2
Prediction of the fraction of ephemeral and intermittent sloughs inundated in spring and summer, St. Denis NWA, Saskatchewan. Shown are regression coefficients (b_0, b_1, b_2) and coefficients of determination (R^2) for each period, based on Eq. 2 in text.

Date	b_0	b_1	b_2	R^2
21–30 April	0.094	0.0058	0.0009	0.79
5–10 May	−0.182	0.0070	0.0018	0.84
4–10 June	−0.412	0.0074	0.0027	0.93
30 June–7 July	−0.729	0.0072	0.0043	0.76

Figure 11
Prediction of fractions of ephemeral and intermittent sloughs being inundated in late May at Hanley and St. Gregor, using Eq. 2 developed for the St. Denis NWA and snowfall data from Saskatoon and Humboldt



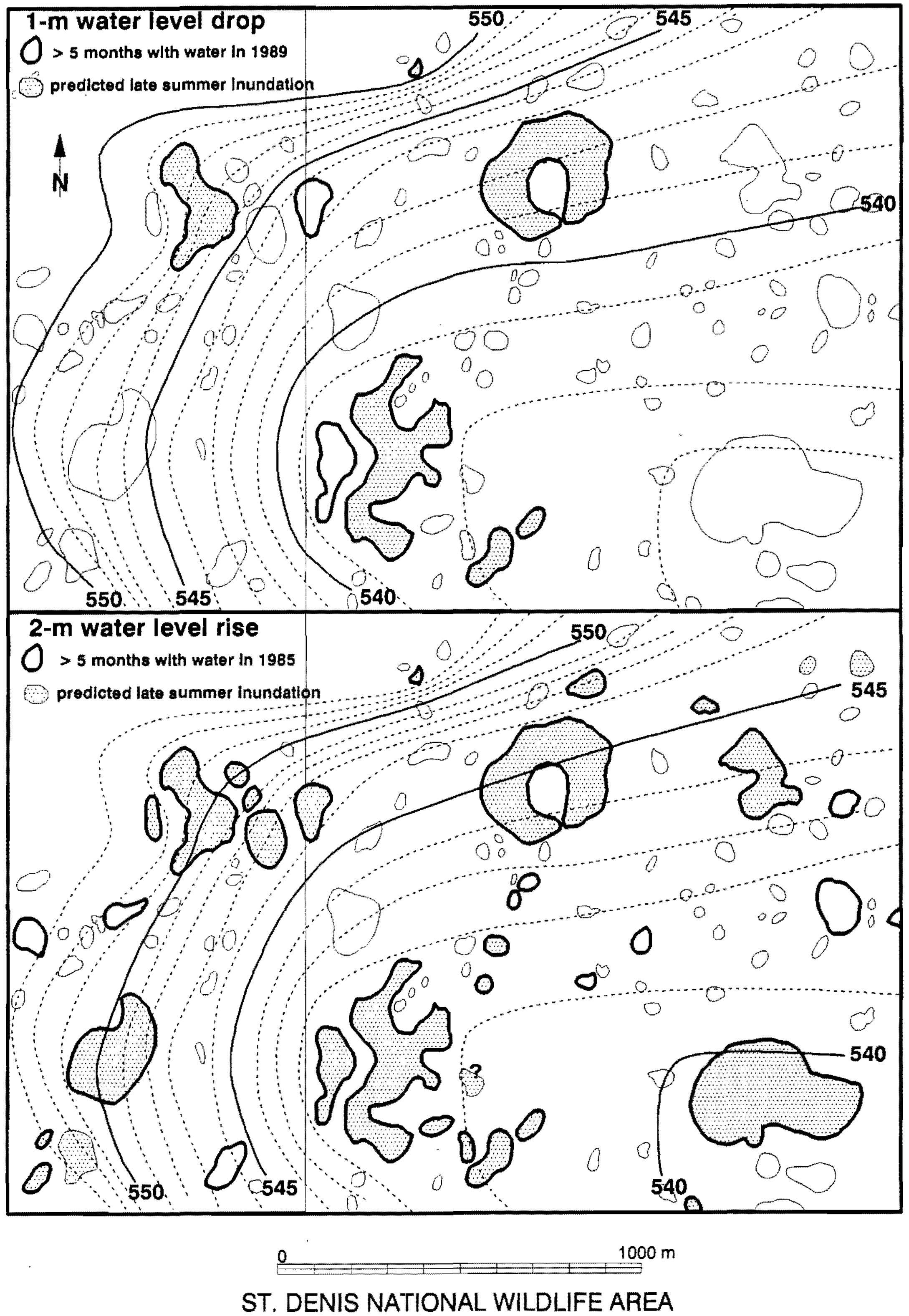
similar, although the elevation of the phreatic surface will vary from year to year. Thus, two contrasting scenarios of inundation for the St. Denis NWA sloughs in late summer can be produced by assuming a general rise of the regional water table in wet years and the reverse in dry years.

Although we did not have a network of wells to define the water table positions in the St. Denis NWA, the conceptual relationship between the groundwater and the slough water level, as depicted in Figure 9, may be used to provide a surrogate indicator of the water table fluctuations. The isolines of slough water level elevations for August 1990 (Fig. 4) were used to simulate the possibility of late summer inundation of individual sloughs. By raising these isolines to simulate wet year conditions, a 2-m pond level rise produces late summer flooding of 28 sloughs (Fig. 12). This pattern compares favourably with the observed conditions for the wet year of 1985. Dropping the water level by 1 m to simulate a dry year yielded only six ponded sloughs, and this compares well with the situation for the dry summer of 1989.

Prediction of wetland inundation and its relationship to breeding ducks

Data obtained from tree rings provide some indication of the environmental conditions on the St. Denis NWA from the 1930s to 1989 (Fig. 8), because estimates of tree growth were positively correlated with the percentage of wetlands inundated in May ($r_s = 0.71$, $n = 10$ years [1980–89], $P < 0.03$) and in July ($r_s = 0.61$, $P < 0.05$). Wetland inundation in May was positively correlated with July inundation patterns ($r_s = 0.87$, $P < 0.01$), a result also reported by Leitch and Kaminski (1985) for their grassland study area in southern Saskatchewan. Ducks nesting on the NWA likely encountered periods of drought and periods of abundant wetlands each decade, with prolonged droughts occurring in the early 1930s, 1940s, and 1950s, and again in the late 1950s. In 1975–89, dry years were more frequent than in earlier years and seemed more severe, a trend consistent with prairie-wide patterns. We found only a moderate correlation between the tree ring index at the NWA and estimated conserved soil moisture for the Prairie provinces (Boyd 1981: Fig. 6) during 1941–79 ($r_s = 0.52$, $n = 38$ years, $P < 0.001$), implying that it would be unwise to extrapolate our findings to areas distant from the NWA. Nevertheless, it appears as though ducks breeding near the NWA had to contend with several series of dry years, from 1929 to 1933, from 1942 to 1946, and from 1957 to 1964. The last two periods coincided with widespread drought (e.g., Trauger and Stoudt 1978; Boyd 1981).

Figure 12
Comparison of predicted late summer inundation, assuming a 1-m drop and a 2-m rise of the 1990 slough water level, with the observed patterns of slough inundation for 1989 (a dry year) and for 1985 (a wet year)



Conclusions

Given that spring wetland inundation can be predicted with some certainty and that spring and summer wetland abundances are correlated, it appears likely that future wetland conditions for breeding waterfowl can be assessed from current and past estimates of snowfall. However, other factors must be considered. First, the equations developed from data collected at the St. Denis NWA to predict wetland inundation performed well when compared with independent data, but much unexplained variation remained (Fig. 11). Clearly, soil moisture in fall and topography may strongly influence this relationship. Second, further information is needed regarding summer wetland abundance and quality and their relationships to survival of both adult and growing ducks. Finally, it would be instructive to test the wetland inundation model using data from other areas and to predict inundation patterns in future years for areas of similar topography.

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