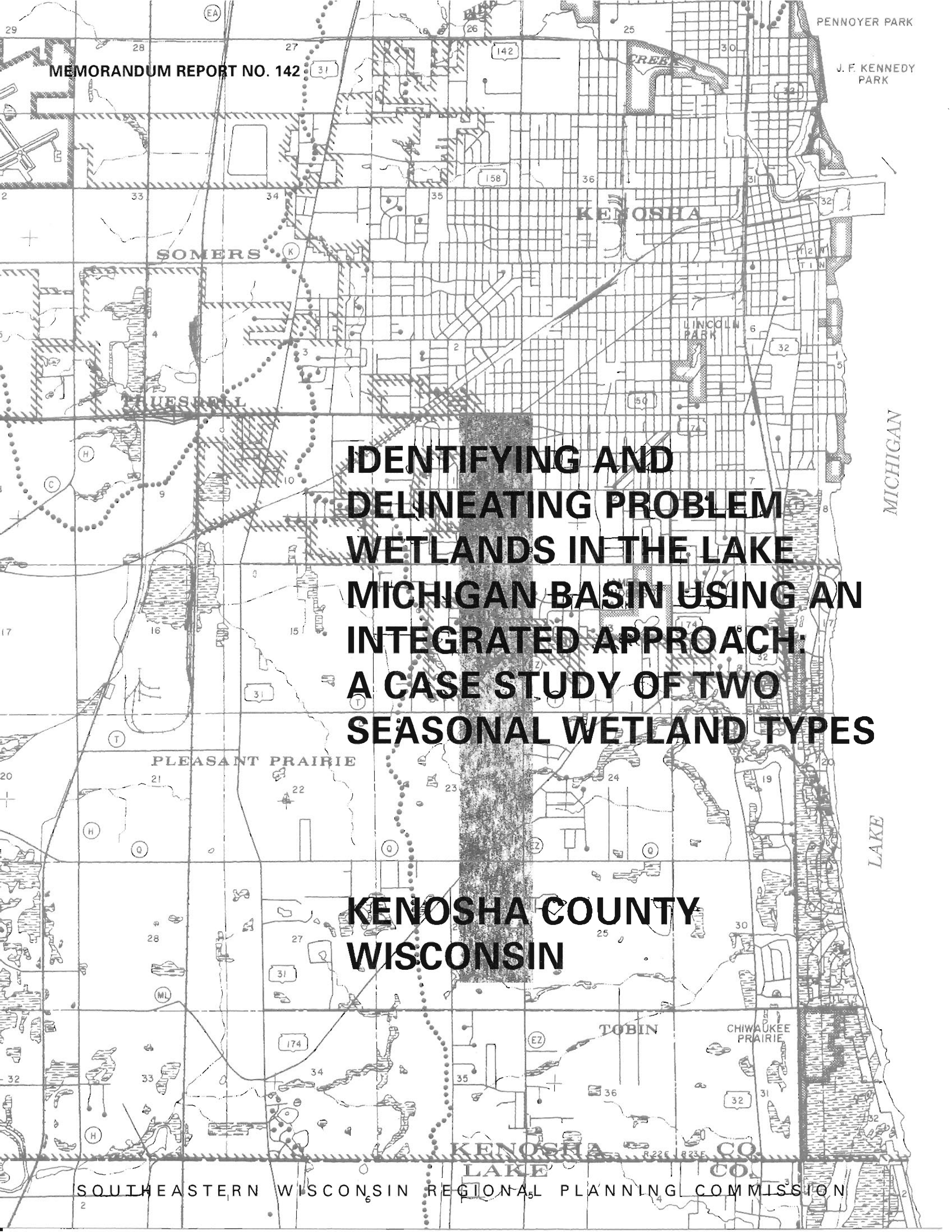
MEMORANDUM REPORT NO. 142



IDENTIFYING AND DELINEATING PROBLEM WETLANDS IN THE LAKE MICHIGAN BASIN USING AN INTEGRATED APPROACH: A CASE STUDY OF TWO SEASONAL WETLAND TYPES

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IDENTIFYING AND DELINEATING PROBLEM WETLANDS IN THE LAKE MICHIGAN BASIN USING AN INTEGRATED APPROACH: A CASE STUDY OF TWO SEASONAL WETLAND TYPES KENOSHA, WISCONSIN

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INTRODUCTION

The Problem

Wetland issues have become prominent in society today as the effects of large-scale wetland losses are being assessed. It has been estimated that 53 percent of the wetlands of the conterminous United States have been lost since European settlement in the 1700s. In Wisconsin, it is estimated that 50 percent of our wetlands have been converted to other uses. With recognition of the importance of this loss, appropriate delineation of remaining wetlands within the Great Lakes Drainage Basin is needed to assess the effectiveness of wetland protection plans, and cumulative and secondary impacts. However, our understanding of the underpinnings of wetlands (i.e. hydrology, soils and vegetation), and their interaction with each other, is often not sufficient to meet these goals.

Wetland science has only recently become an area of active research. Hence, many of the basic tenets that are taken for granted in other sciences are missing or incomplete. Furthermore, our understanding of inland freshwater wetlands (the type most prevalent in Wisconsin's coastal zone) is considered very poor compared to other wetland types. At certain times of the growing season drier members of this category (i.e. low prairies and sedge meadows) are difficult to identify and delineate as wetlands and, as such, most easily convert to other uses. Accordingly, widespread examples of these wetland types are rarer, both in and out of the Lake Michigan basin. As a result of these factors, there does not exist a substantial body of previous work and our understanding has primarily been restricted to extrapolation from other ecosystems or wetland types.

Wetland delineation of these "problem" wetlands that are dry during much of the growing season is also hampered by the accepted practice of cursory assessments done in one visit (often at high cost) and a large increase in inexperienced people doing delineations. These problems can result in our continued loss of these wetland types as well as having the potential to regulate uplands that are not wetlands. Further, wetland delineation is often not enough to protect wetland systems. Rather, an understanding of the contributing sources of water to the wetland community is needed. Often these sources are out of the delineated wetland area. Thus, activities outside a wetland can affect the wetland function and value even after the wetland is delineated and "protected" under regulatory jurisdiction. Knowledge of the larger hydrologic system is needed, but is not included in most wetland evaluations.

Finally, this information is important not only to the local coastal area, but to the greater Great Lakes Basin. These drier wetland types have become relatively rare wetland communities in the Great Lake Basin because they are easily drained and developed. Moreover, the areas in the Great Lake Basin that have the appropriate climate conditions for these drier wetland systems have also been among the most heavily developed areas of the basin. Thus, knowledge of these communities will help assess the effects of the wetland loss while at the same time identifying the areas important for preserving the remnant communities that still exist.

The Objective

The specific objective of this study is two-fold. First, the study is designed to characterize the vegetation, soils and water-table hydrology of two problem wetland types (low prairie and sedge meadows) and elucidate the relationships between the wetland components and landscape position.

Second, it is designed to put this information into the context of a quantitative groundwater flow model of the site area to allow identification of sources of water to the wetlands and assessment of wetland vulnerability.

The first objective will provide a basic understanding of these "problem" wetlands and give a data set that is transferable to other freshwater wetlands in and out of the coastal zone. The second objective will allow assessment of time-efficient methodology that can serve as a first line of investigation in lieu of field visits to every potential site. A more detailed description of the project approach is given below.

METHODS

Study Area

The study area encompasses the Carol Beach/Chiwaukee Prairie area of the Village of Pleasant Prairie in Kenosha County, Wisconsin (Map 1). The Carol Beach/Chiwaukee Prairie area is an approximately 1,825 acre beach ridge and swale complex consisting of beach dune, oak savanna, dry to wet prairie, southern sedge meadow, shallow marsh, calcareous and prairie fens, and shrub carr with minor stands of lowland hardwoods. The beach ridges and swales represent the recessional Calumet and Toleston stage terraces of glacial Lake Chicago (Sander and Zimmerman, 1966). The study area is largely subtended by the Granby fine sandy loams and the Boyer loamy sands (Link and Demo, 1970).

Single family residential and related land uses occupy nearly all of the oak savanna, most of the fore dune area, and the beach ridges in selected portions of the study area.

Site Selection and Study Design

A total of six wetland sites were selected representing the two problem wetland types: low (wet to wet-mesic) prairie and sedge meadow. Specific sites were selected based upon floristic characteristics (major dominant species), public access, suitability for instrumentation, and suitability for recurring physical access for monitoring during the growing season.

Vegetation Sampling: The six wetland sites were sampled on three occasions during the growing season—June 17 and 25, 2004, July 28, 2003 and October 8, 2003—to ensure that all plant species and their cover values were recorded. The sampling methods used were percent cover within three 1-square meter quadrats at each sample site. The quadrats were located in each plant community area in the following manner: 5 meters directly north, east, and south of each well, a corner point was established. For the north and east quadrats, this corner point was considered to be the southwest corner of a 1 meter square quadrat. At the south quadrat, the corner point was considered to be the northwest corner. At each sample point meter sticks were used to lay out the quadrat, aligned in the cardinal directions. If the resulting quadrat fell outside of the desired vegetation type, the length and/or the direction to the quadrat was modified accordingly. Thus, there were a total of 18 quadrats established, nine in low prairie, and nine in sedge meadow.

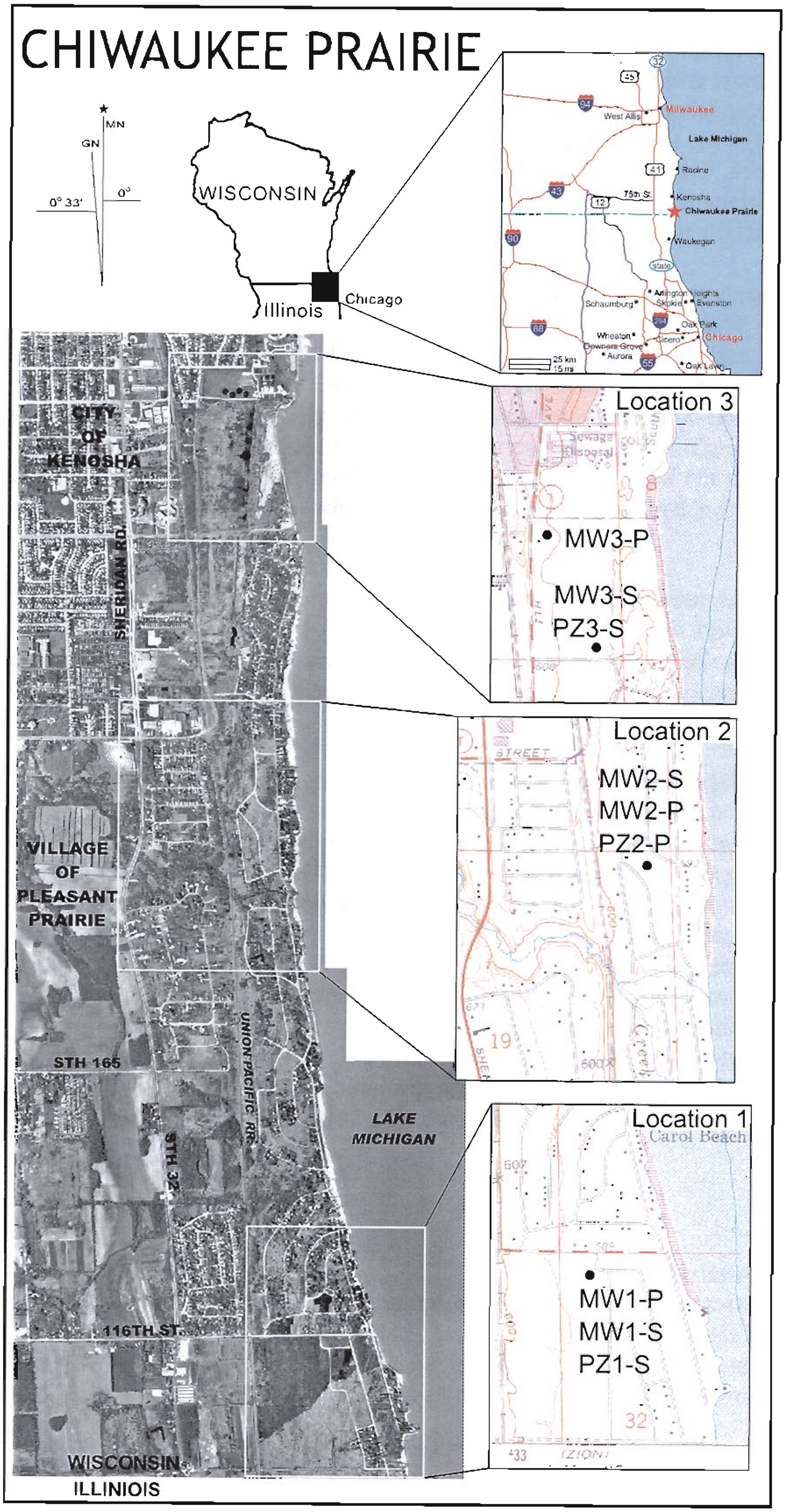
Cover values were recorded for all vascular plant species within each quadrat on the three sampling dates. All plants were identified to the species level. Threatened and endangered species were noted. For unidentified plants, specimens were collected for later identification in the laboratory. On each date, percent cover for each species in each plant community type at each well was calculated as the average cover for the three quadrats. The final percent cover was the mean of the three seasonal values.

Tabular summaries of the species composition of each site were prepared and sites were analyzed using PC-ORD (McCune and Mefford, 1995). In addition, the hydrophytic indicator status was applied to each species recorded.

***Soils Sampling*:** A hydric soil is a soil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part. The soils portion of the study includes detailed descriptions of the upper part of the soil column. These data were used to calibrate the specific period of saturation and reduction with soil characteristics, i.e., redoximorphic features, associated with wetness. The depth of interest ranged from the soil surface down to 20 inches below the soil surface. Accordingly, soil samples were collected using a "sharp shooter" spade, soil horizons identified, profiles prepared, and hydric soils indicators identified for each of the six seasonal wetland sample sites. The soil characterizations were performed with the assistance of soil scientists from the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS).

Map 1

LOCATION MAP OF CHIWAUKEE PRAIRIE IN THE
VILLAGE OF PLEASANT PRAIRIE, KENOSHA COUNTY, WISCONSIN



Source: Dr. John D. Skalbeck.

Hydrology Data Collection: Six water-table wells (designated MW) and three piezometers (designated PZ) were installed at three locations in the Chiwaukee Prairie study area (Map 1) between April 23 and 25, 2003, by means of hydraulic push equipment. At each location a low prairie site (designated P) and a sedge meadow site (designated S) was selected based on the plant community composition. A water-table well (long screen intersecting the uppermost ground water) was installed at each of the six plant community sites (two sites at three locations). A piezometer (short screen wells installed below the water-table) was installed at one site in each location within 10 feet of the water-table well. Wells and piezometers consist of 1-inch diameter PVC riser/casing and stainless steel screen. Completion details are given in Figures 1, 2, 3. Well and piezometer locations and top of casing and land surface elevations were determined using GPS survey equipment. A summary of well and piezometer elevation details is given in Table 1.

Water level measurements were measured in the six water-table wells and three piezometers from April 24, 2003, to June 6, 2004. Each water-table well was equipped with a pressure transducer set beneath the water table to record water pressure and temperature at 30 minute intervals. A barometric pressure transducer was installed above the water table in the casing of well MW2-P and set to record barometric pressure and air temperature at 30 minute intervals. The total water pressure measured in each well represents the sum of the barometric pressure and pressure from the height of water above the pressure transducer sensor. The height of water in each well is calculated by subtracting the barometric pressure from the total water pressure. The groundwater elevation was then calculated to 0.01 feet by adding the height of water above the sensor to the elevation of the sensor (see Table 1).

Depth to water (hand measurements) were collected approximately weekly and recorded to 0.01 feet from water-table wells and piezometers during the growing season (April to November, 2003) using an electronic sounder and/or steel tape. During the winter, depths to water measurements were collected approximately monthly. The groundwater elevation was calculated by subtracting the depth to water measurement from the top-of-casing elevation.

Groundwater Flow Model: In order to protect the wetlands in this coastal area, an understanding of the sources of groundwater is crucial. To do this, a process-based quantitative tool synthesizing what is known about the water flows is needed. We constructed a numerical groundwater flow model for the regional groundwater system using the data collected during this study and other existing data. The model required describes sources and sinks of water, general directions of groundwater flow, and estimates of travel times. The model encompasses the entire shallow aquifer system and extends regionally to encompass the entire ground watershed. An analytic element groundwater flow model, using the computer program GFLOW (Haitjema, 1995), was developed. After calibrating the model to existing hydrologic conditions, the model was used to quantify groundwater movement throughout the basin. Using particle tracking (mathematical particles of water), the groundwater travel paths and travel times were simulated to illustrate the groundwater recharge areas important for the wetland communities. Moreover, once the model was constructed, the hydrologic effects of future scenarios (for example, what if ditches were dredged?) could be evaluated. The Wisconsin District of the U.S. Geological Survey constructed this model.

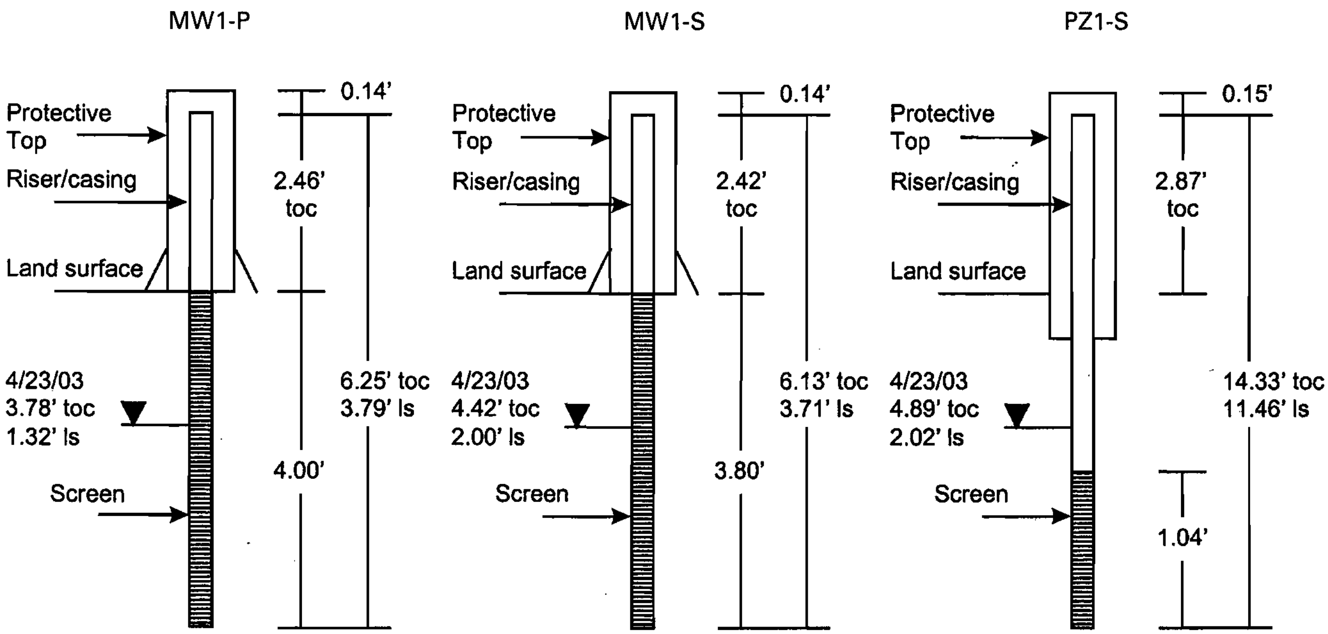
RESULTS

Vegetation Data and Analysis

As noted above, six seasonal wetland sites dominated by herbaceous vegetation were sampled at three different geographic sections of the Carol Beach/Chiwaukee Prairie area. A total of 66 species were recorded from the three low prairie sites and 74 species from the three sedge meadow sites. The percent cover results for the low prairie and sedge meadow sites are set forth in Tables 2 and 3, respectively.

Figure 1

COMPLETION DETAILS FOR WATER-TABLE WELLS AND PIEZOMETER AT LOCATION 1

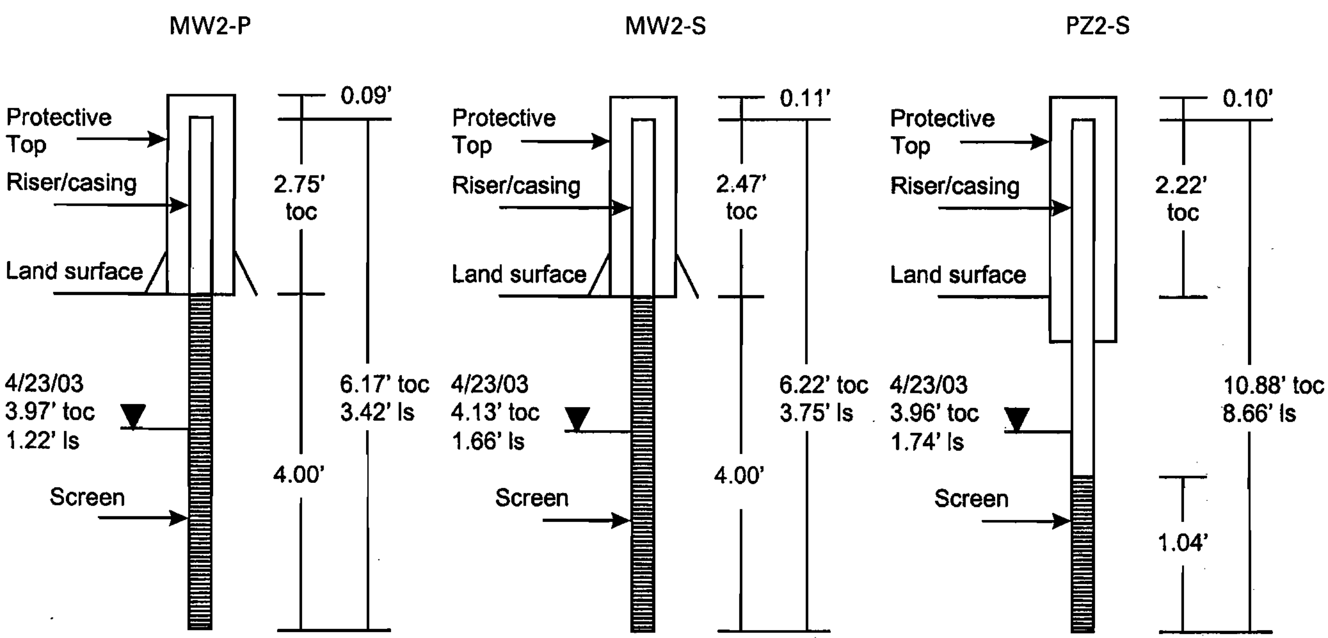


Note: toc = top-of –casing; ls = land surface; solid triangle represents water level at installation.
PVC riser/casing and stainless steel screen diameter is 1-inch.

Source: Dr. John D. Skalbeck.

Figure 2

COMPLETION DETAILS FOR WATER-TABLE WELLS AND PIEZOMETER AT LOCATION 2

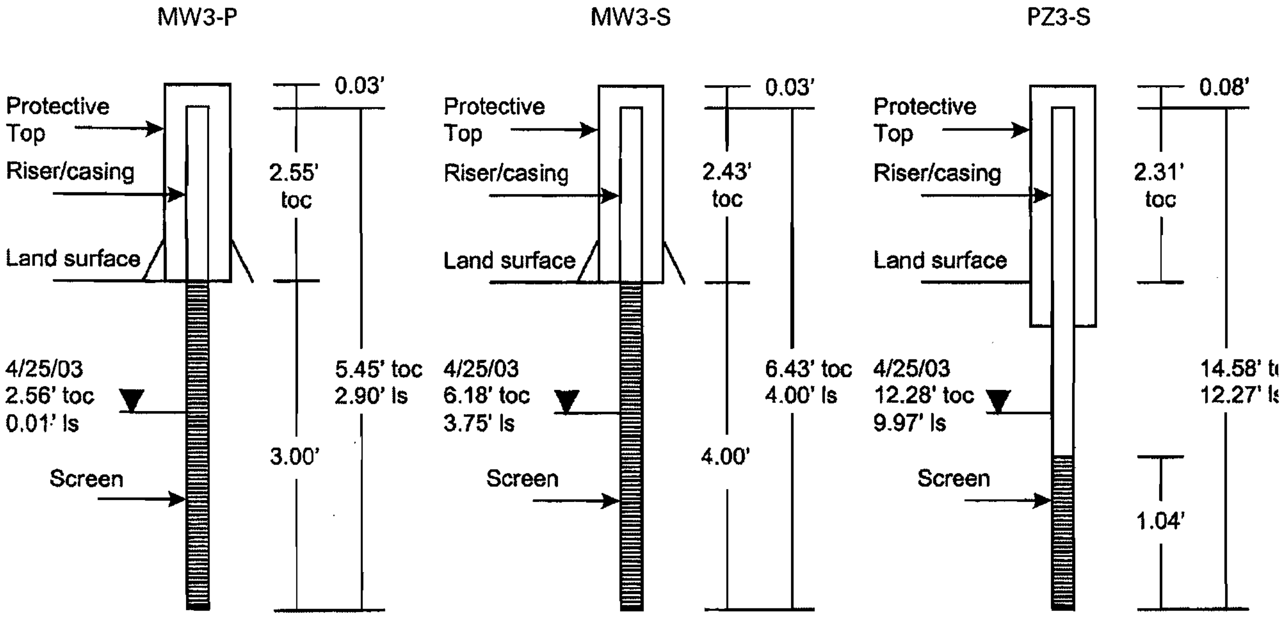


Note: toc = top of casing; ls = land surface; solid triangle represents water level at installation.
PVC riser/casing and stainless steel screen diameter is 1-inch.

Source: Dr. John D. Skalbeck.

Figure 3

COMPLETION DETAILS FOR WATER-TABLE WELLS AND PIEZOMETER AT LOCATION 3



Note: toc = top-of –casing; ls = land surface; solid triangle represents water level at installation.
PVC riser/casing and stainless steel screen diameter is 1-inch.

Source: Dr. John D. Skalbeck.

Table 1

WELL AND PIEZOMETER ELEVATION DETAILS

Well/Piezometer Identification	Riser Height Above Grade in feet	Total Well Depth in feet	Top of Casing Elevation[a]	Land Surface Elevation[a]	Pressure Transducer Sensor Elevation[a]	Well Bottom Elevation[a]
MW1-S	2.52	6.22	590.689	588.17	585.03	584.47
MW1-P	2.65	6.21	590.028	587.38	584.08	583.82
PZ1-S	2.90	14.33	590.954	588.06	NA	576.62
MW2-S	2.80	6.30	594.652	591.85	588.84	588.35
MW2-P	2.54	6.33	595.575	593.04	589.74	589.25
PZ2-P	2.29	10.85	595.396	593.10	NA	584.55
MW3-S	2.42	5.40	596.222	593.80	591.00	590.82
MW3-P	2.46	6.45	595.942	593.48	589.71	589.49
PZ3-S	2.87	14.49	595.947	593.08	NA	581.46

NOTE: NA = Not available

[a]*Elevations are in feet above mean sea level (North American datum of 1929).*

Source: Dr. John D. Skalbeck.

Table 2

CAROL BEACH SEASONAL WETLAND STUDY: LOW PRAIRIE SITES

Species	Low prairie site 1 (percent)	Low prairie site 2 (percent)	Low prairie site 3 (percent)	All sites (percent)
Spartina pectinata	11.1	14.7	21.9	15.9
Helianthus grosseserratus	11.1	9.4	16.7	12.4
Carex stricta	7.1	13.9	14.3	11.8
Solidago graminifolia	7.8	3.9	7.7	6.5
Calamagrostis canadensis	4.0	11.8	3.2	6.3
Solidago ohioensis	- -	15.0	- -	5.0
Helianthus giganteus	1.9	12.8	- -	4.9
Solidago gigantea	7.0	- -	5.9	4.3
Pycnanthemum virginianum	1.1	0.5	9.0	3.5
Andropogon gerardii	8.5	1.2	- -	3.2
Thelypteris palustris	9.4	- -	- -	3.1
Andropogon scoparius	5.9	0.8	- -	2.2
Valeriana edulis	- -	6.7	- -	2.2
Sporobolus heterolepis	6.1	- -	- -	2.0
Silphium terebinthinaceum	- -	- -	5.1	1.7
Rhamnus frangula	0.1	4.8	- -	1.6
Cornus stolonifera	- -	2.5	1.7	1.4
Solidago altissima	3.0	- -	0.7	1.2
Liatris spicata	- -	3.5	- -	1.2
Aster ericoides	3.3	- -	0.1	1.1
Aster simplex	1.4	0.3	1.3	1.0
Fragaria virginiana	1.7	0.2	0.6	0.8
Lycopus americanus	0.1	2.1	0.1	0.8
Eupatorium maculatum	2.0	- -	- -	0.7
Allium cernuum	- -	2.0	- -	0.7
Scirpus atrovirens	- -	- -	2.2	0.7
Desmodium illinoense	- -	- -	2.2	0.7
Polygonum amphibium	- -	- -	1.9	0.6
Rosa carolina	1.8	- -	- -	0.6
Aster azureus	1.9	- -	- -	0.6
Potentilla anserina	1.8	- -	- -	0.6
Lithospermum canescens	0.6	1.0	- -	0.5
Comandra umbellata	- -	1.5	- -	0.5

Table 2 (continued)

Species	Low prairie site 1 (percent)	Low prairie site 2 (percent)	Low prairie site 3 (percent)	All sites (percent)
Iris virginica	1.3	- -	- -	0.4
Rudbeckia hirta	1.1	- -	- -	0.4
Muhlenbergia glomerata	- -	1.1	- -	0.4
Juncus dudleyi	- -	1.0	0.1	0.4
Galium obtusum	1.0	- -	- -	0.3
Aster novae-angliae	0.3	0.6	- -	0.3
Phlox glaberrima	0.5	0.5	- -	0.3
Lythrum alatum	- -	1.0	- -	0.3
Aster puniceus	0.7	- -	- -	0.2
Apocynum sibiricum	0.6	- -	- -	0.2
Equisetum arvense	0.3	- -	0.3	0.2
Rubus strigosus	0.6	- -	- -	0.2
Solidago riddellii	0.2	- -	0.2	0.1
Sorghastrum nutans	0.3	- -	- -	0.1
Viola sagittata	0.3	- -	- -	0.1
Lycopus uniflorus	0.2	- -	0.1	0.1
Heuchera richardsonii	0.2	- -	- -	0.1
Poa sp.	0.1	- -	0.3	0.1
Thalictrum dasycarpum	0.1	0.2	- -	0.1
Stachys palustris	0.3	- -	- -	0.1
Hypoxis hirsuta	- -	0.3	- -	0.1
Carex sp.	- -	0.2	- -	0.1
Eleocharis sp.	0.1	0.3	- -	0.1
Hypericum kalmianum	- -	0.4	- -	0.1
Oxypolis rigidior	- -	0.2	- -	0.1
Lathyrus palustris	- -	- -	0.2	0.1
Cirsium muticum	- -	- -	0.4	0.1
Juncus torreyi	- -	- -	0.2	0.1
Typha latifolia	- -	- -	0.2	0.1
Campanula aparinoides	0.1	- -	- -	0.03
Convolvulus sepium	0.1	- -	- -	0.03
Mentha arvensis	0.1	- -	- -	0.03
Carex lasiocarpa	- -	- -	-0.1	0.03

NOTE: Values represent averages of three sampling dates.

Source: SEWRPC.

Table 3

CAROL BEACH SEASONAL WETLAND STUDY: SEDGE MEADOW SITES

Species	Sedge meadow site 1 (percent)	Sedge meadow site 2 (percent)	Sedge meadow site 3 (percent)	All sites (percent)
Carex stricta	39.8	34.8	21.1	28.6
Thelypteris palustris	8.0	24.0	- -	10.7
Calamagrostis canadensis	- -	20.3	8.9	9.7
Spartina pectinata	5.8	6.9	3.9	5.5
Solidago graminifolia	9.3	0.6	5.1	5.0
Andropogon gerardii	11.7	- -	1.1	4.3
Iris virginica	- -	- -	7.8	3.9
Rhamnus frangula	0.6	10.5	- -	3.7
Convolvulus sepium	- -	10.8	- -	3.6
Pycnanthemum virginianum	1.8	- -	8.7	3.5
Potentilla simplex	- -	- -	8.1	2.7
Helianthus grosseseratus	2.8	- -	4.6	2.7
Juncus dudleyi	- -	- -	7.0	2.3
Solidago gigantea	2.9	0.2	3.5	2.2
Fragaria viginiana	4.1	0.1	0.8	1.7
Polygonum amphibium	- -	1.1	2.7	1.3
Solidago rigida	- -	- -	3.1	1.0
Sporobolus heterolepis	2.8	- -	- -	0.9
Cornus stolonifera	0.6	- -	1.5	0.7
Stachys palustris	0.1	2.0	- -	0.7
Aster simplex	- -	1.7	- -	0.6
Tradescantia ohiensis	1.0	- -	0.7	0.6
Galium obtusum	0.3	0.8	0.6	0.6
Aster azureus	0.9	- -	0.2	0.4
Lithospermum canescens	1.1	- -	- -	0.4
Lycopus uniflorus	- -	- -	1.2	0.4
Helianthus giganteus	0.9	- -	- -	0.3
Aster novae-angliae	0.3	- -	0.6	0.3
Aster pilosus	0.9	- -	- -	0.3
Mentha arvensis	0.1	0.5	0.2	0.3
Silphium integrifolium	1.0	- -	- -	0.3
Potentilla anserina	1.0	- -	- -	0.3
Aster puniceus	0.6	- -	0.4	0.3
Dodecatheon meadia	0.8	- -	- -	0.3
Silphium terbinthinaceum	- -	- -	0.8	0.3
Rudbeckia hirta	0.4	- -	0.1	0.2

Table 3 (continued)

Species	Sedge meadow site 1 (percent)	Sedge meadow site 2 (percent)	Sedge meadow site 3 (percent)	All sites (percent)
Rosa carolina	0.6	- -	- -	0.2
Eupatorium maculatum	0.3	- -	0.3	0.2
Aster ericoides	0.6	- -	- -	0.2
Rubus strigosus	0.6	- -	- -	0.2
Lycopus americanus	0.2	- -	0.4	0.2
Poa sp.	0.1	- -	0.5	0.2
Liatris spicata	0.4	- -	0.2	0.2
Heuchera richardsonii	0.1	- -	0.4	0.2
Helenium autumnale	- -	0.6	- -	0.2
Oxypolis rigidior	0.4	- -	0.1	0.2
Comandra umbellata	0.2	- -	- -	0.1
Pedicularis lanceolata	0.4	- -	- -	0.1
Desmodium illinoense	0.4	- -	- -	0.1
Unident. composite	0.2	- -	- -	0.1
Lysimachia quadriflora	0.3	- -	- -	0.1
Hypericum kalmianum	0.4	- -	- -	0.1
Aster lateriflorus	0.2	- -	0.1	0.1
Cirsium arvense	- -	- -	0.3	0.1
Panicum implicatum	0.1	- -	0.2	0.1
Pedicularis canadensis	0.2	- -	- -	0.1
Equisetum arvense	0.1	- -	0.2	0.1
Phlox glaberrima	0.1	- -	0.2	0.1
Lathyrus palustris	- -	0.3	- -	0.1
Zizia aurea	- -	0.2	- -	0.1
Cirsium muticum	- -	- -	0.4	0.1
Solidago altissima	0.4	- -	- -	0.1
Typha angustifolia	- -	- -	0.2	0.1
Apocynum sibiricum	- -	- -	0.3	0.1
Solidago riddellii	- -	- -	0.2	0.1
Sorghastrum nutans	- -	- -	0.3	0.1
Achillea millefolium	- -	- -	0.3	0.1
Juncus torreyi	- -	- -	0.3	0.1
Sisyrinchium sp.	0.1	- -	- -	0.03
Lythrum alatum	0.1	- -	- -	0.03
Carex trichocarpa	0.1	- -	- -	0.03
Eleocharis erythropoda	0.1	- -	- -	0.03
Hierochloe odorata	0.1	- -	- -	0.03
Viola sagittata	0.1	- -	- -	0.03

NOTE: Values represent averages of three sampling dates.

Source: SEWRPC.

Table 4

MAJOR DOMINANT PLANT SPECIES AT LOW PRAIRIE SITES AND SEDGE MEADOW SITES

LOW PRAIRIE SITES

Low Prairie Site 1		Low Prairie Site 2		Low Prairie Site 3	
Species	Indicator Status	Species	Indicator Status	Species	Indicator Status
Spartina pectinata	FACW+	Solidago ohioensis	OBL	Spartina pectinata	FACW+
Helianthus grosseserratus	FACW-	Spartina pectinata	FACW+	Helianthus grosseserratus	FACW-
Thelypteris palustris	FACW+	Carex stricta	OBL	Carex stricta	OBL
Andropogon gerardii	FAC	Helianthus grosseserratus	FACW-	--	--
Solidago (Euthamia) graminifolia	FACW	Calamagrostis canadensis	OBL	--	--
Carex stricta	OBL	--	--	--	--

SEDGE MEADOW SITES

Sedge Meadow Site 1		Sedge Meadow Site 2		Sedge Meadow Site 3	
Species	Indicator Status	Species	Indicator Status	Species	Indicator Status
Carex stricta	OBL	Carex stricta	OBL	Carex stricta	OBL
Andropogon gerardii	FAC-	Thelypteris palustris	FACW+	Calamagrostis canadensis	OBL
Solidago (Euthamia) graminifolia	FACW-	--	--	Pycnanthemum virginianum	FACW+
--	--	--	--	Potentilla simplex	FACU
--	--	--	--	Iris virginica	OBL

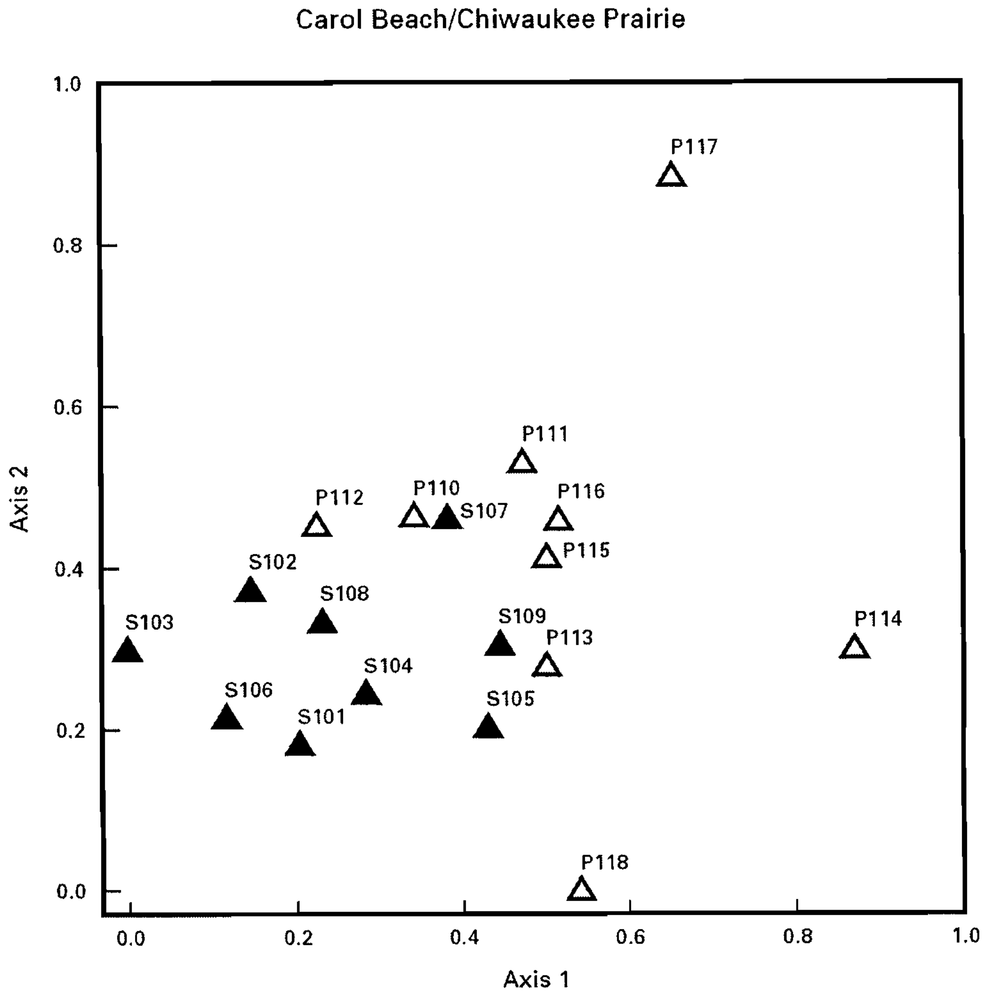
Source: SEWRPC.

Major dominant plant species were determined for each wetland sample site using the 50/20 rule and are listed in Table 4. Eight species are determined to be major dominants at the three low prairies sites, all but one, *Andropogon gerardii* (FAC-), are considered hydrophytes (2 FACW+, 2 FACW-, and 3 OBL). Eight species are also determined to be major dominants at the three sedge meadow sites; all but *A. gerardii* and *Potentilla simplex* (FACU) are considered hydrophytes (2 FACW+, 1 FACW-, and 3 OBL). Subsequently, all six seasonal wetlands are found to be dominated by hydrophytic vegetation based upon percent cover values and all exhibit a positive FAC-neutral test (a secondary hydrology indicator).

The results of a Bray – Curtis ordination of the 18 sample site quadrats are shown in Figure 4. The sedge meadow quadrats clustered together fairly well because of their similar vegetative composition, higher percent cover values for certain major dominant species, i.e. *Carex stricta*, and slightly higher species richness. However, the ordination of the low prairie quadrats shows a much more scattered and variable pattern due to their lower and more variable percent cover values for the major dominant species. The hydrophytic indicator status for each species by plant community type was determined (see Appendix A and B).

Figure 4

RESULTS OF BRAY - CURTIS ORDINATION OF THE 18 SAMPLE SITES



Source: SEWRPC.

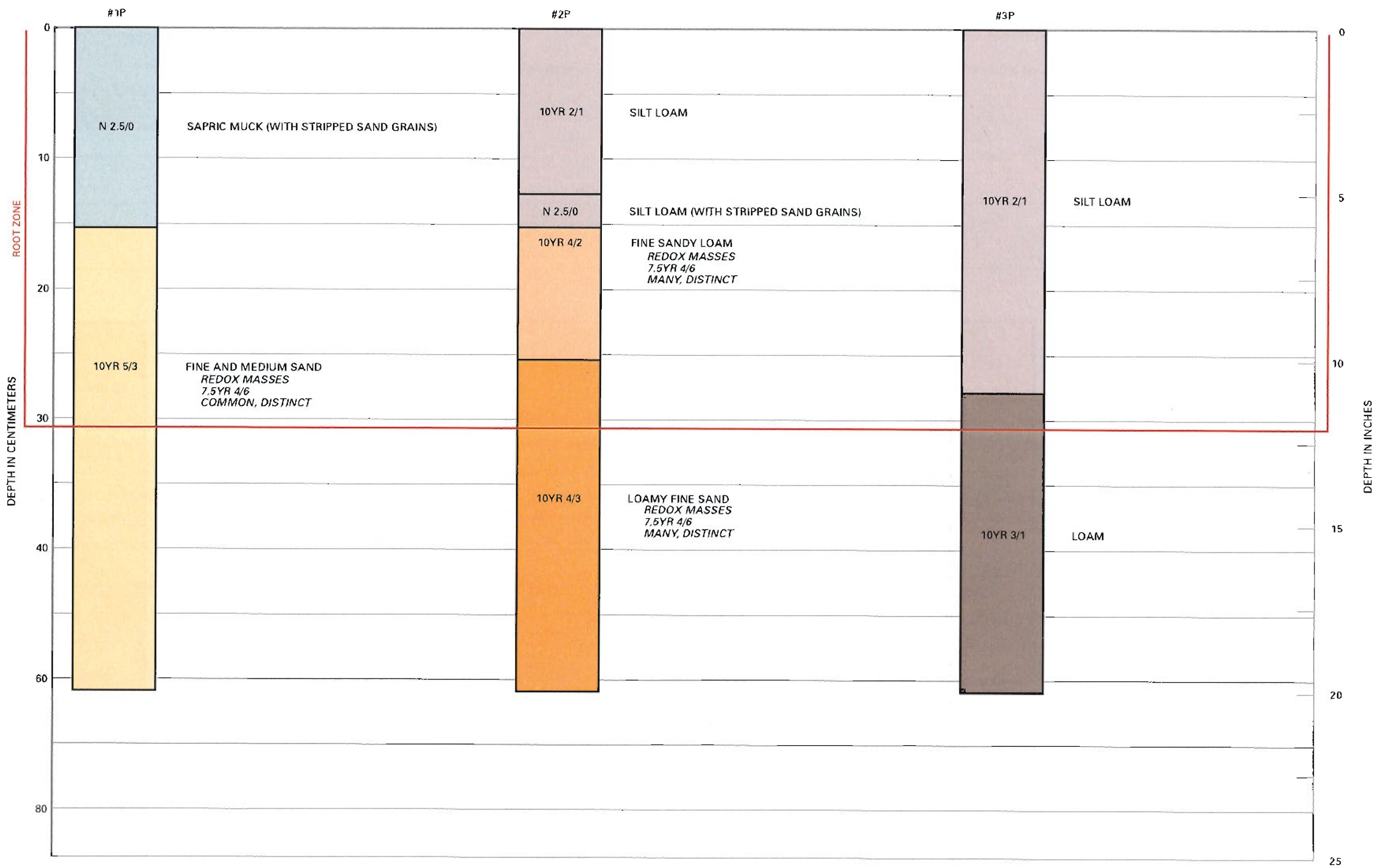
Soils Data and Analysis

Soil samples were collected and profiles prepared by the NRCS Soil Scientist for each of the six wetland sites on June 23, 2004. Each soil profile is shown in Figure 5 and 6.

Hydric soil indicators (NRCS, 2002) were identified at all of the sedge meadow sites and two of the low prairie sites (Site Nos. 1P and 2P). Low prairie site No. 3P had the A4 hydrogen sulfide indicator present during June of 2004. At that time, this sample site was inundated by approximately 4 inches of water during sample collection. The A4 indicator, however, usually disappears when the water levels recede and aerobic conditions develop in the soil column as the growing season progresses. Therefore, this soil would only be classified as a wetland soil during drier periods based upon its low chroma colors.

Figure 5

SOIL PROFILES OF THE LOW PRAIRIE SITES



Legend

Greens — organic soils

Browns — loams

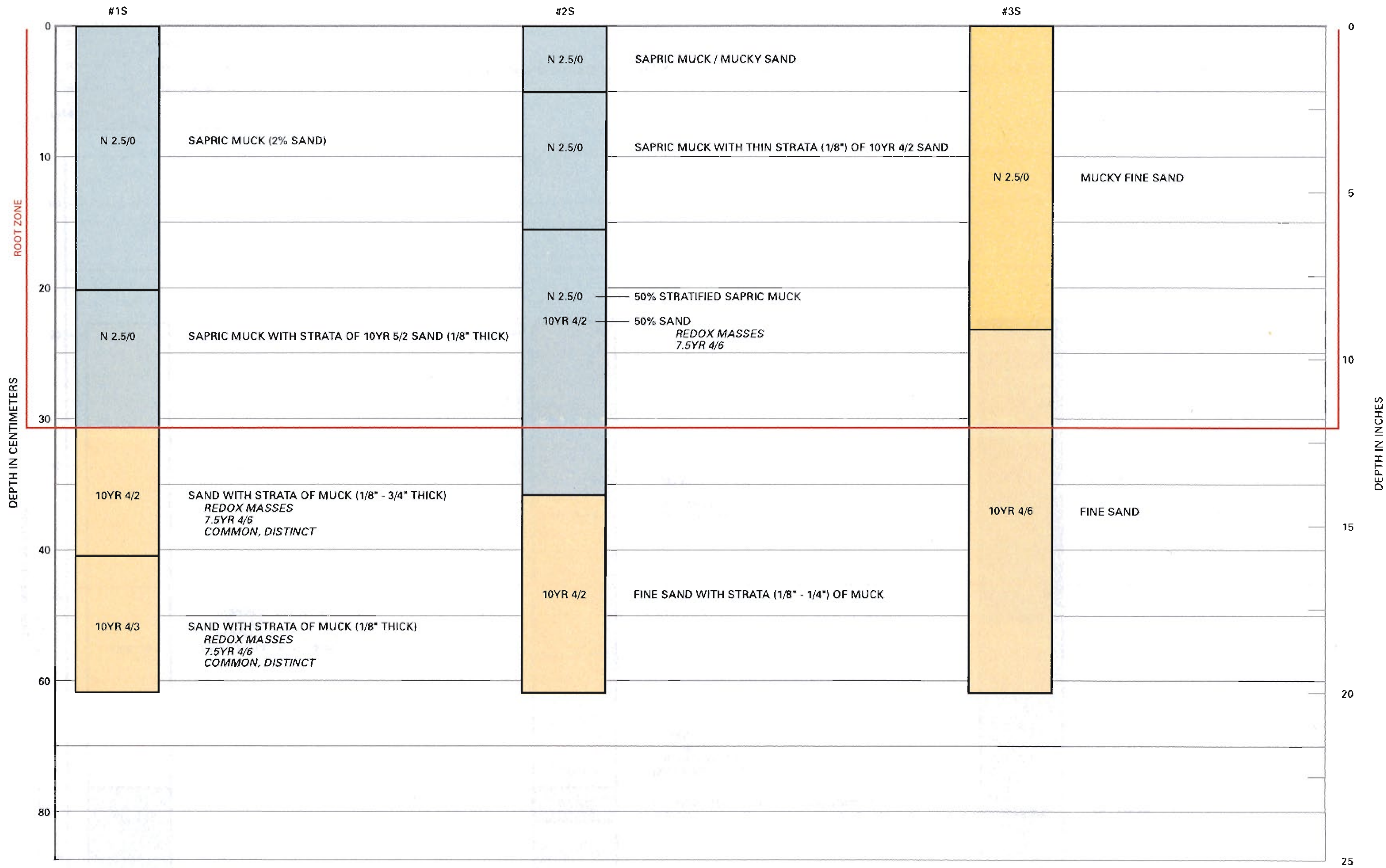
Yellows / Oranges — sands

NOTE FOR EACH SITE PROFILE, TEXTURE CLASS AND MUNSELL COLOR OF EACH SOIL LAYER ARE SHOWN THE ROOT ZONE IS INDICATED AS THE UPPER 31 CM OF THE SOIL PROFILE

Source: U.S. Department of Agriculture Natural Resources Conservation Service and SEWRPC.

Figure 6

SOIL PROFILES OF THE SEDGE MEADOW SITES



Legend

Greens — organic soils

Browns — loams

Yellows — sands

NOTE: FOR EACH SITE PROFILE, TEXTURE CLASS AND MUNSELL COLOR OF EACH SOIL LAYER ARE SHOWN. THE ROOT ZONE IS INDICATED AS THE UPPER 31 CM OF THE SOIL PROFILE.

Source: U.S. Department of Agriculture Natural Resources Conservation Service and SEWRPC.

With the exception of the accumulation of organic matter (Sapric muck) in the upper layers of the sedge meadows and one of the low prairies (Site No. 1P), no consistent pattern of hydric soil indicators was observed for each wetland type. Specifically, in order of their frequency, hydric soil indicators identified at the sites include A10. two-cm muck (Site Nos. 1P, 2P, and 2S); A5. Stratified layers (Site Nos. 1S and 2S); S1. Sandy mucky mineral (Site Nos. 1P and 3S); A2. Histic epipedon and TS5. Chroma 3 sandy redox (Site No. 1P); and A4 Hydrogen sulfide (Site No. 3P).

All six wetland sites were subtended by hydric soils. Five of the stands maintained clear hydric soil indicators as defined in the NRCS *Field Indicators of Hydric Soils in the United States*, version 5.0, 2002.

Water Level Data and Analysis

Groundwater elevations from pressure transducer sensor and hand measurements of water levels are shown in Figures 7 through 9. Land surface, root zone, and well bottom elevation are included with groundwater elevations from the sensor and hand measurements. Groundwater elevations from piezometer hand measurements are included with the results from the adjacent water-table well at the same site (low prairie or sedge meadow). Good agreement exists between groundwater elevations from sensor and hand measurements of water levels in each water-table well throughout the study period.

Table 5 provides a summary of groundwater elevation statistics from water-table well and piezometer data; however, the study statistics are most reliable from the piezometer data. Because piezometers are completed with screens at greater depths than water-table wells, the entire fluctuation of groundwater elevations are measurable. The highest maximum groundwater elevation is found in well MW3-P at Location 3 in the northern end of the study area while the lowest minimum elevation is observed in piezometer PZ1-S at Location 1 in the southern portion of the study area. The greatest range in elevations (difference between minimum and maximum) is observed in piezometer PZ3-S. Well MW3-S shows the least range groundwater elevations; however, this statistic is misleading because water-table wells do not record the actual minimum groundwater elevations. When groundwater elevations fall below the pressure transducer sensor in water-table wells between August and November, the elevations are not recorded. At Location 1, the mean groundwater elevation for well MW1-S (586.73 feet above mean sea level) is over a foot higher than the mean for piezometer PZ1-S (585.feet above mean sea level); however, elevations from these wells show good agreement throughout the study period (see Figure 7). Thus, the mean for well MW1-S is anomalously high because no groundwater elevation data was collected from well MW1-S between August and November. A similar trend is also observed at Location 2 where well MW2-P and piezometer PZ2-P show good agreement (see Figure 7); however, the mean groundwater elevation for MW2-P is nearly 0.9 feet higher than the mean for piezometer PZ2-P. Again, the lowest groundwater elevations are not recorded between August and November in well MW2-P. Unlike locations 1 and 2, at Location 3 groundwater elevations in well MW3-S do not match with elevations in piezometer PZ3-S (see Figure 9). This difference between the locations can be explained by assessing the local geology.

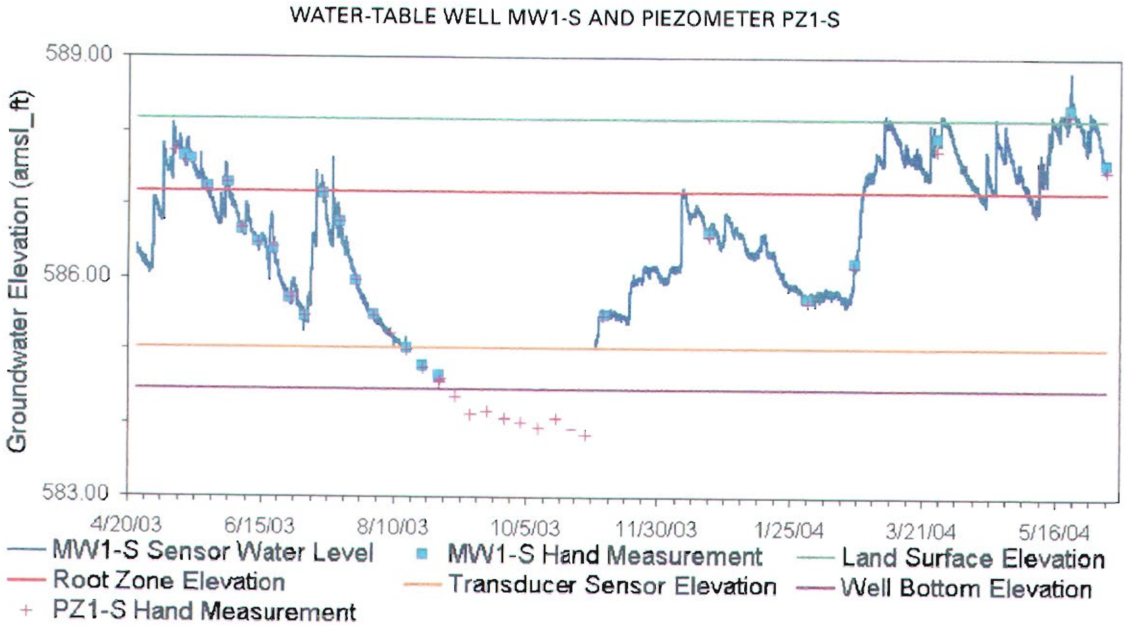
Figure 10 shows the geologic logs from cores collected during well and piezometer installation along with the screen intervals of the wells and piezometers at each location. Locations 1 (south) and 2 (middle) show similar subsurface lithology with sand overlying clay. The screen intervals indicate that the lower portions of water-table wells are within the same sand water-bearing zone as the piezometers. At Location 3 (north), the piezometer is screened in a thin gravel zone while the water-table wells are screened in stiff clay and separated from the piezometer screen by about 7 to 8 feet of clay. The observed subsurface stratigraphy and disparate groundwater elevations suggest that the water-table wells and piezometer measure water-bearing zones that are not in direct hydraulic communication.

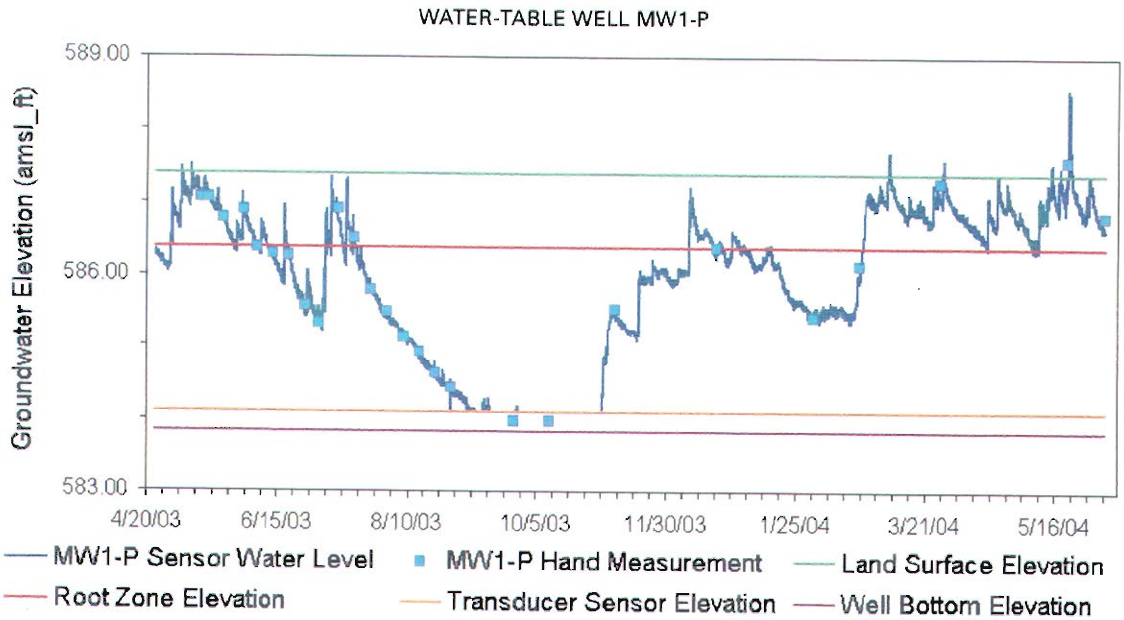
Evapotranspiration Evaluation

Groundwater elevations in water-table wells MW1-P and MW1-S from Location 1 were analyzed over two-day periods in the summer and winter to assess evapotranspiration effects on the water table. Groundwater elevations declined significantly (over 0.20 feet) from sunrise to sunset on July 18 and 19, 2003, in both wells (Figure 11).

Figure 7

GROUNDWATER ELEVATIONS AT LOCATION 1 SEDGE MEADOW SITE AND AT LOCATION 1 LOW PRAIRIE SITE

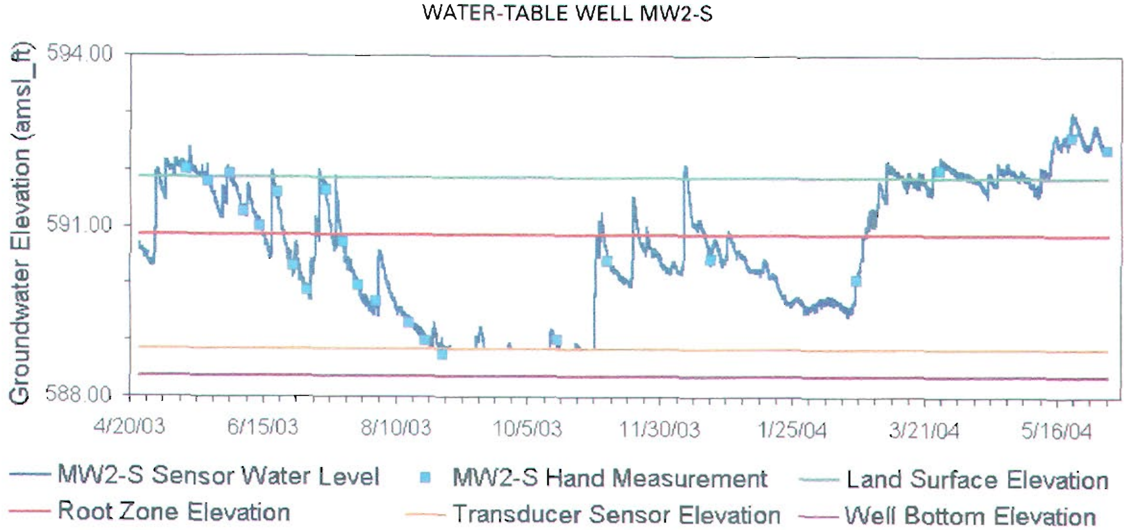


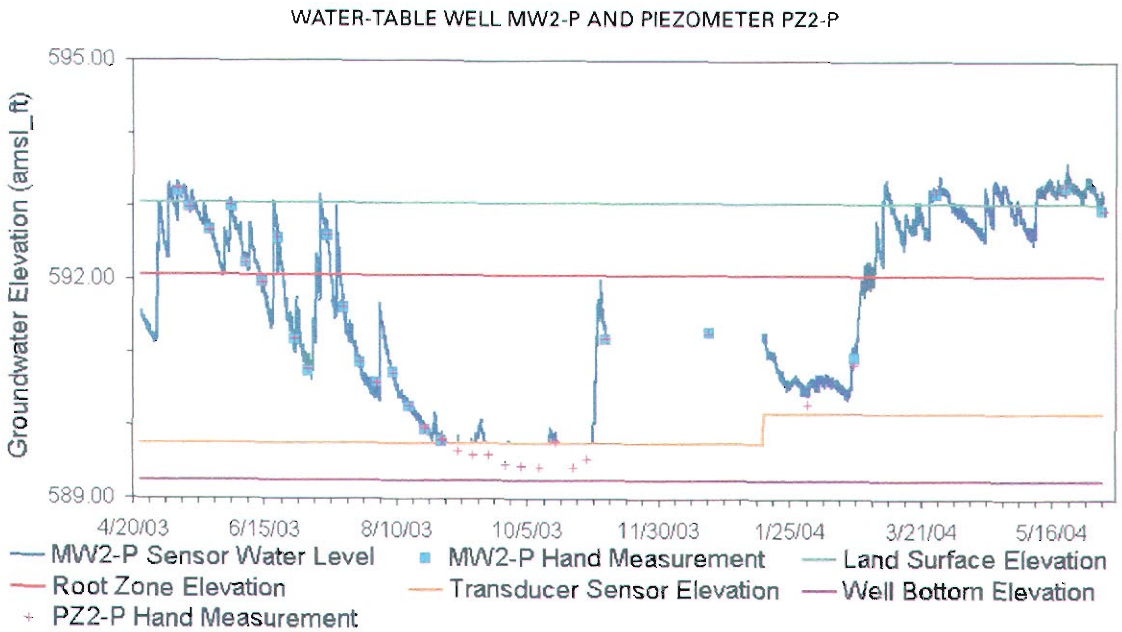


Source: Dr. John D. Skalbeck.

Figure 8

GROUNDWATER ELEVATIONS AT LOCATION 2 SEDGE MEADOW SITE AND AT LOCATION 2 LOW PRAIRIE SITE

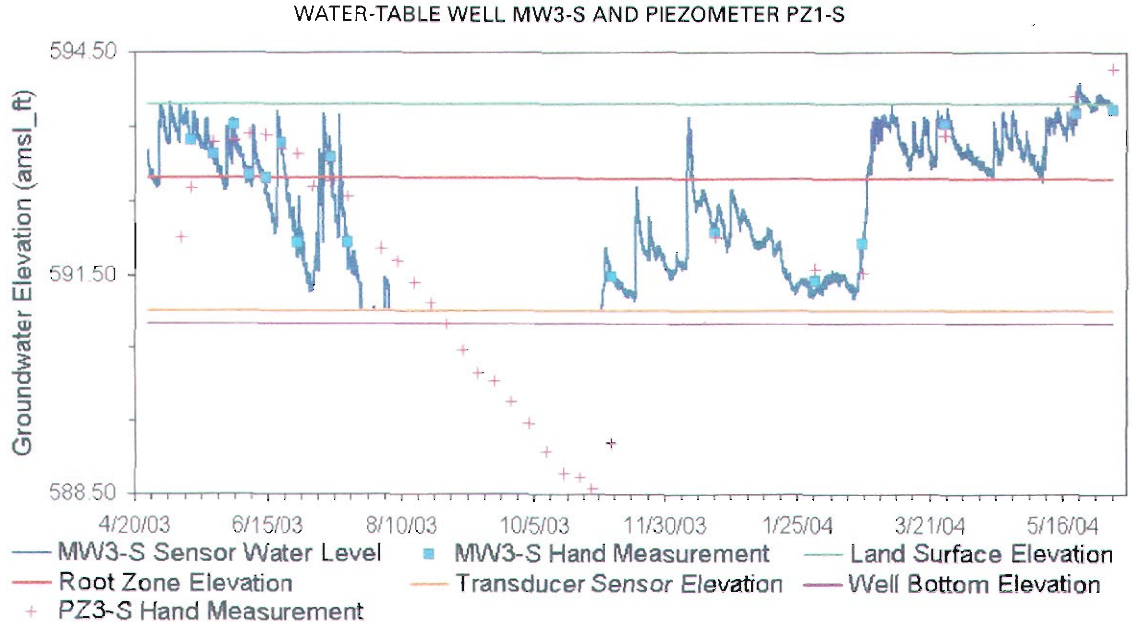


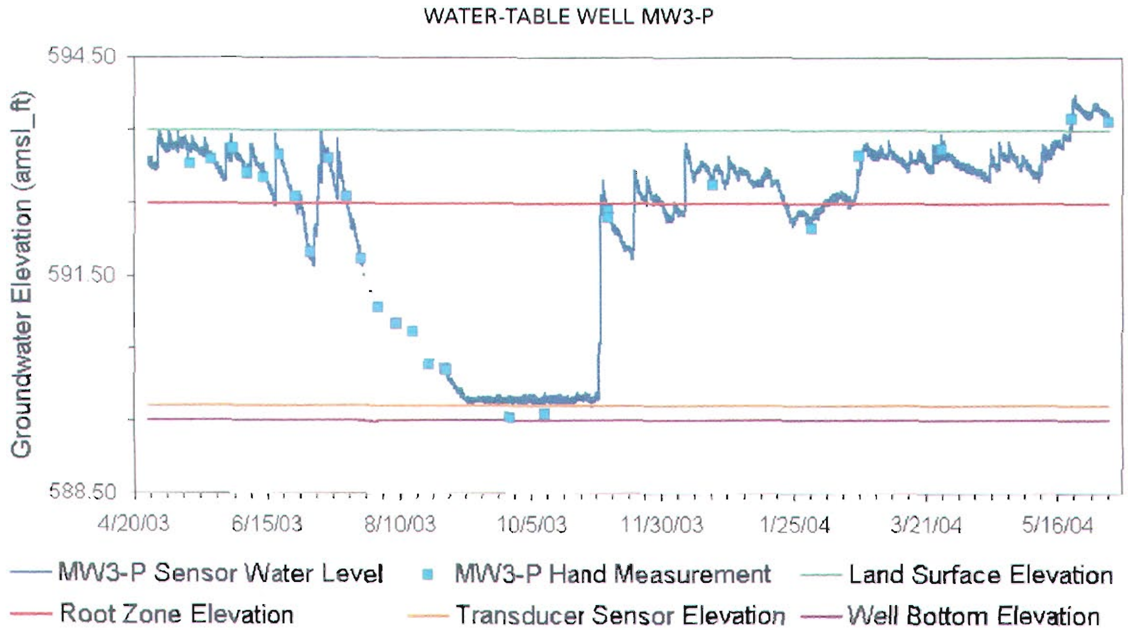


Source: Dr. John D. Skalbeck.

Figure 9

GROUNDWATER ELEVATIONS AT LOCATION 3 SEDGE MEADOW SITE AND AT LOCATION 3 LOW PRAIRIE SITE





Source: Dr. John D. Skalbeck.

Table 5

GROUNDWATER ELEVATION STATISTICS

Well/Piezometer Identification	Number of Measurements	Minimum Elevation[a]	Maximum Elevation[a]	Range in feet	Mean Elevation[a]	Standard Deviation in feet	Variance in feet
MW1-S	15711	585.03	588.79	3.76	586.73	0.86	0.74
MW1-P	17067	584.08	588.54	4.46	568.19	0.79	0.63
PZ1-S	34	583.85	588.24	4.39	585.71	1.36	1.85
MW2-S	17150	588.84	593.00	4.16	590.87	1.04	1.08
MW2-P	14432	589.74	593.59	3.85	591.81	1.20	1.43
PZ2-P	34	589.43	593.31	3.88	591.06	1.37	1.88
MW3-S	14674	591.02	594.05	3.04	592.61	0.83	0.69
MW3-P	14844	589.99	593.97	3.98	592.85	0.51	1.17
PZ3-S	32	588.58	594.28	5.70	591.57	1.70	3.04

[a]Elevations are in feet above mean sea level (North American datum of 1929).

Source: Dr. John D. Skalbeck.

During the evening of July 18, however, groundwater elevations remained generally constant. Groundwater elevations in these same wells show no significant difference between the daylight and night hours over two days in early January, 2004 (Figure 11). The decline in groundwater elevations only during daylight hours in the summer indicates that evapotransporation is drawing down the water table in these wells.

Groundwater Flow Model

A summary of findings of the groundwater flow model is attached to this report as Appendix C.

DISCUSSION AND CONCLUSIONS

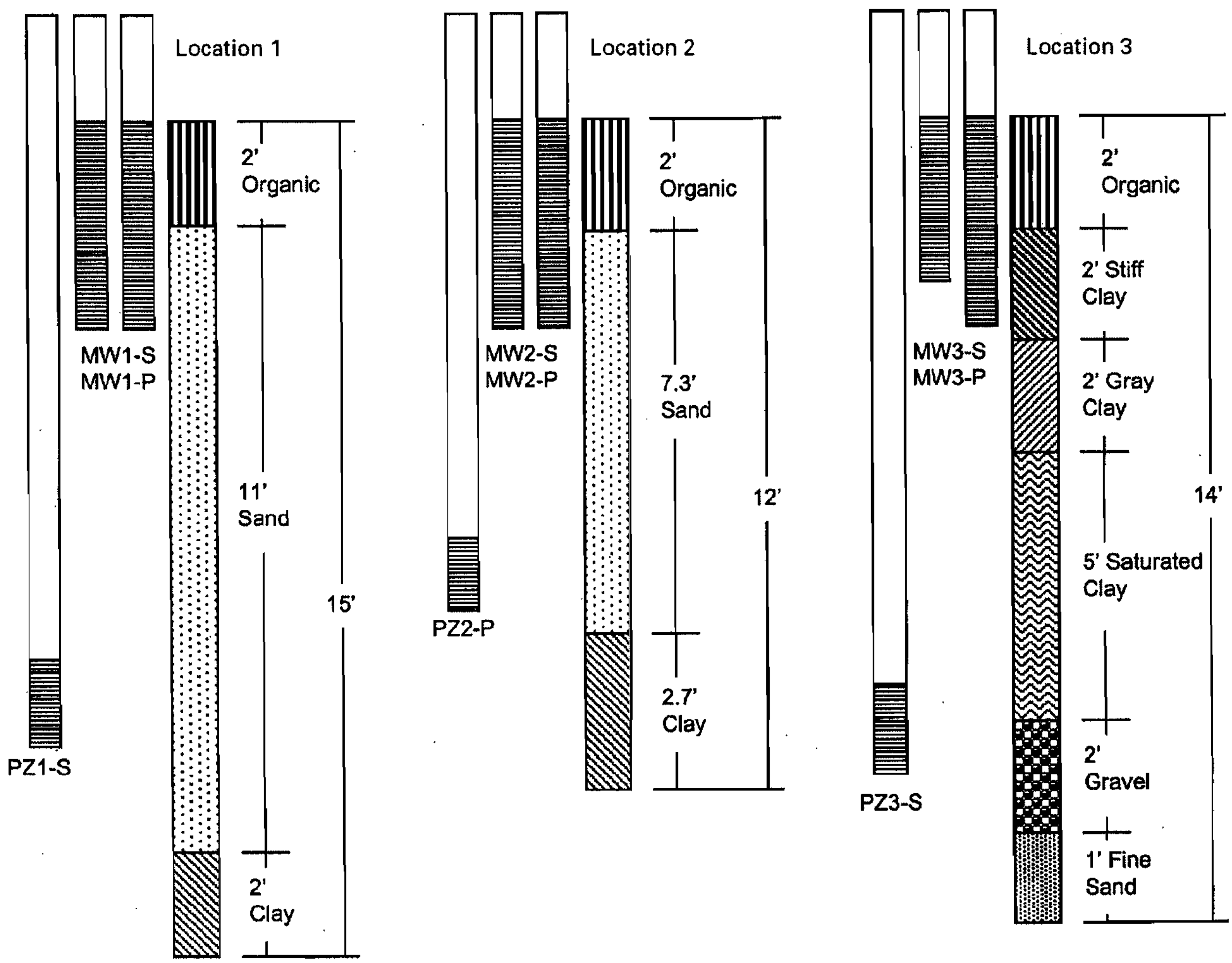
To make a positive wetland determination, one positive wetland indicator from each of the vegetation, soil, and hydrology parameters must be observed and recorded. Certain exceptions can be made for problem areas, including seasonal wetlands. The two wetland types selected for this study typically exhibit seasonal hydrology characteristics which may or may not be measured during the latter portion of the growing season. The application of these wetland indicators to the studied set of wetlands is herein discussed.

As noted above, all six seasonal wetlands are dominated by hydrophytic vegetation based upon percent cover values. Specifically, seven, or 88 percent, of the eight major dominant species recorded at the three low prairie sites are hydrophytes. Six, or 75 percent, of the eight dominant species recorded at the three sedge meadow sites are hydrophytes. Subsequently, all six seasonal wetlands meet the 1987 wetland delineation manual requirement that more than 50 percent of the dominant plant species be hydrophytes.

Several indicators may be used to determine if a given soil meets the definition and criteria for hydric soils. These indicators are set forth in the 1987 wetland delineation manual and in the most recent version of the NRCS field guide for identifying and delineating hydric soils. As also noted above, all six seasonal wetlands are subtended by hydric mineral soils. Specifically, the low prairie sites are predominantly low chroma silt loams and/or have histic epipedons. The sedge meadow sites are predominantly histic epipedons over fine sands or mucky fine sands. Under normal conditions, the above described vegetative and soil conditions may be consistently described in coastal low prairies and sedge meadows throughout the growing season. Hydrology indicators are the usual

Figure 10

GEOLOGIC LOGS WITH MONITORING WELL AND PIEZOMETER SCREEN INTERVALS AND TOTAL DEPTHS



Note: Land surface elevations normalized to common surface plane.

Source: Dr. John D. Skalbeck.

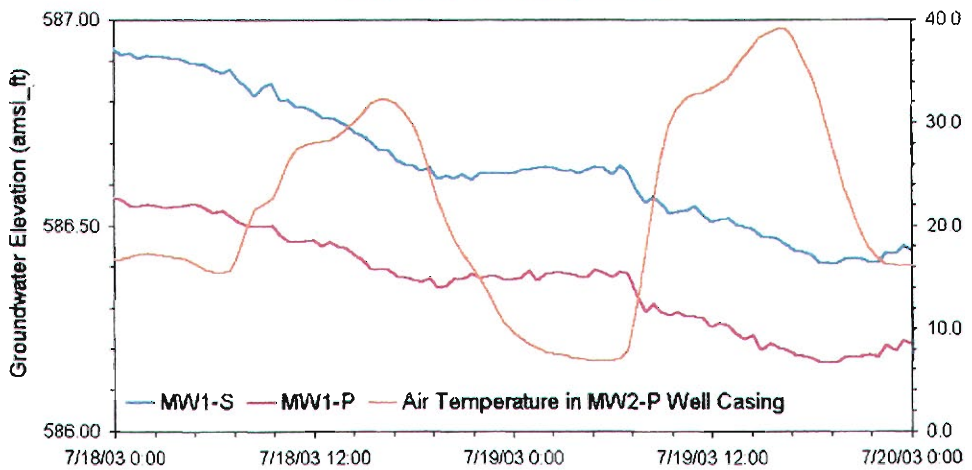
variable in the delineation of these wetland types. Late growing season conditions in the upper Midwest are typically dry in most years. This results in the absence of many or most hydrologic indicators in wetlands dominated by herbaceous vegetation.

The groundwater elevations collected during this study are useful for hydrologic characterization of wetlands. Table 6 summarizes the wetlands assessment for this study. The U.S. Army Corps of Engineers Wetland Delineation Manual (p. 30, U.S. Army Corps of Engineers, 1987) delineates hydrologic zones based on duration of inundation and/or soil saturation during the growing season. For this study, duration of inundation is represented by the percent of time during the growing season that the groundwater elevation is at or above the upper part of the root zone (1 foot below ground surface). The growing season is defined as the portion of year when soil temperatures at 19.7 inches (50 cm) below the soil surface are higher than biological zero (5°C or 41°F)

Figure 11

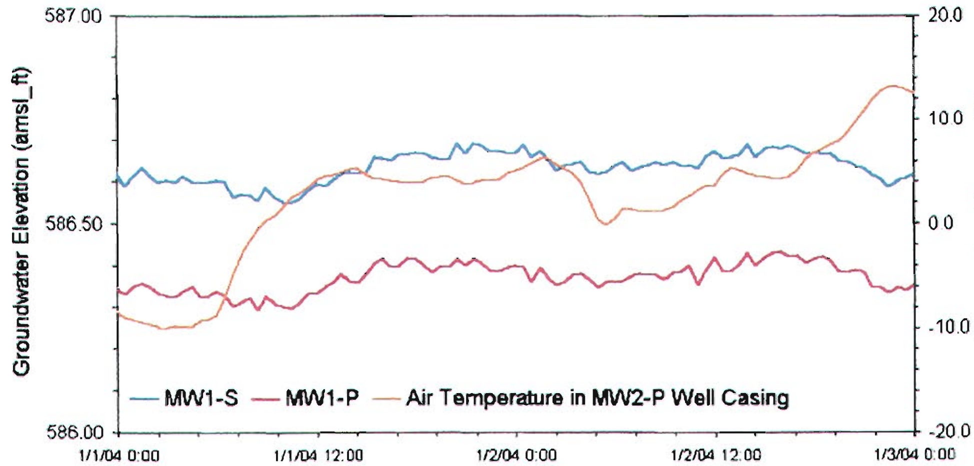
GROUNDWATER ELEVATIONS IN WATER-TABLE WELLS AT LOCATION 1

DURATION OF TWO SUMMER DAYS



NOTE: GRAPHS CLEARLY SHOW DECLINE IN WATER LEVELS FROM SUNRISE TO SUNSET DUE TO EVAPOTRANSPIRATION. GROUNDWATER ELEVATIONS REMAINED GENERALLY CONSTANT DURING THE NIGHT.

DURATION OF TWO WINTER DAYS



NOTE: TRENDS SHOW NO INDICATION OF EVAPOTRANSPIRATION.

Source: Dr. John D. Skalbeck.

(U.S. Department of Agriculture, 1985). This can be approximated by number of frost-free days based on average temperatures from 5 of 10 years (U.S. Department of the Interior, 1970). The growing season of 2003 for eastern Kenosha is from April 14 to November 2 (202 days). The first ten days of the 2003 growing season were not recorded, as water level measurements did not begin until April 24, 2003. Thus, the duration of inundation and/or soil saturation during the growing season documented from this study is slightly under-represented.

Table 6

WETLAND CRITERIA ASSESSMENT

Well Number	Number of Growing Season Days with Water In Root Zone[a]	Duration of Inundation/Soil Saturation During Growing Season[b] (percent)	USACOE Wetlands Hydrologic Zones[c]
MW1-S	27	13	IV
MW1-P	50	25	IV
MW2-S	60	30	III
MW2-P	54	27	III
MW3-S	55	27	III
MW3-P	73	36	III

NOTE: Growing season defined as April 14 to November 2, 2003. Portion of year when soil temperatures at 19.7 inches below the soil surface are higher than biological zero (5 degrees Celsius) (U.S Department of Agriculture, 1985). Approximated by number of frost-free days from average 5 to 10 years (U.S. Department of Interior, 1970) for eastern Kenosha County. Number of growing season days: 202.

[a] *Root zone defined as 0 to 1 foot below ground surface.*

[b] *Number of growing season days with water in root zone divided by number of growing season days.*

[c] *Wetlands Delineation Manual (U.S. Army Corps of Engineers, 1987).*
Zone III – Regularly inundated or saturated
Zone IV – Seasonally inundated or saturated

Source: Dr. John D. Skalbeck.

Table 6 shows that duration of inundation and/or soil saturation for water-table wells MW1-S and MW1-P was 13 percent and 25 percent, respectively, during the 2003 growing season. This indicates that Location 1 is classified as seasonally inundated or saturated (Hydrologic Zone IV) according to the U.S. Army Corps of Engineers Wetlands Delineation Manual (U.S. Army Corps of Engineers, 1987). Wells MW2-S and MW2-P were inundated/saturated for 30 percent and 27 percent of the 2003 growing season, and Wells MW3-S and MW3-P were inundated or saturated for 27 percent and 36 percent of the 2003 growing season. These results indicated that Locations 2 and 3 are classified as regularly inundated or saturated (Hydrologic Zone III).

The results from this study represent the condition of these coastal wetland locations during dry conditions and low lake water levels. A summary of monthly and annual precipitation data for Kenosha, Wisconsin, is given in Table 7. Comparison of 2003 monthly and annual data with 2002 data and averages of the 1971-2000 National Climate Data Center (NCDC) Normals shows below average precipitations during the study, especially during the 2003 growing season. While the 2002 annual precipitation was slightly below the 1971-2000 NCDC Normals, the 2003 annual was about 20 percent less than the 1971-2000 NCDC Normals. Only in March and November of 2003 (both outside the growing season) was precipitation higher than the 1971-2000 NCDC Normals. Precipitation during August through October of 2003 was generally half the monthly values from the 1970-2000 average. A result of high precipitation during the month of November, 2003 was recorded as a sharp rise in groundwater elevations in water-table wells. Historical average monthly lake levels for Lake Michigan/Huron from 1918 to 2003 (Figure 12) and from 2002 to 2003 (Figure 12) show current lake levels near record low. The

Table 7

PRECIPITATION DATA FOR KENOSHA, WISCONSIN

Date	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1971-2000[a]	1.67	1.29	2.34	3.85	3.38	3.59	3.68	4.19	3.49	2.49	2.68	2.09	34.74
2002	1.07	1.09	1.49	4.70	2.80	4.76	2.59	3.72	5.18	2.57	1.61	0.84	32.42
2003	0.43	0.10	2.07	2.09	4.44	2.57	3.65	1.02	1.52	1.56	5.20	2.28	26.93

NOTE: Data in inches.

[a]*National Climate Data Center (NCDC) Normals*

Source: Midwestern Regional Climate Center (http://mcc.sws.uiuc.edu/Precip/WI/474174_psum.html).

monthly average lake level during the 2003 growing season is only about 0.2 to 0.3 feet above the historical low. Lake levels this low were last observed in the mid-1960s.

The diurnal effect of evapotranspiration on groundwater levels within the root zone, particularly in the mid to latter portions of the growing season, is significant in both coastal low prairies and sedge meadows. A drop of several inches was noted from morning to evening. This becomes important when measuring wetland hydrology, particularly at the wetland edge, i.e., water levels recorded in the morning are within the root zone, hence a positive indicator of wetland hydrology versus water levels recorded in the late afternoon which drop below the root zone, a negative indicator of wetland hydrology. This is a significant finding not only for seasonal wetlands, but for all wetland types.

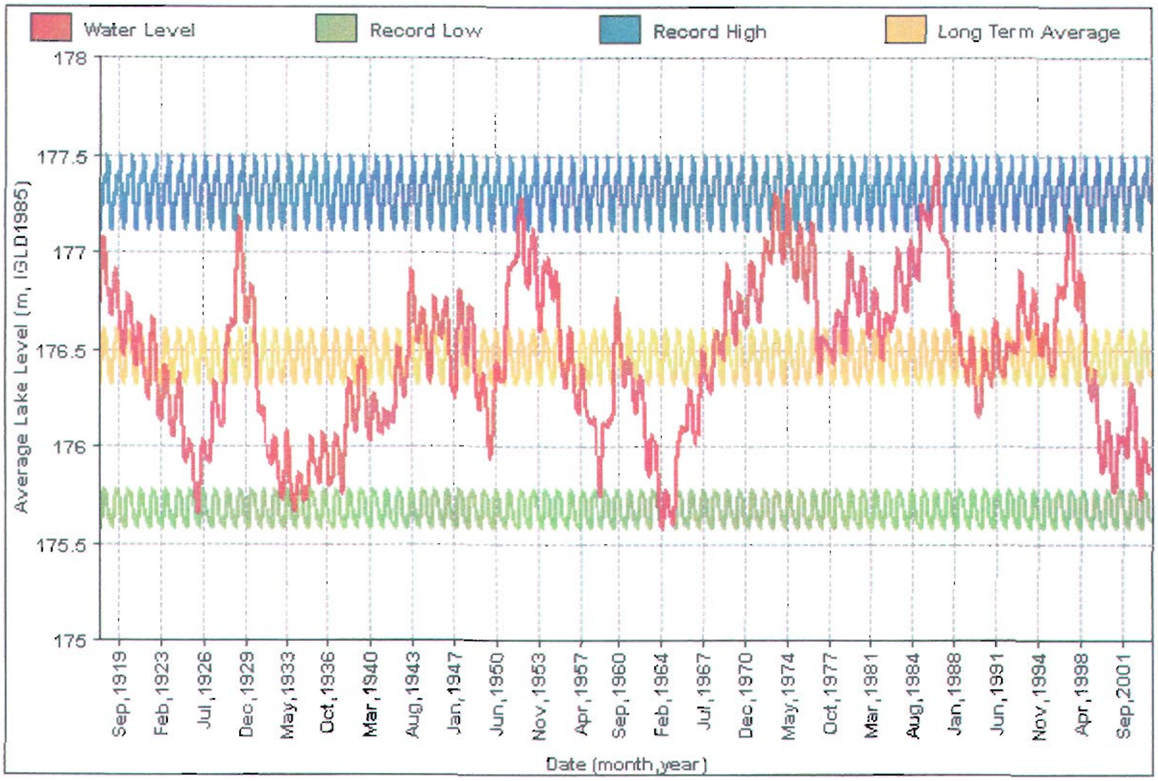
These data support the inclusion of coastal seasonal wetlands under the Federal and State wetland definition, as these wetlands clearly meet all of the vegetation, soils, and hydrology criteria in the early to mid portions of the growing season. However, any sampling conducted from the mid to latter portions of the growing season, particularly in dry years, will exhibit only the hydrophytes and hydric soils. The hydrology for these two wetland types will be significantly below the upper portion of the root zone during this period. Hence, the wetland hydrology criteria will not be met. Even certain hydric soil field indicators may disappear, e.g., A4 Hydrogen Sulfide indicator at Site No. 3P.

Based upon the foregoing findings, it is recommended that the delineation of coastal low prairies and sedge meadows occurring on ridge and swale complex and depressional topographies be based upon the wetland vegetation and soils criteria during the mid to latter portions of the growing season. Further, the collection of hydrologic data involving direct measurement of groundwater levels for all wetland types should be collected during the morning hours, particularly in moderate (0.8 to 2.5 inches per hour) to very rapid (10 or more inches per hour) permeable soils.

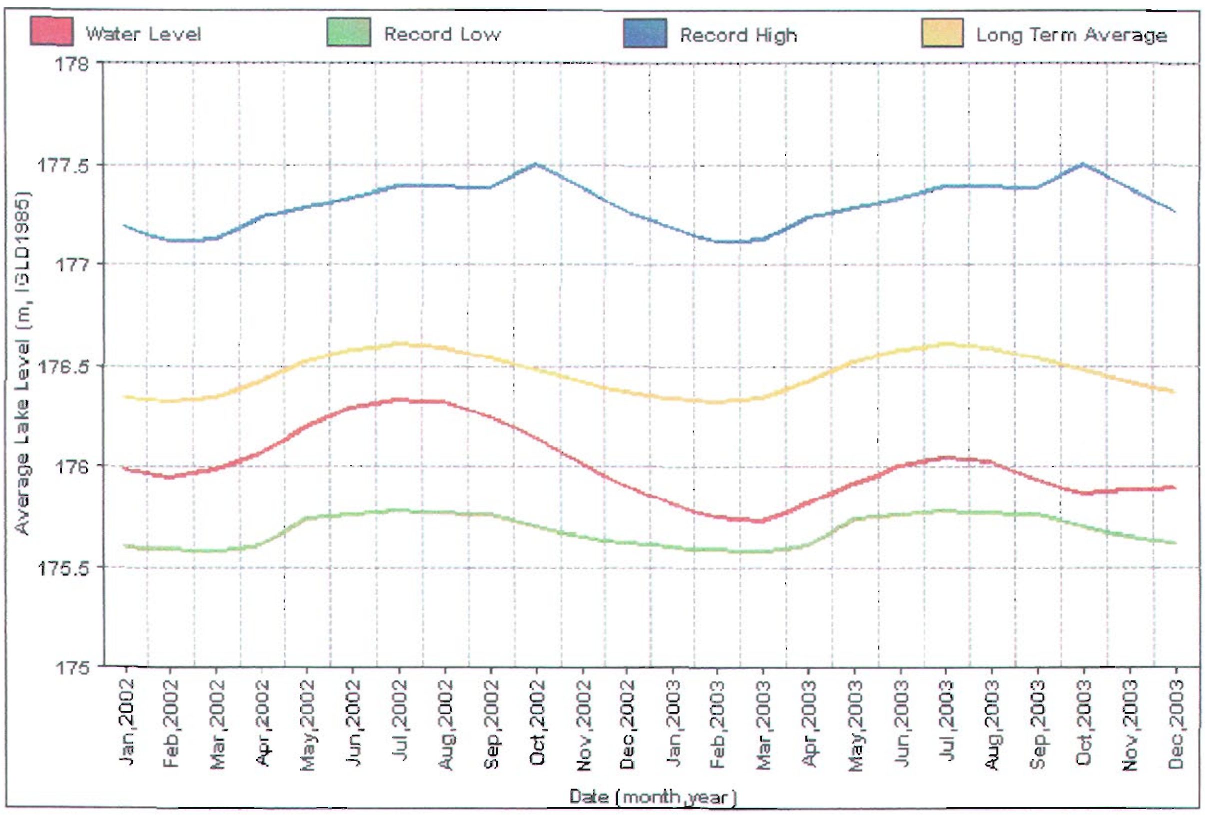
Figure 12

AVERAGE MONTHLY LAKE LEVELS FOR LAKE MICHIGAN AND LAKE HURON

1918 TO 2003



2002 TO 2003



Source: U.S. Department of the Army Corps of Engineers.

APPENDICES

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Appendix A

WETLAND INDICATOR STATUS OF RECORDED CAROL BEACH/CHIWAUKEE PRAIRIES MACROPHYTES: LOW PRAIRIES 2004

Major Dominant Species	Indicator Status
Andropogon gerardii	FAC-
Calamagrostis canadensis	OBL
Carex stricta	OBL
Helianthus grosseserratus	FACW-
Solidago graminifolia	FACW-
Solidago ohioensis	OBL
Spartina pectinata	FACW+
Thelyperis palustris	FACW+

Nondominant Species	Indicator Status
Allium cernuum	NI
Andropogon scoparius	FACU-
Apocynum sibiricum	FAC+
Aster azureus	NI
Aster ericoides	FACU-
Aster novae-angliae	FACW
Aster puniceus	OBL
Aster simplex	FACW
Campanula aparinoides	OBL
Carex lasiocarpa	OBL
Carex sp.	NI
Cirsium muticum	OBL
Comandra umbellata	FACU
Convolvulus sepium	FAC
Cornus stolonifera	FACW
Desmodium illinoense	NI
Eleocharis sp.	NI
Equisetum arvense	FAC
Eupatorium maculatum	OBL
Fragaria virginiana	FAC-
Galium obtusum	FACW+
Heuchera richardsonii	FAC-
Hypericum kalmianum	FACW-
Hypoxis hirsuta	FAC
Iris virginica	OBL
Juncus dudleyi	FAC
Juncus torreyi	FACW
Lathyrus palustris	FACW

Nondominant Species-continued	Indicator Status
Liatris spicata	FAC
Lithospermum canescens	NI
Lycopus americanus	OBL
Lycopus uniflorus	OBL
Lythrum alatum	OBL
Mentha arvensis	FACW
Muhlenbergia glomerata	FACW+
Oxypolis rigidior	OBL
Phlox glaberrima	FACW
Poa sp.	NI
Polygonum amphibium	OBL
Potentilla anserina	FACW+
Pycnanthemum virginianum	FACW+
Rhamnus frangula	FAC+
Rosa carolina	FACU-
Rubus strigosus	FACW-
Rudbeckia hirta	FACW
Scirpus atrovirens	OBL
Sliphium terebinthinaceum	FACU
Solidago altissima	FACU
Solidago gigantea	FACW
Solidago riddellii	OBL
Sorghastrum nutans	FACU+
Sporobolus heterolepis	FACU-
Stachys palustris	OBL
Thalictrum dasycarpum	FACW-
Typha latifolia	OBL
Valeriana edulis	FACW+
Viola sagittata	FACW-

Summary of indicator status	Number
OBL	18
FACW	23
FAC	6
FAC-	3
FACU	9
UPL	0
NI	7

Source: SEWRPC.

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Appendix B

WETLAND INDICATOR STATUS OF RECORDED CAROL BEACH/CHIWAUKEE PRAIRIES MACROPHYTES: SEDGE MEADOWS 2004

Major Dominant Species	Indicator Status
Andropogon gerardii	FAC-
Calamagrostis canadensis	OBL
Carex stricta	OBL
Iris virginica	OBL
Potentilla simplex	FACU-
Pycnanthemum virginianum	FACW+
Solidago graminifolia	FACW-
Thelyperis palustris	FACW+

Nondominant Species	Indicator Status
Achillea millefolium	FACU
Apocynum sibiricum	FAC+
Aster azureus	NI
Aster ericoides	FACU-
Aster lateriflorus	FACW-
Aster novae-angliae	FACW
Aster pilosus	FACU+
Aster puniceus	OBL
Aster simplex	FACW
Carex trichocarpa	OBL
Cirsium arvense	FACU
Cirsium muticum	OBL
Comandra umbellata	FACU
Convolvulus sepium	FAC
Cornus stolonifera	FACW
Desmodium illinoense	NI
Dodecatheon meadia	FACU
Eleocharis erythropoda	OBL
Equisetum arvense	FAC
Eupatorium maculatum	OBL
Fragaria virginiana	FAC-
Galium obtusum	FACW+
Helenium autumnale	FACW+
Helianthus giganteus	FACW
Helianthus grosseserratus	FACW
Heuchera richardsonii	FAC
Hierochloe odorata	FACW
Hypericum kalmianum	FACW-
Juncus dudleyi	FAC
Juncus torreyi	FACW
Lathyrus palustris	FACW

Nondominant Species-continued	Indicator Status
Lycopus americanus	OBL
Lycopus uniflorus	OBL
Lysimachia quadriflora	OBL
Lythrum alatum	OBL
Mentha arvensis	FACW
Oxypolis rigidior	OBL
Panicum implicatum	FAC
Pedicularis canadensis	FACU+
Pedicularis lanceolata	FACW+
Phlox glaberrima	FACW
Poa sp.	NI
Polygonum amphibium	OBL
Potentilla anserina	FACW+
Rhamnus frangula	FAC+
Rosa carolina	FACU-
Rubus strigosus	FACW-
Rudbeckia hirta	FACU
Silphium integrifolium	NI
Silphium terebinthinaceum	FACU
Sisyrinchium sp.	NI
Spartina pectinata	FACW+
Sporobolus heterolepis	FACU-
Solidago altissima	FACU
Solidago riddellii	OBL
Solidago rigida	FACU-
Sorghastrum nutans	FACU+
Stachys palustris	OBL
Tradescantia ohiensis	FACU+
Typha angustifolia	OBL
Unident. composite	NI
Viola sagittata	FACW-
Zizia aurea	FAC+

Summary of indicator status	Number
OBL	17
FACW	22
FAC	8
FAC-	3
FACU	16
UPL	0
NI[a]	8

[a]*Includes an unidentified composite*

Source: SEWRPC.

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Appendix C

USGS TECHNICAL MEMORANDUM: SUMMARY OF FINDINGS RELATED TO GROUNDWATER MODELING FOR CHIWAUKEE WETLANDS PROJECT: JUNE 21, 2004

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JUN 2 1 2004

United States Department of the Interior

U.S. GEOLOGICAL SURVEY
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Technical Memorandum

To: Don Reed, SEWRPC
From: Daniel Feinstein, Randy Hunt, Cheryl Buchwald, Charles Dunning, USGS
Subject: Summary of Findings related to Ground-Water Modeling for Chiwaukee Wetlands Project
Date: 21 June 2004

Objectives of Modeling

The freshwater wetlands in the coastal zone of Lake Michigan in southeastern Wisconsin and northeastern Illinois are a precious resource. The Carol Beach/Chiwaukee Prairie wetlands are dry during much of the growing season, but at other times they interact with ground water when the water table rises into the root zone of the vegetation. Water level data from wells installed in these wetlands demonstrates that this ground-water-fed condition occurs over much of the year. The objectives of this ground-water modeling study are to better understand the shallow ground-water conditions in the vicinity of these seasonal wetlands and to develop a planning tool that can be used to help protect them. The modeling puts great emphasis on the relation between ground-water and surface-water bodies that include perennial creeks and Lake Michigan as well as wetlands. It identifies expected recharge areas that act as sources of waters to the wetlands and simulates future effects of land-use changes associated with potential development on wetland ground-water levels.

Study Area and Watershed

The site under study is located along Lake Michigan in southeastern Kenosha County, Wisconsin and northeastern Lake County, Illinois (Figure 1).

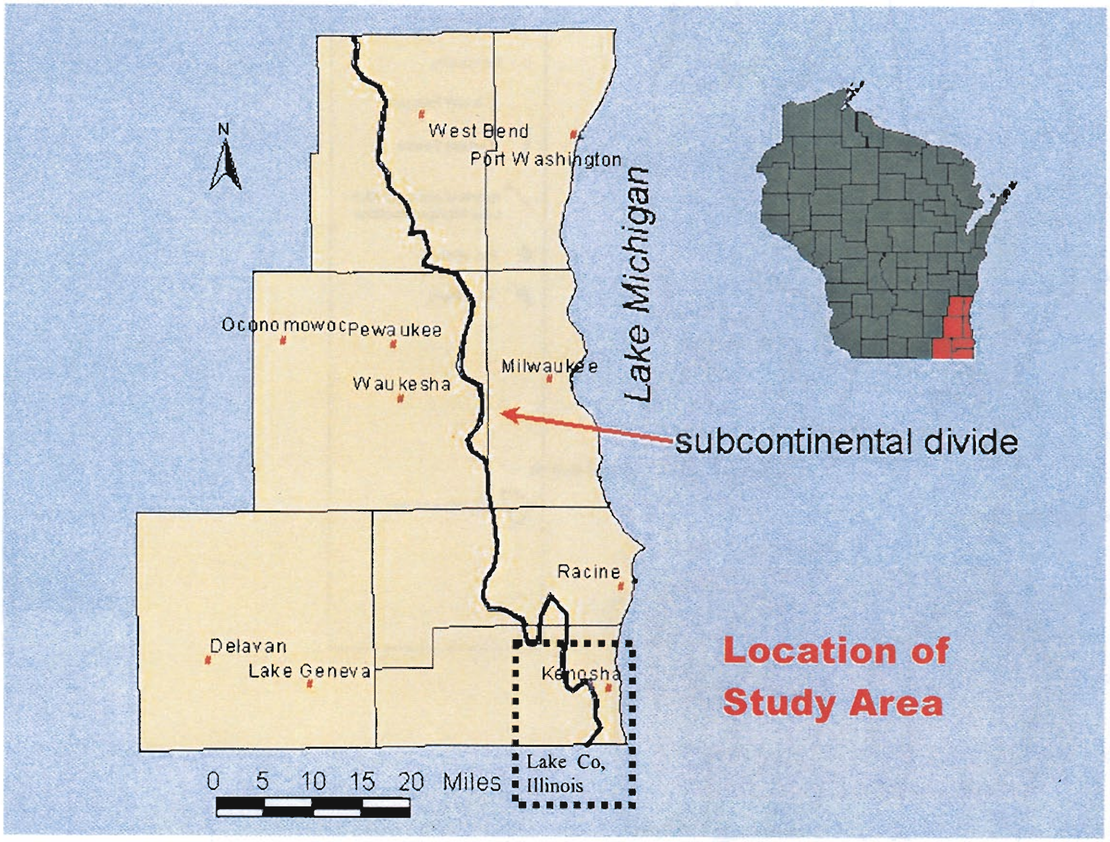

Figure 1. Location map.

The Great Lakes Basin surface-water divide runs through the study area. To the west of the divide, surface runoff discharges to the Des Plaines River and its tributaries. To the east of the divide, discharge is to creeks tributary to Lake Michigan, directly to Lake Michigan, and to wetlands in low-lying areas. The location of the ground-water divide between the Des Plaines watershed and the Great Lakes Basin is strongly influenced by the surface-water divide location.

The creeks tributary to Lake Michigan are Barnes Creek, Tobin Creek, and Winthrop Creek (Figure 2). Fens (wetlands that have appreciable ground-water discharge and have particular assemblages of vegetation) occupy part of the beach area along Lake Michigan.

Urbanized areas lie to the north of the creeks (the city of Kenosha) and to the south (the city of Winthrop Harbor). The Pike River watershed drains the city of Kenosha and the land to the north. The Dead River watershed south of the study area drains most of Winthrop Harbor.

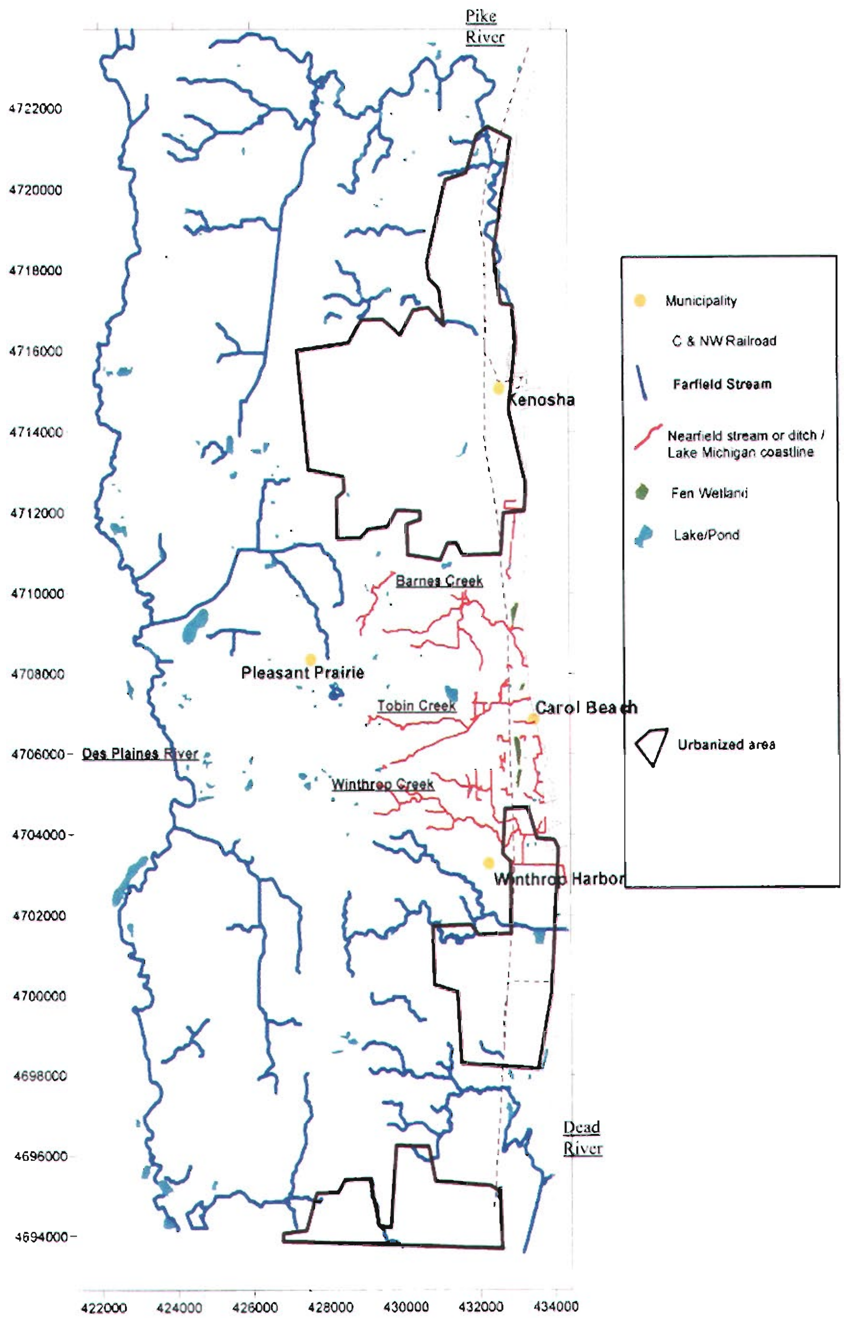

Figure 2. Study area: Hydrography.
Distances in meters. Fen locations from Southeastern Wisconsin Regional Planning Commission, 1985, Map 7.

The largest wetland in the study area is called the Chiwaukee Prairie; it is located in the southeastern corner of Kenosha County east of the city of Pleasant Prairie just south of the community of Carol Beach (Figure 3).

Figure 3. Chiwaukee Prairie location showing sites previously used for monitoring wells.

Geology and Conceptual Model

The presence of coastal wetlands in the study area is linked to the formation of beach-ridge plains along Lake Michigan. Beach-ridge plains are composed of linear ridges of mostly coarse-grained sediment that are built up by the action of storm waves along the upper part of the beach (Chrzastowski, 2001). These deposits have lateral continuity for great distances along the shore. As the lake level changes, new ridges are formed approximately parallel to earlier sets. Between the ridges, organic-rich and more fine-grained material accumulates in low-lying swales. The swales are candidate locations for wetlands.

The "washboard" beach-plain topography is most pronounced south of Zion in northeastern Illinois. It is more muted in the vicinity of the Chiwaukee Prairie where the elevation difference between ridges and swales is small, on the order of one to two feet. The beach-ridge deposits end at the northern edge of the study area at the southern border of the city of Kenosha. Well logs suggest that the deposits in the northern part of the study area north of Barnes Creek are less sandy than to the south.

The beach-plain is generally about one-half mile wide in the study area. It is bounded on the landward side by a line of bluffs that consist of clayey till (Figure 4). The bluff marks the most inland advance of Lake Michigan. The C & NW railroad lines follow the crest of the bluff. West of the bluff the topography assumes the hummocky relief typical of glacial moraine deposits. The till deposits between Lake Michigan and the Des Plaines River are called the Lake Border Moraine (Schneider, et al., in preparation). The tills are underlain by Silurian dolomite (Figure 4). Well logs indicate that the dolomite below the study area has a fairly flat upper surface at an elevation of about 535 feet. The beach deposits and moraine deposits constitute an unconfined aquifer in which ground-water flow is controlled largely by density and stage of surface water features.

Ground water flows from the upland moraine areas toward Lake Michigan. It is also flows toward creeks that occupy v-shaped ravines incised into the glacial sediments. It is likely that the ravines were cut 10,000 to 5,500 years ago when lake levels were hundreds of feet lower than today (Chrzastowski, 2001).

Most of the precipitation to the moraine is returned to the atmosphere by evapotranspiration or runs off to local streams. Studies in southeastern Wisconsin suggest that only 10% or less of precipitation percolates to the water table in areas of clay-rich till along Lake Michigan (Cherkauer, 2004). A higher percentage infiltrates in sandy areas such as beach-ridge deposits.

Recharge to the water table flows most easily through fractures in the clay till and through sand bodies buried in the moraine (Figure 5). In the absence of pumping, the flow pattern in the unconfined aquifer is expected to be largely horizontal. Part of the ground water moves upward to creeks and other water bodies, part moves parallel or under the surface water toward Lake Michigan. A relatively small part leaks downward to the Silurian dolomite bedrock. Calculations performed with a recently-constructed regional ground-water model for southeastern Wisconsin (Feinstein, et al., 2004) indicate that the net flux to the bedrock in the study area is on the order of 5% or less of the total recharge.

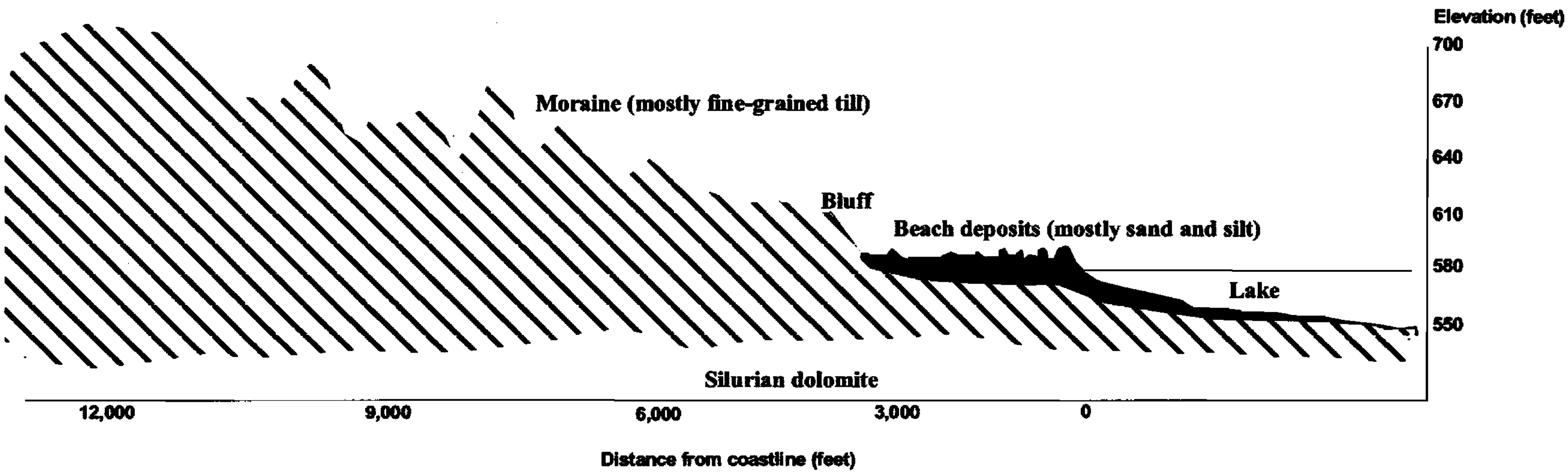

Figure 4. Schematic Geologic Cross Section (adapted from Chrzastowski, 2001, Figure 5).

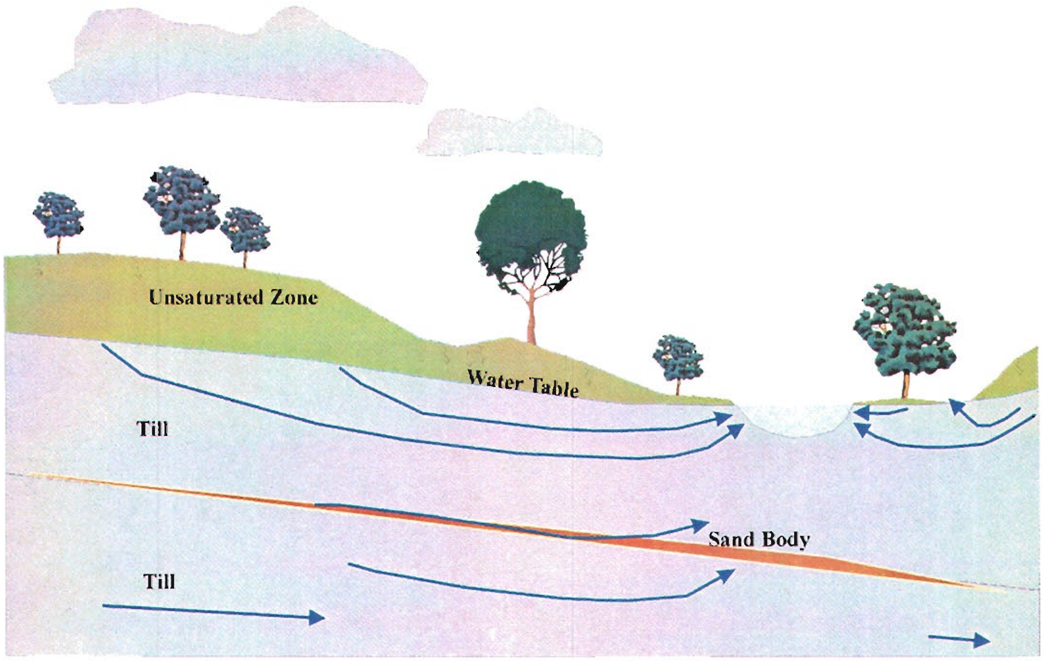

Figure 5. Schematic hydrogeologic section.

The primary outputs of the ground-water flow model are 1) the water-table surface at the top of the shallow flow system, and 2) the distribution and rate at which ground water discharges to surface-water bodies such as creeks. The rate of ground-water discharge is called "baseflow". Because the flow in the creeks is a combination of ground-water baseflow and stormflow, the ground-water flow model is best suited for non-storm periods.

The model is constructed to reproduce the average ground-water head and flow pattern under average, current conditions. It is important to note that average, current conditions refer to conditions after a period of moderate precipitation with Lake Michigan at the 577-foot level obtaining in the fall of 2003. The model does not reflect conditions after a period of protracted drought, nor events during spring snowmelt when recharge is very high.

The primary inputs to the ground-water flow model are 1) recharge zones, 2) hydraulic conductivity zones, and 3) locations and stages of surface water features. The first two inputs were adjusted until a good match was obtained between the observed water table elevations and the simulated water-table surface. Inputs were also adjusted to obtain a good match between observed ground-water baseflow and the simulated flux at monitored locations. This process of matching target observations to simulated output by adjusting model parameters is called "model calibration". The following section is devoted in part to discussing how field data were collected to provide calibration targets.

Data Compilation and Collection

The data compilation and collection falls into a variety of categories.

GIS Mapping

The topography of Chiwaukee Prairie area is a strong control both on the pattern of ground-water flow and the location of wetlands. Through use of Digital Elevation Model (DEM) data as processed by GIS software, it is possible to map the topography on 30-meter centers. A relief map based on these data is shown in Figure 6. The beach plain and bluff (at about elevation 610 feet) show up clearly along the coast of Lake Michigan, as does the hummocky topography of the inland moraine. The abrupt thinning of the aquifer at the bluff causes part of the ground water flowing from east from the uplands to discharge to the land surface before reaching the Lake. The figure shows the location of three major wetlands in the study area.

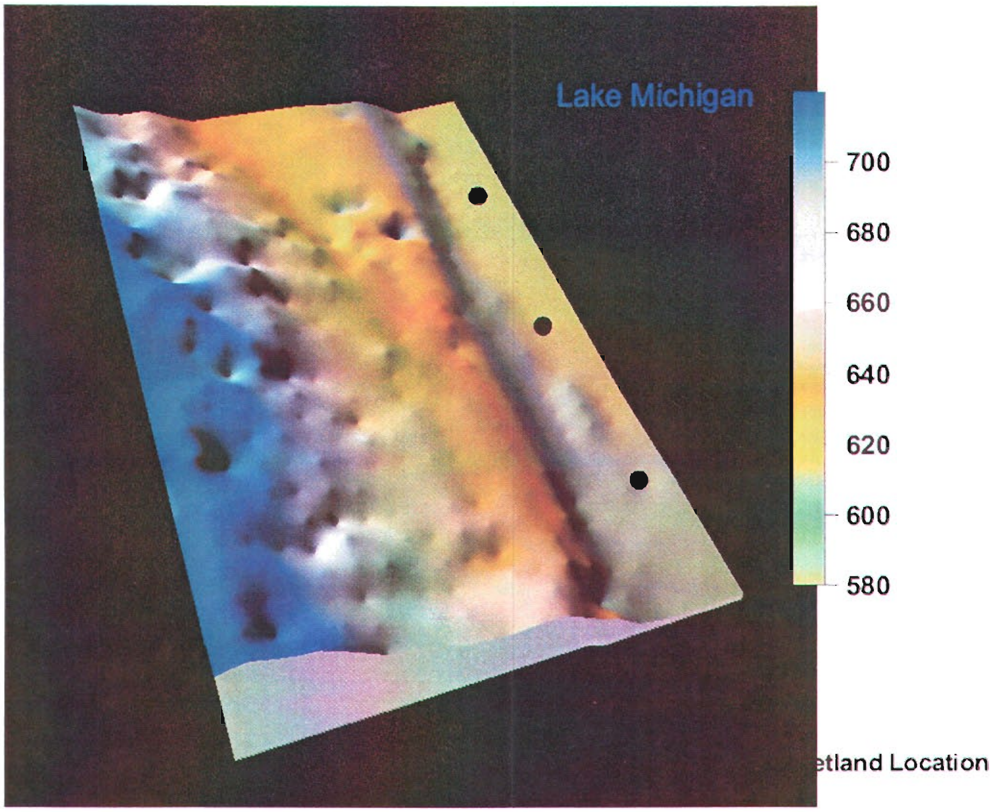

Figure 6. Study Area: Land surface.
Distances in meters. Elevations in feet. Wetlands identified as sites #1, #2, #3.

A closed depression located affects flow conditions at the north end of the study area just south of the city of Kenosha. This small-scale topographic feature is bounded by the bluff (and railroad tracks) on the west and by beach dunes on the east. It causes runoff and ground water to drain locally to a north-running ditch (Figure 7). Wetland #3 occupies part of this closed depression. To the south of this area, drainage is controlled by creeks flowing from west to east.

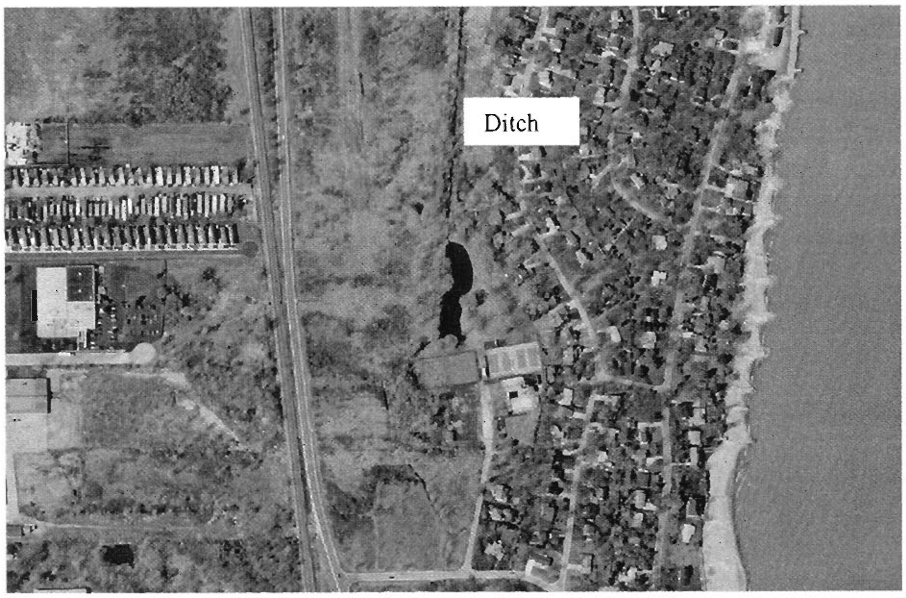

Figure 7. Closed depression at north end of study area just south of Wetland Site #3. Elsewhere in the study area, watercourses are all oriented from west to east (e.g, Barnes Creek, Tobin Creek, and Winthrop Creek).

Previous modeling

Another source of information for this study is the regional ground-water model recently completed by the U.S. Geological Survey (USGS) and the Wisconsin Geological and Natural History Survey (WGNHS) for southeastern Wisconsin. Figure 8 shows the recharge and hydraulic conductivity distribution from the regional model for Kenosha County and surrounding areas (Feinstein et al., 2004).

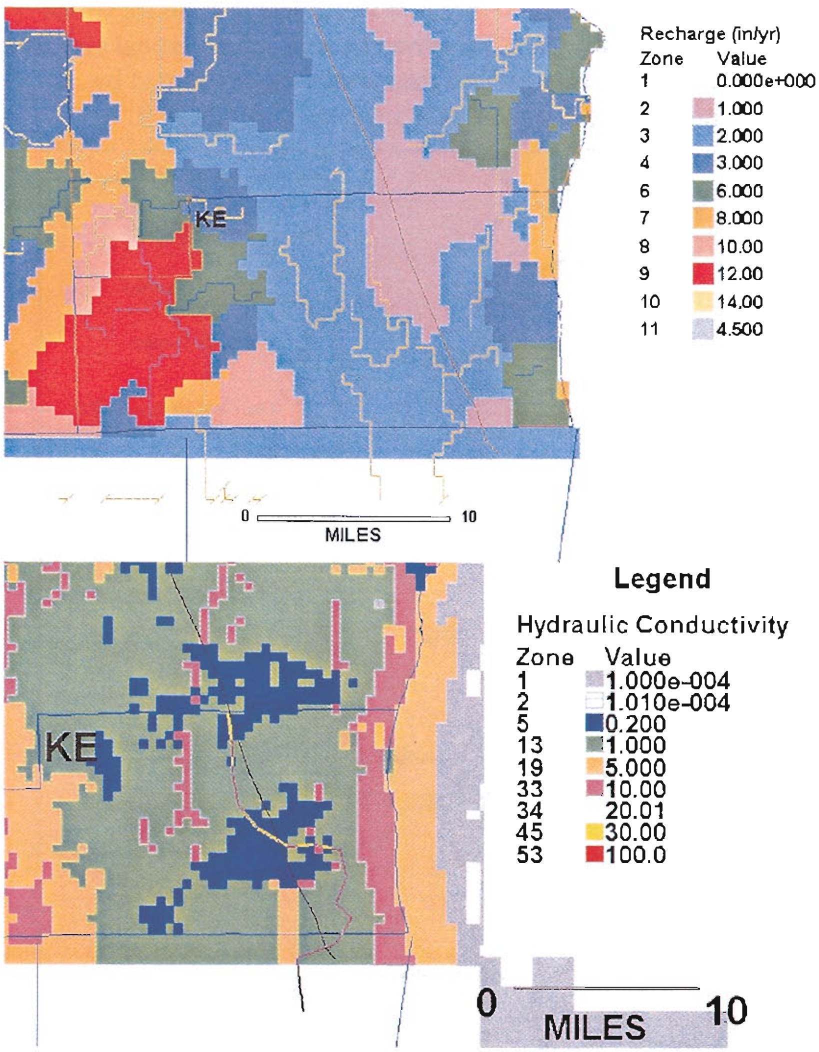

Figure 8. Recharge and hydraulic conductivity zones from regional model of southeastern Wisconsin.

Both recharge and hydraulic conductivity show a zonation that is influenced by the presence of the sandy beach ridge deposits along the coast, particularly in southeastern Kenosha County in the vicinity of Carol Beach and Chiwaukee Prairie. The contrast in the regional model between higher recharge and hydraulic conductivity along the coast and lower values associated with the upland moraine provides the framework for zoning parameter values in this modeling study.

GPS data collection

Because ground-water/surface-water interactions are central to understanding how water is routed in the study area, it is important to have precise knowledge of the levels in the many water bodies that serve as ground-water discharge locations (including Lake Michigan, the Des Plaines River, creeks, ponds, wetlands, and roadside ditches). For this purpose, the Global Positioning System (GPS) unit operated by the WDNR was used to measure water levels at 46 locations around the study area including Lake Michigan. The GPS generally measures vertical elevations to an accuracy better than 0.1 feet. These relatively precise data were complemented by hundreds of DEM points near watercourses. Both sets of data are shown in Figure 9.

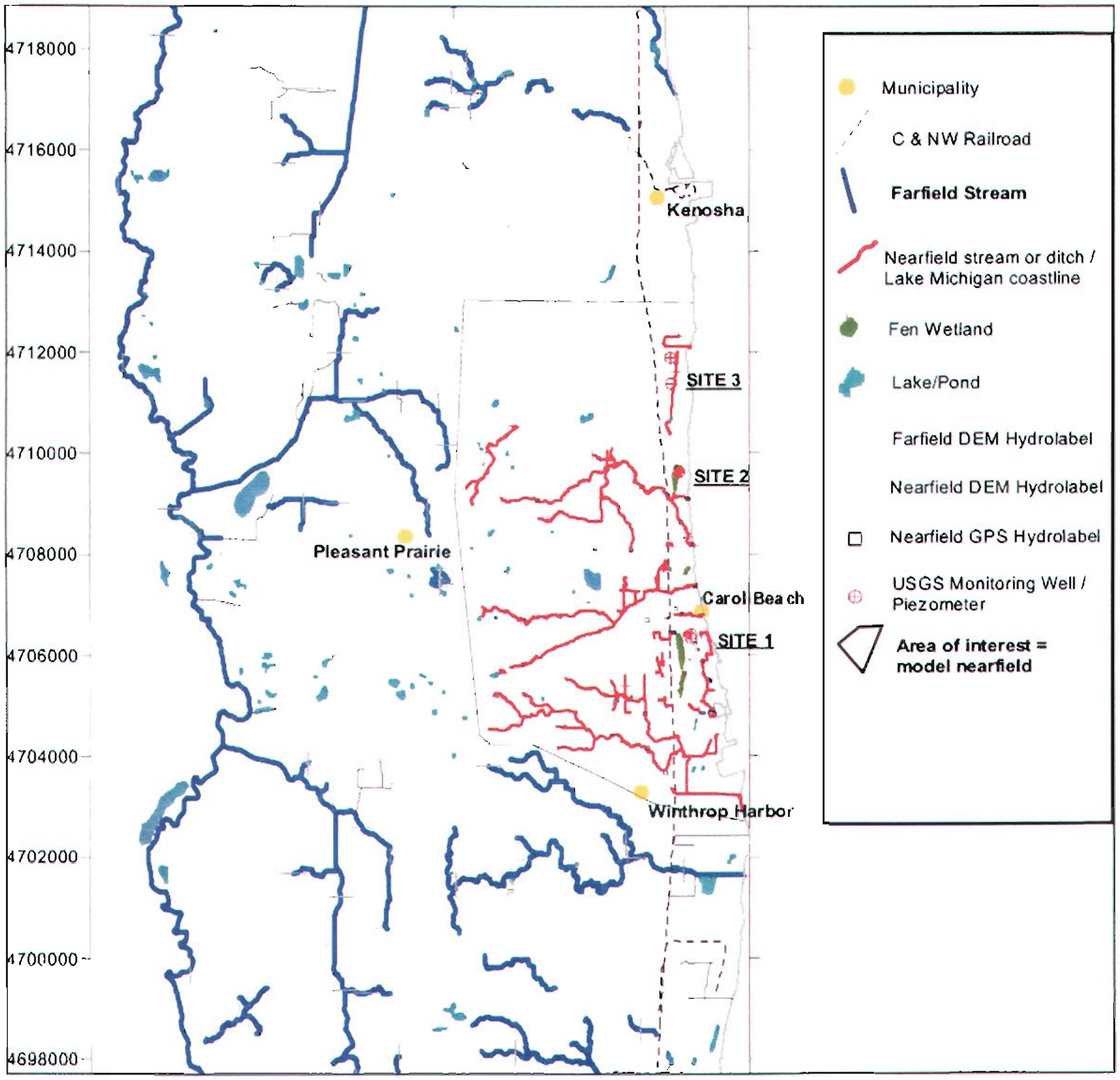

Figure 9. Data collection: Location of GIS Digital Elevation data and GPS Elevation Measurements.

The DEM data are limited in accuracy because they are derived from a grid on 30-meter centers, and, therefore, are located on average 15 meters away from the point of interest. As a result, they are unlikely to fall, for example, within the ravines that define the important creeks that drain into Lake Michigan. For this reason, the DEM data have a bias to overestimate the water levels of streams. Where thc DEM points fall close to GPS locations at water bodies, it is possible to compare the two elevation measurements. The graph in Figure 10 indicates that on average the GPS elevations are about 3 feet below the DEM elevations. For this reason, when DEM points were used to define stage elevations for rivers and creeks, the elevation input to the model was lowered by 3 feet relative to the DEM.

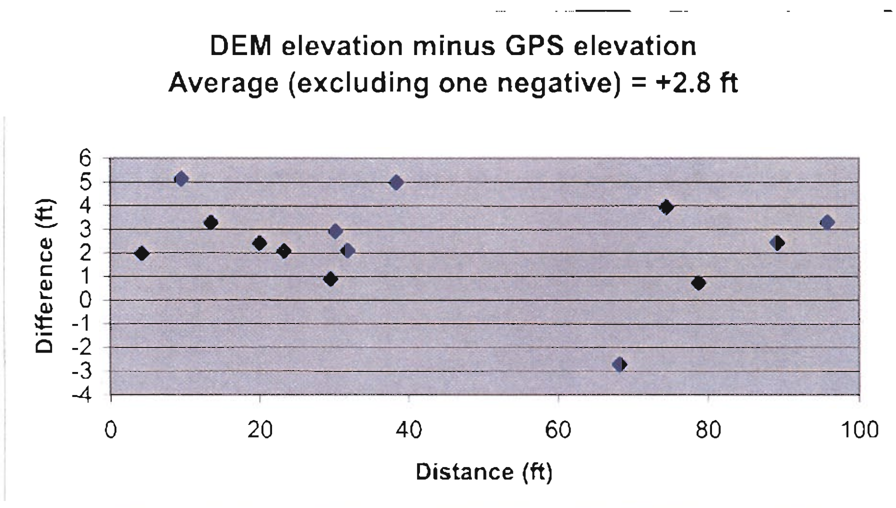

Figure 10. Bias in Digital Elevation data – comparison to GPS elevations

The microtopograhy of the beach ridge influences the exact location of ground-water discharge. To investigate this effect, a surveyor from the Wisconsin Department of Natural Resources (Ken Anderson) used an advanced Global Positioning System (GPS) instrument to measure the elevation of the land surface along a transect from the bluff to Lake Michigan through wetland site #1 in Figure 6.

The undulations in the land surface correspond to the muted ridge and swale topography of the beach ridge. The exact location of the wetland corresponds to one of the north-south trending swales crossed by the transect (Figure 11).

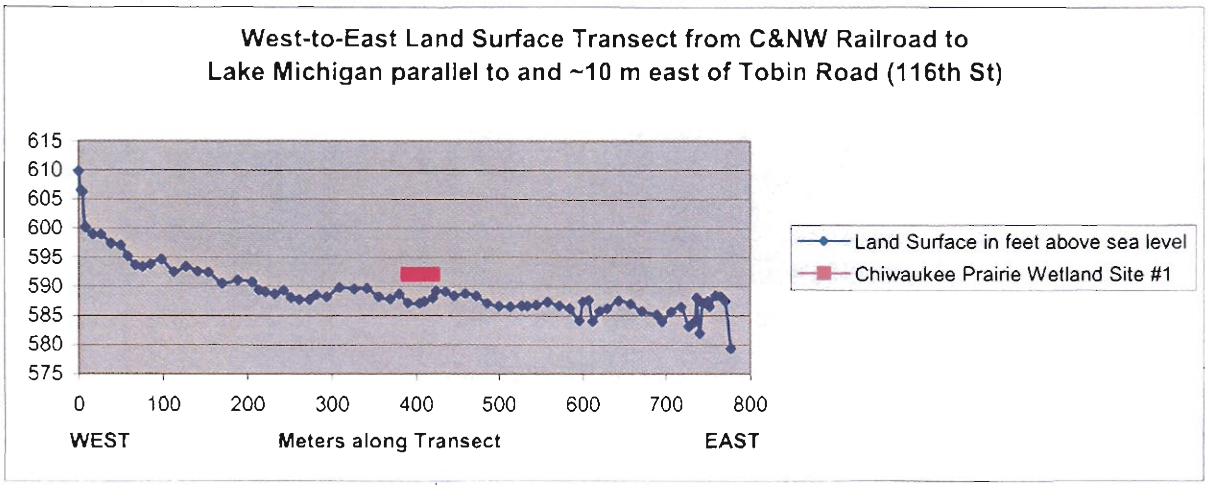

Figure 11. Chiwaukee Prairie: Microtopography from railroad bluff to Lake Michigan at Wetland #1. Distances in meters. Elevations in feet.

Well Installation and Monitoring

Six water-table monitoring wells and three deeper piezometers were installed by USGS personnel as part of this study and monitored by students under the direction of Prof. John Skalbeck at University of Wisconsin-Parkside. Their locations, corresponding to the three coastal wetlands, are shown in Figure 12. Site #1 falls within the Chiwaukee Prairie wetland.

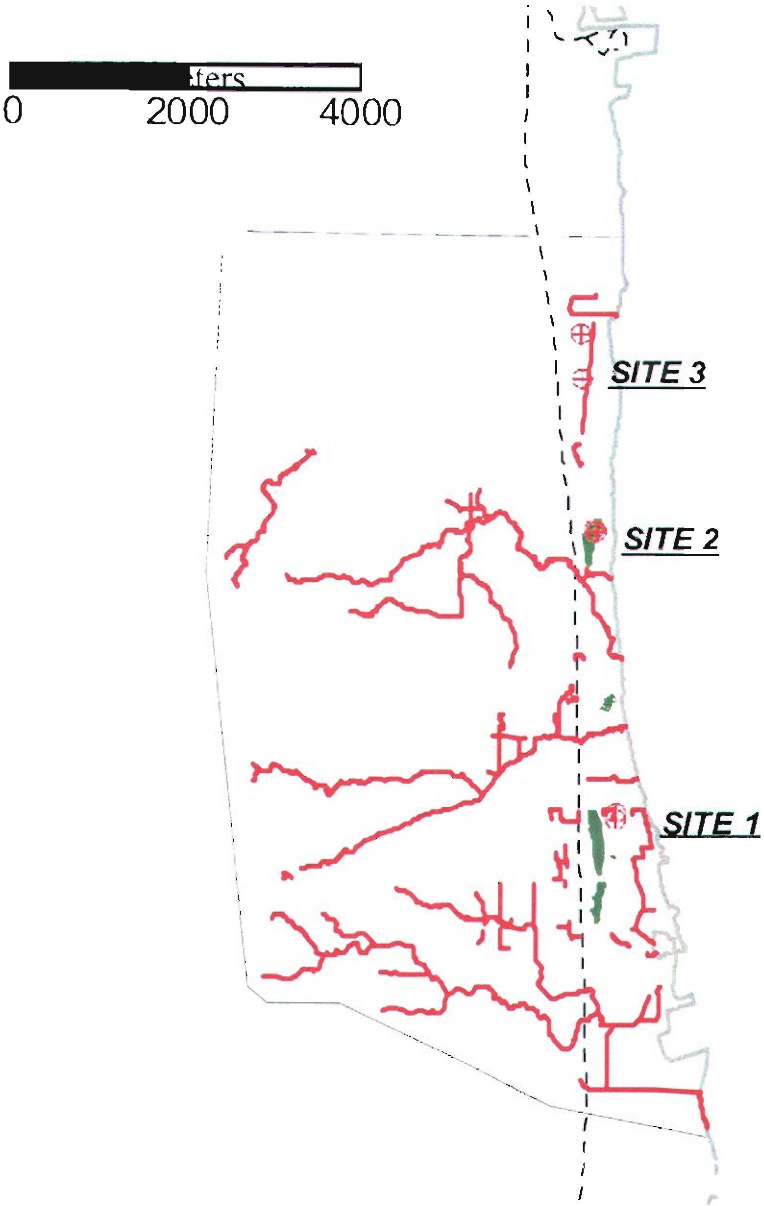

Figure 12. Sites of new monitoring wells and piezometers.
Red crosses show well locations. Red lines are surface-water bodies. Green areas are fens.

The initial borings at the three sites showed that the beach deposits consisted chiefly of sand in the southern and middle locations, but that the northern location was underlain by more fine-grained and heterogeneous deposits. Figure 13 contains geologic logs showing the various materials encountered at the three sites.

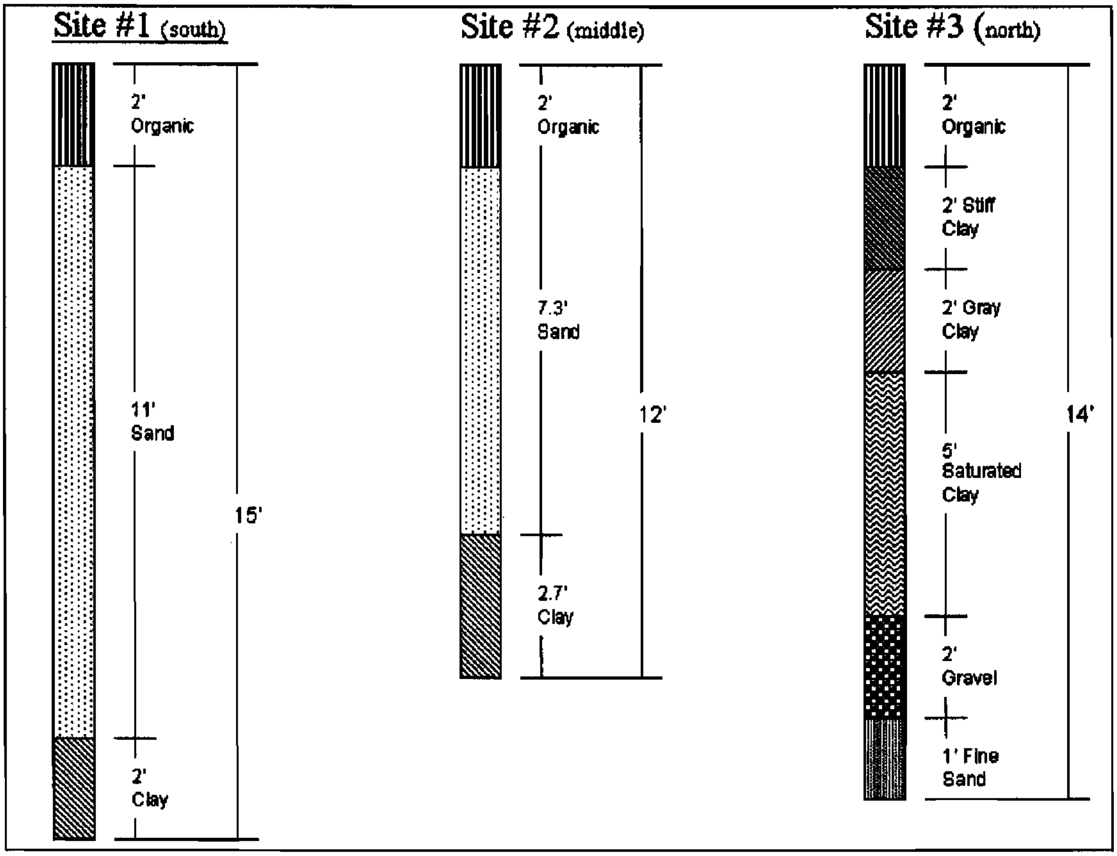

Figure 13. Geologic Borings.

At each site, three wells were installed using a USGS Geoprobe rig. One water-table well at each site was placed in an area characterized by prairie-type vegetation; a second water-table well was placed in an area characterized by sedge-like vegetation. At each site the water-table well at either the prairie or sedge setting was accompanied by a one piezometer open at a greater depth so that vertical gradients at the wetland site could be recorded. Table 1 lists the wells by wetland site and identifies the part of the wetland sand where the nested pair of wells is located.

Table 1. Naming conventions for new wells.

The USGS wells are named as follows (S is sedge, P is Prairie, MW is water table, PZ is piezometer):

Site #1	
North:	MW1-P
South:	MW1-S
	PZ1-S
Site #2	
Northwest:	MW2-P
	PZ2-P
Southeast	MW2-S
Site #3	
North	MW3-P
South	MW3-S
	PZ3-S

Ground-water levels were recorded continuously at the water-table monitoring wells and manually at the piezometers. Part of the data record for each of the three sites is shown in Figure 14. Knowledge of the range of water-table elevations at each site provides calibration targets for the ground-water model to match.

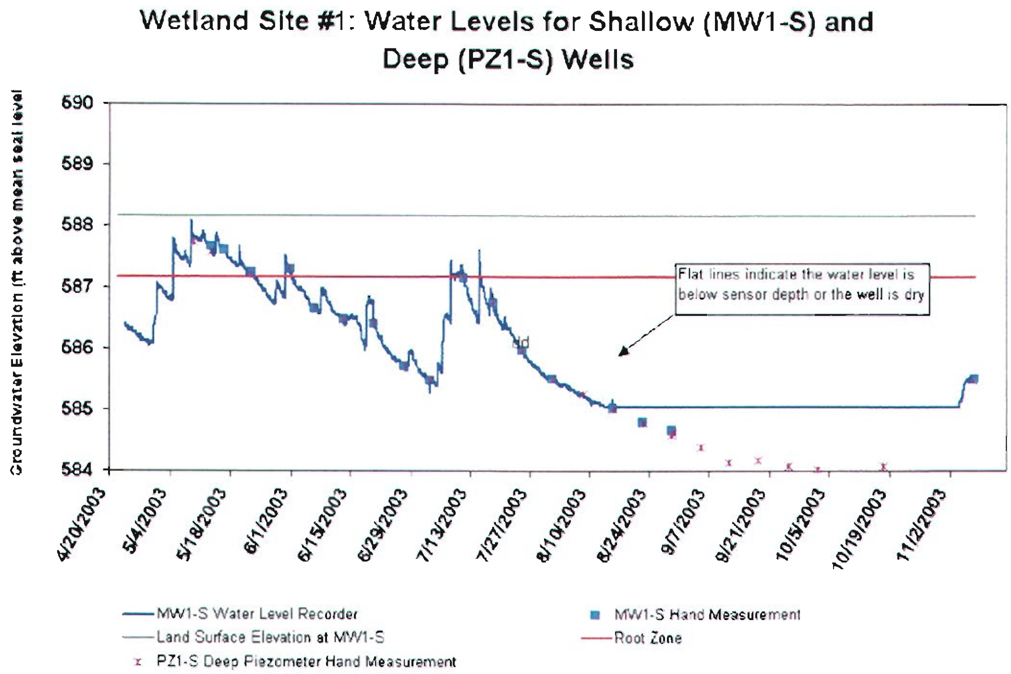

Figure 14a. Measured water levels in the sedge meadow at Site #1.

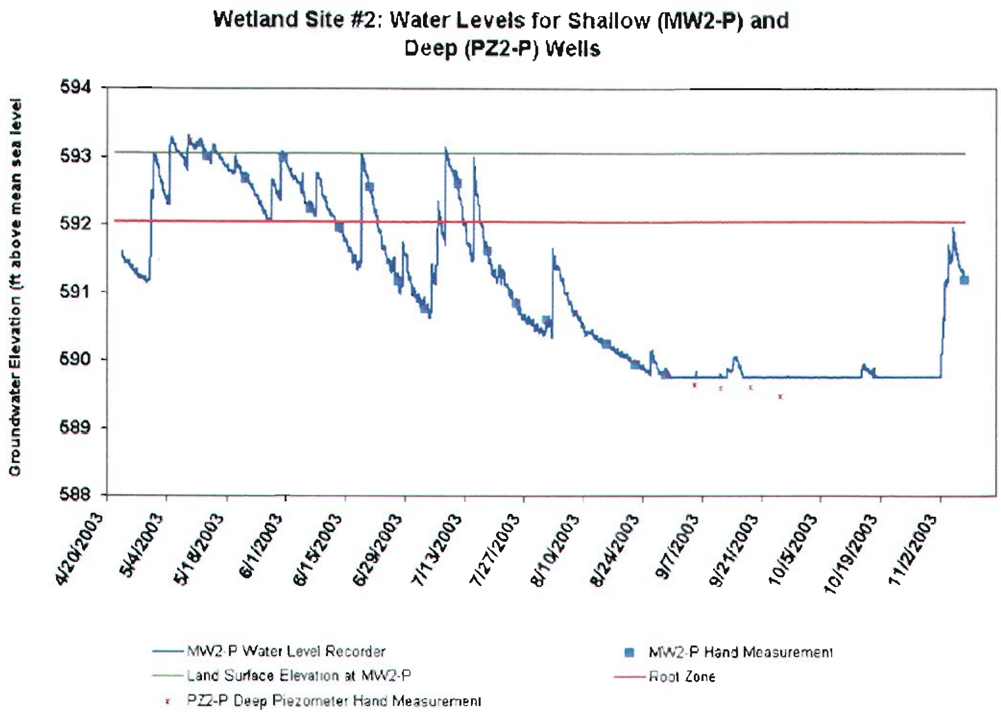

Figure 14b. Measured water levels in the wet prairie at Site #2.

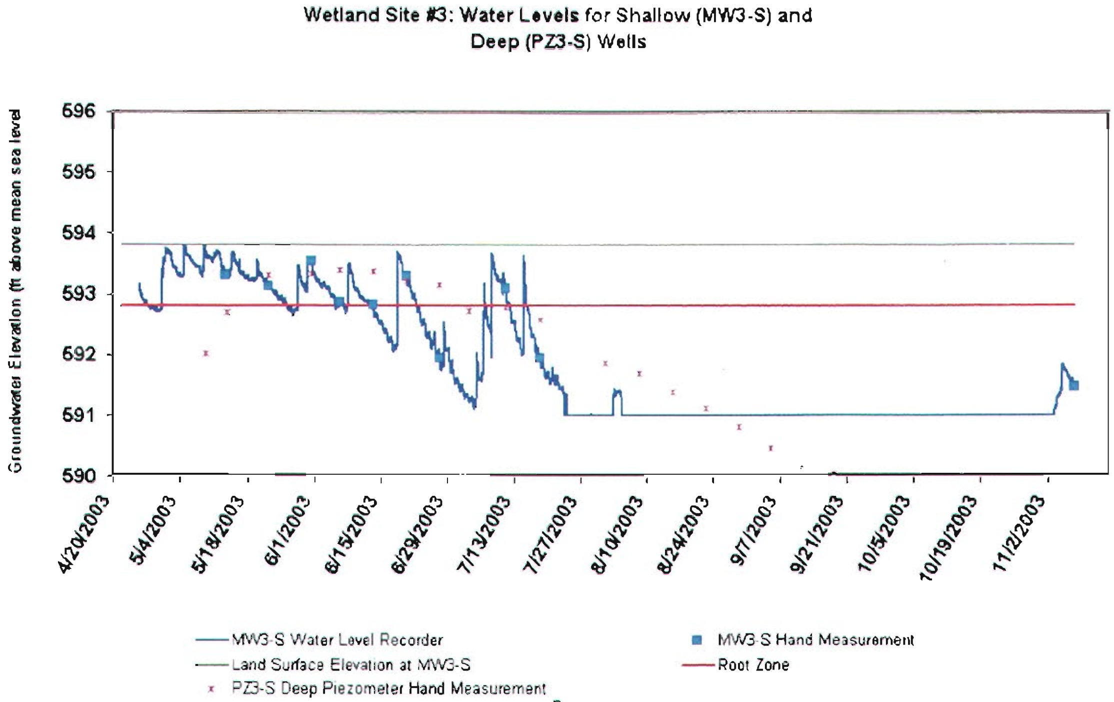

Figure 14c. Measured water levels in the sedge meadow at Site #3.

No wells were installed in the uplands as part of this study. As a result, other sources of data were needed to provide observations against which the model could be calibrated. Well construction logs provided by drillers are one such source. However, examination of these logs showed that the water levels recorded by the drillers were commonly 20 feet below land surface (Figure 15). Given the presence of perennial creeks throughout the study area, it is very unlikely that the water-table elevation is in fact so deep. The most probable explanation for this discrepancy is that the water levels in the unconfined aquifer had not recovered to their true static elevation when measured by the drillers.

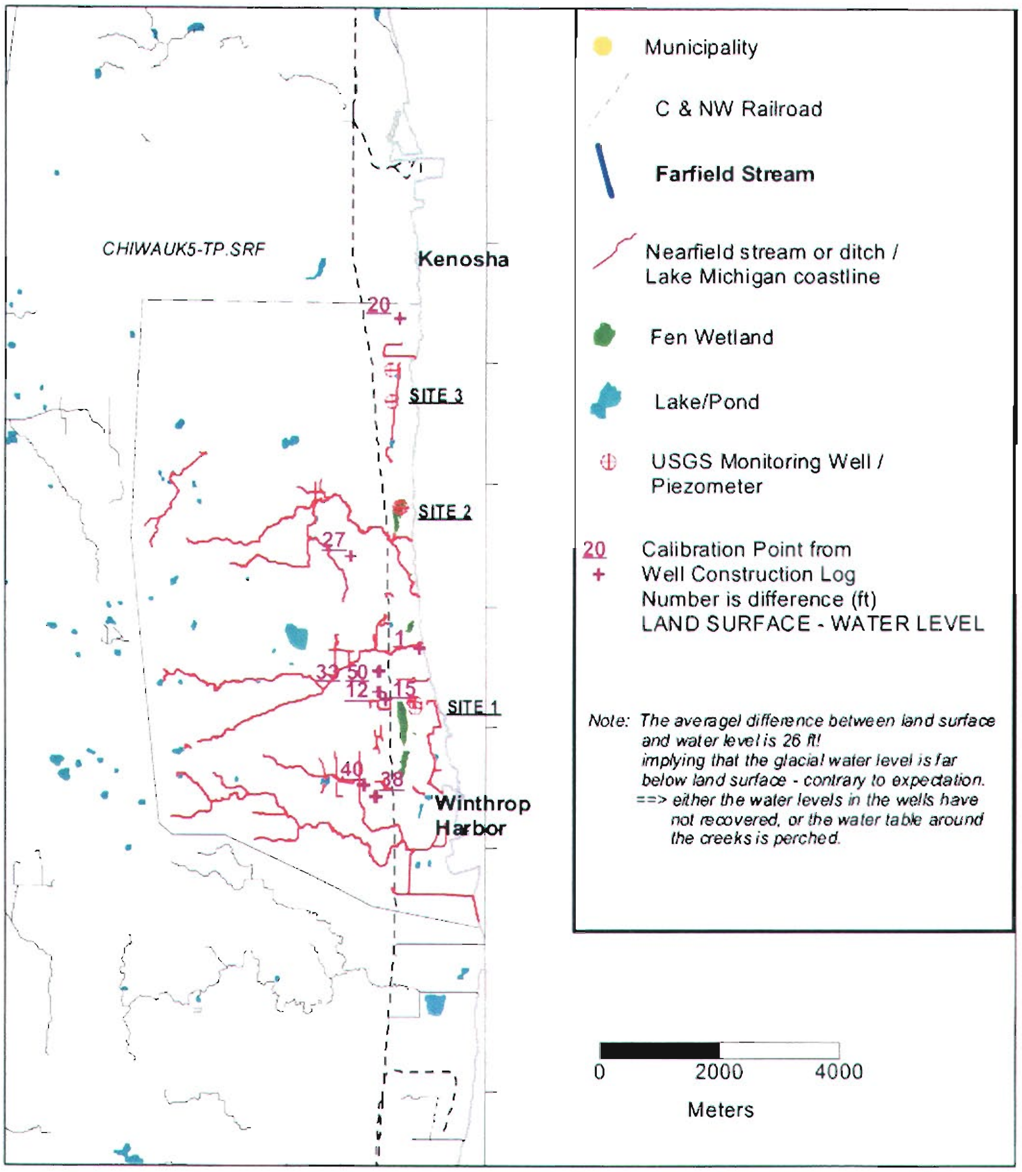

Figure 15. Depth to water in well-construction logs.

As an alternative to water levels from well construction logs, the water-table output of the model was calibrated to depths below the land surface prescribed for different areas of the model domain. East of the bluff, the water table is expected to be very close to the surface and, therefore, the calibration target is the approximate land surface elevation. In the area west of the bluff the water table is expected to be one to five feet below the land surface. In the highest parts of the moraine near the divide with the Des Plaines River, the water table is expected to be ten or more feet below land surface. These general targets are based on professional judgment given the common behavior of unconfined systems in till-dominated settings and in coastal environments.

Stream Gaging

The model simulates not only water-table elevations across the study area, but also ground-water baseflow to different watercourses. As part of the field study undertaken for this project, flow in three creeks was measured at two different times with standard USGS stream-gaging equipment. Figure 16 shows the location of these baseflow targets.

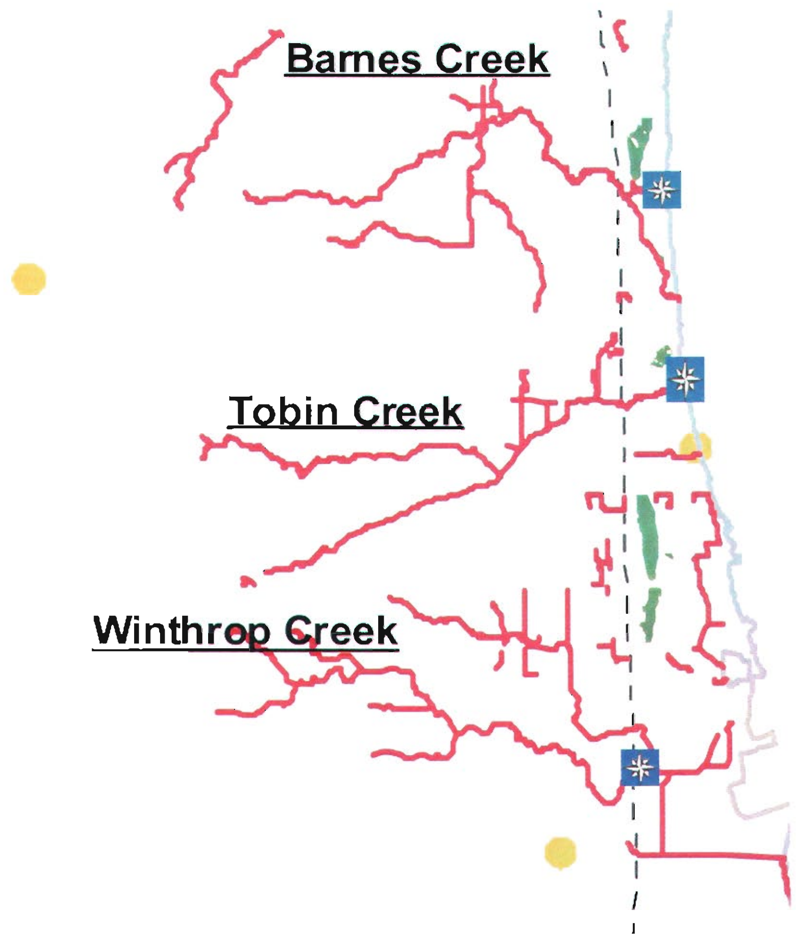

Figure 16. Streamgage locations.

Stream gaging is conducted by measuring the flow velocity at many stations along a transect that intersects the entire stream channel, integrating the velocities across the cross-sectional area each station represents, and then summing the individual discharges to estimate the total streamflow in the channel. The following table reports the number of stations and the total streamflow, in units of cubic feet per second, at the three sites for the two measurement dates:

Table 2. Streamflow measurements.

Creek	Date	Number of Stations	Integrated Streamflow (cfs)
Barnes	8/29/03	12	0.095
Barnes	11/02/03	32	2.061
Tobin	8/29/03	16	0.150
Tobin	11/02/03	36	0.524
Winthrop	8/29/03	10	0.131
Winthrop	11/02/03	34	1.922

The data collected at the streamgage locations cannot be used directly to estimate ground-water baseflow. The reason is that the flow measured during the two time periods is a mixture of baseflow and surface runoff. Statistical methods exist to separate the two components, but they cannot be calculated from snapshots of streamflows.

At high level of flow, for example when the rate is exceeded only 10% of the time, surface runoff accounts for almost all the stream discharge. At low levels of flow, for example when the rate is exceeded 90% of the time, ground water baseflow accounts for almost all the stream discharge. In general, the total ground-water baseflow component falls between the flow exceeded 50% of the time and the flow exceeded 80% of the time. These two flows are called the Q_{50} and the Q_{80} for the stream. In till-dominated areas where surface runoff is relatively high, the ground-water baseflow is likely to fall between the Q_{65} and Q_{80} flows.

There is no historical record of streamflow for Barnes, Tobin, or Winthrop Creek. However, such a record does exist for the nearby Des Plaines River – it is shown in Figure 17.

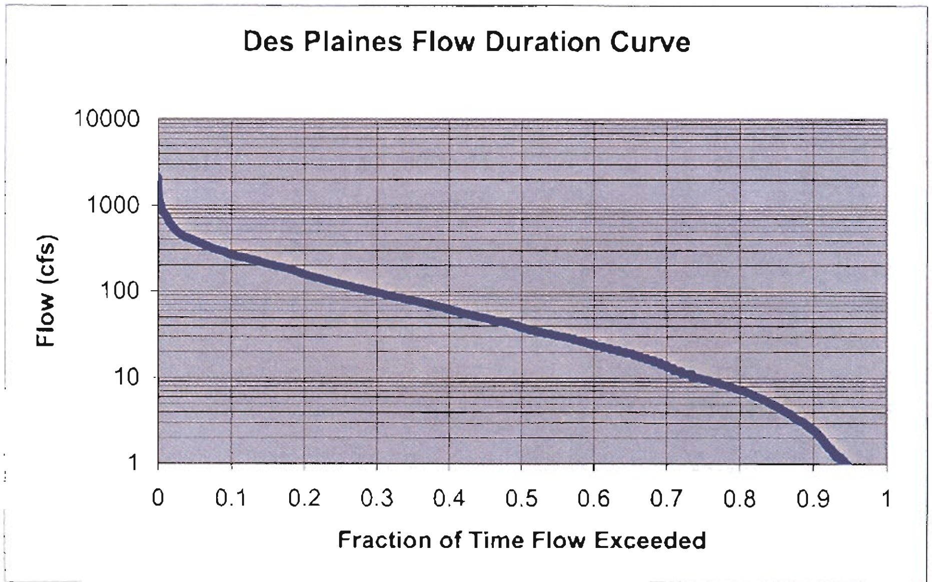

Figure 17. Des Plaines Flow duration curve used to calculate baseflow at flux targets.

Given this record, it is possible to determine the relative flow for the Des Plaines on the dates the gage measurements were made on the local creeks. The two sets of measurements were made on August 29, 2003 and November 2, 2003. For the first date (a dry period), the flow in the Des Plaines corresponded to the Q_{95} of the flow duration curve. For the second date (a wet period), the flow in the Des Plaines corresponded to the Q43 of the flow duration curve.* If the assumption is then made that the flows in the creeks also corresponded to *their* Q_{95} and Q_{43} values, then it is possible to estimate the Q_{65}, and Q_{80} for the creeks. Table 2 describes the details of this procedure. The result is a set of flow values for each creek that provide a range for each measurement date within which the ground-water baseflow is likely to fall. Examination of the bottom of the table shows that the estimated range for Barnes Creek and Winthrop Creek are fairly narrow and fairly consistent for the two measurement dates. They provide good calibration targets at the gage locations for the simulated ground-water baseflow.

* The Des Plaines streamflow from November 3, 2003 was used in the calculation because its flow in the presence of rainfall and runoff from a large basin lags behind the flow of creeks draining small basins.

Table 3. Calculation of baseflow estimates (cfs).

Measured fluxes at streams in Chiwaukee study area:

	8/29/03	11/02/03
Barnes (artificial outlet)	0.095	2.061
Tobin	0.150	0.524
Winthrop	0.131	1.922

Notes:

1) 8/29/03 represented very low flow period. Difficult to make measurements.
2) 11/02/03 represented rainy period. Flux was rising quickly.

Analysis:

1) Correlate measured fluxes with Des Plaines gaging station at Russell Road (# 05527800)
2) Assume that 11/03/03 value at Des Plaines corresponds to 11/02/03 value at 3 flux target locations (given lag time for larger stream).
3) On 11/03/03, Des Plaines flux was 51.0 cfs, corresponding to Q43 flow duration.
4) Flow duration data for Des Plaines implies that Q80:Q43 = 0.12. Q50:Q43 = 0.67. Q65:Q43=0.32.
5) To calculate range for baseflow targets, multiply measured fluxes by 0.12x to get Q80 estimate and by 0.67x to get Q50 estimate.

The corresponding calculation for 8/29/03, a day of very low but stable flow, assumes

1) Correlate measured fluxes with Des Plaines gaging station at Russell Road (# 05527800)
2) Assume that 8/29/03 value at Des Plaines corresponds to 8/29/03 value at 3 flux target locations because Des Plaines flows stable over previous and following days
3) On 8/29/03, Des Plaines flux was 1.50 cfs, corresponding to Q95 flow duration.
4) Flow duration data for Des Plaines implies that Q80:Q95 = 4.2 Q50:Q95 = 22. Q65:Q95 = 11.
5) To calculate range for baseflow targets, multiply measured fluxes by 4.2x to get Q80 estimate and by 22x to get Q50 estimate.

Baseflow targets (cfs)	11/02/03		8/29/03	
	Q80	Q65	Q80	Q65
Barnes (artificial outlet)	0.25	0.66	0.4	1.0
Tobin	0.06	0.17	0.6	1.6
Winthrop	0.23	0.62	0.55	1.4

Model Construction

The software used in constructing the model for this study is GFLOW2000 (Figure 18).

Figure 18. Ground-water flow code (Haitjema 2000).

This program belongs to the category of analytic element (AE) groundwater codes. The AE method superimposes a series of closed-form analytic solutions that reproduce different aspects of the ground-water system. The method has been extensively documented (Strack, 1989; Haitjema, 1995), and has been successfully used in hydrologic settings throughout Wisconsin (for example, Hunt and Krohelski, 1996, Hunt et al., 2000,).

The GFLOW2000 (GFLOW) model is a single-layer, steady-state code, in which the aquifer is assumed to be infinite. The model uses the Dupuit-Forchheimer approximation by which a three-dimensional-flow problem is reduced to a two-dimensional, horizontal-flow problem. For this approximation to be appropriately applied, the length of a flowline must be large compared to the aquifer thickness. Within the study area, the unconfined glacial aquifer averages about 100 ft thick while the length of the flow path from the surface-water divide to Lake Michigan is on the order of 20,000 feet. Therefore, this aquifer is very thin relative to its horizontal extent, suggesting that ground-water flow in this setting is essentially a horizontal-flow problem and can be appropriately evaluated using a Dupuit–Forchheimer approximation.

This GFLOW model contains a conjunctive solution (Mitchel-Bruker and Haitjema, 1996) that considers both surface-water and ground-water flow. Because of the close connection between surface water and ground water in and around the wetlands, the ability of GFLOW to integrate the two systems is central to the modeling effort. Important hydrologic features (rivers, streams, and lakes) are represented in the GFLOW model domain as analytic elements or strings of analytic elements (linesinks). Each element provides an analytic solution to the ground-water-flow equation, and the addition of individual solutions provides a solution for the ground-water-flow system.

Values for aquifer parameters and recharge rate can vary across the GFLOW model domain. The model domain is comprised of a farfield and a nearfield (Figure 19). The farfield is beyond the area of interest, but is included in the model to define hydrologic boundary conditions for the nearfield. Farfield elements are constant-head boundaries and near-field elements are head-dependent boundaries. Farfield elements are usually coarsely defined and consist only of water-level information, estimated using USGS topographic or DEM data. The nearfield is the area of primary interest and contains important local hydrologic detail; that is, areas where recharge and/or aquifer parameter values differ from regional values. A hydrologic inhomogeneity is represented in the GFLOW model by a closed set of elements within which the non-regional parameter values are present. Nearfield analytic elements are made to more closely match the geometry of surface-water features, thus, require more linesink vertices and solutions. Solutions for nearfield elements also require information on the width and resistance of the represented feature.

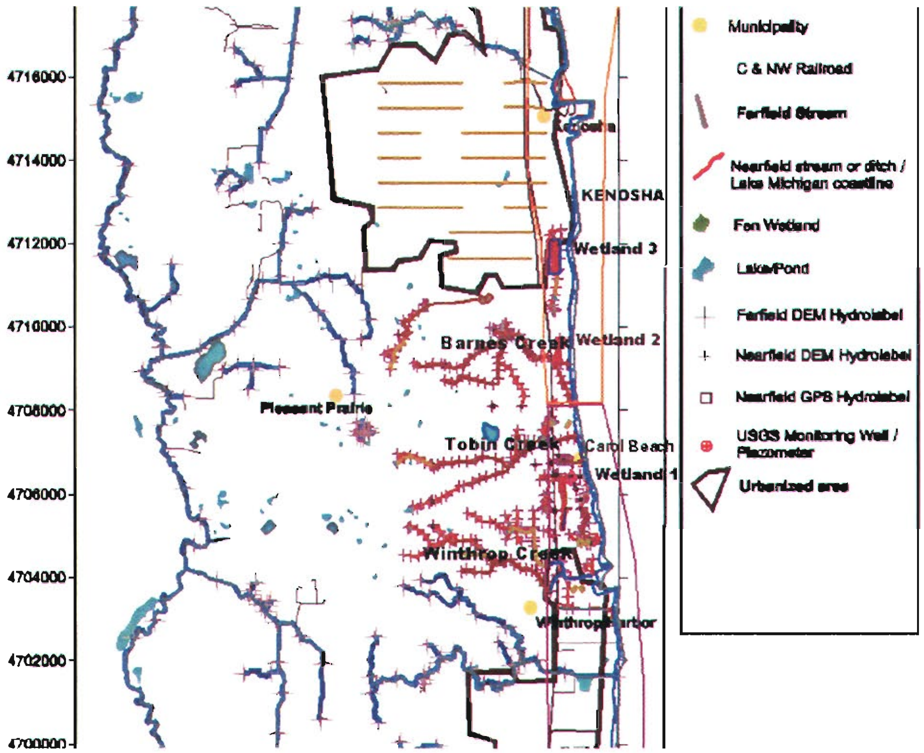

Figure 19. Elements of GFLOW model.

Blue lines are farfield linesinks
Purple crosses mark known elevations along nearfield linesinks
Olive lines are sewer drains underlying Kenosha
Orange border encloses a high-recharge beach zone underlain by fine sediments
Purple border encloses a high-recharge beach zone underlain by coarse sediments
Zone west of beach is low-recharge moraine inhomogeneity underlain by fine sediments
Wetlands 1, 2 and 3 are represented by model drains at elevation 1 ft below land surface
Lake Michigan represented by linesink set to 577 ft elevation

The GFLOW model domain is not discretized into a grid; therefore, an exact solution for the flow equation can be calculated at any point in the domain. As a result, interpolation of heads or velocities is not necessary. Flow can also be examined at various scales without changing model input parameters or boundary conditions. This allows one GFLOW model to act as both a regional and site-scale model without modification.

The model contains three hydraulic conductivity (K) zones and three recharge zones (Figure 19). The first K zone corresponds to the upland moraine west of the bluff that separates it from the beach deposits. The clay-rich glacial sediment in this zone is expected to have a relatively low permeability. Two K zones correspond to the beach-ridge plane east of the bluff where some sand deposits overlie till. The section of the beach-ridge plain located north of Barnes Creek is expected to have lower permeability than the southern part. This assumption is based on the morphology of the deposit (Chrzastowski, 2001) and the logs from the geologic borings installed at the site. It is worth pointing out that GFLOW is a one-layer ground-water flow code, and, therefore, the K value assigned to an area underlain by multiple strata (i.e., sand and till) is a "composite" hydraulic conductivity that reflects the K of each strata weighted by its thickness.

The first recharge zone includes most of the upland moraine west of the bluff. The recharge rate is expected to be relatively low because the fine-grained till at the surface enhances surface runoff. In the area of the model occupied by the city of Kenosha, the recharge is expected to be very low because paved surfaces block infiltration. The third recharge zone corresponds to the beach plane area. Because it is flat and sandy, the recharge rate is expected to be relatively high near the coast.

In summary, there is a relatively low regional recharge value and a relatively low regional K value assigned to the upland moraine; there is a higher recharge value assigned to the beach area which is divided between relatively low and relatively high K zones; and there is zero recharge assigned to the urbanized area of Kenosha along with a relatively low K value.

Lake Michigan is represented by two linesinks in the model. One nearfield linesink follows the coastline. It is given some resistance to reproduce the loss of head as ground water moves from the glacial sediments through the lakebed. The second farfield linesink parallels the first a short distance to the east. Both linesinks are given a stage of 577 feet, corresponding to the average measured Lake Michigan elevation in 2003. The effect of the double linesink is to ensure that all the discharge to the Lake derives from its landward side.

The other nearfield linesinks in the model are divided into two types. Those with running waters (e.g., Barnes Creek) are given a relatively low resistance because the streambed is assumed to be relatively permeable. Those with standing water (e.g., ponds or wetland) are given a higher resistance to simulate the effect of the buildup of fine, organic-rich material. The stages of all water bodies are assigned based on GPS elevations, if available; otherwise they are assigned based on DEM data adjusted for the expected 3-foot bias. The widths of bodies with running water are, in some cases, based on field observation, in other cases derived from topographic maps. The widths of ponds and wetlands input to the model correspond to the extent of the water body that has active exchange with the ground water, calculated using the methodology of Hunt et al. (2003).

In the case of the nearfield creeks, the simulated flow along linesinks that represent the stream is accumulated ("routed") to allow GFLOW to calculate baseflow at the flux target locations. In the case of the wetlands, the linesinks were assigned a stage reflecting the elevation of the root zone (depth of 1 foot below land surface).

The stages of the farfield linesinks correspond to bias-corrected DEMs. A special set of farfield linesinks was used to simulate the effect of sewers below the city of Kenosha that are expected to drain ground water.

Model Calibration

The values assigned the three hydraulic conductivity (K) zones and the three recharge zones were adjusted with the aim of matching:

1) the baseflow flux targets for the three creeks;
2) the measured water-table targets at the three wetland sites;
3) the expected depth to water table in different parts of the model domain.

The depth from the land surface to the water table is calculated at about 500 points on 30-meter centers across the study area.

The first part of Table 4 shows the parameter values input to the final, calibrated version of the model. The second part shows the simulated flux to the three creeks at the gaging locations. The simulated values are compared to the Q_{80} and Q_{65} estimated flows for each creek. The third part of the table shows the simulated water-table elevations at the three wetland locations, as well as the range of observed values for the period April 2003 through November 2003. The last part of the table compiles total fluxes to different ground-water discharge locations. It is noteworthy that the model simulates that less than 30% of the recharge to the ground-water flow system within the Great Lakes Basin discharges directly to Lake Michigan. Most of the recharge circulates to inland surface-water bodies such as creeks, ponds, and wetlands.

The graph in Figure 20 relates the simulated water-table elevation to the land surface at points on 30-meter centers throughout the model domain. The average difference of 7.8 feet in Figure 20 is the average depth below land surface of the simulated water table. The deviations of the red crosses on the plot below the blue line indicate water-table depth below land surface. At low land-surface elevations (577 feet to 600 feet), the simulated water-table elevation is, on average, at the land surface. At moderate land-surface elevations (600 feet to 700 feet), the simulated water-table elevation tends to fall about 5 feet below land surface. At high land-surface elevations (above 700 feet), the simulated water-table elevation generally falls more than 20 feet below land surface. These results accord with the qualitative targets established for the calibration procedure.

Examination of Table 4 and Figure 20 indicate that all calibration targets are met reasonably well. The model is at the high end of the observed range of water-table elevations at two of the wetland sites and is at the low end at the third site. The simulated baseflow falls within the expected Q_{65} to Q_{80} flow duration range for the three creeks.

Table 4. Calibrated Model.

GFLOW model represents "average water" conditions as opposed to "high water" in April and May.

RUN	**FINAL**	
Lake Level	**577 ft**	
Moraine Recharge	2.5"/yr	
Beach Recharge	8"/yr	
Kenosha Recharge	0"/yr	
Moraine K	3 ft/day	
North Beach K	3 ft/day	
South Beach K	8 ft/day	
Creek Resistance	1 day	
Pond, Fen Resistance	5 days	
Bottom	Silurian top (535 ft)	
		Target
Barnes Flux	**0.66 cfs**	Q80: 0.25 to 0.4, Q65: 0.66 to 1.0
Tobin Flux	**0.35 cfs**	Q80: 0.06 to 0.6, Q65: 0.17 to 1.6
Winthrop Flux	**0.49 cfs**	Q80: 0.23 to 0.55, Q65: 0.62 to 1.4

Measured Head Targets (feet)		
Mean depth to water table	**7.8**	
Wetland 1	**588**	583-588
Wetland 2	**589.5**	589-593
Wetland 3	**593.2**	588.5-593.5

OUTPUT in cfs

Nearfield streams	**2.38 cfs**
Nearfield 0.11 cfs	
Wetland 1	**0.36 cfs**
Wetland 2	**0.00 cfs**
Wetland 3	**0.07 cfs**
Lake Michigan	**1.20 cfs**
Sum	**4.12 cfs**
% discharge to Lake	29%

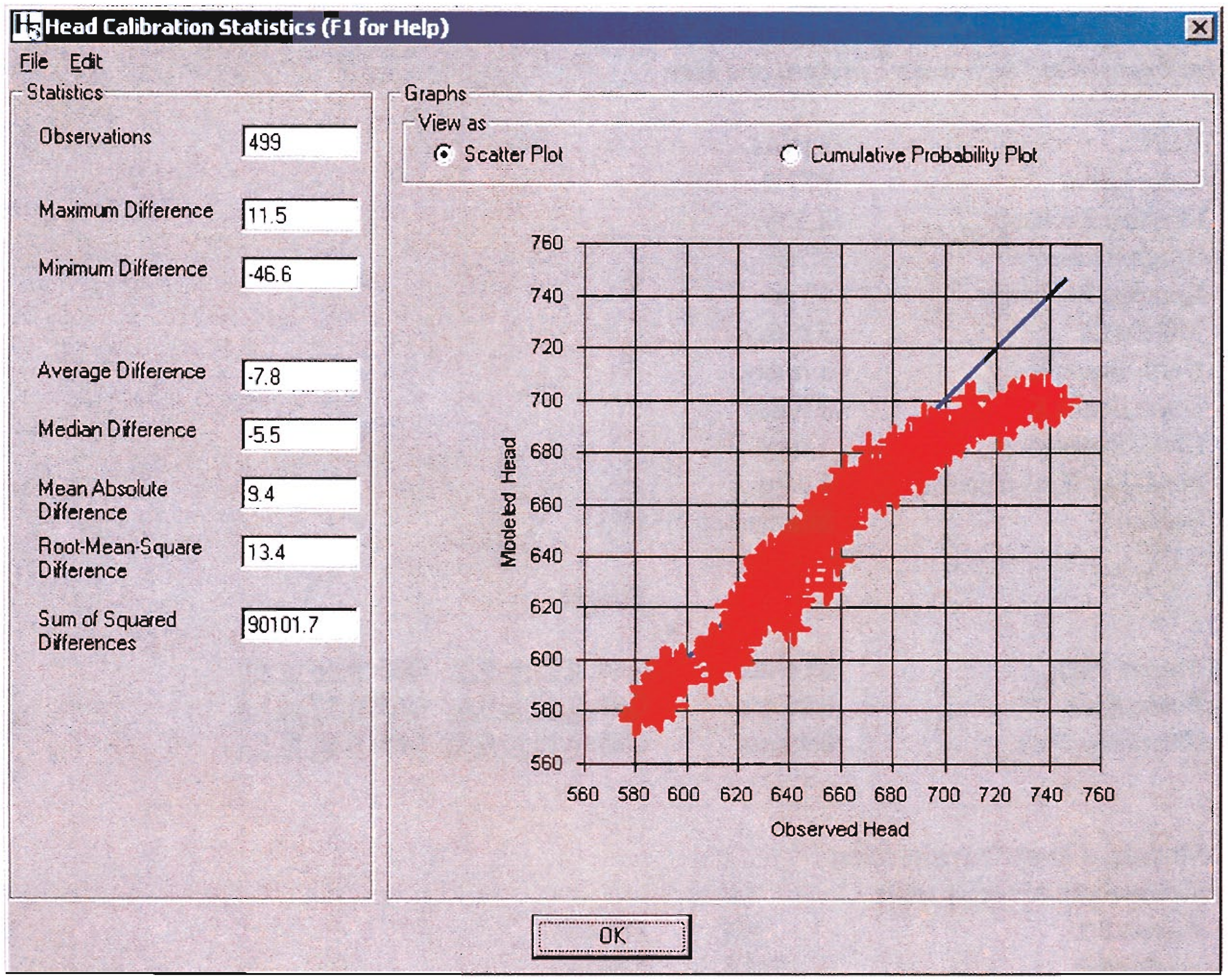

Figure 20. Calibration – Relation of Water Table to Land Surface.

The water-table output from this final simulation is shown in Figure 21. The ground-water divide between the Des Plaines basin and the Great Lakes basin cuts through the 700-foot head contour. The relative baseflow discharged to the creeks is shown in Figure 22.

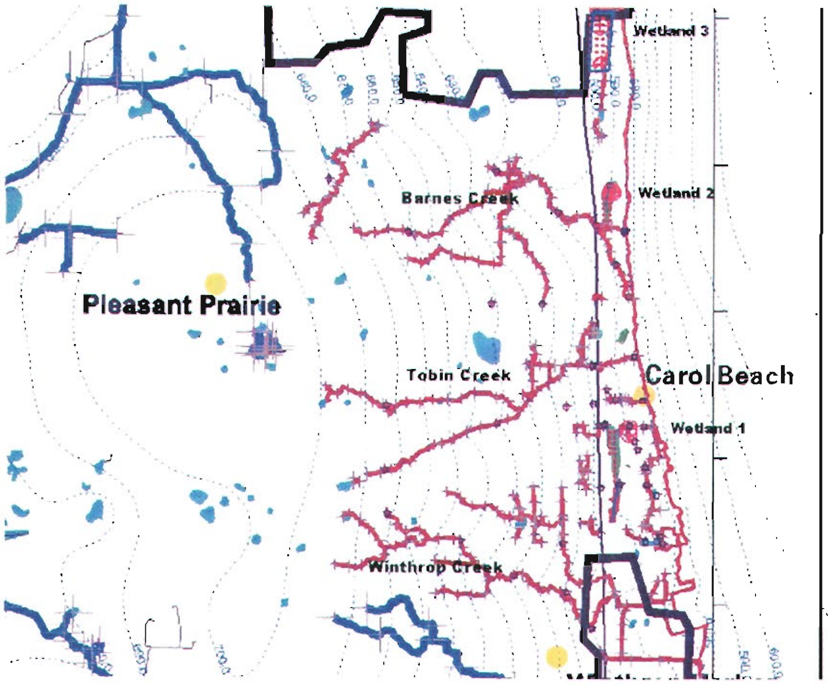

Figure 21. GFLOW results: Simulated water-table contours (in feet).

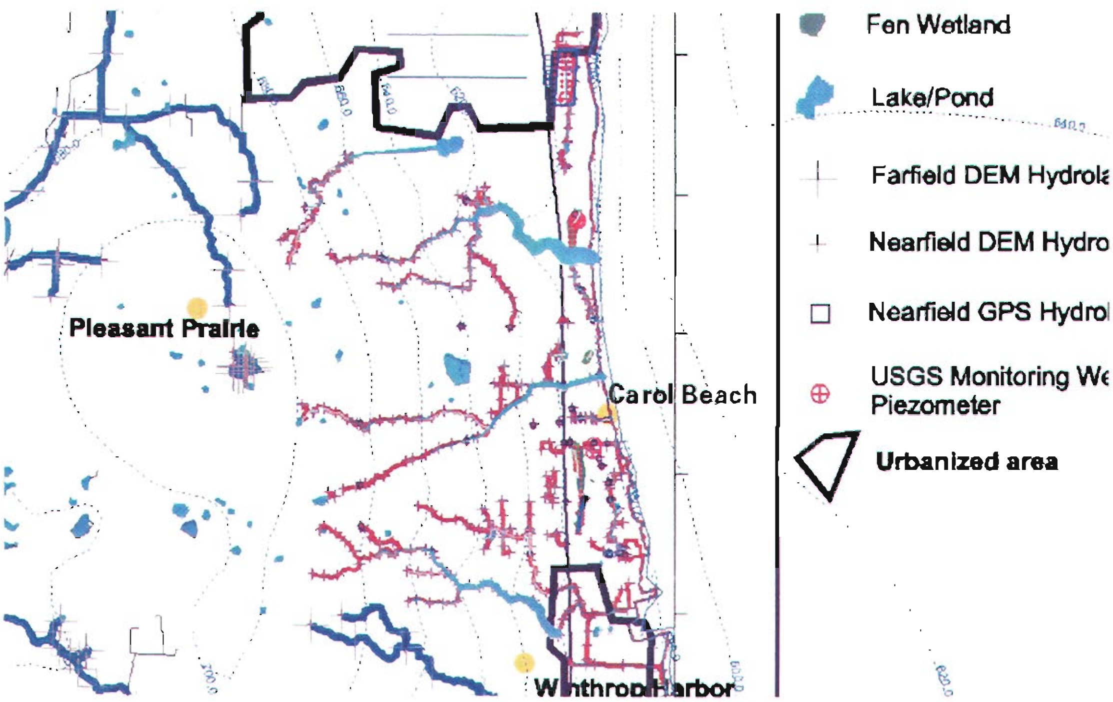

Figure 22. GFLOW results: Baseflow in streams

A series of additional runs were conducted to determine if the calibrated results were sensitive to changes to the model reflecting uncertainty about:

- the resistance of the Lake Michigan lakebed;
- the depth from which wetlands draw ground water;
- the configuration of Barnes Creeks lower channel (where an artificial outlet diverts water from the natural outlet);
- and the configuration of the ditches that drain into a harbor at the Wisconsin/Illinois boundary.

All of these changes had very small effect on the model results. In particular, they had virtually no effect on the pattern of ground-water flow to wetlands.

Model Results

The GFLOW model indicates that the ground water in the Great Lakes portion of the study area flows generally eastward from a divide located approximately 6000 meters (3.7 miles) west of the lake (Figure 23). However, the flow directions are affected by the presence of surface-water discharge (e.g., Barnes Creek).

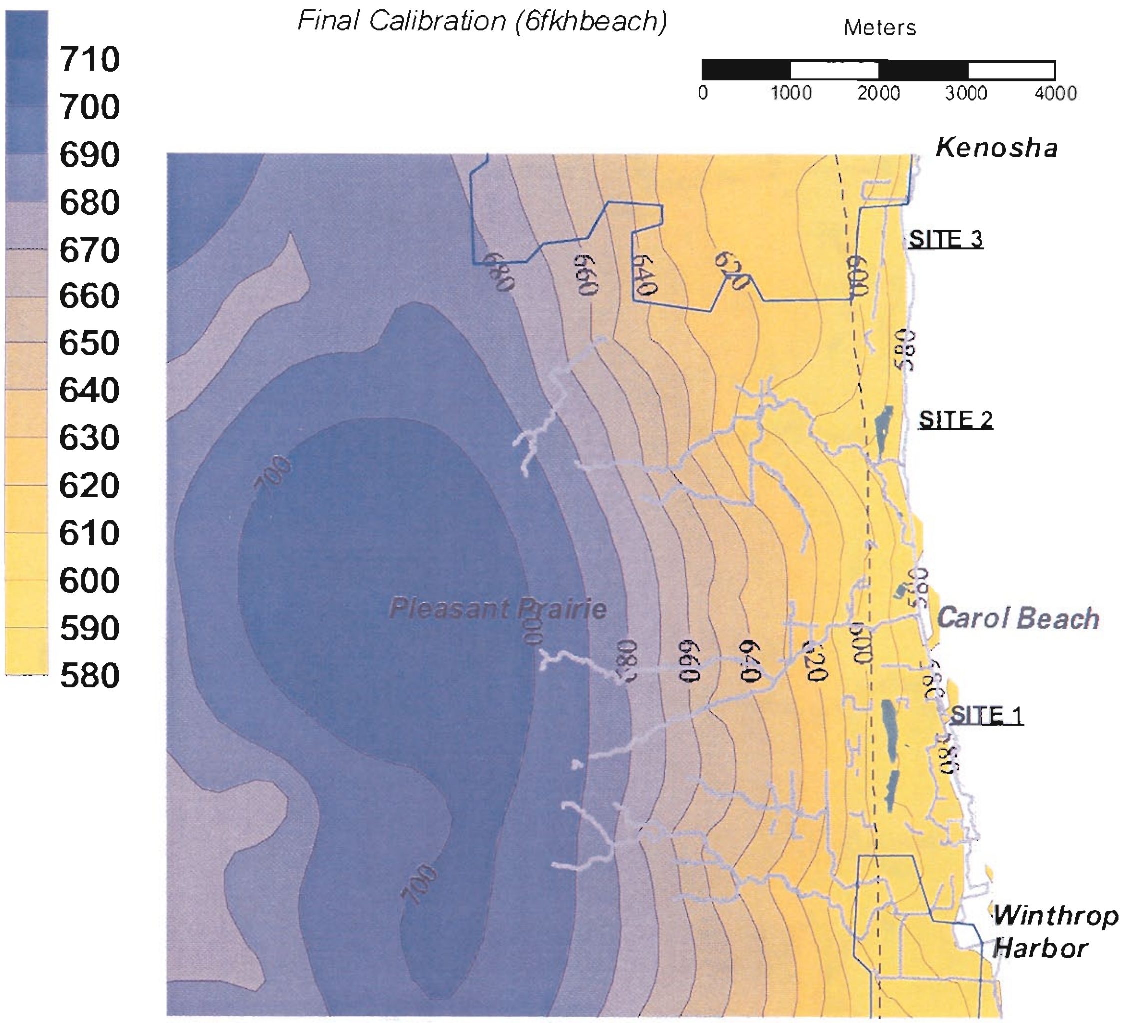

Figure 23. Color flood of GFLOW water-table output. Water table elevations in feet.

Part of the ground water flowing toward the Lake intersects wetlands. The simulated capture zones of the wetlands (that is, the part of the land surface where recharge is likely to circulate to and discharge at the wetlands) are shown by the brown pathlines in Figure 24.

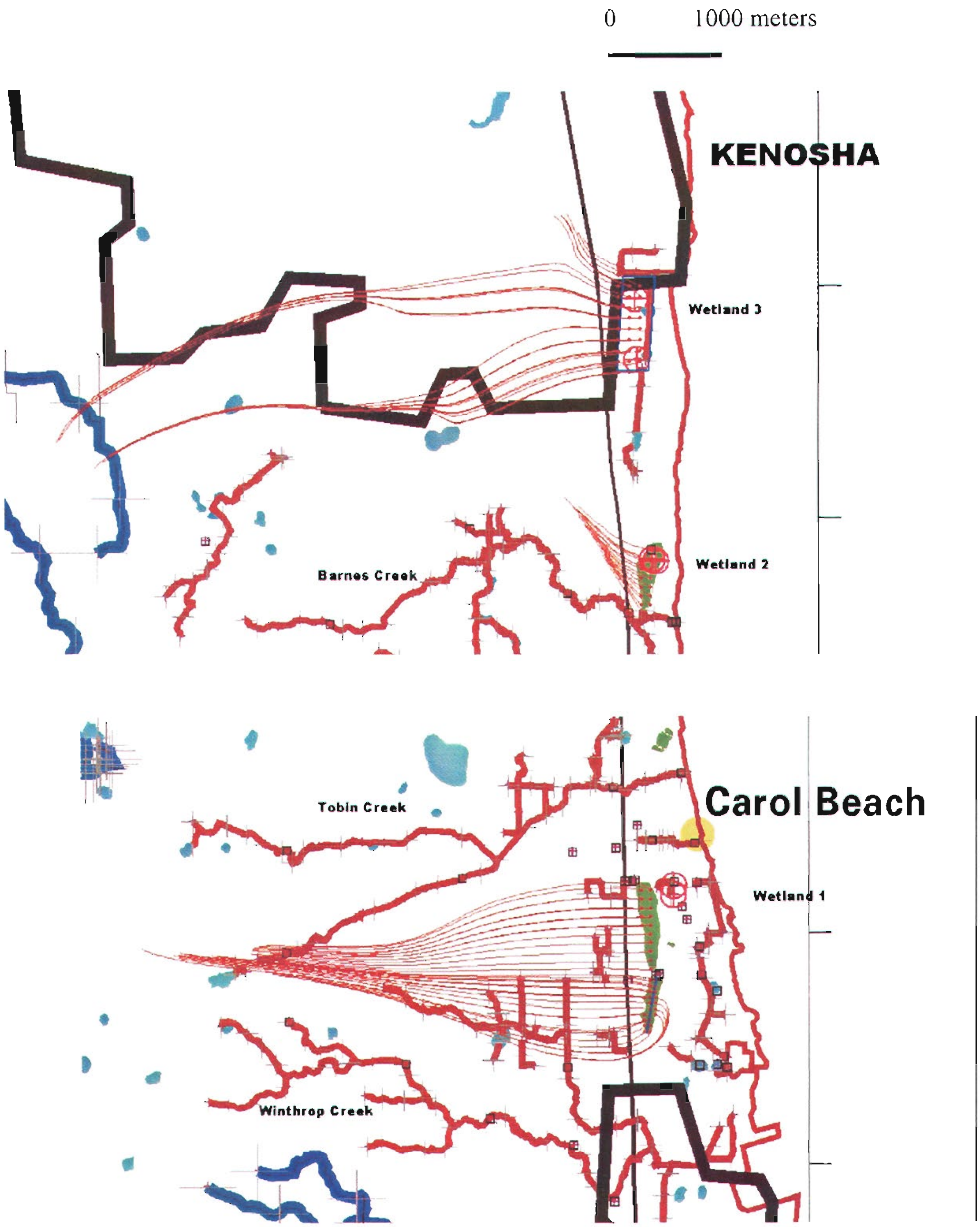

Figure 24. GFLOW results: Ground-water capture zones for wetlands.

The simulated capture zone at the southern-most wetland (site #1) extends about 3400 meters (2 miles) upgradient of the eastern edge of the Chiwaukee Prairie. According to the GFLOW model, the groundwater travel times range from 0 to 100 years and average about 25 years.*

The simulated capture zone of the middle wetland (site #2) is relatively small. It extends about 870 meters (one half mile) upgradient of the wetland and is oriented to its northwest. Ground water further to the south is diverted to Barnes Creek. The simulated ground water travel times range from 0 to 40 years and average about 15 years.

The configuration of the simulated capture zone of the northern-most wetland (site #3) is strongly influenced by the presence of paved areas to its west where recharge is small or absent. According to the model some ground water travels over 5,000 meters (over 3 miles) before discharging to this area. The wetland draws water from the north as well as the west. The range of simulated travel times is from 0 to 200 years, averaging 60 years.

* Calculation of travel times requires an additional model parameter – effective porosity. In this study a value of 10% is assumed for effective porosity to reflect the mixture of sand, silt, and clay in the glacial sediments.

Scenario Testing

The calibrated GFLOW model was applied to determine the effect of changing environmental conditions on the water-table elevation in the vicinity of the wetlands. Fluctuations in the water-table elevation can have a dramatic effect on the health of a wetland fed by ground water. In particular, falling ground-water levels can transform the wetland vegetation.

Five scenarios were simulated:

Scenario #1	Lake Michigan level (and creek outlets) rise from 577 ft to 580 ft
Scenario #2	Lake Michigan level (and creek outlets) rise from 577 ft to 583 ft
Scenario #3	Ditches installed along coastline
Scenario #4	Recharge reduced to zero due to intense development on upland moraine
Scenario #5	Recharge reduced to zero due to intense development on beach bluff

Scenarios #1 and #2 reflect the fact that Lake Michigan in 2003 stood at historically very low levels and is likely to rise in the future. The change in water-table elevations in response to rising levels is shown in Figures 25 and 26. The model forecasts that the water table around the wetland sites will respond strongly to Lake level changes.

Scenario #3 is meant to account for future action to lower water levels in the Carol Beach area by dredging existing ditches or installing new ones. Figure 27 shows the location of three hypothetical ditches dug below the water table. The locations are close to the wetland sites, but they do not cross them. It is assumed that the head in the ditches is maintained at 588 feet (by pumping), a level that is two or three feet below the average water-table elevation. The model indicates that the discharge from these ditches would be on the order of 10 to 20 gallons per minute. Figure 28 shows the simulated drop in the water table in the study area and at the wetland locations. For the ditch locations selected, the drop is generally less than 1 foot.

Scenarios #4 and #5 simulate the effect of intensive development of areas upgradient of the wetlands. In one case, land-use changes in the upland moraine are assumed to eliminate all recharge to a relatively large area. In the second case, land-use changes along the bluff are assumed to eliminate all recharge to a restricted area adjacent to the wetlands. The model forecasts that upland development would affect the wetland ground-water elevations by producing a maximum drop of about one foot. If development were to occur right up to and all along the bluff, the drop in sensitive areas could exceed 2 feet. These results suggest that the proximity of the development to the coastal wetlands is a key control on future conditions and, perhaps, is a more important factor than the size of the area developed.

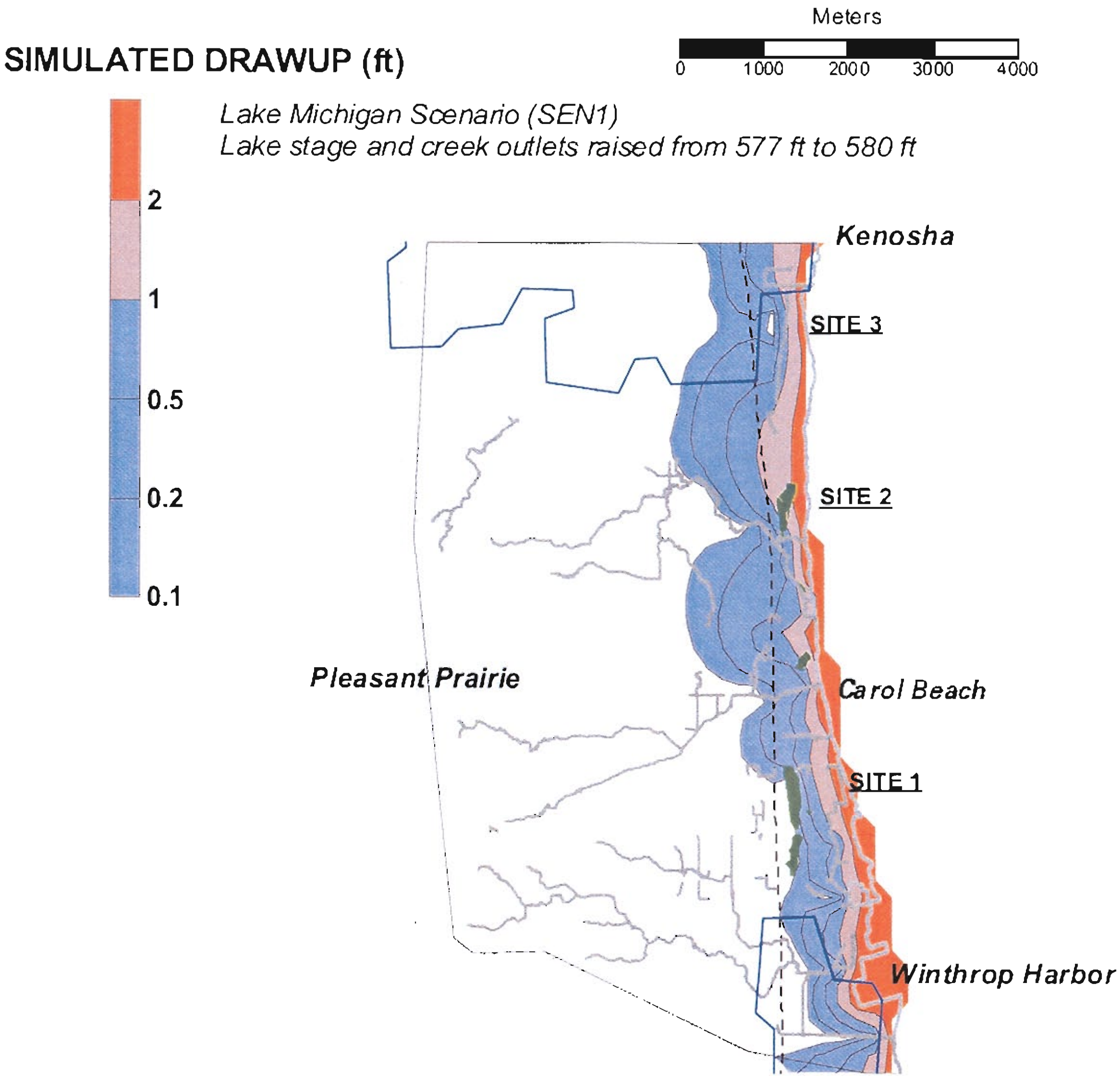

Figure 25. Scenario #1: Simulated effect of Lake Michigan level rise from 577 to 580 ft on water-table elevation.

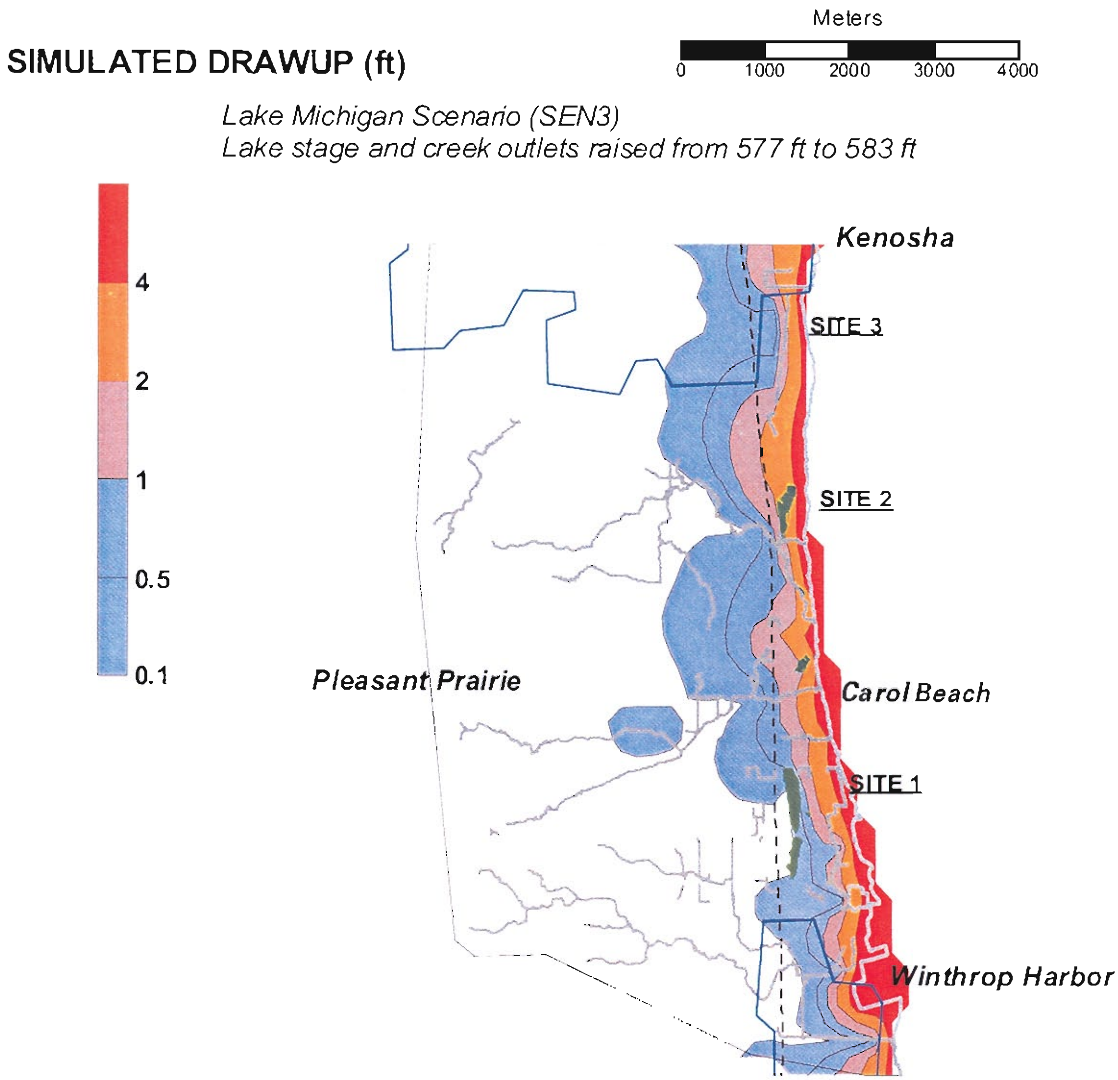

Figure 26. Scenario #2: Simulated effect of Lake Michigan level rise from 577 to 583 ft on water-table elevation.

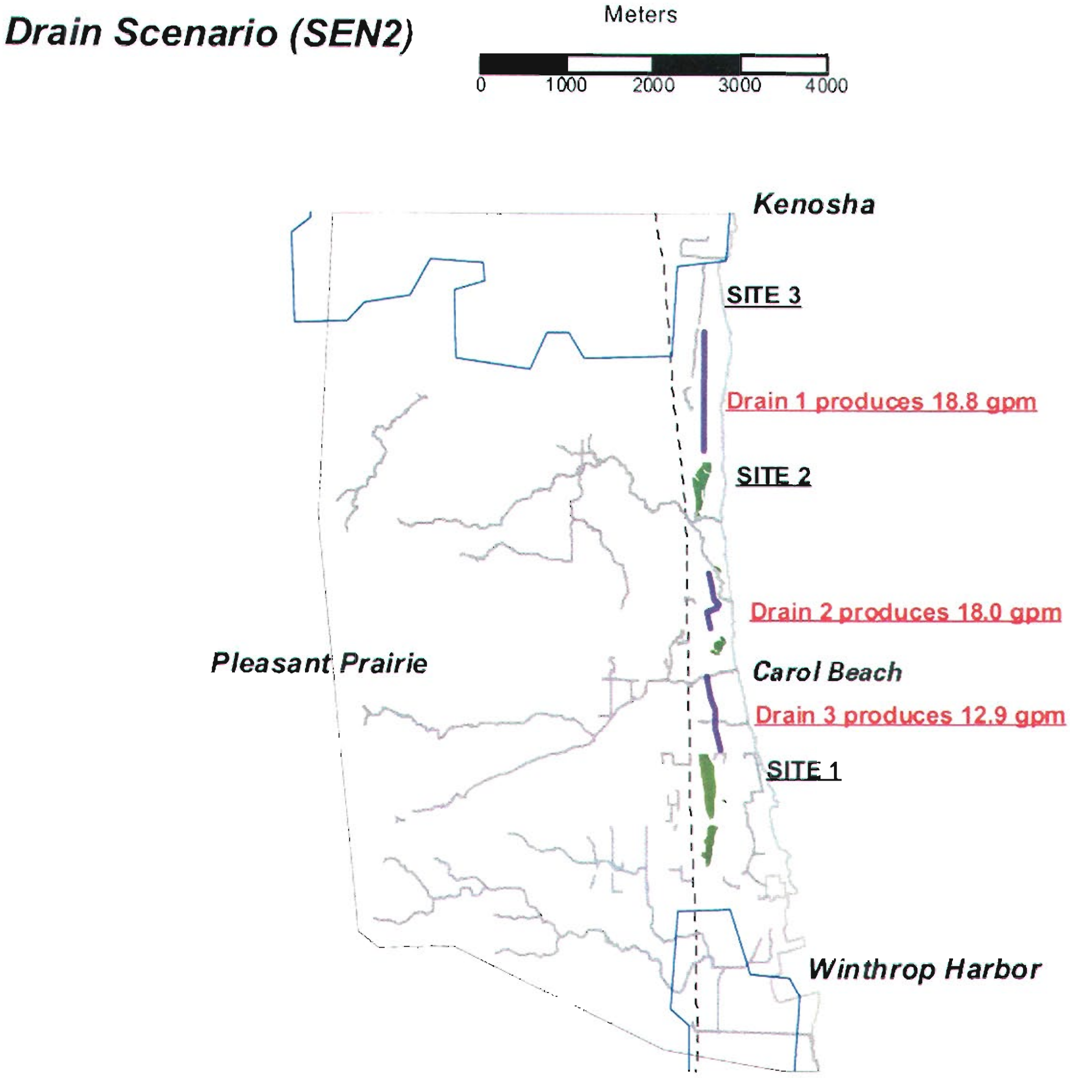

Figure 27. Scenario #3: Hypothetical drains for dewatering - location and simulated discharge.

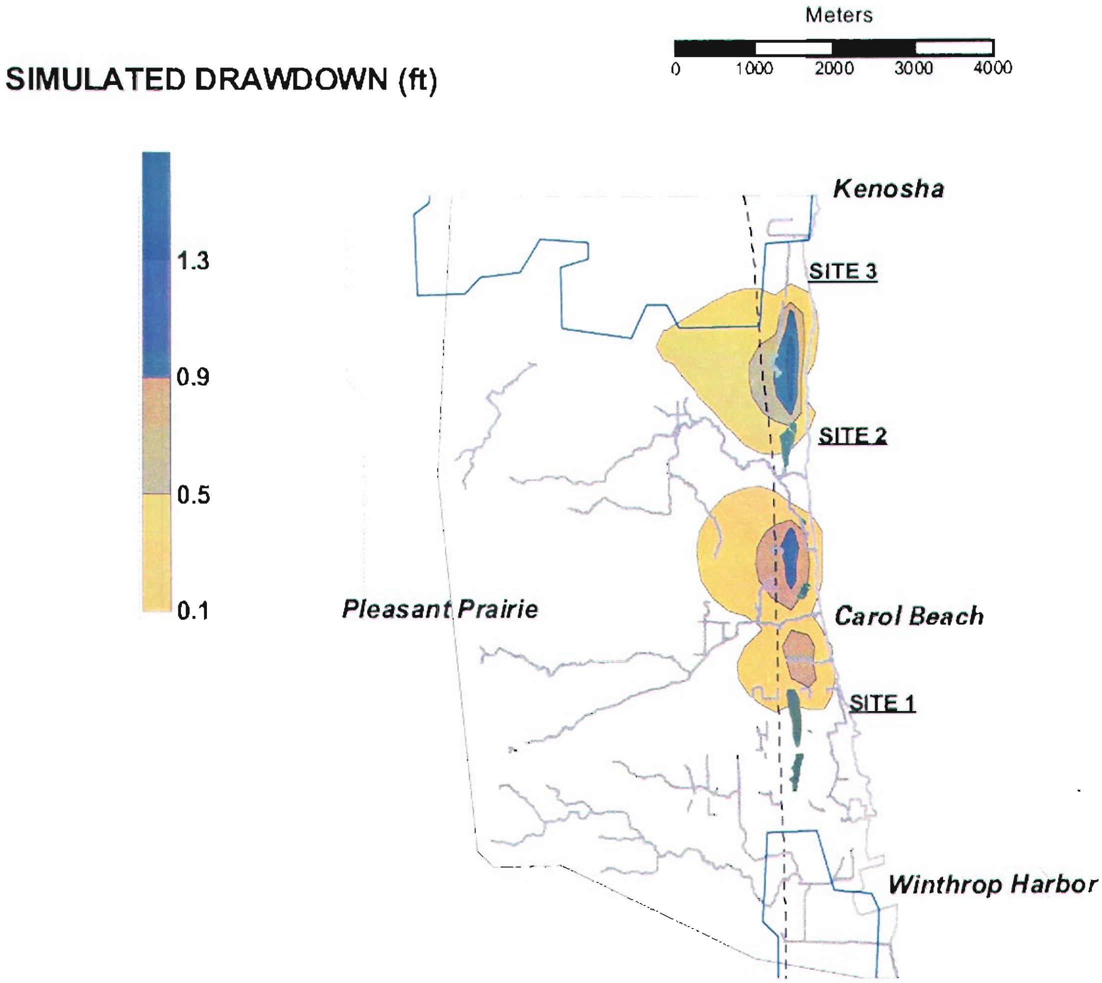

Figure 28. Scenario #3: Hypothetical dewatering drains – simulated drawdown.

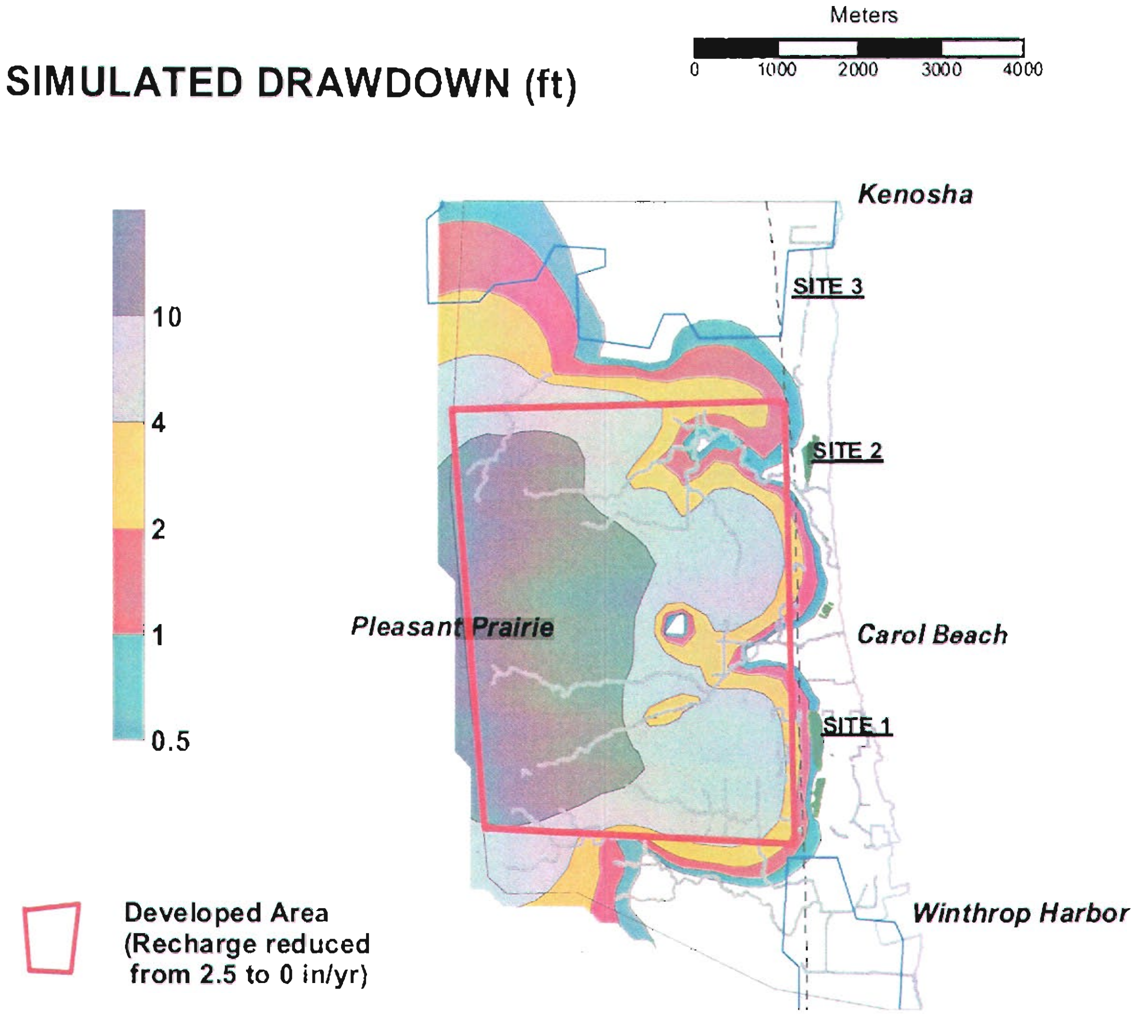

Figure 29. Scenario #4: Simulated effect of hypothetical development in upland areas on water-table table elevation.

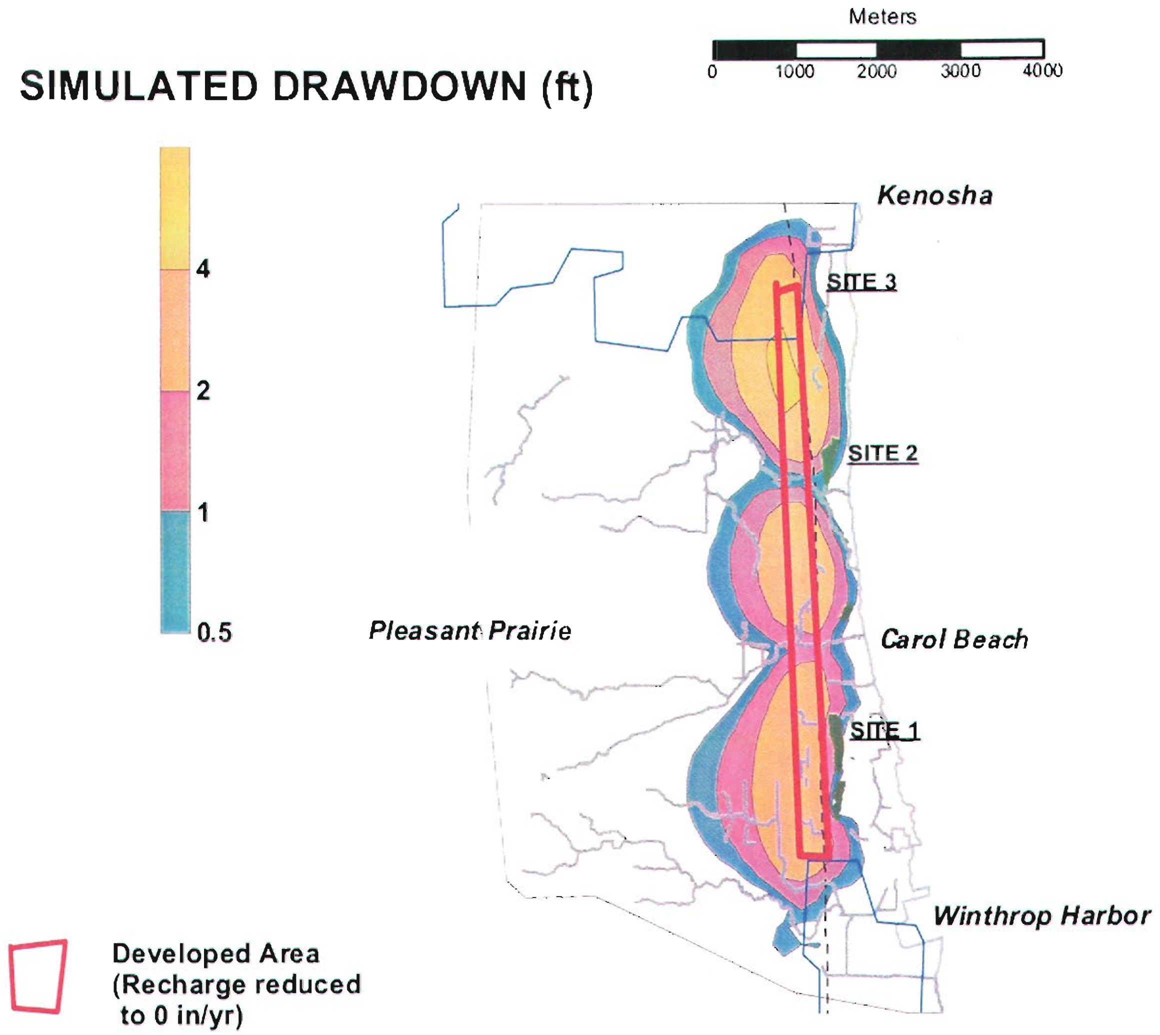

Figure 30. Scenario #5: Simulated effect of hypothetical development along beach bluff on water-table elevation.

Model Limitations

All models are simplifications of reality. While much effort was put into accounting for ground-water sinks throughout the study area in terms of location and stage, the natural variability in the amount of recharge to the water table was accounted for only by means of a few zones that neglect small-scale heterogeneity. The same is true for the natural variability in the permeability of glacial material. Even more important, the code only simulates steady-state conditions and, therefore, in no way reproduces the dynamics of the seasonal rise and fall in the water table which have such a large effect on wetland vegetation. For example, the model does not simulate how periodic oscillations in lake stage affect the ground-water level below the wetlands, nor the length of time the root zone is saturated by ground water for different hydrologic events.

It is likely that the shape and extent of the simulated capture zones for the three wetlands is largely independent of all these limitations. The delineation of these contributing areas is mostly determined by overall mass balance considerations linked to the overall recharge rate and the location of competing sinks such as creeks. However, more locally determined model results (for example, the drawdown expected at a particular wetland owing to the installation of a drainage ditch) could be somewhat influenced by small-scale heterogeneity in the surrounding deposits that are not included in the model. As for the transient response of the ground-water/wetland system to seasonal recharge, this subject can be simulated with transient flow-model codes. It is often best studied directly by collection and analysis of continuous water-level and precipitation data in conjunction with mapping of wetland vegetation.

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Appendix D
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