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Hydrology and history: land use changes and ecological responses in an urban wetland

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Abstract

The impacts of changing land use on hydrology and dominant plant species from 1850–1990 were investigated in a palustrine wetland in southern Wisconsin, USA. Aerial photographs, historic maps and water levels of the area were used to determine changes in land use, wetland vegetation, and groundwater and surface flows over time. Piezometers and water table wells were monitored weekly for two years. Vegetation was quantified in four one-square meter quadrats at each water level measurement site. Linear regression models and multivariate ordinations were used to relate wetland plant species to hydrologic, chemical and spatial variables. The current hydrologic budget of the wetland was dominated by precipitation and evapotranspiration, although overland flow into the wetland from the subwatershed has increased twenty-fold since 1850. Water level stabilization in the adjacent Yahara River, creek channelization, and groundwater pumping have decreased inputs of groundwater and spring-fed surface water, and increased retention of precipitation. *Typha* spp. and *Phalaris arundinacea* L. have increased in the wetland, while *Carex* spp. have decreased. *Phalaris arundinacea* was found most often in the driest sites, and the sites with the greatest range of water levels. *Typha* spp. dominated in several hydrologic settings, indicating that water depth was not the only factor controlling its distribution. The distributions of dominant plant species in the wetland were most closely correlated with site elevation and average water levels, with some weaker correlations with vertical groundwater inflows and specific conductance.

Introduction

During the last 140 years, the watershed surrounding what is now known as the Monona Wetlands Conservancy in Dane County, Wisconsin, has been increasingly urbanized, and the wetland itself has been greatly altered; over the same time, native grasses and sedges have been declining, while invasive or exotic species such as reed canary grass (*Phalaris arundinacea* L.), narrow-leaved cattails (*Typha angustifolia* L.) and hybrid cattails (*Typha X. glauca*) have been spreading. In addition, a functional assessment of the wetland showed that the wetland's functions as well as its biodiversity have been severely degraded as the result of off-site impacts (Water Resources Management Workshop, 1990).

Changes in land use and land management frequently result in alterations in the hydrology and water chemistry of wetland areas. These landscape-level alterations can change the plant community, and hence the functions, of the wetland. Altered wetlands often become dominated by non-native or invasive plant species (Grace and Wetzel, 1981; Weisner, 1993) which can lower the biodiversity of the wetland, decrease its functional value for humans and other species, and even result in complete wetland loss (Reed and Cahoon, 1992). Research has clearly documented that different plant species require different combinations of water levels, water chemistry and soil types (e.g., Nicholson, 1995), but only for very few species are these exact combinations understood. This lack of information makes it difficult to predict the impacts of land use changes or to identify appropriate restoration actions.

The goal of this study is to investigate the relationships between vegetation patterns, hydrology, water chemistry and changes in land use in the wetland and the watershed, in order to determine possible

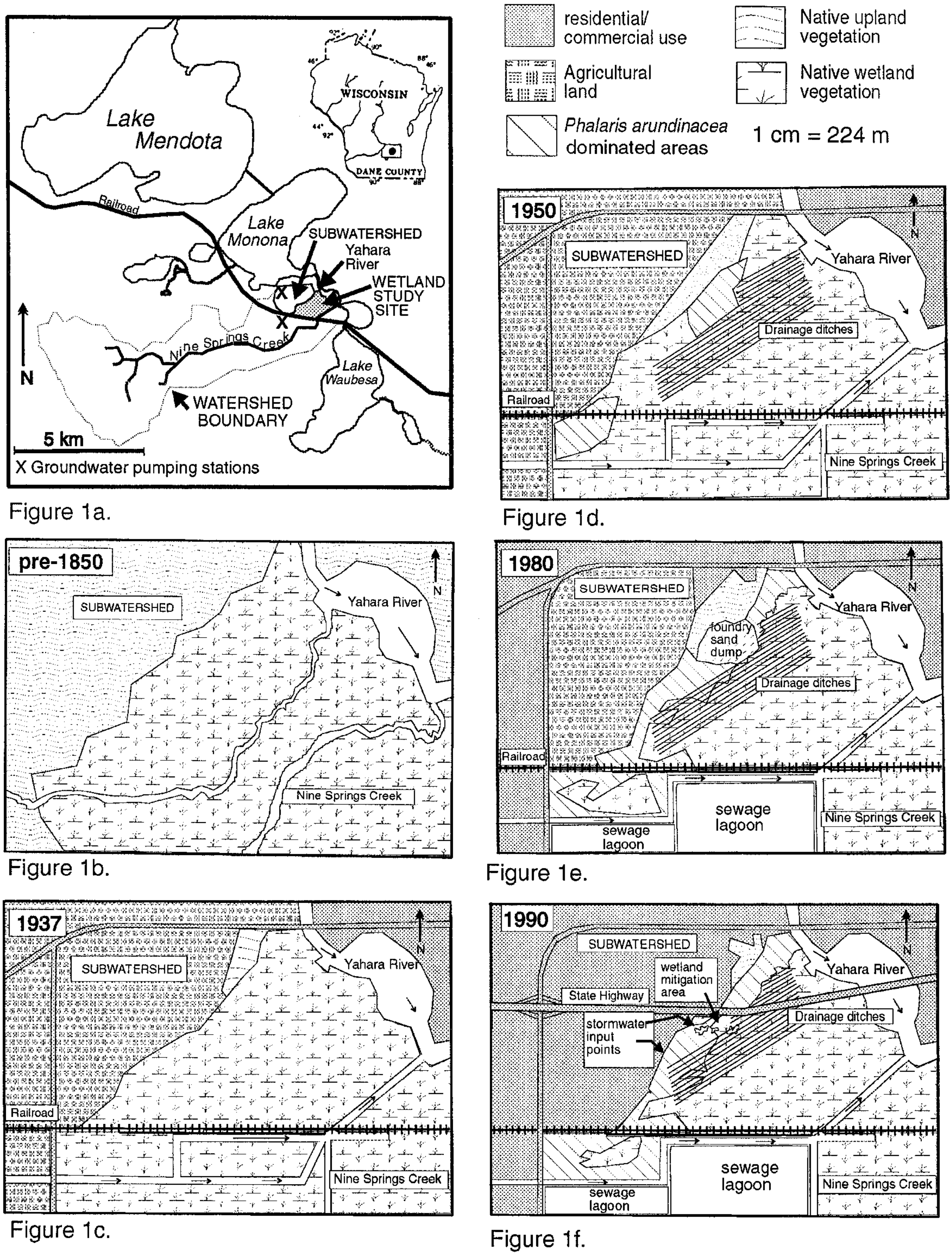

Figure 1. Watershed and wetland use in the Monona Wetlands Conservancy, 1850–1990.

causes for the decline in biodiversity of this highly impacted urban wetland and to determine the feasibility of restoration of native species.

Site description

The site chosen for this study is a 92 ha urban peatland called the Monona Wetland Conservancy, located in the City of Monona, in Dane County, Wisconsin (Figures 1a–f). The site and its hydrologic budget are described in more detail in Owen (1993, 1995). The wetland is dominated by grasses and sedges, with a few areas of shrubs. Underlying this vegetation is a layer of sedge peat (Histosol) which ranges from 0.6 to 1.8 m thick, followed by a 0.1–2.5 m layer of marl in many areas, and finally a layer of glacial lacustrine clay and silt, between 3–15 m thick. Sandstone of the late Cambrian age underlies these glacial lake deposits starting at a depth of 28–33 m. The wetland is bordered on its east side by the Yahara River, on the south side by a railroad, and on the north side by a highway and local roads.

Methods

To characterize the historic hydrologic setting, land use patterns and vegetation in the wetland and its watershed, aerial photos from 1937, 1950, 1968 and 1980 were used, along with descriptions of impacts to the wetland and changes in vegetation (Bedford et al., 1974; Hollister, 1991). The configurations of the wetland, watershed and streams in the 19th century were characterized using historic maps (approx. 1850) and historic accounts of pre-settlement vegetation in the Lake Monona and Lake Waubesa area (Mollenhoff, 1982). To estimate the changes in surface runoff into the wetland resulting from changes in land use, the Soil Conservation Service rainfall-runoff model was used (Barfield et al., 1985). Changes in groundwater flow conditions were estimated based on historic driller's logs (Wisconsin Geologic and Natural History Survey, 1947) and on the results of groundwater simulation models conducted by the U.S. Geological Survey (1978).

To characterize the current hydrologic, chemical and biological conditions, a two-year study was conducted in 1990–91. A more detailed analysis of the wetland's hydrology is presented elsewhere (Owen, 1995). Thirteen piezometer nests and 27 stage gages were installed in the marsh, and three piezometer nests were installed in the upland next to the marsh. The piezometer nest locations were chosen to get a good coverage of the wetland to detect surface and groundwater flow patterns. The marsh piezometers, constructed of 3.175 cm diameter PVC pipe with 23.5 cm screens and closed bottoms, were installed by hand using a 5 cm diameter bucket auger in June of 1990. At each nest, a shallow piezometer was installed to the bottom of the first layer, which was usually peat. The screens on these piezometers were slotted with a hack saw. Deep piezometers were installed to 30–60 cm below the bottom of the peat, which in most cases was glacial lacustrine silty clay with some marl and sand mixed in at the top. These piezometers had 23.5 cm screens with 0.20 cm slots. Each nest also contained a stage gage in a 60 cm deep open well. Additional stage gages were installed at seven locations in the river or canal, as well as in the stormwater ditches leading into the marsh. Leopold-Stevens (model #68 type F) 8-day water table recorders were installed in the open holes at 3 locations. Water levels in all piezometers and stage gages were monitored at least weekly from June 21–Nov. 23, 1990, and from March 27–Nov. 2, 1991. Elevations of piezometers, stage gages, and ground surfaces were surveyed each year. Elevations of the water level in each piezometer nest were used to calculate vertical horizontal hydraulic gradients, using Darcy's Law.

The electrical conductivity (specific conductance) and temperature of the water in the peat and clay and of the wetland surface waters at all piezometer sites and stage gages were measured in situ in unpurged piezometers using a downhole probe once each season in 1991, using a Yellow Springs Instrument Company Model 33 conductivity meter. One sample from each major area and depth of the wetland was taken in July of 1991 and analyzed for major cation by atomic absorption spectrophotometry in the University of Wisconsin Soils and Water Analysis Lab. In addition, the pH of the water in all piezometers and wells at 8 of the piezometer sites was measured in July of 1991 using a Beckman pH meter.

Vegetation in the wetland was mapped and quantified using aerial photos and ground surveys. Fifty-two, 1-m^2 quadrats were used to quantify the vegetation around each piezometer nest. One quadrat was placed in each of the first untrampled areas encountered on the north, south, east and west sides of the piezometer nest, no more than 2 m from the piezometer. The percent cover and frequency of each species (Kershaw and Looney, 1985) were recorded in July of 1990, and the data from the four quadrats were averaged for each of the thirteen piezometer/stage gage sites. The aerial photos used to assist in the mapping of current vegetation were orthographic color photographs taken in April of 1990 for the Dane County Regional Planning Commission. Based on the quadrats and the visual inspections, the wetland was mapped into dominant plant association types. Ground elevations were taken at each piezometer nest, as well as in several other points and the dominant vegetation at each point was recorded, to estimate the average elevation in each dominant vegetation type.

The vegetation and environmental data were then analyzed using Bray-Curtis, TWINSPAN and DECORANA multivariate ordinations (Gauch, 1982) on the program PC-ORD (McCune, 1993) using linear regression on the statistical package MINITAB to seek correlations between environmental parameters and plant species abundances (after arcsine square root transformation where appropriate). The environmental parameters examined, with their shorthand names in parentheses, are as follows: Average, maximum and minimum depth to water table each year (= average water table, maximum water table, minimum water table), the difference between maximum and minimum water levels each year (= range), magnitude and direction of vertical flow gradients from the upper level of the peat to the lower level (= shallow gradients) and from the lower level of the peat to the clay layer below (= deep gradients), number of days with upward (discharge) gradients (= duration of discharge), number of days with water standing over the surface (= standing water), number of days with water levels less than 10 cm below ground surface (duration $<$ 10 cm), average specific conductance, pH, elevation, and distance to the river, canal or stormwater ditches.

Results

Both the watershed of the Monona Wetland Conservancy and the wetland itself have experienced many alterations in land use and water management (Figures 1a–f, constructed from old aerial photographs). Historic maps of the area show that a railroad was constructed through the wetland between 1850 and 1855. The railroad bed does not appear to block subsurface flow today (Owen, 1995). By 1937, the wetland was extensively tiled in a further attempt at drainage. The wetland was burned either deliberately or accidentally numerous times, with documented burns in 1968, 1980 and 1992. The wetland area south of this study site was converted to sewage lagoons in the 1960's. Part of the wetland was used as a dump for used foundry sand from approximately 1968 to 1980. In 1988 a highway was constructed through the wetland (most of it is on a bridge over the wetland), foundry sand was removed and ponds and wetlands were restored as part of a wetland mitigation agreement for the highway (Owen et al., 1989).

One of the streams that meandered through the wetland was blocked off between 1880 and 1914, and its flow apparently was directed into the larger of the two streams, called Nine Springs Creek, which was deepened and straightened in an attempt to drain the wetland area. Before channelization of Nine Springs Creek and the other unnamed creek that ran through the wetland, the entire 3367 ha watershed of Nine Springs Creek drained into the wetland study area and the adjacent wetland to the south of it. According to U.S. government surveyor's notes of 1834, this watershed was dominated by oak forest, oak savannah and prairie (Mollenhoff, 1982). Based on current knowledge of rainfall-runoff responses, the wetland probably received little overland flow from the native vegetation except in very large storms, with most of the surface flow coming from the creeks. Currently, no water flows from the creek into the wetland, although there is some horizontal some subsurface flow out from the wetland into the creek (Owen, 1995). Once the creeks were blocked or channelized and their flow routed around the wetland, the size of the area draining into the wetland was reduced to 104 ha.

As development continued in the 104 ha subwatershed, surface runoff increased and was channeled into the wetland through stormwater ditches on the west side of the wetland. By 1990, 63% of the watershed was paved, with a shopping mall and an industrial park draining into the wetland through two large stormwater ditches on the west side. Estimates from the Soil Conservation Service rainfall-runoff model (Barfield et al., 1985), indicated that, if the same rainfall pattern and amount that occurred in April–October 1991 (64.7 cm) fell on the land use shown in aerial photos and historic maps of the watershed, surface runoff would have been 0.64 cm prior to 1850, 5.5 cm in 1937, 2.7 cm in 1950 (runoff decreased because more of the watershed was in pasture than in row crops), 10.1 cm in 1980, and 12.4 cm in 1990. Therefore, the overland flow coming into the wetland today represents a twenty-fold increase over the sur-

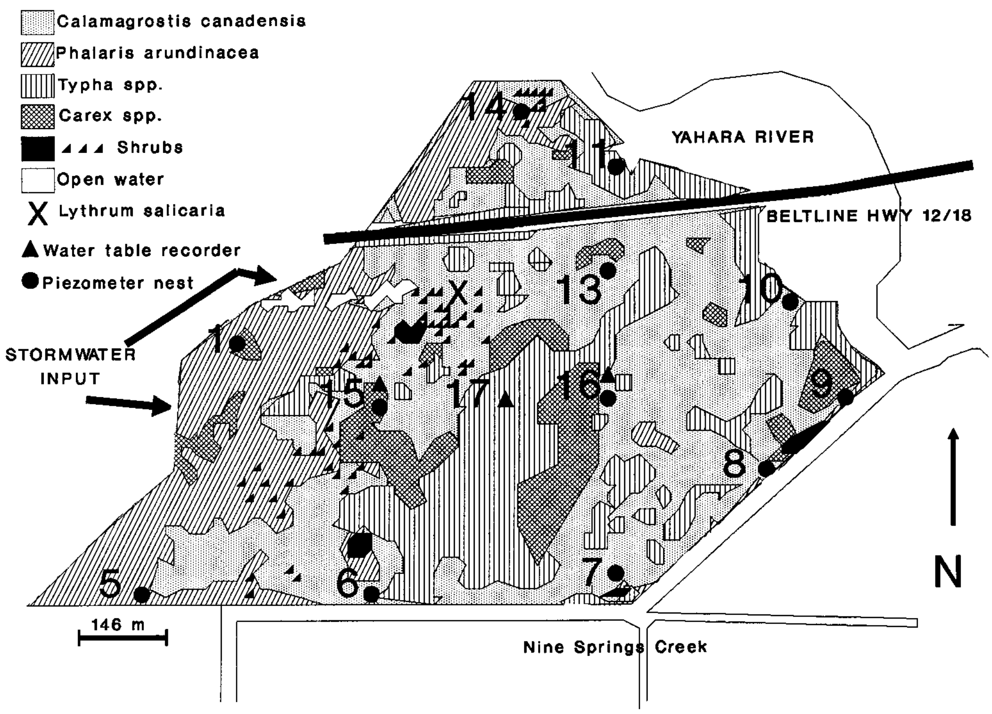

Figure 2. Dominant vegetation in Monona Wetlands Conservancy, 1990.

face runoff that would have been experienced in 1850. All of this increased runoff is directed into the wetland through stormwater ditches on the north and west sides of the wetland, and thence into unchannelized flow in the wetland. The adjacent Yahara River was channelized and its water levels regulated for boating by 1937 (Hollister, 1991). Water levels in the Yahara River are kept 30–60 cm higher since the construction of the Lake Waubesa dam in approximately 1937 (Ken Koscik, pers. comm., 1997). Today, there is little flow between the Yahara River and the wetland (Owen, 1995), and it is reasonable to conclude that the water levels in the marsh are higher today than they were prior to regulation of the river levels.

There is also evidence to indicate that groundwater flow into the wetland has been diverted as a result of groundwater pumping in municipal wells next to the wetland. Driller's logs from 1947 (Wisconsin Geologic and Natural History Survey, 1947) showed that groundwater flowed upward, occasionally in artesian flow, into the areas around the wetland; however, recent hydrologic studies in the wetland (Wisconsin Dept. of Transportation (WDOT), 1978; Owen 1995) showed that, in some parts of the wetland, there are weak downward gradients, or recharge, from the wetland to the clay below. Two high-capacity municipal wells were drilled within 0.5 mile of the wetland in the mid-1960's. Computer simulation models showed a 23 m drawdown in the sandstone aquifer and a 3–6 m drawdown in the surface water table resulting from groundwater pumping (McLeod, 1978). Current maps of the aquifers do confirm the existence of this cone of depression. Groundwater represented 2% and 1% of the total inputs and 3% and 5% of the total outputs in 1990 and 1991 (Owen, 1995).

Water levels in the wetland were controlled by precipitation and evapotranspiration during the time of this study (Owen, 1995). Precipitation contributed 92% and 82% of the inputs to the wetland in 1990 and 1991; both years were 110–125% of normal precipitation for 1950–1980 (National Oceanic and Atmospheric Administration, 1990 and 1991). Stormwater runoff into the wetland through the ditches on the north and west sides provided 6% and 17% of the total inputs. Evapotranspiration constituted 97% and 94% of the outputs. Historically, groundwater inputs may have been larger, as discussed earlier, and surface inputs via overland flow were much smaller.

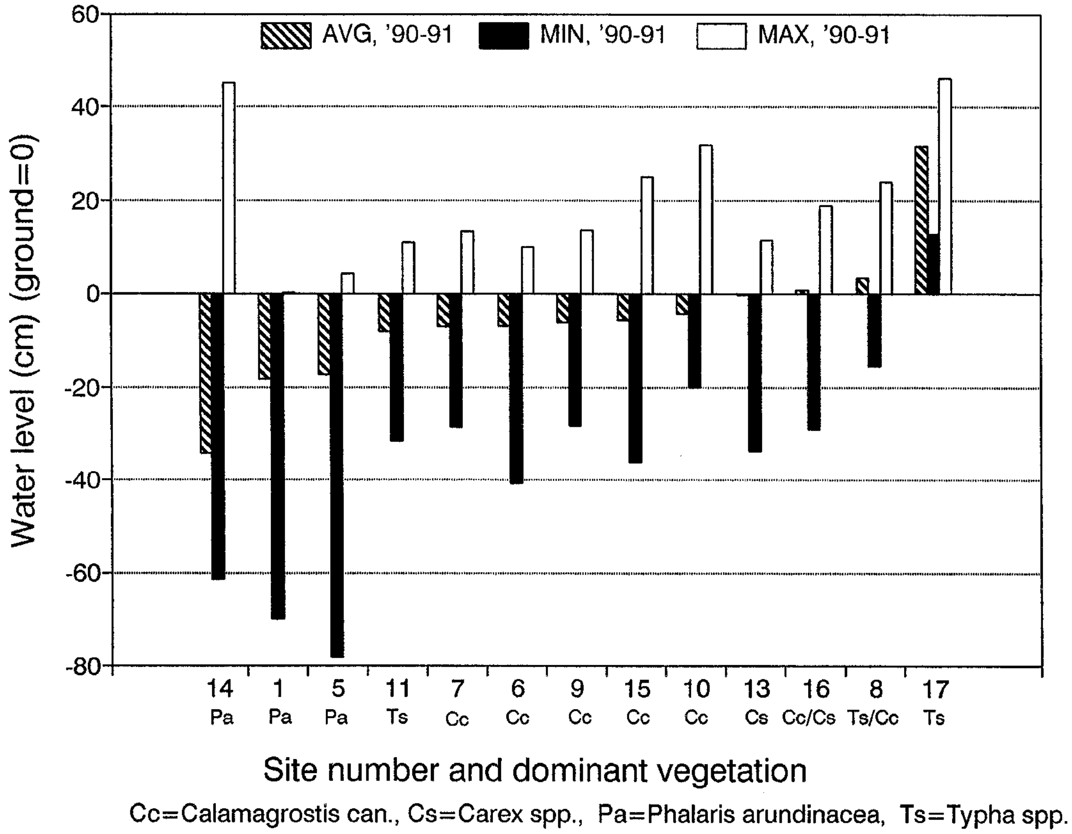

Figure 3. Average, maximum and minimum water levels and dominant vegetation at measurement sites in the Monona Wetlands Conservancy, 1990–91. Sites are presented from left to right in order of lowest to highest average water table.

Vegetation

Figures 1a–f show the large-scale changes in vegetation in the wetland. *Phalaris arundinacea*, and *Typha* spp. appeared to be increasing their coverage in the wetland, while *Carex* spp. appeared to be declining. These interpretations of the aerial photographs are supported by long-time observers of the wetland (Bedford et al., 1974). Ninety-three plant species are known to occur in this wetland (Owen, 1993); 44 of those species were found in the quadrats around the 13 piezometer nests/stage gages. The wetland today was dominated by four major plant associations, as named by the dominant plant species: (1) *Phalaris arundinacea* L.; (2) the *Typha* group, *Typha angustifolia* L., *Typha latifolia* L., and the hybrid *Typha X. glauca*; (3) *Calamagrostis canadensis* L.; and (4) the *Carex* group, *Carex lasiocarpa* Ehrh., *Carex aquatilis* Wahl. and *Carex lacustris* Willd. (Figure 2).

The drier parts of the wetland are dominated by *Phalaris arundinacea*, the slightly wetter sites are dominated by *Calamagrostis canadensis*, even wetter sites are dominated by *Carex* spp., and the wettest sites are dominated by *Typha angustifolia* (Figure 3). Depths to water table in the peat at different sites in the wetland were largely determined by the elevation of the site; correlations between average water levels and site elevation were − 0.68 in 1990 and − 0.67 in 1991. Distance to the river, the canal or the stormwater ditches in the upland showed very poor correlations with water levels at each of the sites ($r^2 < 0.10$). Higher-elevation sites, therefore, were drier even if they were very close to the river or to other potential input sources.

Table 1 presents the average percentage cover, average, maximum and minimum water levels for several of the most common species in the wetland. Also shown in Table 1 are the best correlations of each species with the hydrologic and chemical pa-

Table 1. Average percent cover, water levels and best correlations for individual plant species. n = number of sites at which species was found (out of 13 water level/piezometer nest sites monitored weekly).

Species	% Cover			Water levels				Best correlation (see Methods)
	n	Avg.	std. dev.	Avg.	std. dev.	Min.	Max.	
Calamagrostis canadensis	11	29.0	24.0	– 6.3	6.4	– 34	15	Elevation: $r^2 = -0.45$, $p = 0.017$
Carex aquatilis	3	3.1	1.8	– 1.9	3.1	– 30	15	Conductivity: $r^2 = 0.21$, $p = 0.136$
Carex lacustris	6	8.1	14.0	– 6.1	5.5	– 32	15	Duration of discharge: $r^2 = 0.28$, $p = 0.075$
Carex lasiocarpa	2	9.6	6.8	0.27	0.46	– 31	15	none possible
Galium tinctorium	9	0.8	0.40	– 3.8	3.8	– 29	18	Standing water: $r^2 = 0.57$, $p = 0.005$
Impatiens capensis	5	11.0	7.5	– 6.4	2.6	– 30	16	Max. water level: $r^2 = 0.29$, $p = 0.072$
Lysimachia thrysiflora	10	4.7	3.1	– 6.8	9.8	– 32	21	Conductivity: $r^2 = -0.21$, $p = 0.135$
Phalaris arundinacea	4	47.0	46.0	– 18.9	9.9	– 51	16	Avg. water level: $r^2 = -0.68$, $p = 0.0001$
Phragmites communis	4	5.0	4.2	– 1.8	3.7	– 24	20	Distance to canal: $r^2 = 0.35$, $p = 0.043$
Polygonum punctatum	6	1.3	1.6	– 2.4	4.0	– 26	19	Minimum water level: $r^2 = 0.20$, $p = 0.149$
Polygonum sagittatum	7	0.63	0.2	– 4.9	3.5	– 29	18	Elevation: $r^2 = 0.45$, $p = 0.017$
Sagittaria latifolia	7	7.6	7.4	– 3.1	4.0	– 27	18	Maximum water level: $r^2 = \dot{0}.27$, $p = 0.086$
Scutellaria galericulata	6	0.26	0.35	– 2.7	4.0	– 31	17	Elevation: $r^2 = -0.23$, $p = 0.112$
*Typha angustifolia**	6	9.2	10.0	1.2	14.0	– 18	24	Avg. water level: $r^2 = -0.12$, $9 = 0.269$
Typha latifolia	3	3.5	1.3	– 4.9	2.8	– 35	16	Distance to river: $r^2 = -0.19$, $p = 0.151$

* Includes the hybrid *T. X. glauca*

rameters examined in each piezometer nest or stage gage (see Methods section for a description of each parameter). Low correlation coefficients for most of the plant species indicate that these hydrologic data do not explain much of the variation in vegetation. This could be the result of small sample size, since there were only thirteen piezometer nests/stage gage sites in the wetland with four quadrats around each site, or this may simply reflect the complexity of the system. Alternatively, this trend may indicate that current hydrologic and chemical conditions, at least as determined in this brief 2-year study period, are not the major cause of the distribution of plant species in this wetland.

The sites dominated by *Phalaris arundinacea* (Pa) were the driest, and also had the largest hydrologic amplitude. The sites dominated by *Phalaris arundinacea* were not diverse; an average of 75% of each plot at these sites was covered with *Phalaris*, with local abundances of *Solidago canadensis* and Aster simplex in two of the plots, and very small amounts of *Calamagrostis canadensis*, *Carex lacustris*, *Lathyrus palustris*, and *Lysimachia thrysiflora*. The average ground elevation for Phalaris-dominated sites in the wetland was 257.67 ± 0.09 m AMSL. These areas had the lowest average water table and the lowest minimum water table (Table 1). The areas dominated by *Phalaris arundinacea* were also subject to the most extremes in water levels (greatest range), averaging 67 cm difference between the minimum water levels and the maximum water levels observed in this study period. The percentage cover of *Phalaris arundinacea* was correlated with low average water levels ($r^2 = -0.68$, $p < .001$) and high range ($r^2 = 0.47$, $p = 0.004$). Site 1, with the least *Phalaris* of these three sites, also had the smallest fluctuations (Figure 3). Specific conductances of surface water samples taken from the *Phalaris* dominated areas averaged quite high, 647 ± 172 μS/cm.

At slightly lower elevations, averaging 257.51 ± 0.04 m AMSL, *Calamagrostis canadensis* (Canada bluejoint grass) dominated. Figure 3 shows the hydrologic regime that was typical for this plant community; this hydrologic regime was very typical of the wetland, and much of the wetland was dominated by this plant community (Figure 2) of *Calamagrostis canadensis*, which commonly grew in association with *Carex aquatilis*, *Carex lacustris*, *Impatiens capensis*, *Lysimachia thrysiflora*, *Sagittaria latifolia*, *Solanum dulcamara*, *Galium tinctorium*, *Rumex orbiculatus*, *Polygonum sagitattum*, *Polygonum punctatum* and *Typha latifolia*. Sites 6, 7, 9, 10 and 15 were dominated by *Calamagrostis*, while site 16 was co-dominated by *Calamagrostis* and *Carex* spp. Table 1 shows that abundance of *Calamagrostis* was negatively correlated with site elevation ($r^2 = -0.45$, $p = 0.03$). Specific conductances of surface water in the areas dominated by *Calamagrostis* averaged 452 ± 198 μS/cm, which is fairly low for this region. *Calamagrostis* was found where the water levels averaged 6.3 cm below ground, and ranged from a minimum of 34 cm below ground to a maximum of 15 cm above ground. This hydrologic amplitude of 49 cm over the length of this study period was not as extreme as the range of water levels seen in the *P. arundinacea*-dominated areas.

Where the average water levels were near ground level (Figure 3), *Carex lacustris* and *C. lasiocarpa* dominated, with some *C. aquatilis*. Since little of the wetland area was dominated by sedges (Figure 2), only two of the piezometer nests were located in sedge-dominated or mixed sedge/*Calamagrostis* areas. Sites 13 and 16 had higher average water levels than did the sites dominated by *Phalaris arundinacea* or *Calamagrostis canadensis*. *Carex aquatilis* and *Carex lasiocarpa* prefer the wetter sites, while *Carex lacustris* were found in a wider range of hydrologic conditions (Table 1). Both *C. aquatilis* and *C. lacustris* showed weak correlations with high specific conductances, which averaged 642 ± 290 μS/cm at these sites. Both species also showed a weak correlation with small upward flow (groundwater discharge) gradients, which averaged 0.15 cm/cm at site 13 and 0.01 cm/cm at site 16.

The wettest sites are dominated by *Typha angustifolia* and possibly the hybrid *T. X. glauca* (Figure 3). The lowest elevations occurred in the middle of the marsh, near site 17, where the average elevation was 257.28 m. This area had the highest average water levels relative to ground level, and a small range in water levels. Historic photographs and maps indicated that a small unnamed creek flowed through this area into the Yahara River before construction of the railroad and channelization of Nine Springs Creek (Figure 1a and 1b). Aerial photographs before 1968 showed a mix of vegetation through the middle of the marsh where cattails now dominate at site 17.

The creeks that were channelized to run around, instead of through, the wetland are largely fed by springs from a dolomite and sandstone aquifer (Dane County Regional Planning Commission (DCRPC), 1992), so presumably the historic wetland received more cold, high oxygen, alkaline spring-fed surface water from these creeks as well as from subsurface seepage flow from the larger, forested watershed. Specific conductances at the *Typha* dominated sites were the lowest in the wetland, averaging 378 ± 46 μS/cm. Vertical gradients were downward but extremely weak at these sites, averaging 0.005 cm/cm in the upper layers of peat and 0.025 cm/cm in the lower layers, from the clay to the peat.

Interestingly, site 11, next to the Yahara River, was dominated by cattails but showed different hydrology than the cattail area in the middle of the wetland at site 17 (Figure 3). The hydrologic regime at site 11 was much more similar to that of Site 7 and 10, which are both dominated by *Calamagrostis canadensis*. The elevation of site 11 was similar to that of the *Calamagrostis*-dominated sites, and was 34 cm higher than that of Site 17, where *Typha* spp. also dominate. This indicates that factors other than hydrology determined the dominant species at this area along the Yahara River.

Bray-Curtis ordination of the piezometer nest sites according to all hydrologic and chemical factors indicated that one of the three *Phalaris*-dominated sites, site 5, was hydrologically and chemically similar to a site dominated by *Calamagrostis canadensis*, site 6 (Figure 4). This indicated that conditions here were adequate for establishment of native species, if the Phalaris were physically removed. The hydrology and chemistry of sites 1 and 14, on the other hand, are so dissimilar to any other sites where native wetland species are dominant that removal of *Phalaris* from these areas would be fruitless under current conditions.

Discussion

These analyses indicate that the wetland may be receiving more stormwater-derived overland flow and less groundwater flow, from the spring-fed creeks or from subsurface sources, today than in the past. Overall water levels are higher in the wetland as result of water level stabilization downstream, especially in the middle of the wetland.

It is likely that the timing of the water inputs may have also changed, since groundwater flow tends to be steady, whereas surface runoff, particularly from developed areas, tends to come in quickly and in large quantities, followed by long periods of no inflow, as is the situation in the wetland today (Owen, 1993). These flashy inputs have probably contributed to the spread of *Phalaris arundinacea*, which was found more often in the areas with the greatest fluctuation in water levels. All three of the *Phalaris*-dominated sites receive more surface or shallow subsurface flows of water from the adjacent uplands than the rest of the wetland, but these inputs primarily occur only in spring

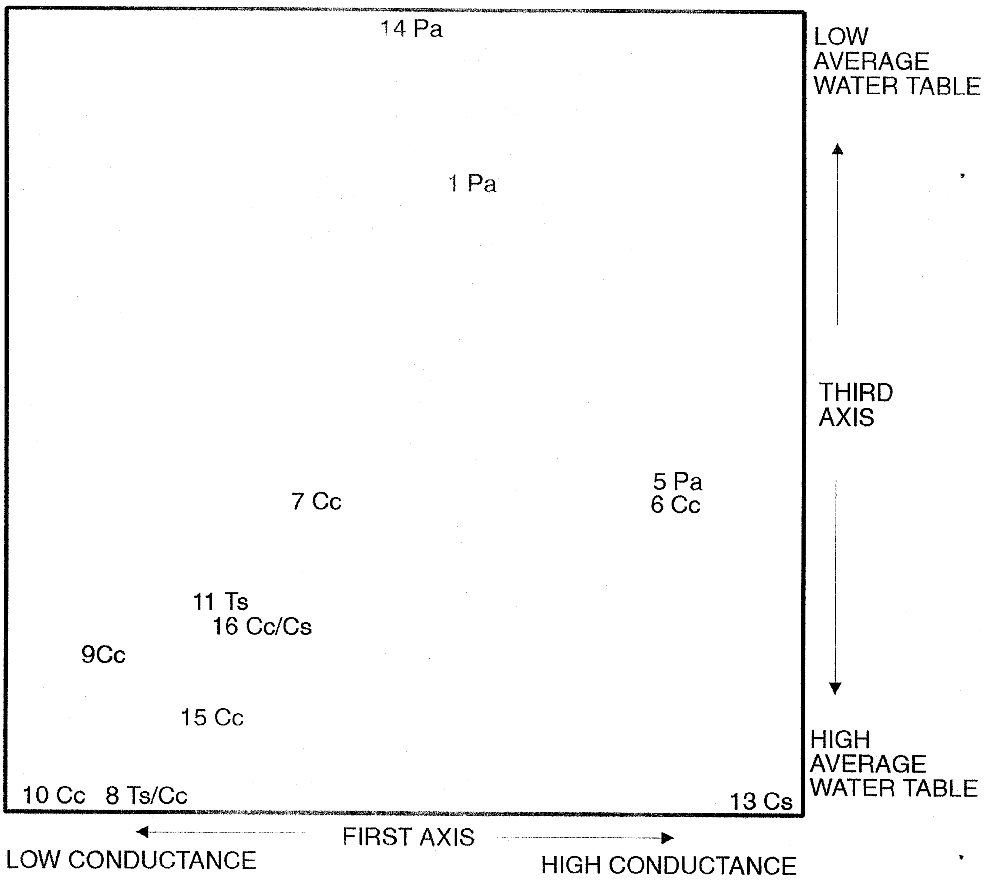

Figure 4. Bray-Curtis multivariate ordination of measurement sites into environmental factor spece. Bast correlation with first axis was average specific conductance ($r^2 = 0.998$), while the best correlation with the third axis was average height of the water table relative to the ground surface ($r^2 = 0.90$). Numbers shown are water-level measurements sites (see Figure 2); letter codes following represent the dominant vegetation at each site. Cc = *Calamagrostis canadensis*; Cs = *Cares* spp.; Pa = *Phalaris arundinacea*; Ts = *Typha* spp.

or after occasional very large summer storms. Other studies have also found that *Phalaris arundinacea* has better growth in drier sites than other hydrophytes (Coops et al., 1996), and that spring flooding does not affect its growth, while prolonged summer flooding reduced its total biomass (Klimesova, 1994), which is consistent with the findings here. Restoration of one of these *Phalaris arundinacea*-dominated areas is possible because the physical conditions are still sufficient to support native species, but removal of the *Phalaris arundinacea* first would be necessary, using some combination of flooding, herbicides, burning or mowing (Apfelbaum and Sams, 1987; Gillespie and Murn, 1992).

The historic alterations in the watershed and the wetland have also changed the quality of the groundwater and surface water coming into the wetland. The water running off parking lots, agricultural areas and roadways in this area is typically warmer and higher in sodium, heavy metals and nutrients (DCRPC, 1992). Studies in this wetland show that the surface runoff is indeed high in sodium and trace elements, while groundwater from the aquifer below is higher in calcium and magnesium (Kammerer, 1981; Owen, 1993). The data in this study, however, did not show any correlations between *Phalaris arundinacea* or *Typha* spp. and major cations or anions, indicating that changes in hydrology rather than in water quality were the cause of their expansion, with one exception as noted below. *Carex* spp. did show weak correlations with higher specific conductances, indicating that they may have a preference for the groundwater-quality conditions.

One of the major changes noted in the wetland vegetation besides the spread of *Phalaris arundinacea* was the spread of *Typha* spp. particularly *Typha angustifolia* and the hybrid *Typha X. glauca*. The center of the wetland, as well as the area bordering the Yahara River, appear from aerial photos and historic accounts to have been dominated by *Carex* spp. and *Calamagrostis canadensis*. Since both of these species were not found in deeper water such as that in the middle of the wetland, the change in hydrology of this area easily explains the invasion of *Typha* spp. here, in the area of one of the old creek beds. The water is deeper because the level of the Yahara River has been raised between 30–60 cm in the last 60 years through the construction of a water control structure downstream.

Surprisingly, deeper water does not explain the dominance of *Typha* spp. along the Yahara River, where the hydrologic regime on the floating mat is identical to the hydrologic regime favored by *Calamagrostis canadensis* in other parts of the wetland. *C. canadensis* is growing along with the cattails at Site 11, so clearly this species can survive there, but it is being outcompeted by the cattails. Here, the dominance of *Typha* over *C. canadensis* may be explained by the deteriorating water quality in the Yahara River, which drains several eutrophic lakes (DCRPC, 1992). Numerous studies document the competitive advantage of cattails under high-silt and high-nutrient conditions (e.g., Wilcox et al., 1984).

Because of its location in a regional discharge area, this wetland would be expected to receive groundwater from regional and local flow systems in an area of limestone; however, the thick layer of glacial lacustrine clay below most likely reduced the amount of upward groundwater flow into the wetland. The wetland may have received more surface water from groundwater-fed creeks. Since the local groundwater is high in magnesium and calcium, specific conductances of this water would be high, and would be expected to favor poor fen vegetation typical of a spring-fed channel, such as *Carex lasiocarpa*, and *Carex aquatilis* (Nicholson, 1995).

Channelization of these spring-fed creeks around the wetland probably removed much of this cation-rich water; groundwater pumping may have removed the rest. Increased surface runoff from developed uplands, and stabilization of the water levels in the Yahara River, have increased the amount of overland flow coming into the wetland and decreased the amount of water flowing between the wetland and the Yahara River. It is possible that the beds of sedges now seen in the wetland are remnant populations, reflecting the hydrologic conditions of an earlier era, and which are now being outcompeted by exotic and more common species. Restoration of native vegetation may be possible in a few areas, but in most parts of the wetland in which invasive species dominate, the physical conditions can no longer support the native species.

References

Apfelbaum, S.I. and Sams, C.E. 1987. Ecology and control of reed canary grass (*Phalaris arundinacea* L.). Natural Areas J. 7: 69–74.

Barfield, B.J., Warner, R.C. and Haan, C.T. 1985. Applied Hydrology and Sedimentology for Disturbed Areas. Oklahoma Technical Press, Stillwater OK.

Bedford, B.L., Zimmerman, E.H. and Zimmerman, J.H. 1974. Wetlands of Dane County. Dane county Regional Planning Commission and the Wisconsin Dept. of Natural Resources.

Coops, H, Van den Brink, F.W.B. and Van der Velde, G. 1996. Growth and morphological responses of four helophyte species in an experimental water-depth gradient. Aquatic Botany 54: 11–24.

Dane County Regional Planning Commission. 1987. Groundwater Protection Plan for Dane County Wisconsin. Appendix G of the Dane County Water Quality Plan. Madison, WI.

Gauch, H.G. 1982. Multivariate Analysis in Community Ecology. Cambridge University Press, NY.

Grace, J.B. and Wetzel, R.G. 1981. Habitat partitioning and competitive displacement in cattails (Typha): Experimental field studies. The American Naturalist 118: 463–474.

Gillespie, J. and Murn, T. 1992. Mowing controls reed canary grass, releases native wetland plants (Wisconsin). Restoration and Management Notes 10: 93–94.

Hollister, E. 1991. The Madison-Metro Sludge Storage Lagoon as bird habitat with special emphasis on shorebirds, waterfowl and marsh birds. Report to the Madison-Metro Sewer District. Madison, WI.

Kammerer, P.A. Jr. 1981. Groundwater Quality Atlas of Wisconsin. US Geological Survey, Information Circular 39.

Kershaw, K.A. and Looney, J.H.H. 1985. Quantitative and Dynamic Plant Ecology. Edward Arnold, London.

Klimesova, J. 1994. The effects of timing and duration of floods on growth of young plants of *Phalaris arundinacea* L. and *Urtica dioica* L.: An experimental study. Aquatic Botany 48: 21–29.

Koscik, K. 1997. Director of Dane County Dept. of Public Works. Personal communication with the author, Dec. 4, 1997.

Mcleod, R.S. 1978. Water-level Declines in the Madison Area, Dane County, Wisconsin. U.S. Geological Survey in Cooperation with the Madison Water Utility, Open-file Report 78–936, 15 pp.

McCune, B. 1993. Multivariate Analysis on the PC-ORD System. Oregon State University, Corvallis, Oregon.

Mollenhoff, D.V. 1982. Madison: A History of the Formative Years. Kendall/Hunt Publishing company, Dubuque IA.

National Oceanic and Atmospheric Administration, 1990–91. Climatological Data: Annual Summary for Wisconsin. Vol. 95 and 96. Washington, DC.

Nicholson, B.J. 1995. The wetlands of Elk Island National Park; vegetation classification, water chemistry and hydrotopographic relationships. Wetlands 15: 119–133.

Owen, C.R. 1995. Water buget and flow patterns in an urban wetland. J. Hydrology 169: 171–187.

Owen, C.R. 1993. Policy-relevant Science: Hydrologic Functions of an Urban Wetland. Doctoral Dissertation. University of Wisconsin, Madison WI.

Owen, C., Q. Carpenter, Q. and DeWitt, C. 1989. Evaluation of Three Wetland Restorations Associated with Highway Projects. Report to the Wisconsin Dept. of Transportation, Madison. 110 pp.

Reed, D.J. and Cahoon, D.R. 1992. The relationship between marsh surface topography, hydroperiod, and growth of Spartina alterniflora in a deteriorating Louisiana salt marsh. J. Coastal Research 8: 77–87.

Water Resources Management Workshop. 1990. Urban Wetlands in the Yahara-Monona Watershed: Functional Classification and Management Alternatives. University of Wisconsin Water Resources Management Workshop. Institute for Environmental Studies. Madison, WI.

Weisner, S.E.B. 1993. Long-term competitive displacement of Typha latifolia by *Typha angustifolia* in a eutrophic lake. Oecologia 94: 451–456.

Wilcox, D.A., Apfelbaum, S.I. and Hiebert, R.D. 1984. Cattail invasion of sedge meadows following hydrologic disturbance in the Cowles Bog wetland complex, Indiana Dunes National Lakeshore. Wetlands 4: 115–128.

Wisconsin Department of Transportation. 1978. Hydrological study of Upper Mud Lake Marsh, U.S. Highway 12 and 18, South Madison Beltline. Unpublished data. Madison, WI.

Wisconsin Geologic and Natural History Survey. 1947. Driller's well logs. Unpublished data. Madison, Wisconsin.