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RESTORATION OF OUR LAKES AND RIVERS WITH WETLANDS – AN IMPORTANT APPLICATION OF ECOLOGICAL ENGINEERING

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ABSTRACT

The role of wetlands, both natural and man-made, in improving water quality of streams, rivers, and lakes is illustrated with examples of fringe, instream, and riparian wetlands. Fringe wetlands have been shown to reduce inputs to freshwater lakes, instream wetlands can improve habitat and provide some water quality function to small streams, and riparian wetlands along larger rivers provide important roles in both capturing sediments and nutrients from the river itself and serving as buffer between uplands and the river. Two major experimental riparian wetland sites in Midwestern USA are introduced: The Des Plaines River Wetland Demonstration Project and the Olentangy River Wetland Research Park.

KEYWORDS

Nutrient budgets; Midwestern USA; phosphorus; riparian ecosystem; water quality; wetlands.

INTRODUCTION

The fringe and riverine wetlands that were once connected to lakes, streams, rivers, and estuaries are, to a large extent, gone from the landscape in many parts of the world. Without these "kidneys of the landscape," watersheds have lost part of their ability to maintain a biogeochemical balance and the deepwater systems are no longer buffered from upland regions. The net result has been the loss of a valuable biological habitat and poorer water quality. Without wetlands, populations of waterfowl, fish, reptiles, and amphibians have suffered extensive losses throughout the world. Without wetlands, fertilizers, pesticides, and sediments from farms and urban areas have nowhere to go except directly into waterways. Had some of the natural wetlands been left on the landscape, perhaps our natural biodiversity would have been just a little richer and water pollution problems would not be as pervasive.

We are now at a stage in our understanding of the landscape to prescribe the restoration and construction of wetlands, sometimes where they were formerly found, and sometimes where they were not, to enhance the physical, chemical, and biological integrity of our streams, rivers, and lakes. In presettlement times, many of our streams, rivers, and lakes were connected to extensive wetland systems. Many of those wetlands (90% in the case of the state of Ohio) have been lost to agricultural and urban development. We are now finding ways to restore some of these lost wetlands and recover some of their lost functions through ecological engineering, the application of ecology related to building ecosystems that have human value. This paper will describe some of the major functions of wetlands in the landscape and will discuss the overall findings of several studies on the role of wetlands in protecting and restoring our streams, rivers, and lakes.

WETLANDS AS ECOTONES

Natural wetlands are often ecotones, i.e. transition zones, between uplands and deepwater aquatic systems (Fig. 1). Deepwater systems, for our discussion here, could include deepwater lakes or streams and rivers. This location in the landscape "allows wetlands to provide valuable functions, such as those of organic exporters or inorganic nutrient sinks. This transition position also often leads to high diversity in wetlands, which 'borrow' species from both aquatic and terrestrial systems, and has given some wetlands the distinction of being cited as among the most productive ecosystems on earth" (Mitsch and Gosselink, 1993).

Figure 1 also illustrates some of the functions of wetlands in comparison to uplands or deepwater systems. While uplands, i.e., corn fields, and some deepwater aquatic systems, i.e., eutrophic lakes, can be highly productive, wetlands are more frequently highly productive when they are found as open systems at the interface between deepwater and upland systems. Whereas uplands are generally sources of minerals due to the degrading nature and deepwater systems either accumulate both inorganic and organic sediments (as in lakes) or quickly transport materials to downstream systems (as in streams and rivers), wetlands can provide roles as either sources, sinks, or transformers of chemicals. In fact, it is common to see wetlands such as salt marshes as importers of nutrients during part of a year and exporters during other parts of the year.

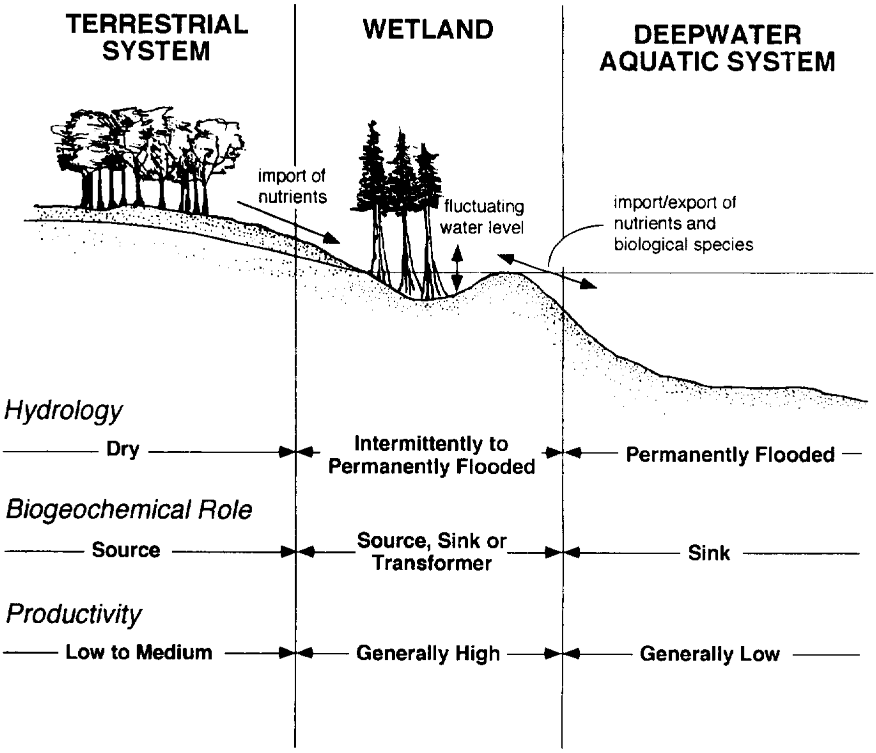

Figure 1. Wetlands as interface systems between uplands and deepwater aquatic systems such as rivers, streams, and lakes (from Mitsch and Gosselink, 1993, © Van Nostrand Reinhold, reprinted with permission).

WETLANDS AS BIOGEOCHEMICAL AGENTS

There has been much discussion and research by wetland scientists as to whether wetlands are nutrient *sources, sinks,* or *transformers* (Mitsch and Gosselink, 1993). A wetland is considered a sink if it has a net retention of an element or a specific form of that element (e.g. organic or inorganic); that is, if the inputs are greater than the outputs. If a wetland exports more of an element or material to a downstream or adjacent ecosystem than would occur without that wetland, it is considered a source. If a wetland transforms a chemical from, say, dissolved to particulate form, but does not change the amount going into or out of the wetland, it is considered to be a transformer. Part of the interest in this source-sink-transformer question was stimulated by studies that hypothesized the importance of salt marshes as "sources" of particulate carbon for the adjacent estuaries and other studies that suggested the importance of wetlands as "sinks" for certain chemicals, particularly nitrogen and phosphorus. The two concepts of one wetland being a source and a sink for various materials are not mutually exclusive; a wetland can be a sink for an inorganic form of a nutrient and a source for an organic form of the same nutrient.

WETLANDS AS BIOLOGICAL RESERVOIRS

Wetlands have been called biological "supermarkets" for their role in supporting foodchains. They serve as both habitat and food sources for wildlife and aquatic life in adjacent bodies of water (Mitsch and Gosselink, 1993). Part of this biological role of wetlands comes from their high productivity (except for isolated wetlands such as bogs, which can be very low in productivity) and their position in the landscape where they borrow species from both uplands and deepwater aquatic systems. Welcomme (1979), Risotto and Turner (1985), and Turner (1988a, 1988b) have all reported a strong relationship between fishery yields and floodplains of lowland rivers, both because fish spawn and feed in floodplains during flood stages on the river (Lambou, 1990; Hall and Lambou, 1990), and because the productivity of large, lowland rivers depends on the exchange of nutrients with the floodplains (Junk *et al.*, 1989). The connection between coastal wetlands and offshore shrimp fisheries has been illustrated by Turner (1977). The role of wetlands as habitat for waterfowl is well known and many wetlands adjacent to large bodies of water are maintained as waterfowl havens (Mitsch and Gosselink, 1993).

LANDSCAPE SETTINGS FOR WETLANDS

Some of the landscape settings for wetlands, both natural and constructed, are shown in Fig. 2. Many wetlands are found as *fringe wetlands* around lakes, lagoons, gulfs, and other deepwater systems (Fig. 2a). Some wetlands are simply part of the river or stream that they are protecting (Fig. 2b) as *instream wetlands*. In other cases, wetlands are found as *riparian wetlands* of rivers and streams, receiving only seasonal flooding but otherwise are separated from the river except for return flows and lateral flows from uplands (Fig. 2c). Examples of natural and man-made wetlands that function as water quality protection systems are discussed for each category.

Fringe Wetlands

With interest in controlling nonpoint source pollution, several studies have investigated if wetlands that fringe larger bodies of water, especially lakes, can be sinks of nutrients and sediments when receiving nonpoint sources from both rural and urban areas. In an early study of this type of wetland, Johnston *et al.* (1984) estimated the accumulation of upstream nutrients and sediments for a seasonally flooded lakeside wetland in Wisconsin, USA. Here the sediment accumulation was estimated to be 2.0 kg m^{-2} yr^{-1} while phosphorus retention was 2.6 g P m^{-2} yr^{-1} and nitrogen accumulation was 12.8 g N m^{-2} yr^{-1}. This type of wetland is thought to be very important for maintaining food chains in the adjacent body of water and is often viewed as an "outwelling" system that retains inorganic nutrients and exports organic material that serves as the basis for aquatic foodchains.

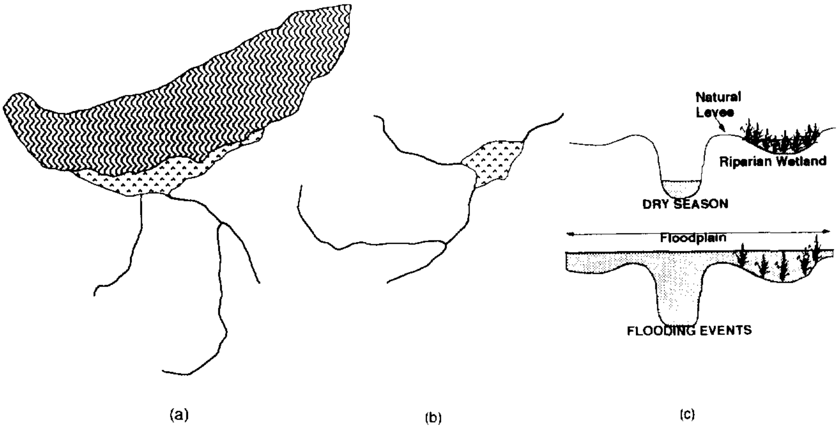

Figure 2. Illustration of three major locations of wetlands: (a) fringe wetland along lake; (b) instream wetland and (c) riparian floodplain wetland (revised from Mitsch, 1992a).

Table 1. Comparison of phosphorus retention capabilities of Old Woman Creek wetland on Lake Erie, Ohio, USA, by different measurements. All numbers except % retention are in mg-P/m^2-day (from Mitsch, 1992b)

Method	Inflow	Outflow	Retention	% Retention
Empirical Model I	36-63	---	14-19	30-39
Empirical Model II	17-33	---	8-13	39-47
Field Data	2.2	1.4	0.8	36
Sediment Core	---	----	22	---
Simulation Model*				
Dry Year	32	21-27	5-12	17-36
Normal Year	45	24-33	12-22	27-48
Wet Year	84	40-64	20-44	24-52

* for nine-month period only; high % retention in range is with high lake level, low % retention is with normal lake level

Old Woman Creek Wetland on Lake Erie. Studies of a freshwater marsh along Lake Erie's shoreline in northern Ohio by our research team and others have shown that the wetland is effective in ameliorating nutrient loading from an agricultural watershed to the lake and that the effectiveness is dependent on the amount of annual runoff and the level of the lake (Klarer and Millie, 1989; Mitsch and Reeder, 1991, 1992; Mitsch *et al.*, 1994). Data from our studies, reported elsewhere (e.g. Mitsch and Reeder, 1991, 1992; Mitsch, 1992b), illustrated a significant range in calculated phosphorus retention by this lake-fringe wetland depending on the hydrologic conditions of both the watershed that feeds the wetland and the water level fluctuations and seiches that occur on the lake and hence influence the wetland (Table 1). Only the simulation model takes macrophyte and algal uptake into consideration in its calculation. The sediment core measurement is the result of one deep core taken in the late 1980s while the empirical model is a "black box" approach that does not account for specific processes.

Instream Wetlands

Ever since studies identified freshwater wetlands for their role as nutrient sinks at Tinicum Marsh near Philadelphia (Grant and Patrick, 1970), there has been much interest in studying the biogeochemical role of these flow-through riverine systems. Studies by Klopatek (1978) in a Wisconsin riverine marsh in midwestern USA and by Simpson *et al.* (1978) in a tidal freshwater wetland in the Chesapeake Bay region of eastern USA also showed the capacity for marsh wetlands to be at least seasonal sinks for inorganic forms of nitrogen and phosphorus in instream settings. A two-year study of the potential of managed marsh wetland in upper New York State to remove nutrients from agricultural drainage gave inconsistent results, with the wetland acting as a source of nitrogen and phosphorus in the first year and a net sink in the second year (Peverly, 1982).

Ross Labs Mitigation Wetlands. Few wetlands have been constructed or restored in instream settings. In one wetland reconstruction project recently completed in central Ohio, a 6 ha wetland was built in a small stream in an urban setting to replace a wetland that was lost due to a corporate development. This wetland has provided a wildlife haven in an urban setting, developed a very diverse vegetation community due to the introduction of plants, and even provided some water quality benefits.

While structural attributes such as vegetation survival (herbaceous and woody) were monitored at this site, the functional aspects of the wetland, particularly phosphorus retention, were also estimated through a combination of field data collection and model simulations. Results showed a low efficiency (16%) yet substantial mass (2.9 gP m^{-2} yr^{-1}) retention of phosphorus by this wetland only 1 year after its construction (Fig. 3). Estimates of basal area and average diameter after 50 years of tree species planted at the site were also developed using a computer model. Simulations suggested that the basal area would be comparable to forested wetlands elsewhere but that the survival of these trees was very dependent on the hydrologic regime chosen for this wetland.

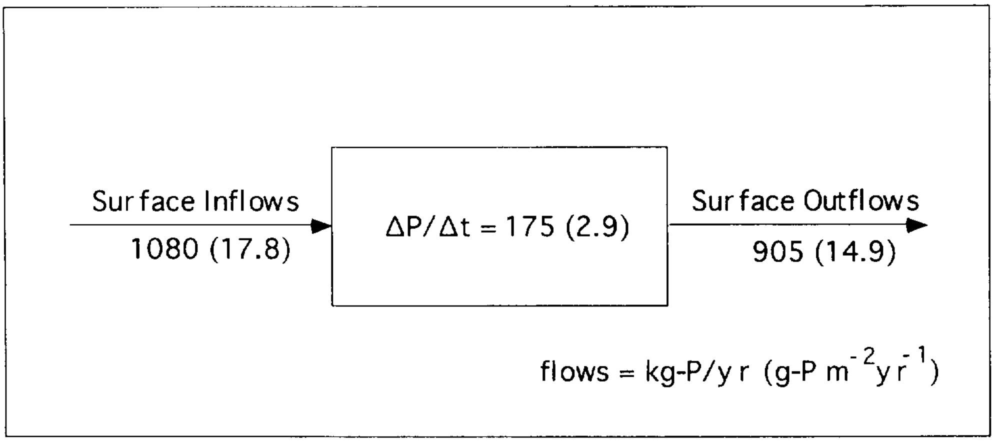

Figure 3. Phosphorous budget estimated for mitigation wetland in central Ohio. Budget was determined from a combination of field measurements and a simple simulation model (from Niswander, 1994).

Riparian Wetlands

The functioning of riparian wetlands as nutrient sinks, suggested nearly 20 years ago by Kitchens *et al.* (1975) in a preliminary winter-spring survey in a swamp forest-alluvial river swamp complex in South Carolina, has been extensively studied since then. Mitsch *et al.* (1979) developed a nutrient budget for an alluvial river swamp in southern Illinois and found that ten times more phosphorus was deposited with sediments during river flooding (3.6 g-P m^{-2} y^{-1}) than was returned from the swamp to the river during the rest of the year. The swamp was thus a sink for a significant amount of phosphorus and sediments during that particular year of flooding although the percent retention was low (3–4.5%) because a very large volume of water passed over the swamp during flooding conditions. Kuenzler *et al.* (1980) found that 94% of the phosphorus transported to the U.S. Coastal Plain floodplain swamps of North Carolina was carried by surface water and that there was a significant retention of phosphorus by the swamp, resulting in low concentrations of phosphorus downstream of the wetland.

Kemp and Day (1984) and Peterjohn and Correll (1984) described the fate of nutrients as they are carried into forested wetlands by agricultural runoff. The former study found that a Louisiana swamp forest acted primarily as a transformer system, removing inorganic forms of nitrogen and serving as a net source of organic nitrogen, phosphate, and organic phosphorus. Peterjohn and Correll (1984) found that a 50-meter-wide riparian forest in an agricultural watershed near the Chesapeake Bay in Maryland removed an estimated 89% of the nitrogen and 80% of the phosphorus that entered it from upland runoff, groundwater, and bulk precipitation. The study estimated that there was a net removal of 11 kg ha^{-1} yr^{-1} of particulate organic nitrogen, 0.83 kg ha^{-1} yr^{-1} of dissolved ammonium nitrogen, 47.2 kg ha^{-1} yr^{-1} of nitrate nitrogen, and 3.0 kg ha^{-1} yr^{-1} of particulate phosphorus. A similar study of a floodplain forest in Georgia found 14% retention and 61% denitrification of nitrogen (for a total loss of 75% of the incoming nitrogen) and 30 % retention of phosphorus (Lowrance *et al.*, 1984). The Maryland and Georgia studies did not consider any river flooding in the calculations of their nutrient budgets. Several other studies (e.g. Schlosser and Karr, 1981a, 1981b; Lowrance *et al.*, 1984; Cooper *et al.*, 1986; Kuenzler and Craig, 1986; Jordan *et al.*, 1986; Whigham *et al.*, 1986; Fail *et al.*, 1989; Cooper, 1994) have demonstrated the way in which riparian ecosystems can be effective in removing as well as modifying nutrients and sediments from agricultural runoff before it reaches the stream or river.

Des Plaines River Wetland Demonstration Project. We have been involved in the study of constructed riparian wetlands for improving water quality of rivers for the past 6 years at the Des Plaines River Wetland Demonstration Project, located 80 km north of Chicago in the town of Wadsworth, Illinois, USA (Fig. 4). The site has been the site of major research on the role of wetlands in providing water quality enhancement and habitat for a river systems (Hey *et al.*, 1989). The Des Plaines River drains a watershed of approximately 545 km^2 (80% agricultural and 20% urban) and has high levels of suspended solids (60 to 100 $mg \cdot L^{-1}$) and total phosphorus (from 100 to 200 $\mu g\text{-}P \cdot L^{-1}$). Experimental Wetlands (EWs) 3 through 6 (Fig. 4) were constructed to investigate the role of hydrologic flow-through conditions on ecosystem function. The experimental wetlands, 1.9 to 3.4 ha in size, are hydrologically isolated from one another. A pump station was installed on the river to deliver known amounts of river water to each wetland. Experimental Wetlands (EWs) 3 and 5 were high flow wetlands, with flow averaging 35-38 cm/wk, while Experimental Wetlands (EWs) 4 and 6 were low flow wetlands, with flow averaging less than 10-16 cm/wk. The research focused on the role of hydrology in determining ecosystem function in the wetland and the role of the wetland in improving river water quality. Details of the overall research project, summarized in a special issue of *Ecological Engineering* by Sanville and Mitsch (1994) showed a considerable reduction in nitrogen and phosphorus, major spatial patterns of river sediment retention, higher aquatic productivity in high flow systems, and a marked improvement in waterfowl and wildlife on the site over preconstruction conditions (Sanville and Mitsch, 1994).

Olentangy River Wetland Research Park. To supplement research conducted at the Des Plaines River wetland project and to do so in a university environment where teaching and research on wetlands are joined together, the Olentangy River Wetland Research Park was established at The Ohio State University in Columbus, Ohio, USA in 1993. The wetland site, as it now appears, is shown in Fig. 5. The Olentangy River Wetland Research Park, located on a 50-ha site immediately north of Ohio State's Columbus campus, has the goals of: (1) research on the ecological processes in constructed riverine wetlands for improving river and runoff water quality and providing suitable wetland habitat; (2) research on developing proper design criteria for constructed wetlands and on monitoring success of constructed wetlands; (3) graduate and undergraduate teaching on wetland ecology; and (4) demonstration of the feasibility of wetland ecotechniques to agencies, private developers, and the public. Project design began in 1989 with initial funding developed in early 1991-92. Phase 1 construction of the project was mostly completed in 1993. This phase consists of building two 1.0-ha wetland basins (called deepwater marshes) and constructing the necessary water delivery and electrical systems to support experimentation with the wetland basins.

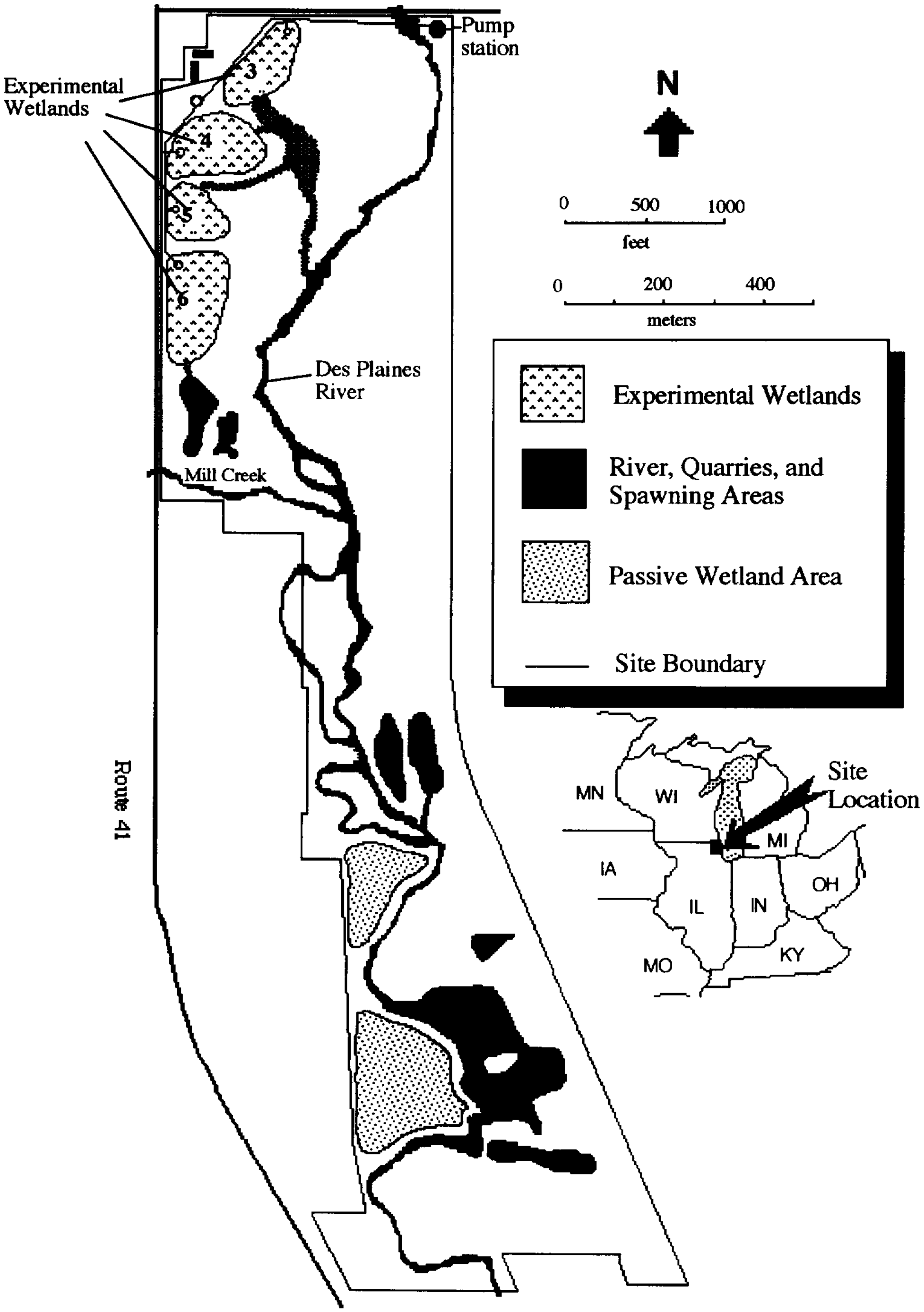

Figure 4. The Des Plaines River Wetland Demonstration Project, northeastern Illinois, USA.

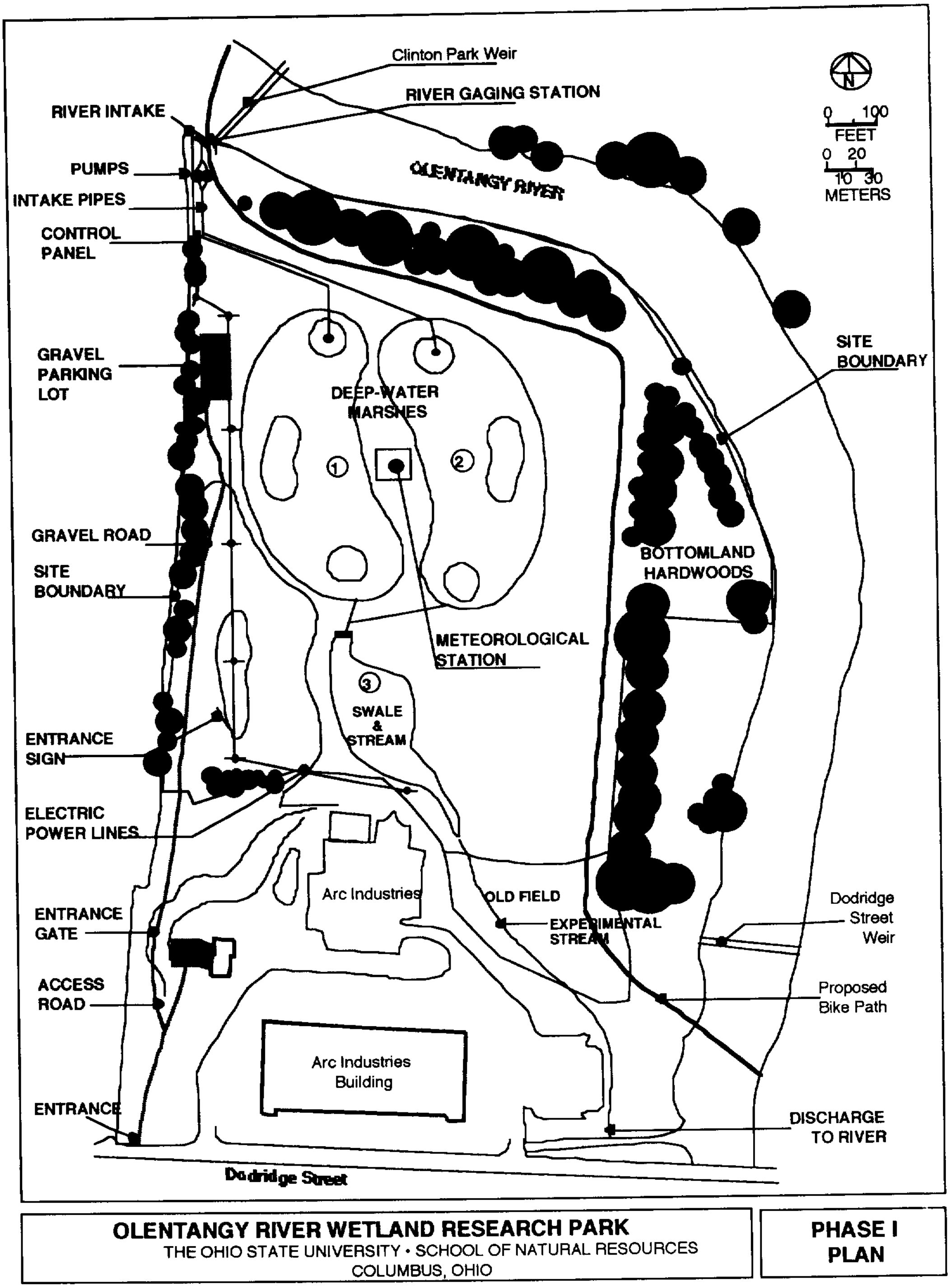

Figure 5. Olentangy River Wetland Research Park, Columbus, Ohio, USA.

Almost 20 000 m^3 of soil were excavated for the two wetland basins; the soil was deposited on the southwest corner of the site, out of the 100-year floodplain. An entrance road, parking lot and gate were also installed on the site. Two pumps, one a conventional pump and the other a "biologically-friendly" pump that will allow river organisms to enter the wetland, were installed in parallel in underground vaults to bring river water into the basins. Research studies now emphasize monitoring ecological changes that occur when wetlands are established on the site. Since water was first introduced to the site in March 1994, many changes have taken place. Waterfowl moved to the site almost immediately and invertebrate and amphibian populations have begun to develop. Vegetation representing approximately 14 species was introduced by hand-planting in May 1994; current surveys show a high survival rate by *Scirpus* spp. as vegetation grows and reproduces through the first season. Over 687 soil samples (three depths at 229 locations) were taken from the constructed wetland basins after construction but prior to water being introduced into the basins. These samples, now stored in the laboratory, will serve as the basis for estimating changes in soil characteristics after water is added. Surveys conducted by wildlife experts of bird populations at the site continued through 1993 with a total of 88 bird species spotted at the site since sampling began in 1992. Ninety-two percent of all bird species observed were found to utilize the bottomland hardwood forest while 60% were found in the old field/construction site. As water accumulates on the landscape and upland and wetland vegetation become established, the diversity and numbers of birds will recover and probably surpass preconstruction conditions. A simulation model has been used to estimate the effectiveness of the constructed deepwater marshes on water quality, particularly phosphorus. Two versions of the model were developed to optimize experimental design of the wetland basins and to predict phosphorus retention. Simulations compared results using the mean river flow and the means of simulations using actual river flow. Significantly different hydrologic conditions and phosphorus retention were estimated from these two approaches. Nine classes from three OSU colleges used the site in 1993 and, overall, 18 OSU departments or units from five colleges used the site for teaching, research, or other activities through 1993. It will serve as a teaching and research facility on wetland function for many years to come.

Table 2. Comparison sediment and phosphorus retention in wetlands in Eastern and Midwestern USA (from Mitsch *et al.*, 1979; Peterjohn and Correll, 1984; Johnston *et al.*, 1984; Mitsch and Reeder, 1991; Niswander, 1994)

Wetland Site	sediment			phosphorus		
	loading $g/m^2 \cdot yr$	retention $g/m^2 \cdot yr$	% retention	loading $g\text{-}P/m^2 \cdot yr$	retention $g\text{-}P/m^2 \cdot yr$	% retention
Natural Wetlands						
Riparian S Illinois forested wetland	15,000	447	3	80.2	3.6	4.5
Riparian NE Illinois bottomland forest	—	590	—	—	—	—
Fringe coastal Ohio Lake Erie marsh	—	—	—	8	0.8	10
Fringe lake-edge Wisconsin marsh	—	2000	—	—	2.6	—
Riparian Chesapeake Bay bottomland	—	—	—	—	0.3	—
Fringe Florida cypress swamp	—	—	—	—	3.1	—
Restored/Constructed Wetlands						
Riparian Des Plaines River Wetlands	220-2100	200-2100	88-98	0.4-4	0.4-4	63-98
Instream Ross Labs Wetland, Ohio	—	—	—	17.8	2.9	16

CONCLUSIONS

We do not have all the approaches to designing wetlands to replace natural wetland functions. We do have confidence, based on a few case studies, that wetlands can be reintroduced to the landscape to improve our rivers and lakes. Whether these wetlands are fringe wetlands around lakes, instream wetlands along small streams, or riparian wetlands on the banks of larger rivers, the probability of them performing important water quality functions is high when they are not isolated. Not all of these wetlands perform equally, however, so we must be cautious to attempt to generalize. But, comparisons between the function of natural and man-made wetlands provide useful insight. For example, Table 2 illustrates that several of the wetlands described above are markedly different in the % retention of sediments and phosphorus but the amount they retain is within a relatively narrow range. Search for general ecological principles and landscape design criteria is aided by ecological engineering.

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