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# Aspects of Functional Analysis of Mitigated Wetlands Receiving Highway Runoff

SHAW L. YU, T. ANDREW EARLES, AND G. MICHAEL FITCH

The wetland mitigation and storm water management provisions in the 1987 Clean Water Act significantly affect transportation agencies. A common requirement of these federal storm water management provisions and state storm water regulations is the use of best-management practices (BMPs). The Virginia Department of Transportation has constructed more than 200 wetlands and many storm water BMPs, such as detention basins. A potentially cost-effective approach to satisfying wetland mitigation requirements and storm water regulations is to use mitigated wetlands as storm water BMPs. A multifunctional evaluation of two mitigated wetlands receiving highway runoff is presented to examine the feasibility of using mitigated wetlands as storm water BMPs. Influent and effluent water quality and quantity were monitored at the sites during storm events. Vegetation density and diversity and wetland wildlife were examined as functional indicators because they were believed to be the most likely to be impaired by highway runoff. Data collected were stored in a geographic information system, which was developed to serve as a database for current and future monitoring of mitigated wetland sites. Both sites had peak reductions in excess of 40 percent, with attenuation of greater than 90 percent for a system combining a detention basin and a mitigated wetland in series. Removal rates were as high as 90 percent for total suspended solids, 65 percent for chemical oxygen demand, 70 percent for total phosphorus and orthophosphate, and 50 percent for zinc. Despite having highway runoff as a primary water source, both sites support apparently healthy and diverse vegetative communities and provide habitat for a variety of wildlife.

Wetland mitigation and storm water management provisions in the 1987 Clean Water Act significantly affect transportation agencies. As a part of permit conditions, Section 404 requires that a highway agency create artificial wetlands to compensate for the loss of natural wetlands when they are displaced by a highway construction activity. Section 402 further directs the U.S. Environmental Protection Agency (EPA) to regulate storm water runoff from certain areas under the National Pollutant Discharge Elimination System (NPDES). Highway storm water runoff, runoff from highway construction sites with five or more disturbed acres, and runoff from maintenance and storage facilities are subject to NPDES permit requirements.

In addition to EPA regulations, the Virginia Department of Transportation (VDOT) must comply with the Chesapeake Bay Preservation Act, the Virginia Stormwater Management Regulations, and the Virginia Erosion and Sediment Control Regulations. A common requirement of these regulations is the use of best-management practices (BMPs), such as detention ponds and infiltration practices, to control runoff quantity and quality.

VDOT has constructed more than 200 wetlands in Virginia and many storm water BMPs, such as detention basins. Wetland mitigation is a significant item in the VDOT road-building budget, and

compliance with storm water regulations can add between 10 and 15 percent to the cost of an average construction project. A potentially cost-effective approach to satisfying wetland mitigation requirements and storm water regulations is to use mitigated wetlands as storm water BMPs. It is believed that if a mitigated wetland site is properly engineered and maintained, it will perform adequately as a storm water BMP without jeopardizing its desired wetland functions.

Constructed wetlands have been used for decades to treat municipal and industrial wastewater and are considered to be more cost-effective than advanced wastewater treatment systems. However, using wetlands for controlling nonpoint source pollution has only recently been investigated. A number of studies conducted since the mid-1980s on the use of constructed wetlands for urban storm water treatment point to their ability to improve storm water runoff quality. Martin and Smoot (1) found removal rates between 41 and 73 percent for total suspended solids (TSS), lead, and zinc in a study of the pollutant removal efficiency of a combined detention pond and wetland system receiving runoff from a four-lane concrete roadway. Significant removal of solids and metals in wetlands has also been reported (2-4), with removal of greater than 40 percent of dissolved and 90 percent of total zinc, lead, nickel, and iron (5) in some instances, largely attributable to deposition of solids. A number of studies have reported removal of nitrogen and total phosphorus in the range of 10 to 50 percent and 16 to 70 percent, respectively (1,6-9).

The complexity of nutrient cycling in wetland systems leads to a wide range of removal efficiencies for nitrogen and phosphorus. Depending on seasonal effects, vegetation type, and management practices, wetlands may serve as a source, sink, or transformer of nutrients (4,10). Well-designed wetlands may attain long-term nutrient removals on the order of 25 percent for total nitrogen and 45 percent for total phosphorus (TP) (11).

EPA encourages the use of constructed wetlands for nonpoint source pollution control, especially in agricultural areas (12), and recognizes the need to combine wetland protection and nonpoint source pollution control strategies (13). A report prepared for the Federal Highway Administration describes the applicability of constructed wetland technology for nonpoint source pollution from highways (14):

Artificial wetlands offer many more options for the management of highway runoff . . . the constructed wetland can be sized to accommodate a projected hydraulic load and to provide a specific residence time; constructed within the highway right-of-way, in median strips, in cloverleaves, or alongside the highway, and designed to facilitate operations and maintenance.

Although data collected to document the performance of wetlands constructed for storm water quality improvement are increasing (15,16), most studies have examined wetlands designed specifically for water-quality improvement instead of mitigation. As a result,

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few studies have taken a multifunctional approach (8). Such an approach is critical to evaluating the use of mitigated wetlands as BMPs, because, foremost, the purpose of such a wetland must be to compensate for the loss of a multifunctional natural wetland.

## PURPOSE AND SCOPE

The purpose of this study was to evaluate the potential of using mitigated wetlands as storm water BMPs. Two mitigated wetlands were selected for monitoring to assess the impacts of highway runoff on wetland functions and to document water-quality benefits. Influent and effluent water quality and quantity were monitored at sites during storm events to evaluate the effectiveness of the wetlands as BMPs. Vegetation density and diversity and wetland wildlife were examined as functional indicators for the wetlands because these functions were believed to be the most likely to be impaired by highway runoff. A geographic information system (GIS) was developed to serve as a database for data collected during current and future monitoring of mitigated wetland sites.

## METHODOLOGY

### Site Selection

VDOT lists more than 220 mitigated wetland sites, most located in the coastal region of Virginia. Sites were reviewed by VDOT's Environmental Division and the research team to determine candidate sites for sampling and monitoring. Candidate sites were selected based on the following criteria:

- Located on state or public property;
- Storm water runoff from highways as main water source;
- Wetland at least 5 years old;
- Clearly defined inlet(s) and outlet(s); and
- Easy access.

Candidate sites were visited by the research team and compared before final selection for sampling and monitoring. The most common reason a particular site was not selected was a lack of well-defined inlets and outlets.

Two sites were chosen for functional evaluation: the commuter rail parking lot mitigation area in Brooke, Virginia, and the Route 288 mitigation area in Chesterfield, Virginia. These sites are indicated in Figure 1. The Brooke site consists of a 0.08-ha (0.2-acre) emergent detention pond and a 2.83-ha (7-acre) mitigated wetland in series. The site receives storm water runoff from a commuter parking lot, a grassed area, and a railway. The Brooke site was constructed in 1991. The Route 288 site is a 2.02-ha (5-acre) cell that is part of a larger mitigation area, approximately 8.09 ha (20 acres) and consisting of three cells. It is located in the median of Route 288 in Chesterfield and receives runoff from this four-lane highway. The wetland was constructed in 1992.

### Field Monitoring and Laboratory Analysis

Flow measurements were made at inlets and outlets at each site by using depth sensors attached to American Sigma 900MAX portable automatic samplers. For channels with irregular geometry, contracted rectangular weirs were used as the primary flow measurement device. A tipping bucket rain gauge was also installed at each site.

Storm water samples were collected for storms occurring after at least 72 dry h. Samples were mixed to form a flow-weighted composite sample for analysis. Analytical parameters for analysis were selected based on recommendations by the Nation-Wide Urban Runoff Program to characterize urban runoff.

Composite samples were analyzed for TSS, orthophosphate (OP), TP, chemical oxygen demand (COD), and zinc. Analyses were performed according to EPA-approved methods at the University of Virginia Stormwater Laboratory (17,18) and at a local contract laboratory.

To assess the health and diversity of vegetation, square meter vegetation counts were conducted at both sites between midspring and late fall 1996. Multiple counts were made in three primary

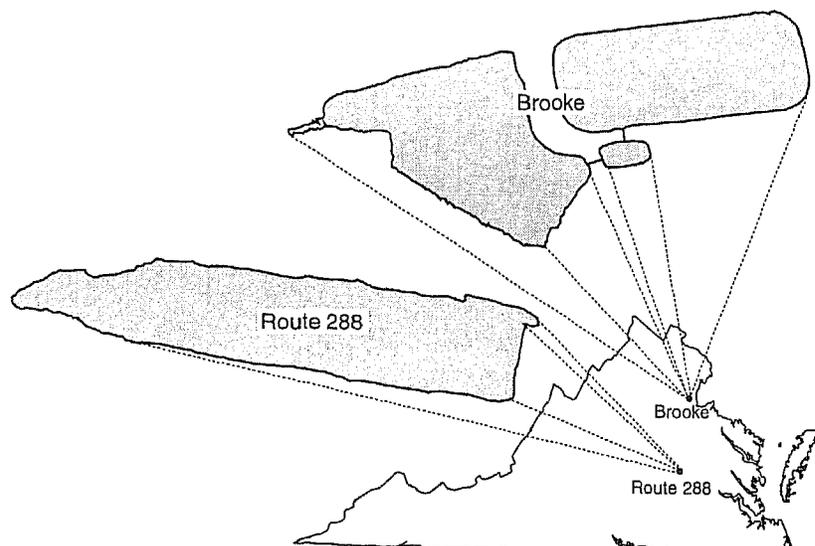


FIGURE 1 Study site locations and delineations.

zones of each wetland: an inlet zone, a middle zone, and an outlet zone. Density of vegetation was noted on a qualitative scale ranging from sparse to abundant, and vegetative health was assessed qualitatively.

Observations of wildlife, whether from visual identification or indirect evidence such as animal tracks, were made each time the sites were visited (approximately once a week).

### GIS Development

The GIS being developed has three components: a mitigation site database, a future mitigation site selection tool, and a GIS/storm water management model interface.

The mitigation site database was developed by using PC Arc/Info and ArcView. Coordinates for existing mitigation sites were taken from project files, U.S. Geological Survey quad sheets, and global positioning system (GPS) readings. For the majority of the sites, a single set of coordinates was used to represent the site as a point feature. For some of the larger, more active sites, including Route 288 and Brooke, GPS was used to delineate the entire wetland boundary. Existing attributes, previously stored in a rudimentary database, were transferred to the attribute table of the spatial coverage. Additional information, such as digital photographs and detailed maps indicating major areas of vegetation, inlets, outlets, and other features, was hot-linked to specific sites if it was available.

### Data Analysis

Two methods were used to examine the water quality of the constructed wetlands. First, a mass balance was used to determine mass removal efficiency during storm events based on volumes of inflow and outflow and event mean concentrations (EMCs) from the composite samples. Mass removal efficiency (MRE) was calculated as

$$\text{MRE (percent)} = \frac{(\text{volume in} \times \text{concentration in}) - (\text{volume out} \times \text{concentration out})}{(\text{volume in} \times \text{concentration in})} \times 100$$

Second, EMC removal efficiency, which is equivalent to the average percentage reduction in EMC, was determined (*J*). EMC removal was calculated as

$$\text{EMC efficiency (percent)} = \left( 1 - \frac{\text{average outlet EMC}}{\text{average inlet EMC}} \right) \times 100$$

## RESULTS

### Hydrology

The primary source of water for both sites was storm water runoff. A slight base flow was observed at Route 288, and some ground-water inflow is expected at Brooke; however, the vast majority of inputs at both sites are from surface runoff. Conditions at both sites ranged from permanently flooded regions where deep (up to 1 m) pools exist to intermittently flooded regions where surface water is

present during storm events and near-saturated to saturated soil conditions prevail during dry weather. The Route 288 site has approximately 0.5 ha (25 percent of total area) of open water, and the Brooke site has approximately 0.4 ha (14 percent of total area) of open water. Over a 3-year monitoring period, the fraction of open water at the Route 288 site increased significantly because of ponding resulting from the construction of a beaver dam at the outlet. Saturated soil conditions and shallow standing water were prevalent at the Route 288 site, and slightly drier conditions (near saturated to saturated) were prevalent at Brooke. The detention basin at Brooke is intermittently flooded, with water levels rising as high as 2 m during large storm events and near-saturated to saturated soil conditions prevalent during dry periods.

An important hydrologic function of wetlands is flood control. This function is critical for mitigated wetland sites where development results in more runoff because of increased imperviousness. Results from six storm events monitored at Route 288 and five monitored at Brooke indicated that both wetlands significantly reduce peak flows during storm events. The average peak reduction at the Route 288 site was 40 percent for rainfall events ranging from 18.3 to 51.6 mm (0.72 to 2.03 in.). The most intense storm monitored at Route 288, with 40.4 mm (1.59 in.) of rain in 4 h, resulted in a peak reduction of 58 percent. At the Brooke site, inflows and outflows were monitored for rainfall events ranging from 3.81 to 47.24 mm (0.15 to 1.86 in.). The detention basin is a major factor in peak reduction, reducing peak inflows an average of 83 percent. Data from the Brooke wetland indicated average peak reductions of 46 percent, resulting in an average peak reduction of nearly 90 percent for the system. The most intense event monitored, with 47.24 mm (1.86 in.) of rain in 50 min, resulted in a peak reduction of 93 percent for the entire system.

### Water Quality

Between July 1995 and November 1996, 12 and 13 storm events were monitored at the Brooke and Route 288 sites, respectively. Of these, 8 complete events each were sampled at both the Brooke (4 for the detention basin, 3 for the wetland, and 1 for the entire system) and Route 288 sites. To determine mass balance removal efficiencies, a complete event was considered to be a storm event in which flow was measured and water samples were collected at all monitoring stations at a site. Problems with the automatic sampling, such as insufficient sample volume for analysis or contamination because of sample overflow, were the most common cause of incomplete storm events. At the Route 288 site, a beaver dam at the outflow hindered flow measurements and sample collection for 5 events. In most of these cases, outflow was minimal because of the storage created by the dam, resulting in extremely high mass removal efficiency. These events were excluded from removal efficiency analysis.

EMC and mass removal efficiencies for both sites are presented in Figure 2. Both appear to be efficient in removing the parameters studied, the exception being the export (indicated by a negative removal efficiency) of OP by the Brooke system. The Route 288 site was quite efficient at removing nutrients, with TP and OP removal around 70 percent. The Brooke site was most efficient at removing TSS (90 percent) and COD (around 70 percent). Although OP is exported by the Brooke site, TP removal is greater than 20 percent, indicating that this site acts as both a sink and transformer of phosphorus. The increase in dissolved reactive phosphorus is likely attributable to the decay of organic matter in the basin and wetland.

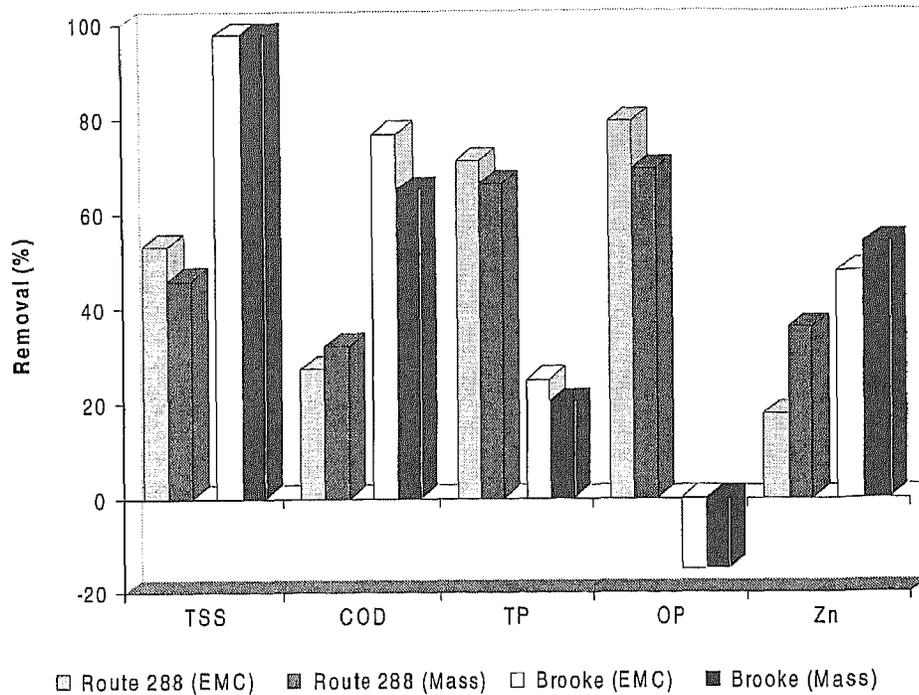


FIGURE 2 Mass and EMC removal efficiencies.

Further, because of the stringent quality assurance/quality control holding time for OP, results are based on only a subset of all storms sampled.

EMC and mass removal efficiencies are similar at both sites. This indicates that mass removal at Route 288 and Brooke is due primarily to decreases in pollutant concentration instead of simply storage. In general, one would expect EMC removal efficiency to be a more conservative (lower) estimate of removal efficiency than mass removal efficiency because the former is essentially the mass removal efficiency with the assumption of zero storage. Some EMC removal efficiencies in Figure 2 are actually greater than the mass removal efficiency because direct rainfall onto the wetland (assumed to have minimal pollutant concentrations) resulted in additional outflow when little storage was available.

Although both sites improve storm water quality, the water-quality function of the wetlands is quite different. Average inflow concentrations are indicated in Figure 3. Both inflow into the entire system and inflow into the wetland (which is also outflow from the detention basin) are shown for the Brooke site. Inflow concentrations for all parameters monitored were within a typical range for highway runoff and similar to those monitored at other wetlands in Virginia that receive highway runoff (15,16,19). The average concentrations for all parameters monitored were higher for the Route 288 site and indicate the differences in the land use of the drainage areas (a four-lane highway with average daily traffic of 50,000 vehicles for Route 288 versus a commuter parking lot for Brooke). A comparison of average inflow concentrations for the two sites revealed that inflow concentrations are between two and eight times higher at Route 288 than at the Brooke wetland.

The relatively low inflow concentrations for the Brooke wetland indicate that a significant portion of removal at the Brooke site occurs in the detention basin rather than in the wetland. EMC removal efficiencies for the Brooke basin and the Brooke wetland are compared

in Figure 4. For all parameters except TSS, EMCs in the wetland outflow were actually higher than those in the wetland inflow. Although significant removal occurs in the Brooke detention basin, the wetland actually functions as an exporter of COD, phosphorus, and zinc. Even though the TSS removal efficiency of the wetland is nearly as high as that of the basin, the wetland contribution to removal is minimal because inflow concentrations to the basin are nearly three times higher than wetland inflow concentrations.

### Vegetation

Mitigation plans at both sites specified planting a variety of emergent plants, shrubs, and woody species. No planting was performed for the Brooke detention basin. Both mitigation plans specified in-kind replacement of any species not surviving after the first year. Planting for the Brooke site took place in 1991, and planting for the Route 288 site was completed in 1992.

From spring to late fall of 1996, vegetation surveys were conducted at both sites. The research team catalogued all species observed, determined dominant vegetation in wetland zones, and surveyed square meter plots to determine the relative frequency of various species. Tables 1 and 2 list vegetation planted and vegetation observed by the research team during 1996 site visits at the Brooke and Route 288 sites, respectively, and Figure 5 indicates dominant species in various sections of the wetlands.

The number of species observed in the 1996 surveys indicated diverse plant communities at both sites and excellent survival of planted species. Of the nine planted species at the Brooke site, all were observed in field surveys. At the Route 288 site, the increased water depth attributable to the beaver dam favored the emergent species. *Juniperous virginiana* (eastern red cedar) and *Pinus taeda* (loblolly pine) were beginning to die in newly submerged areas;

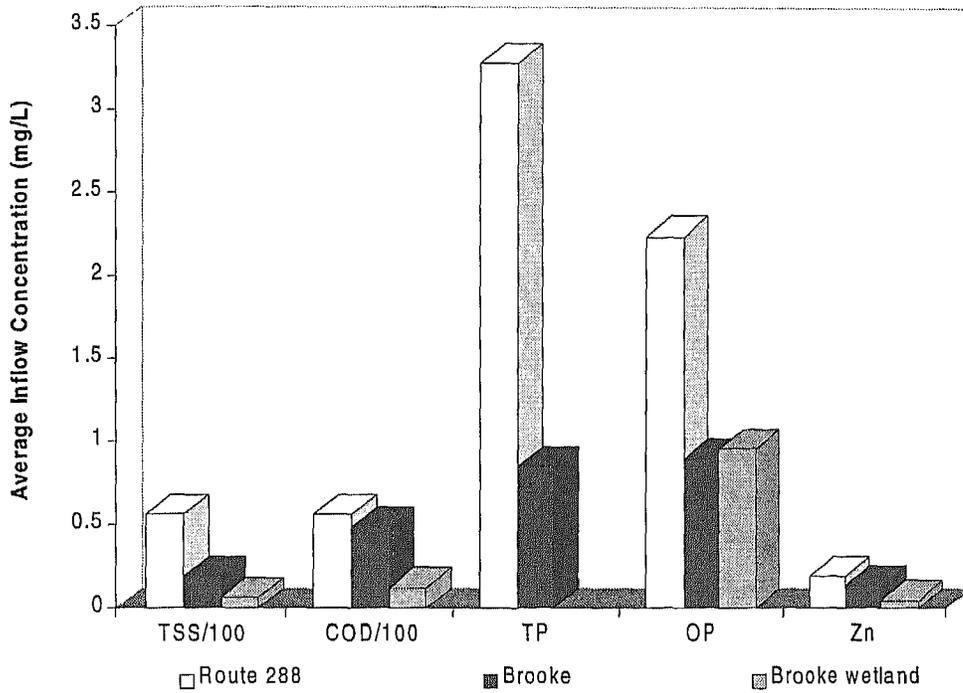


FIGURE 3 Average inflow EMCs.

however, in higher marsh areas, these species were colonizing. Water-tolerant woody species, particularly *Salix nigra* (black willow), were flourishing in the shallow water conditions. The increased water depth near the outlet of the Route 288 site created an open water area with a strong community of *Lemna spp.* (duckweed) and sparse *Typha latifolia* (cattail) stands. At both sites, *Cicuta*

*maculata* (water hemlock) was common in shallow water areas, but few mature plants were observed. This is likely attributable to plants such as *Scirpus cyperinus* (wool grass) and *Typha latifolia* (cattail), which provide competition and shade. Vegetation density was moderate to dense in all but the open water areas of the two sites.

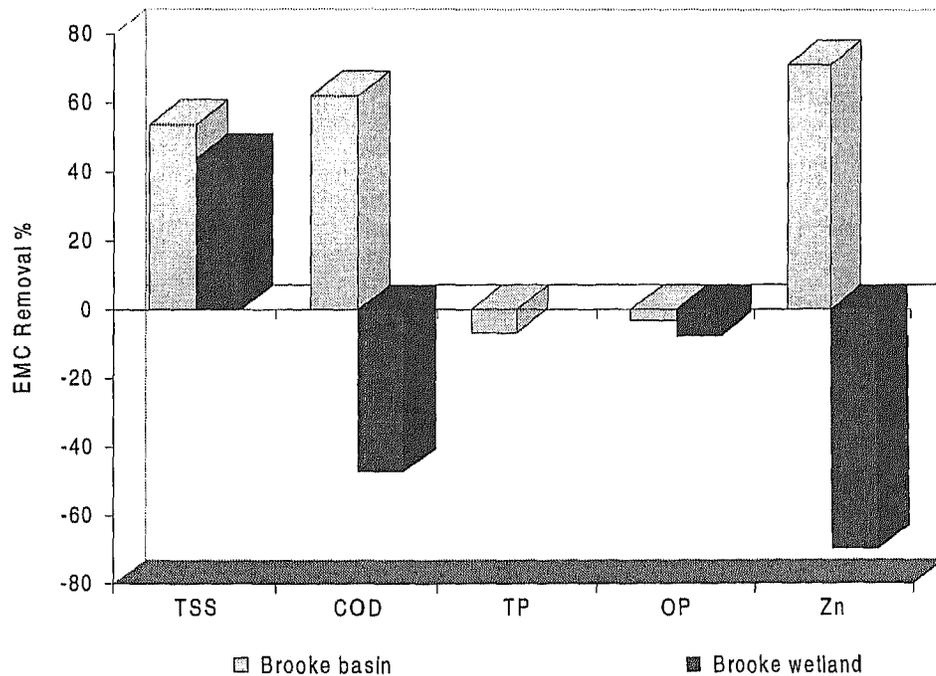


FIGURE 4 Comparison of EMC removal efficiencies for Brooke detention basin and wetland.

TABLE 1 Planted and Observed Vegetation at Brooke Site

Type	Planted 1991	Observed 1996
Emergent, floating aquatic vegetation, wildflowers	<i>Peltra virginica</i> (arrow arum)	<i>Peltra virginica</i> (arrow arum)
	<i>Saururus cernuus</i> (lizard's tail)	<i>Saururus cernuus</i> (lizard's tail)
	<i>Leersia oryzoides</i> (rice cutgrass)	<i>Leersia oryzoides</i> (rice cutgrass)
		<i>Cicuta maculata</i> (water hemlock)
		<i>Juncus effusus</i> (soft rush)
		<i>Typha latifolia</i> (broadleaf cattail)
		<i>Carex scoparia</i> (broom sedge)
		<i>Carex spp.</i> (lurid sedge)
		<i>Lemna spp.</i> (duckweed)
		<i>Eupatorium spp.</i> (Joe-Pye-weed)
		<i>Pluchea camphorata</i> (stinking marsh-fleabane)
		<i>Sphagnum magellanicum</i> (sphagnum moss)
		<i>Erigeron annuus</i> (daisy fleabane)
Shrubs	<i>Alnus serrulata</i> (common alder)	<i>Alnus serrulata</i> (common alder)
	<i>Cephalanthus occidentalis</i> (buttonbush)	<i>Cephalanthus occidentalis</i> (buttonbush)
	<i>Sambucus canadensis</i> (common elder)	<i>Sambucus canadensis</i> (common elder)
Woody species	<i>Betula nigra</i> (river birch)	<i>Betula nigra</i> (river birch)
	<i>Liquidambar styraciflua</i> (sweetgum)	<i>Liquidambar styraciflua</i> (sweetgum)
	<i>Acer rubrum</i> (red maple)	<i>Acer rubrum</i> (red maple)
		<i>Fraxinus pennsylvanica</i> (green ash)
		<i>Pinus taeda</i> (loblolly pine)

Emergent vegetation was also present in the Brooke detention basin. Primary species were *Scirpus cyperinus* (wool grass), *Typha latifolia* (cattail), *Solidago spp.* (goldenrod), and *Juncus effusus* (soft rush). Vegetation was dense in this basin.

Although the number of plants is one measure of diversity, the relative abundance of these various species is also important. Although

the scale of the 1-m plots is too small to evaluate the composition of woody species in an area, such plots reveal considerable information on emergent species diversity. Figures 6 and 7 indicate the relative abundance of species in the Brooke and Route 288 wetlands, respectively. These figures are based on composites of all meter plots surveyed at the site in 1996 to provide an overall composition of

TABLE 2 Planted and Observed Vegetation at Route 288 Site

Type	Planted 1992	Observed 1996
Emergent, floating aquatic vegetation, wildflowers	<i>Scirpus cyperinus</i> (wool grass)	<i>Scirpus cyperinus</i> (wool grass)
	<i>Typha latifolia</i> (broadleaf cattail)	<i>Typha latifolia</i> (broadleaf cattail)
		<i>Juncus effusus</i> (soft rush)
		<i>Rhynchospora capitellata</i> (small-headed beak rush)
		<i>Eleocharis rostellata</i> (beaked spike rush)
		<i>Scirpus atrovirens</i> (green bulrush)
		<i>Carex scoparia</i> (broom sedge)
		<i>Carex spp.</i> (lurid sedge)
		<i>Cicuta maculata</i> (water hemlock)
		<i>Ludwigia alternifolia</i> (seedbox)
		<i>Sphagnum magellanicum</i> (sphagnum moss)
		<i>Polygonum punctatum</i> (water smartweed)
	Shrubs	<i>Alnus serrulata</i> (common alder)
<i>Cephalanthus occidentalis</i> (buttonbush)		<i>Cephalanthus occidentalis</i> (buttonbush)
Woody species	<i>Betula nigra</i> (river birch)	<i>Betula nigra</i> (river birch)
	<i>Salix nigra</i> (black willow)	<i>Salix nigra</i> (black willow)
	<i>Juniperous virginiana</i> (eastern red cedar)	<i>Juniperous virginiana</i> (eastern red cedar)
	<i>Pinus taeda</i> (loblolly pine)	<i>Pinus taeda</i> (loblolly pine)
		<i>Acer rubrum</i> (red maple)
	<i>Fraxinus pennsylvanica</i> (green ash)	

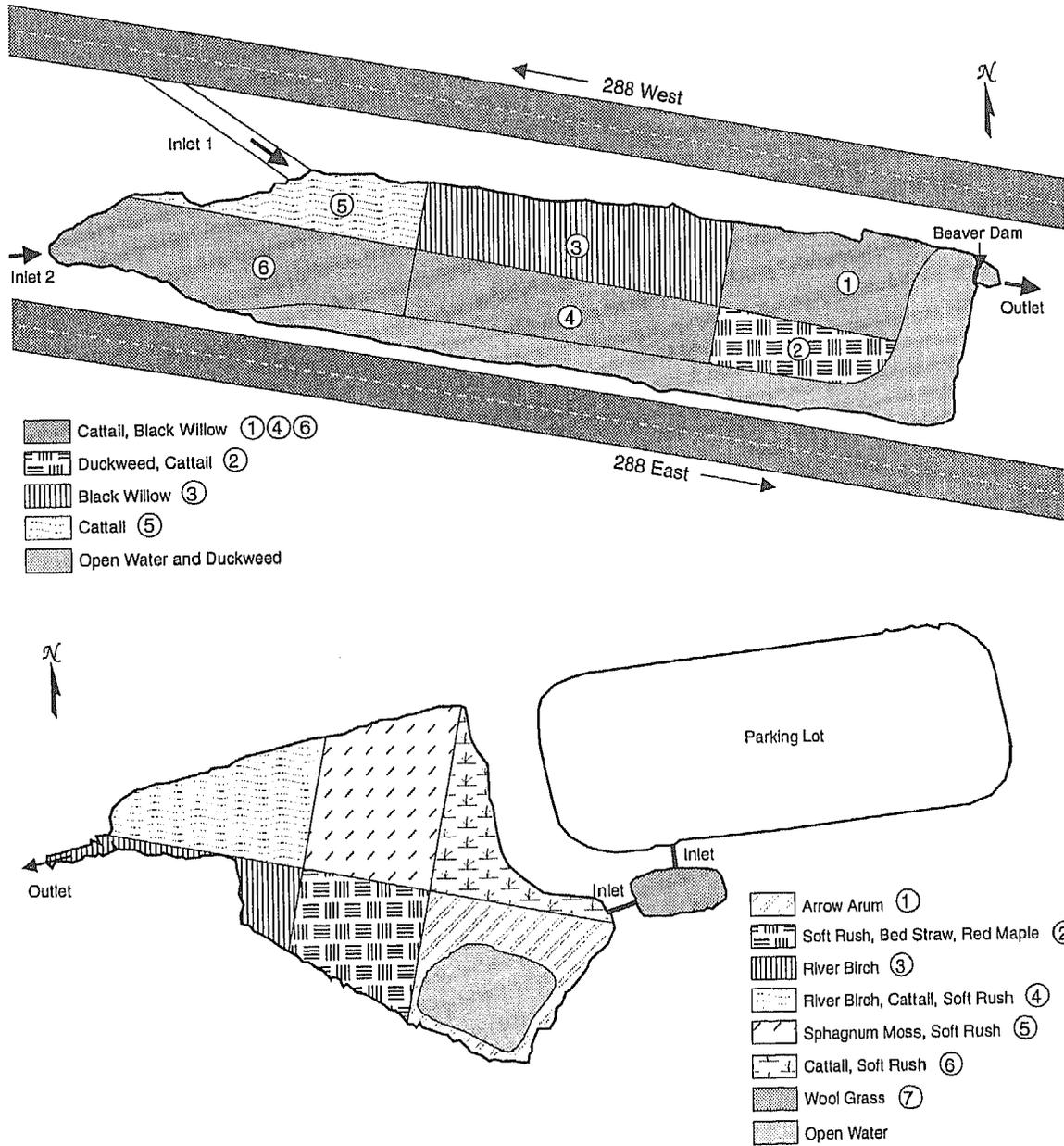


FIGURE 5 Distribution of dominant vegetation at study sites.

the wetland. They do not include woody species or floating aquatic plants that cannot be easily counted individually, such as *Lemna* (duckweed). Both wetlands had a strong presence of *Typha latifolia* (cattail) and *Juncus effusus* (soft rush), but neither species was overwhelming.

**Wildlife**

The research team observed a variety of wildlife at both sites during field visits. Because visits were conducted almost exclusively during daylight hours (most often in midafternoon), nocturnal species and species that prefer cooler periods of the day were not

likely to be observed. Indirect evidence of wildlife, such as tracks and animal feces, was also noted. Ducks, red-winged blackbirds, field mice, several species of snakes, and frogs were observed at both sites. Small fish and snails (*Physella heterostropha*) were observed at Route 288, and beaver and muskrat were quite active at this site. Deer, turtles, and blue heron were also observed at the Brooke site.

Despite the physical barrier and noise associated with its location in the median of a four-lane highway, the Route 288 site appeared to provide a habitat for a range of animals similar to that of the Brooke site, which is adjacent to a stream in a rural area of Stafford County. Frequency of observation was similar at both sites, with observations of wildlife common during even the shortest visits.

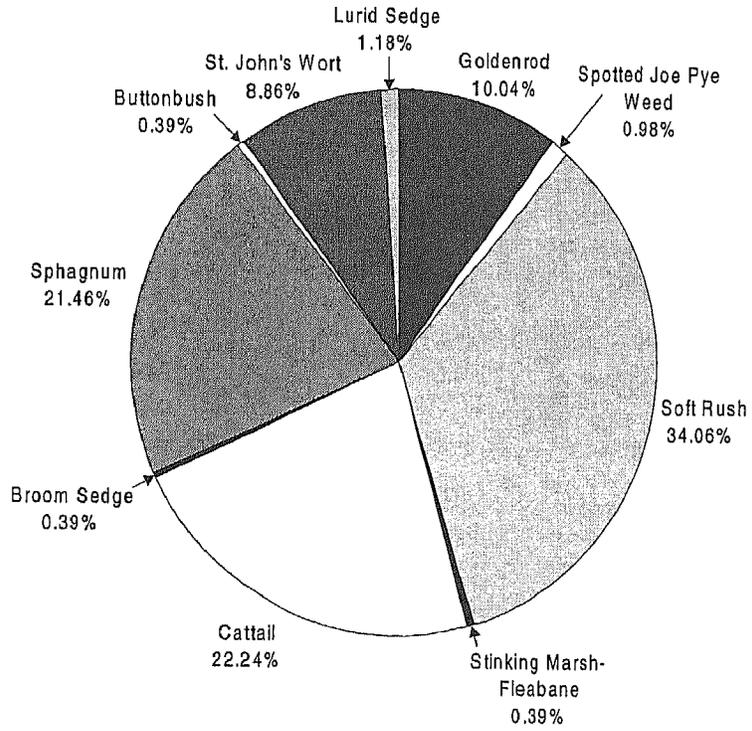


FIGURE 6 Plant species composition for Brooke wetland.

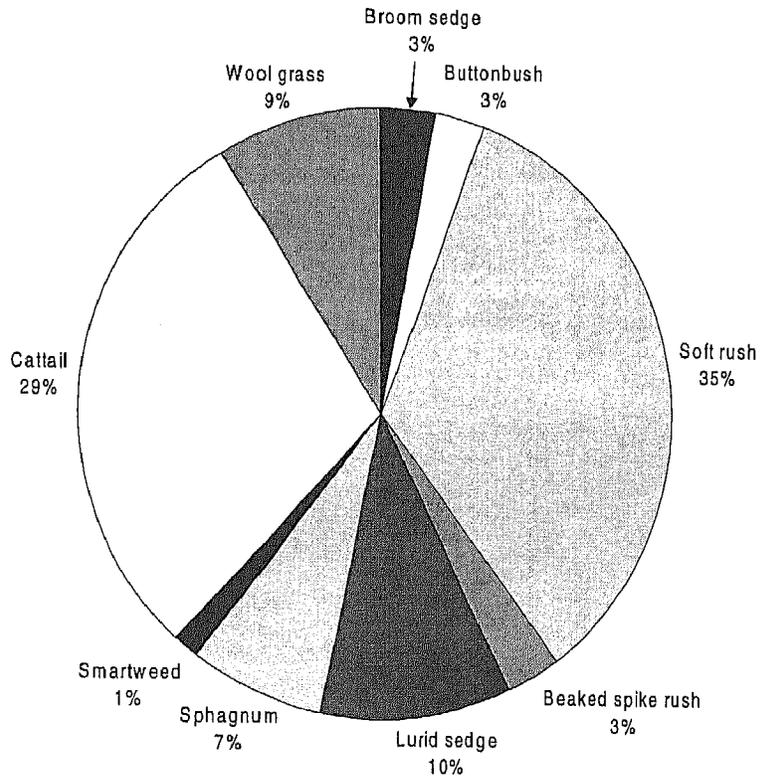


FIGURE 7 Plant species composition for Route 288 wetland.

GIS

Figure 8 presents the completed mitigation site GIS, including the attributes for the selected site and a digitally stored photograph of the site. Various queries can be run on the entire data set or any selected subset. Not only does this system aid in the management of existing mitigation sites by allowing queries for those sites requiring monitoring, it will also serve as a site analysis tool by allowing for comparison of dominant vegetation types present, actual wetland boundaries and areas, habitat creation, and other mitigation goals.

DISCUSSION OF RESULTS

To utilize mitigated wetlands as storm water BMPs, two sets of priorities must be addressed. First and foremost, the mitigated wetland must replace functions lost in the displacement of the natural wetlands for which it is built as compensation. Second, the wetland must be effective at controlling the quantity and quality of storm water runoff. The diverse vegetation and habitat observed at the Route 288 and Brooke mitigation sites coupled with pollutant removal efficiencies and peak attenuation comparable to conventional BMPs such as detention ponds (20) illustrate the ability of well-designed mitigation sites to serve both priorities.

Although the two sites achieved similar average pollutant removal rates, the way they removed pollutants was quite different. At the Route 288 site, direct highway runoff was the primary input

into the wetland; at the Brooke site, runoff entering the site first passed through a vegetated detention basin. At the Brooke site, the majority of pollutant removal occurred in the detention basin, resulting in significantly lower pollutant concentrations entering this wetland. Although the Route 288 wetland had removal rates from 18 to 70 percent for TSS, COD, TP, OP, and zinc, the Brooke wetland exported COD, OP, and zinc to the receiving stream.

Despite these significant differences in the water-quality functions and pollutant inputs of these two wetlands, similarities existed in vegetative diversity and wildlife habitat. Both support more than 20 vegetative species, with significant populations of *Juncus effusus* (soft rush) and *Typha latifolia* (cattail). The balance of emergent vegetation, shrubs, and woody vegetation was also similar. Both wetlands provided a habitat for a variety of wildlife including birds, reptiles, and small mammals. The Brooke detention basin, which receives runoff with pollutant concentrations comparable to those of the Route 288 wetland inflow, also supported dense emergent vegetation.

CONCLUSIONS

- Mitigated wetlands receiving highway runoff may be as effective as conventional BMPs at improving the quality and controlling the quantity of highway runoff. Peak reductions in excess of 40 percent were observed, with attenuation of greater than 90 percent for a system combining a detention basin and a mitigated wetland in

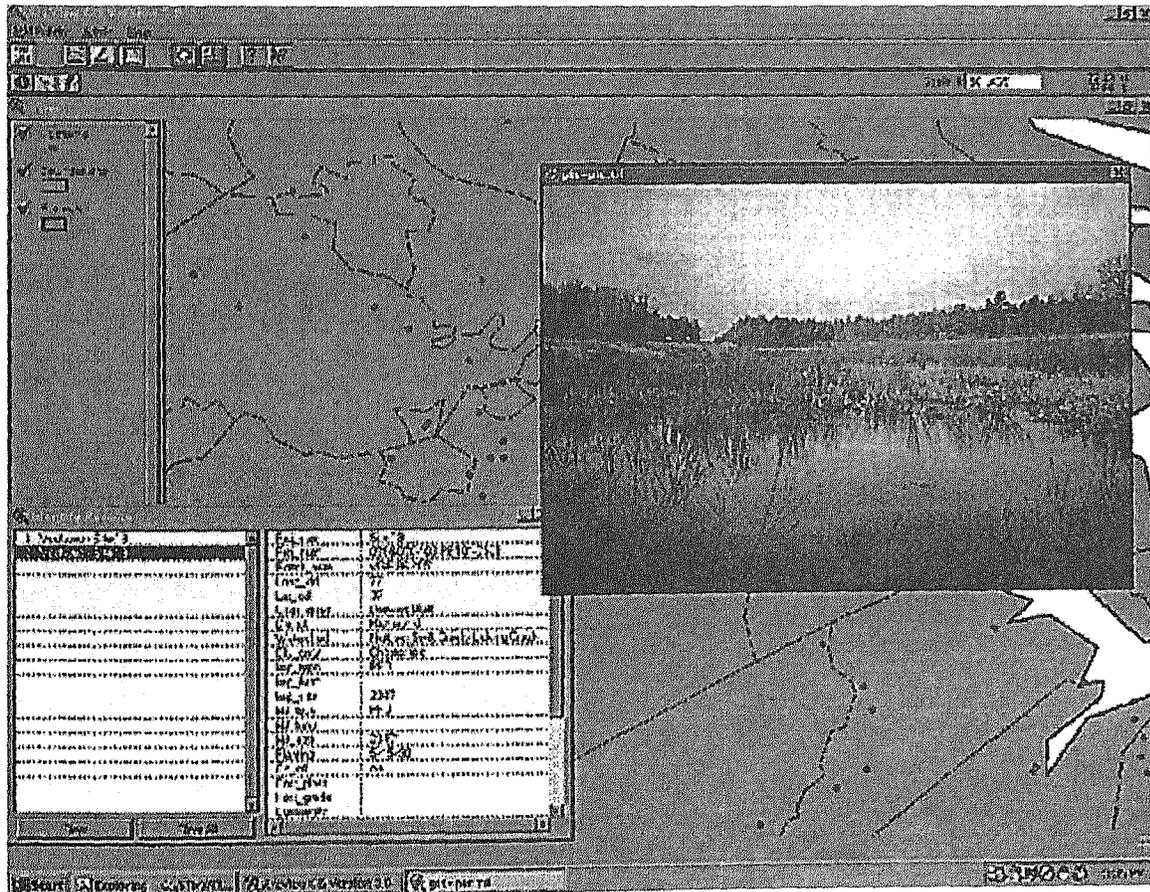


FIGURE 8 Mitigation site GIS with attributes and linked digital photograph.

series. Average removal rates as high as 90 percent for TSS, 65 percent for COD, 70 percent for TP and OP, and 50 percent for zinc were monitored.

- Despite having highway runoff as a primary water source, both sites appear to support healthy and diverse vegetative communities and provide habitat for a variety of wildlife. A comparison of the Brooke wetland, which receives runoff that first passes through a detention basin, and the Route 288 wetland, which receives direct runoff from the highway, revealed little difference in vegetative diversity or apparent health despite inflow concentrations at Route 288 that were two to eight times higher than those at the Brooke site.

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