Methods for Analysis of Highway Construction Impacts on a Wetland Ecosystem --A Multidisciplinary Approach

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ABSTRACT

In 1979 the Arkansas Highway and Transportation Department made application to the U.S. Army Corps of Engineers for a permit, as required by Section 404 of the Clean Water Act, to allow placement of fill material in a wetland during construction of US-67 in White County, Arkansas. Coordination with the Environmental Protection Agency, the Fish and Wildlife Service, and the U.S. Army Corps of Engineers resulted in the Highway Department agreeing to monitor impacts before, during, and after construction as a condition for issuance of the Section 404 permit. The wetland monitoring program and the procedure used to derive the monitoring program are described. In addition, a literature summary is presented for researchers who may be required to analyze impacts on wetland ecosystems.

The purpose of this paper is twofold: (a) to inform the research community of a current wetland research effort and the events that led to this involvement and (b) to present future wetland researchers with a foundation of methods and literature from which to formulate their own impact analysis strategies. A brief discussion of the analytic methods originally proposed and those that, through trial and error, were ultimately implemented in the field is presented.

HISTORY OF THE PROJECT

Since the fall of 1980 the Arkansas State Highway and Transportation Department (AHTD) has been engaged in a monitoring program to determine the impacts of highway construction through a forested wetland ecosystem. This project is apparently unique because (a) it is required as a special provision of a Section 404 permit (Clean Water Act, 1977) for placement of fill material in wetlands, (b) 2.5 years of baseline ecological data had been obtained before construction of the highway, and (c) a floodplain wetland ecosystem in the Mississippi Valley is involved.

Planning for improvement of US-67 from a two-lane to a four-lane divided highway began in the early 1970s. An environmental impact statement for the 28-mile segment from Bald Knob to Newport, Arkansas, was prepared in 1974. Originally, three construction alternatives were considered. Alternative A crossed an upland section of the Ozark foothills and was projected to cost $100,000 more per mile than either of the other alternatives. Alternative B, improvement of the existing two-lane facility on location, would require relocation of 184 residences, 52 businesses, two post offices, and a city hall, which made this alternative economically unfeasible. Alternative C, construction of the facility through a section of the White River floodplain, was chosen as the preferred alternative for the new highway (1).

Application was made in 1979 to the U.S. Army Corps of Engineers (COE) for a Section 404 permit to allow construction and placement of fill in wetlands traversed by the highway project. During permit review and coordination with other agencies, the Environmental Protection Agency (EPA), Fish and Wildlife Service (FWS), and COE raised questions concerning impacts on the wetland complex caused by construction and placement of fill. Following field inspections of the wetland and several months of interagency coordination, an agreement was reached for issuance of the Section 404 permit contingent on AHTD fulfilling eight special provisions, which included

1. Purchase of 175 acres of wetland adjacent to the construction corridor that "shall remain undisturbed for perpetuity,"
2. Placement of a 3-ft-thick sand layer at the base of the roadway embankment to facilitate subsurface flow, and
3. Establishment of a monitoring program to determine the long-term effects of construction through the wetland.

Terms of the 404 permit allow placement of 500,000 cubic yards of permanent earthwork for raising the new highway 7.3 m above the existing surface level.

DESCRIPTION OF THE WETLAND

The Oats Creek wetland is a palustrine, deciduous, forested wetland as defined by Cowardin et al. (2) located east-northeast of Bradford, White County, Arkansas (Figure 1). It is situated in the floodplain of the White River in the Mississippi alluvial plain just below the fall line that separates the maximum limits of the ancient Mississippi embayment from the Ozark uplands (3). The soil is Kobel silty clay that is characterized as poorly drained with low permeability and little urban utility (4).

The study area is roughly rectangular in shape and encompasses approximately 73.5 hectares. The wetland undergoes a prolonged period of inundation annually, usually from December through May. Water depth during inundation varies from a few centimeters to more than 5 meters.

Oats Creek is a third-order stream that arises at the foot of the Ozark uplands and flows approximately 6.5 kilometers to its confluence with Departee Creek. Channel morphology of Oats Creek with-

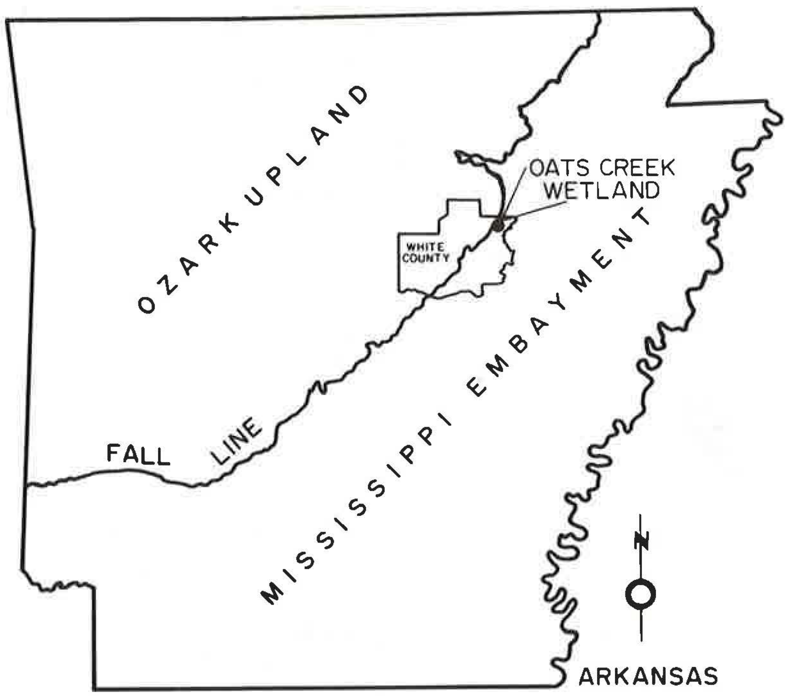

FIGURE 1 Location of Oats Creek wetland study area.

in the study area varies from 5 to 25 m in width and 0.5 to 2.0 m in depth at full bank level. Beaver dams have altered flow within the channel significantly, especially in the western half of the study area. Oats Creek enters the wetland midway up the western boundary, turns south to follow the southern boundary, then north along the eastern boundary before exiting the wetland at the southeastern corner, an area designated the outflow. Figure 2 shows the configuration and physical features of the wetland.

Vegetation in the wetland is divided into four dominance zones as shown in Figure 2. Overcup oak (Quercus lyrata) is the dominant woody species within the wetland and this zone occupies the largest area. The tupelo (Nyssa aquatica) and bald cypress (Taxodium distichum) zone is confined to areas in and adjacent to Oats Creek and areas ponded by beaver dams. The water elm (Planera aquatica) zone occurs in the lower portion of Oats Creek where the channel has become relatively broad and shallow. A zone designated the "upland" zone occurs across the northern edge of the wetland. This is a more diverse zone dominated by willow oak (Quercus phellos), Nuttall's oak (Quercus nutalli), sugarberry (Celtis laevigata), American elm (Ulmus americana), and red elm (Ulmus rubra). "Upland" zone is used strictly as a relative term because elevation changes only 1.5 m from the Oats Creek channel to the upland.

MATERIALS AND METHODS

Research Design

Initial emphasis in research design was on integrating various scientific disciplines (hydrology, biology, ecology, and so forth) into a monitoring system that would (a) obtain information on basic wetland ecosystem form and function, (b) allow a quantified estimate of changes and impacts to the wetland, and (c) be cost-effective. Cost-effective meant keeping total outlay for the monitoring program below a figure that would make one of the other construction alternatives more economically feasible.

First, reference points were established within the wetland so that repetitive sampling could be performed. Reference points are transects parallel to the construction centerline on both the upstream and downstream sides. Cleared right-of-way for the highway corridor is 91.5 m wide for the length of the project. Each reference transect is 91.5 m from the construction centerline and 45.7 m outside of the right-of-way (i.e., clearing and grubbing activities). Transects were placed by a survey crew and survey markers labeled with corresponding construction numbers were set at 30.5-m intervals. Because much of the area is inundated for 6 months of the year, numbered metal tags were attached approximately 6 meters off the ground in the tree nearest the transect marker. Virtually all sample events and sample stations are directly correlated with the two transects and the construction centerline. Figure 3 shows the relationship of the construction right-of-way and sample transects to the wetland.

Monitoring of the wetland study area began in the winter of 1981. The preconstruction phase of monitoring ended with the spring of 1983 sample giving 2.5 years of baseline data on wetland form and function. AHTD is committed to continuing the monitoring program, hereafter described, for 5 years after construction of the highway. At that time an evaluation of the results will determine the scope and duration of further impact monitoring.

Climatic Conditions

Continuous data for wind speed, wind direction, temperature, and rainfall have been taken since the spring of 1981. Rainfall is monitored using a tipping-bucket gauge attached to a miniature strip chart recorder powered by a 115-volt AC source. Initially, 12-volt car batteries in series were used but this power source lacked the longevity necessary during cold winter months. Occasionally line power has failed during storm events causing loss of data.

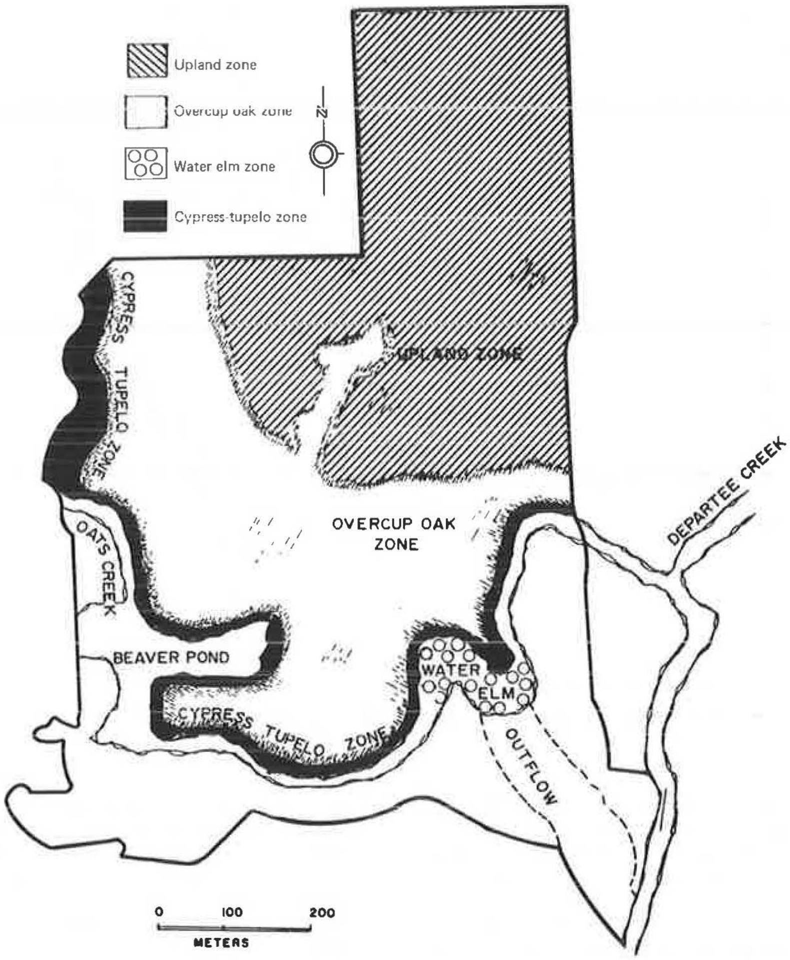

FIGURE 2 Vegetation dominance zones.

Wind and temperature are monitored using a standard battery-powered meteorological station consisting of anemometer and coiled-spring temperature gauge with continuous recording.

The meteorological package was placed in the headwaters of the Oats Creek drainage in open pastureland approximately 2 kilometers from the wetland. It is believed that this deployment provides the best measure of ambient wind and temperature conditions as well as the most useful rainfall data for hydraulic analysis. Ideally, a weather station in the wetland would provide direct comparative meterological information, but spot measurements for comparison are used because of problems with vandalism and humidity. Bimonthly visits to the wetland seem to be sufficient to establish wetland trends as they relate to ambient conditions.

Air and water temperatures are recorded using a centigrade thermometer at five localities within the wetland a minimum of twice a month. In addition, there are week-long intensive sampling periods quarterly during the year at which time air and water temperatures are recorded at 2-hr intervals during daylight hours for 5 consecutive days.

Hydraulics

The coordinating agencies for this project were concerned with alteration of stream flow and water distribution by the possible damming effect of the roadway fill. Placement of a complex (and expensive) series of continuous recording flow meters along each transect to monitor velocity and direction was considered initially. Consultation with the COE and the U.S. Geological Survey (USGS) resulted in implementation of a less complex manual flow monitoring method.

Flow is measured during the wet season (December-May) using an "AA" rotating cup-type current meter. An effort is made to record flow at all water levels and discharge rates so that an inflow-outflow hydrograph can be constructed. Flows are monitored at the US-67 bridge, both upstream and downstream transects, and at the exit point or points for water leaving the wetland. Directional tendencies are determined by visual inspection.

Water level fluctuations are monitored using manual methods. A wire weight gauge is operative from the US-67 bridge, approximately 1.0 kilometer upstream of the wetland. Two staff gauges are used in the channel of Oats Creek, one on the upstream transect and the other approximately 305 meters downstream. These are used to assess fluctuations in water level and calculate the slope of Oats Creek. The wire weight gauge is read daily and staff gauges are read 2 to 20 times a month.

A more intensive hydraulic analysis to establish short-term response to local storm events would require continuous water level monitoring systems. For the long-term analysis of impacts, it was believed that discontinuous data points that encompass maxima and minima would be sufficient. In retrospect, the chosen method of analysis has proven

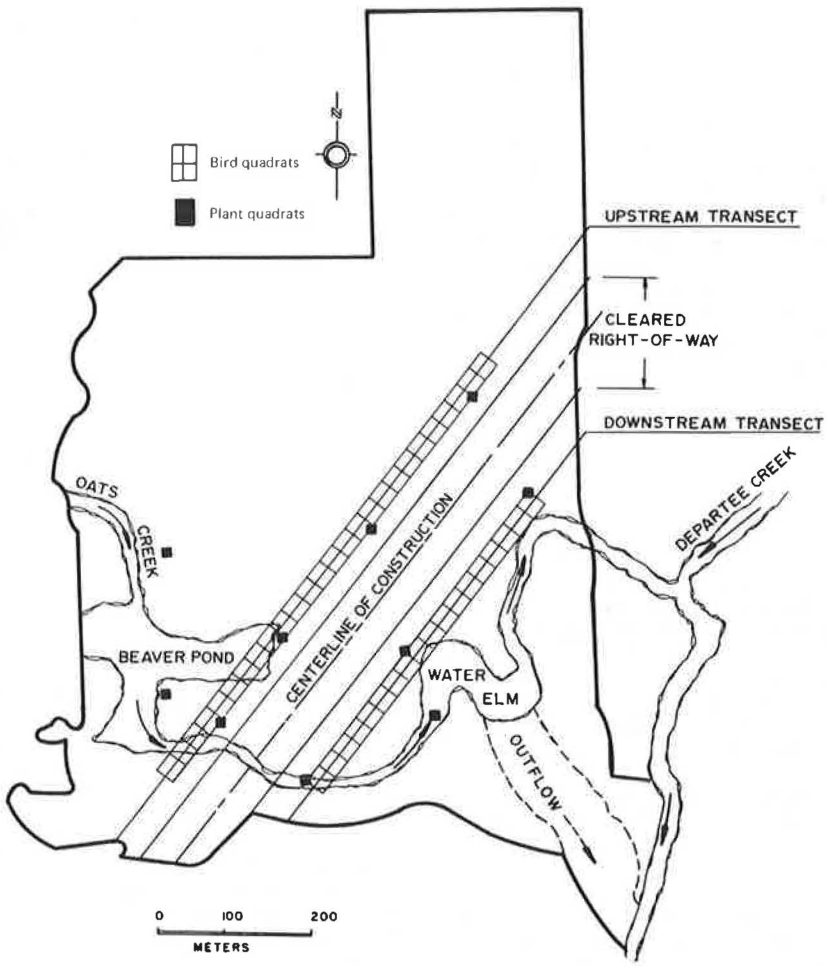

FIGURE 3 Plant and bird sample quadrats.

sufficient because short-term response to storms is negligible due to the broad nature of the Oats Creek floodplain. Major fluctuations in water level appear to be in response to changes in water level of the White River that backs up tributary streams.

Concern for the possible alteration of subsurface water levels and flow patterns was expressed by coordinating agencies. It was believed that the sheer weight of the highway fill might compress underlying soil layers and restrict subsurface flow. This was the reason for including a 3-ft pervious sand layer at the base of the fill as specified in the Section 404 Special Provisions. Theoretically, this sand layer would help maintain lateral transport.

Core samples taken in the wetland showed the substratum to be two tiered. The upper 15-20 cm is composed of an organic layer of humus and detritus--a highly permeable layer. The lower stratum, extending perhaps 6 meters in depth, is a fine-grained, highly compacted layer of clay that is relatively impermeable to the lateral transport of water. The installation of piezometers to monitor subsurface levels was eliminated following this discovery.

Physical Parameters

Any construction project in or near water is likely to contribute increased sediment load to the aquatic system. Three different methodologies are being used to obtain data on pre- and post-construction sedimentation rates.

Suspended sediment samples from the water column are taken from six wetland stations by grab samples at 2-week intervals. Samples are quantified using standard methods (5), and the organic and inorganic fractions are determined.

Two competing methodologies are used to determine relative rates of sediment deposition. Four sediment traps are used along each transect to compare upstream versus downstream rates. A trap consists of a glass sample jar (950 mL) mounted inside a submerged holding container buried to ground level. Jars are collected at 2-week intervals during low water and whenever possible following recession of high water. Collected sediments are filtered, oven dried, weighed, and then burned at 550°C and reweighed to determine the organic fraction of the sample. Organic and inorganic fractions are converted to grams per square meter per day.

The second method involves using stationary circular pads, 34 cm in diameter, that are distributed eight per transect. These concrete disks are retrieved each time they emerge following recession of high water. All material deposited on the surface of the pad is carefully removed by water and brushed into a collecting basin. The contents are then bottled and sent to the laboratory for analysis. The same analytic procedure is used for pad samples that was used for trap samples. Results again are quantified as grams per square meter per day.

Chemical Parameters

Nineteen chemical parameters are being analyzed during this study. Table 1 gives the parameters and method of analysis. After 1 year of analysis, six parameters were discontinued until the beginning of highway construction because of lack of variation. The six parameters are lead, copper, zinc, aluminum, color, and oil and grease. Samples are taken at 2-week intervals from five to seven locations upstream of and in the wetland. Grab samples are taken by wading or from a boat, preserved in the field, refrigerated at 4°C, and sent to the laboratory for analysis. Methods followed are those of the EPA (5), and APHA (6). Figure 4 shows water quality sample stations.

TABLE 1 Water Quality Parameters and Method of Analysis Used in Wetland Analysis

Parameter	Method
Dissolved oxygen	Modified Winkler
Acidity	Titrimetric
Alkalinity	Titrimetric, pH 4.5
pH	Electrometric
Total nitrogen	Kjeldahl, potentiometric
Nitrate (NO_3^-)	Colorimetric, Brucine
Ammonia	Potentiometric, ion selective electrode
Total phosphorus	Colorimetric, ascorbic acid, two reagent
Phosphate (PO_4=)	Colorimetric
Sulfate (SO_4=)	Turbidimetric
Calcium	A.A. spectrophotometric
Iron	A.A. spectrophotometric
Lead[a]	A.A. spectrophotometric
Copper[a]	A.A. spectrophotometric
Zinc[a]	A.A. spectrophotometric
Aluminum[a]	A.A. spectrophotometric
Color[a]	Spectrophotometric
Turbidity	Nephelometric
Oil and grease[a]	Spectrophotometric

[a]Parameter discontinued.

Biological Parameters

Plants

Data on woody plant species are gathered during the summer and fall of each year. Ten permanent plant quadrats, 10 m x 20 m, have been established for this purpose. Six quadrats are located upstream of the construction zone and four are located downstream. An effort was made to establish at least one quadrat in each major vegetation zone (see Figure 3).

The establishment of quadrats along transects was randomized by picking station numbers from a pool of the transect station numbers that occur in a particular vegetation zone. Quadrats established away from transects were located by randomly throwing a marker into the vegetation zone. Orientation of the long axis of each quadrat was determined by spinning a compass.

Within each sample quadrat, all stems >2.5 cm in diameter at breast height (dbh) are counted and identified to species. In addition, height of each individual is visually estimated. Core samples are taken from 3 or 4 trees per quadrat to estimate age of the wetland forest cover and to reconstruct past conditions by dendroclimatic estimation methodology.

Each quadrat has been divided into quarters and one quarter randomly selected for additional analysis. Within the specified quarter each stem <2.5 cm dbh is counted and identified. Each stem is measured for height and recorded as less than 30.5 cm (seedling) or greater than 30.5 cm. A visual estimation of total ground cover is also made.

From the data collected, values for the following are derived: frequency, relative frequency, density, dominance, relative dominance, and importance value.

Leaf litter fall is collected by square meter wooden frame traps with removable cloth bags. The traps are elevated 1.8 m above ground level on wooden legs. Samples are collected bimonthly throughout the year. Litter is sent to the laboratory and dried at 65°C for 24 hr. The dried sample is separated into leaf, wood, and detritus and weighed to the nearest 0.05 gram. The information will generate data on period of senescence and canopy production.

Aerial infrared and black-and-white photographs are taken during spring, summer, and fall. These will be used to determine zones under stress, changes in composition, and periods of inundation.

Benthic Invertebrates

Benthic invertebrates are sampled quarterly from four to seven different locations in the wetland depending on water level (Figure 4). Samples are taken with a petite PONAR dredge (15.3 cm x 15.3 cm) and perserved in 30 percent formalin solution. Three replicates are taken at each location to increase efficiency by sampling different microhabitats. At each location, one replicate is dredged from stream edge, one from midchannel, and one from an intermediate point. When collected, samples are sent to the laboratory and washed with water through a No. 30 sieve to remove silt and debris. Macroinvertebrates are hand picked and identified to lowest possible taxon before storage in 70 percent isopropanol. Problem taxa are sent to specialists at the U.S. National Museum and various universities for identification. Taxa are quantified as numbers of organisms per square meter and weight of organisms per square meter.

Fish

Two collection methods are used to determine species composition of the wetland fish fauna. Gill nets 30.5 m x 1.8 m with 5 cm mesh are fished during the quarterly sample periods. Four nets are fished continuously for a 4-day period with effort made to check each net four times daily. Fish captured are identified to species, weighed (±25 grams), and measured for standard or total length or both. Data are reported as species weight per hour fishing effort or species number per hour fishing effort. Fish in good physiological condition are injected by hypodermic syringe with color-coded water-soluble dye and released. Specimens found dead in the net or in poor condition are preserved for stomach content analysis. A representative sample of each species is kept during each quarter for food habit analysis.

Small species and juveniles of large species are sampled using 3 m x 2.5 m and 1.5 m x 1.2 m small mesh seines. Monthly collections are made to determine species composition and abundance. Each month an effort is made to sample all habitats and seining is continued until three consecutive hauls reveal no additional species or until the surveyors are satisfied that all available species have been obtained. Each species is subjectively classified as rare, common, or abundant for each month's sample. A number of individuals (5-25) of each species are preserved and returned to the laboratory for stomach content analysis.

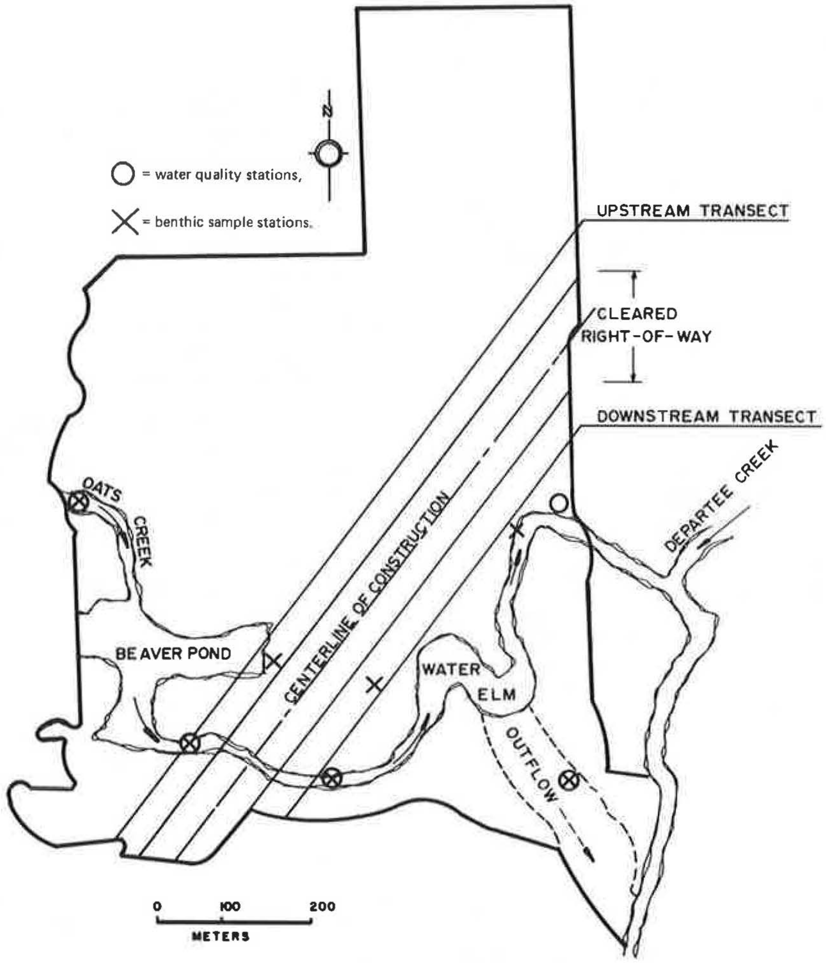

FIGURE 4 Benthic invertebrate and water quality sampling stations.

Reptiles and Amphibians

Reptiles and amphibians are sampled by hand picking, baited traps, and drift fences with drop traps. Turtle species are the dominant component of the wetland herpetofauna. Specimens are captured in gill nets 1.8 m x 0.9 m with 10.1-cm mesh. Captured specimens are sexed, marked by notching the marginal scutes, measured for carapace length, and released. Marking is site specific so that movements of the population can be monitored. Population size will be estimated by mark-recapture methods.

Snakes and frogs are captured by hand and drop traps, identified, and released. No effort has been made to census the population.

Birds

Bird populations in the wetland are sampled four times a year: during winter, spring, and fall migrations and during the breeding season. Sample plots, measuring 30.5 x 30.5 m, were established along the upstream and downstream transects. These plots were placed adjacent to each other with 18 located along the downstream transect and 25 along the upstream transect. This configuration was not randomly chosen but did cover all major habitat types within the wetland (see Figure 3).

Upstream and downstream plots are censused on alternating mornings during 1 week of each season. Each plot is censused twice during the week. An observer begins at the southernmost plot approximately 30 min before sunrise and spends 5 min in each plot recording the numbers and species of birds seen or heard within the boundaries of that plot. Other birds outside the plot are also noted. Swift 10 x 50 mm binoculars are used to identify birds by sight. Birds are not coaxed in any manner.

Censuses are conducted on foot or in a 17-ft aluminum canoe depending on water levels in the wetland. Wind speed, temperature, sky conditions, and weather are noted at the beginning and end of each census. High winds or rain can prevent a census from being conducted.

Birds are also captured in the wetland by mist nets. Ten nets are used each with dimensions of 12 x 2.6 m. Eight of these are placed at ground level and two are placed between 2.0 and 4.6 m above the ground. These two aerial nets are suspended between electrical conduit poles by ropes and pulleys. The other eight nets are suspended between electrical conduit poles 3 m long. Five of the nets are made of 33-mm nylon mesh for the capture of small birds and the rest are made of 36-mm nylon mesh for the capture of small- and medium-sized birds.

Nets are opened approximately 45 min before sunrise and are checked every 0.5-2 hr depending on weather conditions. Birds captured are sexed and aged as appropriate and are banded with aluminum leg bands issued by the Bird Banding Laboratory, U.S. Fish and Wildlife Service.

Several bird species were chosen for a color-banding operation. Color bands are used to allow visual identification of individual birds in the wetland. These species are red-bellied woodpecker, downy woodpecker, tufted titmouse, Carolina chickadee, prothonotary warbler, and Acadian flycatcher. A combination of colored leg bands specific to each individual bird is placed on these species. This allows observers to identify color-banded birds by sight. Information about seasonal and daily movements of individuals of these species in the wetland can then be noted over time. Copies of all banding information are sent to the U.S. Fish and Wildlife Service.

Mammals

A species list of all mammals observed or trapped is kept, and notes are made concerning habitat type, specific location within the wetland, time of day, and behavior of each mammal sighted. Live traps, sizes 0, 2, and 3A, and small snap-traps are used to capture mammals. All large, and most small, mammals are released alive. Trapping locations are chosen subjectively and trapping is done in all habitat types within the wetland depending on seasonal water levels. Traps are set 3 or 4 nights each season and this trapping period usually coincides with avian sampling periods. The qualitative information being gathered will add to basic ecological data for the wetland. Changes in species composition of mammal populations can be noted during and after construction.

DISCUSSION

There is no single procedure for designing an impact monitoring program. For this reason, monitoring programs are as numerous and diversified as the projects and systems for which they are designed. Researchers are required to use their experience and intuition to mold resources (i.e., manpower, funding, equipment) into a basic monitoring design that will answer the question: Did the project have an impact on the system? At the same time, a researcher must realize limitations on these resources and devise a program that yields a maximum of information for the investment. Whether the yield is a qualitative "yes or no" answer or a quantitative "numerical change" answer depends on the researchers' design, scope, and resources.

The research design discussed here evolved in four steps. The first step was to identify (a) the characteristics that make the system unique and (b) those positive attributes of the system that make impact monitoring necessary. Definitive characteristics of this wetland system are water periodicity and vegetation. Positive attributes of the wetland system include its value for fish-spawning habitat, waterfowl habitat, flood retention, nutrient deposition, and high productivity (i.e., serves to produce food for fish, mammals, and so forth).

The second design step was to hypothesize which aspects of the highway construction project would affect or alter characteristics of the system. For the study, it was concluded that clearing right-of-way, placement of fill material, the damming effect of fill, and runoff during and after construction were all probable sources of impacts.

Third, a monitoring methodology was implemented that was thought would reflect numerically or visually any changes or impacts. To accomplish this, baseline data to indicate what "normal" conditions are for the system are needed. How much baseline data is sufficient depends on the complexity of the system being monitored. The simpler the system, the less baseline data is required for an accurate representation of conditions inherent to the system.

In the absence of baseline information for a system, a researcher must use other data sources to infer the presence or absence of impacts. Methods used in studies of similar systems can be repeated (if feasible) and conclusions concerning impacts drawn from inference. Conventionality is the key. Use standard, often repeated methods that provide a large literature data base from which conclusions can be drawn.

The monitoring program discussed here was designed so that methodology (a) is easily repeatable, (b) accounts for seasonal variation, and (c) reflects impacts on parts of the system as well as on the system as a whole.

The final step in the design procedure was to mold the program to a form that allows maximum efficiency. Staff consists of personnel with specialized training in aquatic biology (fish, water chemistry), ornithology, and botany. Therefore, the majority of time and effort is concentrated on these areas of specialization to make the best use of previous training and experience.

LITERATURE SUMMARY

The works listed in this section were of help in defining and refining impact assessment methodology. This list is not, and is not intended to be, all-inclusive.

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CONCLUSION

The use of a multidisciplinary approach does not imply an all-inclusive monitoring program. A good monitoring system should intensively research interrelated parameters (e.g., water quality, aquatic invertebrates, aquatic vertebrates) that are prominent indicators of the normal form and function of the system.

Two suggestions for alleviating problems encountered with this monitoring project are (a) First, decide on a basic monitoring plan as early as possible and stick to it. Additions and deletions after initiation of the program only complicate the final analysis of data. (b) Second, attempt to monitor a reasonable number of parameters as dictated by manpower and funds available. It is better to monitor a smaller number of parameters accurately than a greater number with error.

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Method for Wetland Functional Assessment

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ABSTRACT

State highway agencies and the FHWA are charged with the construction, operation, and maintenance of transportation facilities. These facilities may have impacts on wetland systems. To provide safe and efficient transportation facilities while protecting wetlands it is necessary to determine the functions a specific wetland may perform and what the impact of a facility on the wetland may be. Until now there has not been any one method for assessing all of the potential functional values of a wetland. A new assessment method developed by the FHWA considers the functions of groundwater recharge and discharge, flood storage and desynchronization, shoreline anchoring, food chain support, fish and wildlife habitat, and recreation. The FHWA method is a flexible qualitative screening process that uses the U.S. Fish and Wildlife Service (FWS) wetland classification system. The method uses three types of analyses: the threshold analysis evaluates a wetland's relative functional values, the comparative analysis compares the relative values of two or more wetlands, and the mitigative analysis compares the relative costs and benefits of mitigative features. The FHWA method, completed in March 1983, is available to state highway agencies and others concerned with impacts on wetland systems. Instructions on the use of the method are provided through a training course developed for highway agencies by FHWA.

Before initiating any new construction involving wetlands, highway agencies are required by federal and state regulations to consider how their actions may affect the wetlands. Agencies need to consider the values attributed to the wetland, how it compares with other wetlands, and how any impacts will be mitigated.

PROBLEM

Highway agencies are mandated to provide safe and efficient transportation systems, but these agencies are also charged with protecting wetland resources. Executive Order 11990, Section 1(a) (1), states that each federal agency "shall provide leadership and shall take action to minimize the destruction, loss, or degredation of wetlands, and to preserve and enhance the natural and beneficial values of wetlands in carrying out the agency's responsibilities." The executive order also requires agencies to avoid undertaking, or providing assistance for,