TRANSPORTATION RESEARCH RECORD 969

Wetlands and Roadside Management

TRB
TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1984

Transportation Research Record 969
Price $7.40
Editor: Elizabeth W. Kaplan
Compositor: Lucinda Reeder

modes
1 highway transportation
3 rail transportation
4 air transportation

subject areas
22 hydrology and hydraulics
23 environmental design
40 maintenance

Transportation Research Board publications are available by ordering directly from TRB. They may also be obtained on a regular basis through organizational or individual affiliation with TRB; affiliates or library subscribers are eligible for substantial discounts. For further information, write to the Transportation Research Board, National Research Council, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

Printed in the United States of America

Library of Congress Cataloging in Publication Data
National Research Council. Transportation Research Board.
Wetlands and roadside management.

(Transportation research record; TRR 969)
1. Roadside improvement–Addresses, essays, lecture. 2. Wetlands–Addresses, essays, lectures. I. National Research Council (U.S.). Transportation Research Board. II. Title: Wet lands and roadside management. III. Series: Transportation research record; 969
TE7.H5 no. 969 380 s 84-25501 [TE177]
[625.7'7] ISSBN 0-309-03751-4 ISSN 0361-1981

Sponsorship of Transportation Research Record 969

DIVISION A–REGULAR TECHNICAL ACTIVITIES
Lester A. Hoel, University of Virginia, chairman

GROUP 2–DESIGN AND CONSTRUCTION OF TRANSPORTATION FACILITIES
Robert C. Deen, University of Kentucky, chairman

General Design Section
Samuel V. Fox, Texas State Department of Highways, chairman

Committee on Landscape and Environmental Design
Robert L. Jacobsen, Federal Highway Administration, chairman
Barbara M. Schaedler, Port Authority of New York and New Jersey, secretary
G. Michael Adler, Charles R. Anderson, E. Leroy Brady, Jack E. Burton, Bernard L. Chaplin, Harold D. Dolling, David H. Fasser, Lawrence E. Foote, Joseph E. Gruspier, James R. Johnson, Grant R. Jones, Herman A. J. Kuhn, Charles R. Lee, Hubertus J. Mittmann, Carroll L. Morgenson, Darrel G. Morrison, Thomas J. Mracek, Gip I. Robertson, Jr., W. A. Schmitz, R. Merrick Smith, Clyde D. Walton, Leonard E. Wood

GROUP 3–OPERATION AND MAINTENANCE OF TRANSPORTATION FACILITIES
D.E. Orne, Michigan Department of Transportation, chairman

Committee on Roadside Maintenance
W. M. Gere, South Dakota Department of Transportation, chairman
Suzanne W. T. Batra, William E. Chappel, Robert R. Guinn, William D. Johnson, Wayne G. McCully, James A. McGee, D. James Morre, Bill G. Morris, Peter Ordway, George P. Romack, Robert S. Ross, Robert L. Schroeder, John L. Snuggs, Larry D. Voorhees, Carl B. Wells, Bernard G. Williams

Adrian G. Clary and Lawrence F. Spaine, Transportation Research Board staff

Sponsorship is indicated by a footnote at the end of each report. The organizational units, officers, and members are as of December 31, 1983.

Notice: The Transportation Research Board does not endorse products or manufacturers. Trade and manufacturers' names appear in this Record because they are considered essential to its object.

Contents

Authors of the Papers in This Record

Birkitt, B. F., Florida Department of Environmental Regulation, 2600 Blair Stone Road, Tallahassee, Fla. 32301-8241
Burnside, Fred L., Environmental Division, Arkansas State Highway and Transportation Department, P.O. Box 2261, Little Rock, Ark. 72203
Clary, Raimond F., Jr., Soil Conservation Service, U.S. Department of Agriculture, Lockeford, Calif. 95237
Dougherty, B. J., Biology Department, Florida State University, Tallahassee, Fla. 32306
Foster, Richard E., Jr., Vermont Agency of Transportation, 133 State Street, Montpelier, Vt. 05603
Harris, John L., Environmental Division, Arkansas State Highway and Transportation Department, P.O. Box 2261, Little Rock, Ark. 72203
Hsu, Martha T., Materials and Research Division, Maine Department of Transportation, P.O. Box 1208, Bangor, Maine 04401
Hu, Kang, School of Civil Engineering, Purdue University, West Lafayette, Ind. 47907
Mannino, V. J., Horticulture Department, Louisiana State University, Baton Rouge, La. 70803-2120
Newsom, D. W., Horticulture Department, Louisiana State University, Baton Rouge, La. 70803-2120
Richardson, Bill L., Environmental Division, Arkansas State Highway and Transportation Department, P.O. Box 2261, Little Rock, Ark. 72203
Riverson, John D. N., School of Civil Engineering, Purdue University, West Lafayette, Ind. 47907
Sinha, Kumares C., School of Civil Engineering, Purdue University, West Lafayette, Ind. 47907
Slayback, Robert D., Soil Conservation Service, U.S. Department of Agriculture, Davis, Calif. 95616
Smith, Douglas L., FHWA, Turner-Fairbank Highway Research Center, 6300 Georgetown Pike, McLean, Va. 22101
Stadtherr, R. J., Horticulture Department, Louisiana State University, Baton Rouge, La. 70803-2120
Welch, Wendy K., Environmental Division, Arkansas State Highway and Transportation Department, P.O. Box 2261, Little Rock, Ark. 72203

Effects of Highway Bridges on the Aquatic Biota of Three Florida Rivers

B. F. BIRKITT and B. J. DOUGHERTY

ABSTRACT

Aquatic communities were studied at three bridge sites in Florida rivers to determine whether bridge design features have any adverse impacts on biota. Construction methods were considered where information was available. Benthic macroinvertebrates were collected along transects that extended across each river. Submerged macrophytes and associated epifaunal invertebrates that occurred in one of the rivers were also collected. Numbers of individuals for each of the taxa of benthic and epifaunal invertebrates and biomass for each of the plant species were determined. Dominance, diversity, and evenness values were calculated for sample collections. Significant alteration of the aquatic community occurred at one bridge site. Adverse impacts on the aquatic biota were attributed to bridge design and construction methods. Construction practices rather than bridge design were found to have potentially adverse impacts on the biota at a second site. At the remaining site, only minor disturbance of the aquatic community was detected. Impacts on aquatic communities can be minimized by (a) placing bridges at locations where alteration of the river channel or floodplain can be avoided; (b) designing bridges and selecting construction methods that maintain, as much as possible, the natural hydrological, sedimentary, and illumination characteristics of the river system and that minimize site disturbance, and (c) providing adequate quality control of construction practices.

Florida has extensive marine, river, and lake systems that make the construction of bridges a necessary and costly part of highway construction. Because these aquatic systems are important for recreation and sport and commercial fishing, bridging ideally should not adversely affect aquatic life. Previous studies have shown that aquatic communities are very sensitive to disturbance; therefore, state and federal environmental regulations require that bridge construction projects be reviewed for possible adverse impacts on aquatic systems and that a permit or other authorization be obtained before construction activities are begun. Regulatory agencies have often required bridge design modifications, realignment, and the use of various precautionary measures to minimize the environmental impact of bridging. If not considered early in the planning stages, many of these stipulations can be expensive and may lead to time-consuming delays in permit processing and roadway construction.

The evaluation of the anticipated impacts of bridge construction on aquatic communities has been based on subjective observations and inferences from the general literature. The most comprehensive report on the effects of construction activities on aquatic systems is that of Darnell (1). Darnell stresses the multivariate nature of the impacts of most construction activities on aquatic systems. Because of the complexity of natural systems, individual effects cannot be separated distinctly nor attributed easily to specific causes. A U.S. Department of Transportation training and design manual (2,pp.1-14) identified several potential impacts of bridging. Scour, erosion, shading, changes in sediments, and an increase in suspended solids may have a significant impact on aquatic biota. The report also stated that although construction activities may be of short duration, long-term damaging effects may result from the presence of bridges. Very few data, which quantify the effects of bridge construction or presence on aquatic systems and on which sound regulatory decisions can be based, have been compiled.

This study was designed to assess quantitatively the effects of highway bridge construction and presence on the aquatic biota of river systems in Florida. Data on benthic (bottom-dwelling) invertebrates, submerged macrophytes (aquatic vegetation), and epifaunal invertebrates (organisms living on the surface of the vegetation) were used in this assessment. Aquatic invertebrates were selected for study because of their important role in the food chain for sport and commercial fishes. Submerged macrophytes provide a food source for many invertebrates and some species of fish and assist in maintaining good water quality.

Three rivers were selected for study: (a) the Ochlockonee River, an alluvial river with an extensive floodplain; (b) the Wakulla River, a clear spring run with low sediment transport; and (c) the Braden River, a small blackwater river with low sediment transport. Data on the age, design, orientation, height, and construction techniques for each bridge were obtained from the Florida Department of Transportation (FDOT).

AREA DESCRIPTIONS

Ochlockonee River and I-10 Bridge Site

The part of the Ochlockonee River chosen for study was the site of the Interstate 10 (I-10) crossing. The Ochlockonee River is a mature alluvial stream in the northwest portion of the state. This river flows for approximately 160 miles before entering the Gulf of Mexico (3,p.27). The average width of the river measured at the study site was 107 ft. At the I-10 bridge, the Ochlockonee River drains an area of 1,180 square miles. A 49-year average river discharge of 1,014 cfs has been recorded at the U.S. Geological Survey (USGS) gauging station located approximately 4 miles upstream of the study area (3, p.31). Normal flow elevation of the Ochlockonee River at the study site is 68 ft mean sea level (MSL) with a recorded maximum water stage of 85.2 ft MSL (4).

The Ochlockonee River carries a heavy load of silts and clays that accounts for the relatively high turbidity levels of the water. Preconstruction core borings indicate that the river bottom consists of fine white sand, gray sand, and hard limerock (4). The study area is characterized as coastal lowlands with a floodplain varying from a quarter to half a mile in width (personal communication from Daniel Darden, Florida DOT). No submerged aquatic macrophytes were observed at the study site.

The I-10 bridge is a split roadway design with each bridge 40 ft in width separated by a distance of 64 ft. The 1,210-ft bridge traverses a major part of the floodplain, a small slough to the east, and the main river channel. Each 105-ft-wide span over the river is supported by two round-nosed piers 12 ft long by 3.6 ft wide placed in the river. The elevation of the low member of the bridge is 17.22 ft above the normal flow elevation (68.0 ft) of the Ochlockonee River. The bridge is oriented east-west. Construction of the bridge was completed in 1976 (Daniel Darden).

Wakulla River and US-98 Bridge Site

The second study site was located where US-98 crosses the Wakulla River. The Wakulla River, a clear calcarous spring run located in northwestern Florida, flows southward for a distance of 10.1 miles through flat coastal lowlands before joining the St. Marks River and entering the Gulf of Mexico (5-7).

Although the water at the study site is fresh, the water level is tidally influenced. Water temperature at the site remains fairly constant throughout the year. The average measured width of the river at the study site was 217 ft. A 37-year average river discharge of 432 cfs has been recorded at the USGS gauging station located 4 miles upstream of the study site at FL-365. Normal flow elevation of the Wakulla River is 5.0 ft MSL throughout the river (3, p. 65).

The river floodplain is approximately 280 ft wide on either side of the river at the study site. There is little sediment load in the Wakulla River. The river bottom at the study site consists of sand and silt overlying scattered limerock (6). The river bottom is covered with a dense growth of submerged aquatic macrophytes including *Sagittaria kurziana*, *Vallisneria americana*, *Potamogeton illinoensis*, and *Najas guadalupensis*.

The US-98 bridge over the Wakulla River is a single span built in 1956. It is 36 ft wide, 290 ft long, and traverses the Wakulla River and 45 ft of the floodplain on each side of the river. Filled causeways were constructed across the remainder of the floodplain on either side, and filled approach pads to the bridge constrict the river channel at the study site. The bridge is supported by seven sets of pilings. Each set of pilings consists of five square pilings placed 5.7 ft apart and measuring 1.6 ft on a side. The elevation of the low member of the bridge is 10.7 ft above the normal flow elevation (5.0 ft) of the Wakulla River. The bridge is oriented approximately 27 degrees east of true north (Daniel Darden and 8).

Braden River and I-75 Bridge Site

The third study site is located where I-75 crosses the Braden River in southwestern Florida. The Braden River is a small, slow-moving, blackwater river that meanders 20.2 miles northwest through low, level plains before discharging into the Manatee River (3). The average measured width of the Braden River at the study site was 114 ft. The river drains an area of 51 square miles at the I-75 bridge site (9).

The water is clear and pale brown in color due to a high tannin content. Preconstruction core borings indicated that the river bottom is composed of clayey, silty, fine sand (10), with a thin layer of detritus present at the sediment surface. No floodplain is present along the Braden River. The banks are steep, 4-5 ft high, and interrupted by several small sloughs that drain into the river near the study site. No submerged aquatic macrophytes were observed in the study area.

The I-75 bridge, a split roadway design, was completed early in 1979. The spans are 56 ft wide and separated by a distance of 68 ft. The northbound span is approximately 550 ft long and the southbound span is 600 ft long. The north and south spans are supported, respectively, by eight and nine sets of seven pilings that are placed within the river channel. Each piling measures 1.6 ft on a side. Approach pads for the bridge are placed on the high river banks. The elevation of the low member (20.2 ft) of the bridge is 13.22 ft above the normal high water elevation of the river (7.5 ft MSL). The I-75 bridge is oriented 13° 40' 40" west of true north (10).

METHODS AND MATERIALS

General

Five transects were examined at the Ochlockonee River and I-10 and the Braden River and I-75 sites because of the split roadway design of the Interstate bridges. Three transects were sampled at the Wakulla River and US-98 site. Transects were established perpendicular to the main channel upstream and downstream of the bridges and directly under the bridges at each site. Transects were also located between the bridges at split roadway design sites. Locations of upstream and downstream transects were based on habitate similarity and a subjective determination that these areas were outside the area of impact of the bridge. Transect locations are shown in Figures 1-3. Replicate benthic infaunal samples were obtained at stations along each transect using a petite PONAR grab (0.0256 m^2), except at the Wakulla River site where dense aquatic vegetation necessitated the use of a diver-operated core sampler (0.0079 m^2).

Benthic samples were preserved and stained in situ with Lavdowski's preservative (11) and rose bengal dye (12). Aquatic invertebrates retained on a No. 30 sieve (0.60 mm) were visually sorted and the majority of organisms was identified to the family level.

Site-Specific Sampling Methods

Ochlockonee River and I-10

Five transects were established across the river at locations approximately 75 m upstream and downstream of the bridges, beneath each bridge, and between the bridges as shown in Figure 1. A petite PONAR was used to take three replicate samples of the benthic infauna at stations along each of the five transects. Samples were collected at the I-10 bridge site in October 1978.

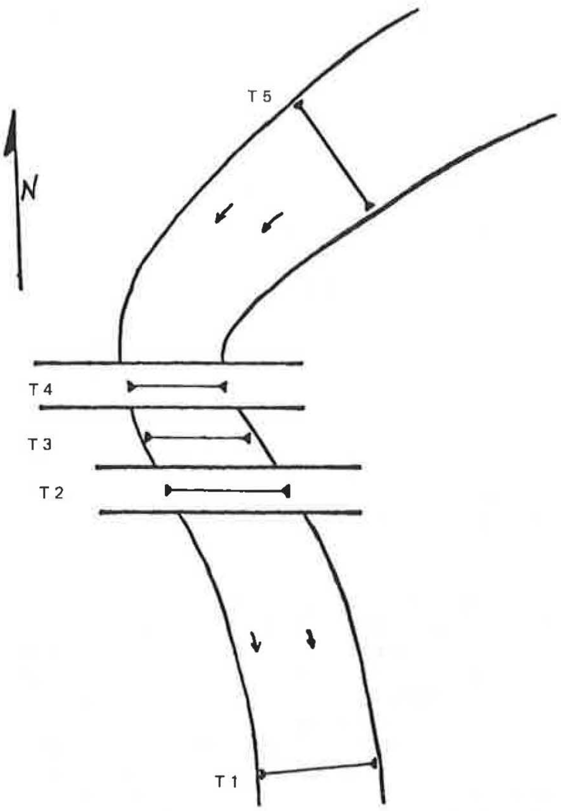

FIGURE 1 Locations of transects at the Ochlockonee River. Transects 2 and 4 are located beneath the bridge. Arrows indicate direction of flow.

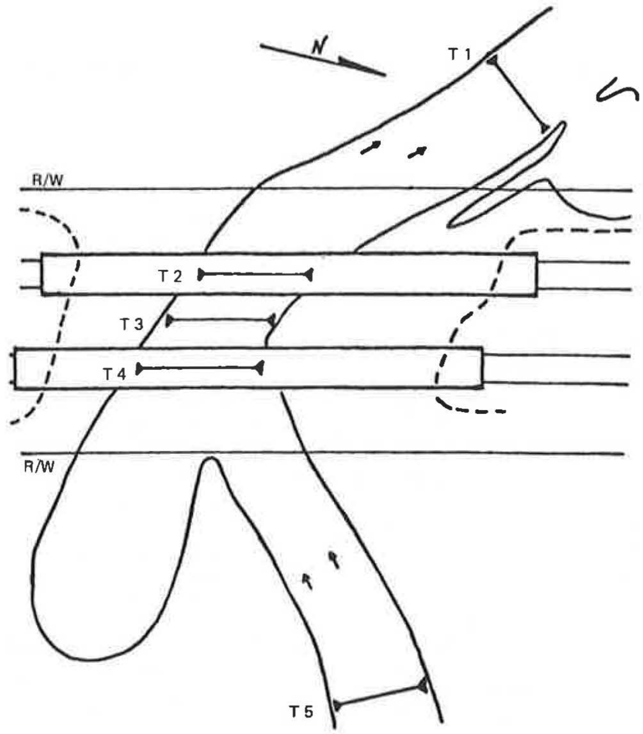

FIGURE 3 Locations of transects at the Braden River. Transects 2 and 4 are under the bridge spans. Lines labeled R/W indicate right-of-way. Dotted lines show toe of slope. Arrows indicate direction of flow.

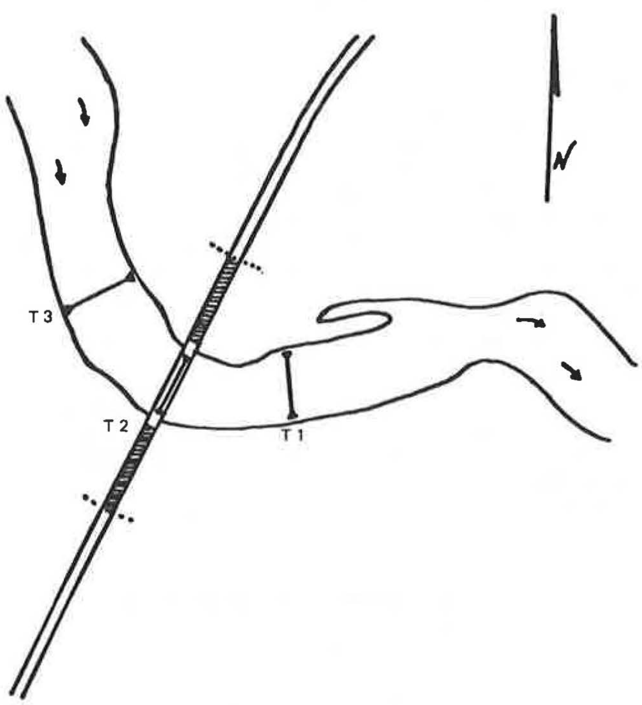

FIGURE 2 Locations of transects at the Wakulla River. Transect 2 is under the US-98 bridge. Arrows indicate direction of flow. Dotted lines show limits of flood plain. Cross-hatching indicates causeway fill.

Wakulla River and US-98

Three transects were established across the Wakulla River at locations approximately 100 m upstream and downstream of the bridge and at the centerline of the bridge as shown in Figure 2. Sampling stations were established at the center of the channel and at points equidistant between the center and each shoreline (three stations per transect). Four replicate benthic invertebrate and submerged macrophyte samples were taken at each station using SCUBA. Benthic infauna was sampled using a coring tube of polyvinyl chloride pipe (10 cm inside diameter). One benthic core sample was taken in each of the vegetation sampling plots. Epibenthic gastropods (Neritina reclivata) encountered within the sample area were collected by hand.

Aquatic macrophytes were sampled following a modified point-quarter method (13). Four sample areas of 2.69 ft^2 (0.25 m^2) were located at 90-degree angles, each 1 m from the center point of the station. Vegetation was removed by cutting individual plants at the water-sediment interface. Biomass of aquatic macrophytes was determined as grams of dry weight per replicate. Dry weight to wet weight conversion factors were determined for plants of the two most abundant species, Vallisneria americana and Sagittaria kurziana (14). Epifauna was removed from the macrophyte samples by rinsing the vegetation in the laboratory and passing the rinse through a No. 30 sieve. Epifaunal invertebrates on the sieve were preserved, stained, and sorted in the same manner as the benthic infauna. All samples were collected in March 1979.

Braden River and I-75

Figure 3 shows the five transects established across the Braden River at locations approximately 137 m upstream and 107 m downstream of the bridges and beneath and between the bridges. Three sampling stations were established per transect in the same relationship as the Wakulla River stations. Three replicate benthic invertebrate samples were obtained at each station using a petite PONAR grab. Samples were collected in August 1979.

Data Analysis

Four parameters were determined for each replicate and used to make statistical comparisons. The total number of organisms obtained (N) and the taxa to which they belong were recorded. Dominance (D), diversity (H'), and evenness (J') indices were calculated (15). The Shannon-Weaver measure of diversity was used in accordance with Pielou (16, pp. 269-311). For the plant biomass data, H' was calculated based on the dry weight biomass for each species and the total biomass for the sample (17). (The reader is reminded to exercise caution in the interpretation of environmental impacts indicated solely by comparisons of dominance, diversity, and evenness indices. These indices are derived mathematically and may not accurately characterize the biotic community. Numbers of individuals and the taxa to which they belong should also be taken into consideration in evaluating the presence or absence of impacts.)

Analyses of the data were performed using a computerized t-test procedure (18). The t-test was used to compare all stations within a transect with each other to determine the amount of intratransect variation. The transect mean for each parameter was compared with the mean value for each of the other transects to detect differences between the transects. Transects were assumed to differ significantly in a given parameter when the difference in transect means was greater than the differences in station means within a transect.

RESULTS AND DISCUSSION

Ochlockonee River

There were no statistically significant differences in the measured parameters of the benthic invertebrates at the Ochlockonee River study site (Table 1). However, when the data for individual taxa were examined, chironomids were found to be much more abundant beneath the bridge spans (transects 2 and 4) than elsewhere. Fifty-eight percent of the chironomids occurred under these spans, rather than the 40 percent that would be expected assuming even distribution.

The chironomid densities in transects 2 and 4 were greatest at stations nearest the piers, rather than evenly distributed along each transect. The disproportionate distribution of chironomids may be explained by a localized alteration of habitat caused by the piers. Accumulations of silt were seen adjacent to the piers. These accumulations are probably the result of deposition caused by a reduction in the speed of currents passing near the piers. Perhaps this silt provided a more suitable substrate for chironomids. No other taxa showed a pattern of abundance that suggested an influence of the bridges. The disturbance of benthic habitats was limited to the immediate vicinity of the piers.

TABLE 1 Dominant Benthic Invertebrates of the Ochlockonee River

Transect	Dominant Group 1	2	3
1	Oligochaeta (Annelida) 42.26%	Chironomidae (Insecta-Diptera) 31.17%	Ephemeridae (Insecta-Ephemeroptera) 13.60%
2[a]	Chironomidae (Insecta-Diptera) 48.87%	Oligochaeta (Annelida) 24.03%	Ephemeridae (Insecta-Ephemeroptera) 11.43%
3	Chironomidae (Insecta-Diptera) 49.38%	Oligochaeta (Annelida) 28.80%	Corbiculidae (Pelecypoda) 13.84%
4[a]	Chironomidae (Insecta-Diptera) 60.95%	Oligochaeta (Annelida) 21.33%	Corbiculidae (Pelecypoda) 7.01%
5	Chironomidae (Insecta-Diptera) 33.47%	Corbiculidae (Pelecypoda) 28.81%	Oligochaeta (Annelida) 25.42%

Note: Higher taxa for each group are given in parentheses. Percent dominance is presented for each.
[a]Transect located under bridge span.

The design and construction of I-10 favored minimal impacts on benthic communities. Only two piers for each bridge were placed in the river adjacent to the main channel, thereby causing little disruption to benthic habitats. These piers were round nosed, causing less eddying and therefore less bottom scouring than would be expected from pilings or piers with flat surfaces. The bridge spans were placed high enough above the water to allow at least partial illumination beneath the bridges. In addition, the approaches to the river channel were bridged, allowing the normal passage of water across the floodplain at flood stage and avoiding increased scouring of bottom sediments. No dredging was done in the river channel during bridge construction.

Wakulla River

Several noteworthy observations were made at the Wakulla River study site. First, no submerged aquatic macrophytes occurred directly under the bridge span, but these plants occurred in abundance in transects 1 and 3 (away from the bridge) and up to the edges of the bridge (Table 2). Based on biomass measurements, the lack of rooted submerged macrophytes under the bridges was determined to be statistically significant. Second, because of the absence of macrophytes, an epifauna was also absent. Epifaunal organisms were ascribed by Odum (19) as having importance in the food chain at Silver Springs, which is very similar to the Wakulla River in habitat and biota. Third, the number of benthic invertebrates was 4 to 5 times higher in transects 1 and 3 (away from the bridge) than in transect 2 under the bridge (Table 3). This difference was at-

TABLE 2 Dry Weight Biomass of Dominant Wakulla River Macrophytes

Transect	Macrophyte: *Sagittaria kurziana*	*Vallisneria americana*	*Potomogeton illinoensis*
1	627.51	452.66	9.42
2[a]	0.0	0.0	0.0
3	815.81	189.69	65.04

Note: Biomass is given as grams per 2.69 ft^2 (0.25 m^2) and is the sum of the station.
[a]Transect located under bridge span.

tributable mainly to the densities of oligochaetes and to a much lesser extent to nematodes and gammarid amphipods. These differences were statistically significant (Table 4). There were no significant differences in diversity, evenness, or dominance of benthic invertebrates in transect 2 compared with the other transects, even though several rather large differences in mean values were observed.

TABLE 3 Dominant Benthic Invertebrates of the Wakulla River

	Dominant Group		
Transect	1	2	3
1	Oligochaeta (Annelida) 71.59%	Gammaridae (Amphipoda) 4.36%	Chironomidae (Insecta-Diptera) 2.95%
2[a]	Oligochaeta (Annelida) 41.08%	Chironomidae (Insecta-Diptera) 16.22%	Gammaridae (Amphipoda) 10.27%
3	Oligochaeta (Annelida) 70.63%	Gammaridae (Amphipoda) 6.90%	Chironomidae (Insecta-Diptera) 3.83%

Note: Higher taxa for each group are given in parentheses. Percent dominance is presented for each.
[a]Transect located under bridge span.

TABLE 4 Summary of Statistically Significant Results

Study Site	Parameter	Transects Compared	t	p
Wakulla River	N	1 and 2	3.13	.008
		3 and 2	3.38	.005
	W	1 and 2	5.43	.001
		3 and 2	8.19	.001
Braden River	H'	1 and 5	4.36	.001
		2 and 5	4.63	.001
	J'	2 and 4	3.41	.004
		2 and 5	3.64	.002

Note: N = number of benthic invertebrates, W = plant biomass, H' = benthic invertebrate diversity, J' = benthic invertebrate evenness, t-value of t-statistic, p = probability associated with t.

Questions arise about why there are no rooted macrophytes under the bridge and why there are fewer benthic organisms under the bridge. Several differences in the physical environment that are caused by bridging apparently have affected the biota. The bridge, at only 10.7 ft above the normal water surface, effectively blocks sunlight in approximately the same dimensions as the area of the bridge. Aquatic macrophytes do not grow under the bridge probably because of insufficient light and unsuitable substrate. Dredging may have been performed at this site because it was common practice at that time (1956) to dredge a river channel during bridge construction. The fact that the river bottom is lower under the bridge than either upstream or downstream of the bridge could be the result of such dredging. Another factor contributing to depauperate biota under the bridge is the alteration of bottom sediments as a result of bridge design. At midchannel along transect 2 (beneath the bridge) the bottom consisted of limestone and only a little sediment indicating scouring. Toward shore, a deep accumulation of silt covered the limestone. In contrast, the bottom along transects 1 and 3 (away from the bridge) consisted primarily of sand with little silt and only occasional outcrops of limestone. The Wakulla River bridge is supported by numerous pilings with flat surfaces placed within the main channel of the river. These interrupt the flow and cause eddying. Filled causeways and bridge approach pads on either side of the river constrict the river channel and act to increase the velocity of the water flowing beneath the bridge and thereby to increase the possibility of scouring. The absence of macrophytes beneath the bridge exacerbates scouring by allowing the full force of the flowing water to reach the bottom without deflection by aquatic vegetation. The low number of benthic invertebrates beneath the bridge is most probably related to the alteration in bottom sediments, although possible effects of shading cannot be discounted.

The results at this study site do not allow the evaluation of the relative importance of each of the design criteria and construction methods that caused environmental impacts. Further, the results do not allow the effects of shading on benthic organisms to be distinguished from the effects of the substrate and other factors. Hynes (20, pp. 112-300) related the distribution of benthic invertebrates to current velocity, sediment composition, presence or absence of vegetation, and shading. Nonetheless, the collective impact of bridging on the biota beneath the bridge has been severe and has persisted since the bridge was built 23 years ago. The impact, however, is localized directly beneath the bridge. In spite of the apparent impact of bridging, statistical analysis indicated that the taxa diversity and dominance patterns of the benthic community were not altered significantly.

Braden River

Significant differences in diversity of benthic organisms between transect 5 and transects 1 and 2 were found at the Braden River site. There were also significant differences in evenness between transect 2 and transects 4 and 5. These differences may not be real biologically because of atypical samples obtained at station 1-I where the junction of a slough entered the river and at station 3-V where an accumulation of detrital material occurred possibly affecting the distribution of organisms. The data must therefore be considered inconclusive with regard to the question of whether bridging has had an impact on the benthic biota. If nothing else, the interference of sloughs illustrates the complexity of environmental impact assessment in aquatic systems.

A nonstatistical assessment of the data allows limited interpretation. Although benthic community structure seems to be unaffected by the presence of the bridge, the decided decrease in the numbers of benthic organisms at the various stations downstream between transect 4 and transect 2 is of particular interest. The only exception in this otherwise pronounced reduction in values was at station 1 of transect 2, where a slight increase was recorded. This station is located just upstream from station 1 of transect 1, which had an atypically high density of benthic invertebrates.

The decrease in densities from transect 4 to transect 2 might be related to bridging. Certain design criteria and construction methods, though, seem not to be causative: Shade does not appear to be a factor because of the high elevation of the bridges and their nearly north-south orientation. Channel dredging was excluded as a construction practice. The bridge approach pads do not interfere with water flow because the water remains within the deeply incised channel at flood stage. In addition, even though large pilings with flat sides were installed within the channel, the low velocity of this river appears to be insufficient to cause scouring of the bottom. Limited scouring may be occurring but is not yet detectable because of the short time since the bridge was constructed. Also, scouring may increase during flood stage.

Two causative agents remain suspect for the decrease in numbers of benthic organisms downstream. One is an accumulation of silt or other surface sediments that may have eroded from the banks during construction. Straw from bales of hay used for checking erosion was obtained with the benthic samples in some areas indicating previous erosion. The silt or other surface sediments would have been transported a short distance downstream before settling to the bottom. Observations are insufficient to test this hypothesis.

The second causative agent may be oil and grease that are present in the sediments at most sampling stations under the bridged area. Petroleum products were allowed to escape into the river during bridge construction. Monitoring at this site during construction of the bridge indicated oily sheens to the river's surface (21). These petroleum products may have been transported a short distance downstream before they were incorporated into the sediments. As a result, benthic organisms may have been exposed to less petroleum at transect 4 than at 3 or especially 2. The effect of petroleum products on benthic organisms in the Braden River can only be surmised. Boesch and Hershner (22) reported that grease and oil adversely impact benthic communities. The sampling may have been done too soon after bridge construction to determine the full effects of petroleum products on benthic organisms.

CONCLUSIONS AND RECOMMENDATIONS

Three main conclusions were obtained from this study.

1. There were no significant impacts on biological productivity or diversity (as measured by benthic invertebrate diversity, dominance, and evenness) because of bridging at the I-10 bridge site on the Ochlockonee River. The absence of impact appears to be due to the favorable consideration of environmental factors in bridge design and construction practices.
2. The US-98 bridge over the Wakulla River appears to have caused severe adverse impacts on the submerged aquatic macrophytes and on the benthic community structure. The impacts are localized beneath the bridge and do not extend beyond it. The adverse impacts probably resulted from dredging during bridge construction, scouring that was caused by hydrologic changes related to construction of the causeway and approach pads in the floodplains, and shading caused by the low elevation of the bridge.
3. The study results at the I-75 bridge across the Braden River were inconclusive because of the complexity of the system. Sloughs entering the river near the study site were the main cause of this complexity. The bridge appears to be of an environmentally sound design. Construction activities may have resulted in undetermined adverse effects on aquatic biota. Large amounts of grease and oil and eroded surface sediments were allowed to be deposited in the river because of inadequate quality control during construction. These petroleum products and perhaps recent sediment deposition caused by surface erosion may be causing a moderately adverse impact on benthic organisms.

At any bridge site, several factors contribute to a given adverse impact. It is nearly impossible to determine which factors of bridge design or construction are the most detrimental. Even if it were possible, a given factor that has a severe impact at one bridge site might have no impact at another because of wide differences in site conditions. However, because of the importance of aquatic invertebrates and vegetation to the fish communities and water quality in a river system, impacts on aquatic biota should be considered in the location, design, and construction of bridges. Several recommendations can be made that would be expected to reduce the impacts of the construction and placement of bridges.

1. Locations should be selected where alteration of the river channel or floodplain can be avoided or minimized.
2. Dredging or other disturbances of natural bottom sediments should be minimized.
3. Bridges should be designed to minimize the alteration of the natural hydrologic characteristics of the river. Preferably, bridges should span floodplains. Culverting, adequate to maintain natural flow patterns, should be placed in any fill causeways. Incorporation of these considerations would help prevent the scouring of bottom sediments caused by increased current flow.
4. Bridge spans should be positioned so that they do not cause continuous shading of the river, especially if aquatic macrophytes occur at the bridge site. Spans should be placed at a sufficient height to allow at least partial illumination under the bridge. A direct east-west orientation should be avoided if possible.
5. Construction methods should be monitored carefully to ensure adequate erosion control, containment of oils and greases, and minimal disturbance of the river system and watershed area by heavy equipment and clear-cutting practices. Timber matting has proven useful in some areas for minimizing site disturbance.

ACKNOWLEDGMENTS

The Florida Department of Transportation (FDOT) provided support funds for the study on which this paper is based. Gary L. Evink and Daniel Darden of FDOT assisted in the review of records for data on bridge design and construction methods and in the collection of samples.

Appreciation is extended to Mark Latch for his critical review of the manuscript and to Belinda Brock and Sharon Estes for typing the paper.

REFERENCES

1. R.M. Darnell. Impacts of Construction Activities in Wetlands of the United States. Report 600/3-76-045. Ecological Research Service, Environmental Protection Agency, 1976.
2. Highways in the River Environment. FHWA, U.S. Department of Transportation, 1975.
3. Gazetteer of Florida Streams. Division of Water Resources and Conservation, Florida Board of Conservation, Tallahassee, 1966.
4. Construction Plans, Interstate Route 10 over the Ochlockonee River. Project 55320-3403. Florida Department of Transportation, Tallahassee, 1968.
5. W.M. Beck, Jr. The Streams of Florida. Bulletin of the Florida State Museum, 1965, pp. 91-126.
6. S.M. Thompson. Vascular Plant Communities and Environmental Parameters Under Tidal Influence on the Wakulla and St. Mark's Rivers, Florida. M.S. thesis. Florida State University, Tallahassee, 1977.

7. G.E. Ferguson, C.W. Lingham, S.K. Love, and R.O. Vernon. Springs of Florida. Florida Geological Services Bulletin 31, 1947, 196 pp.
8. General Highway Map of Wakulla County. Florida Department of Transportation, Tallahassee, 1974.
9. Standard Dredge and Fill Permit No. 41-37-3937 for I-75/Braden River Bridge. Florida Department of Environmental Regulation, Tallahassee, 1977.
10. Construction Plans, Interstate Route 75 over the Braden River. Project 55320-3403. Florida Department of Transportation, Tallahassee, 1975.
11. M.F.M. Guyer. Animal Micrology, Practical Exercises in Zoological Micro-Technique. University of Chicago Press, Chicago, 1953.
12. W.T. Mason, Jr., and P.P. Yevich. The Use of Phloxin B and Rose Bengal Stains to Facilitate Sorting Benthic Samples. Transactions of the American Microscopic Society, Vol. 86, No. 2, 1967, pp. 221-223.
13. E.A. Phillips. Methods of Vegetation Study. Holt, Rinehart and Winston, New York, 1969.
14. B.F. Birkitt, B.J. Dougherty, G.L. Thomas, S.S. Thompson, and A.F. Clewell. Effects of Bridging on Biological Productivity and Diversity. Technical Publication FL-ER-9-79. Florida Department of Transportation, Tallahassee, 1979, 74 pp.
15. R.J. Livingston. Impact of Kraft-Pulp Mill Effluents on Estuarine and Coastal Fishes in Apalachee Bay, Florida, USA. Marine Biology, Vol. 32, 1975, pp. 19-48.
16. E.C. Pielou. Mathematical Ecology. Wiley, New York, 1977.
17. M.S. Zimmerman and R.J. Livingston. Effects of Kraftmill Effluents on Benthic Macrophyte Assemblages in a Shallow-Bay System (Apalachee Bay, Florida, USA). Marine Biology, Vol. 43, 1976, pp. 297-312.
18. N.H. Nie, C.H. Hu, et al. Statistical Package for the Social Sciences. 2nd ed. McGraw-Hill, New York, 1975.
19. H.T. Odum. Tropic Structure and Productivity of Silver Springs, Florida. Ecology Monograph, Vol. 25, 1957, pp. 291-329.
20. H.B.N. Hynes. The Ecology of Running Waters. University of Toronto Press, Toronto, Ontario, Canada, 1970.
21. Braden River Monitoring Report File for Standard Dredge and Fill Permit 41-37-3937. Florida Department of Environmental Regulation, Tallahassee, 1978.
22. D.F. Boesch and C.H. Hershner. The Ecological Effects of Oil Pollution in the Marine Environment. Report to the Energy Policy Project. Virginia Institute of Marine Science, University of Virginia, Charlottesville, 1973.

Publication of this paper sponsored by Committee on Landscape and Environmental Design.

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

JOHN L. HARRIS, FRED L. BURNSIDE, BILL L. RICHARDSON, and WENDY K. WELCH

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-

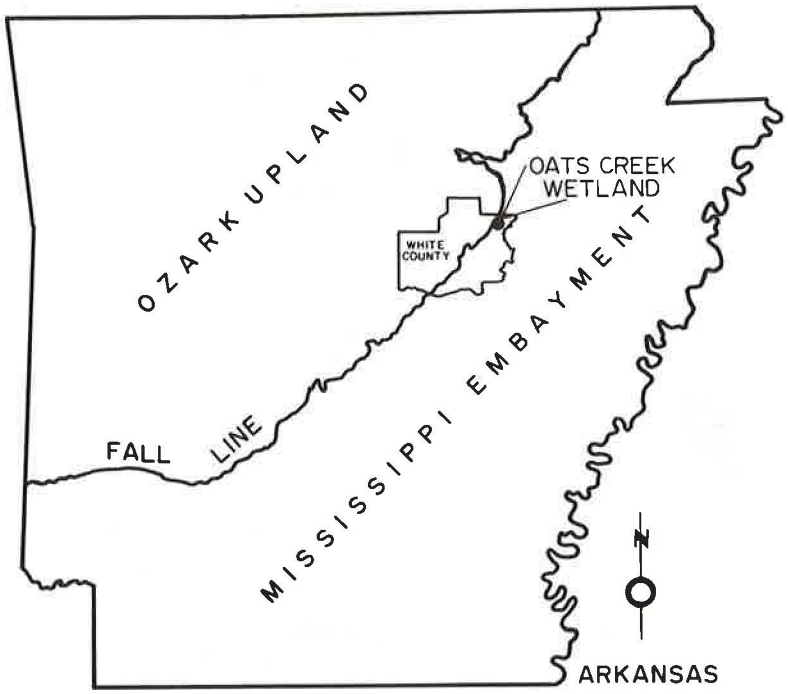

FIGURE 1 Location of Oats Creek wetland study area.

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.

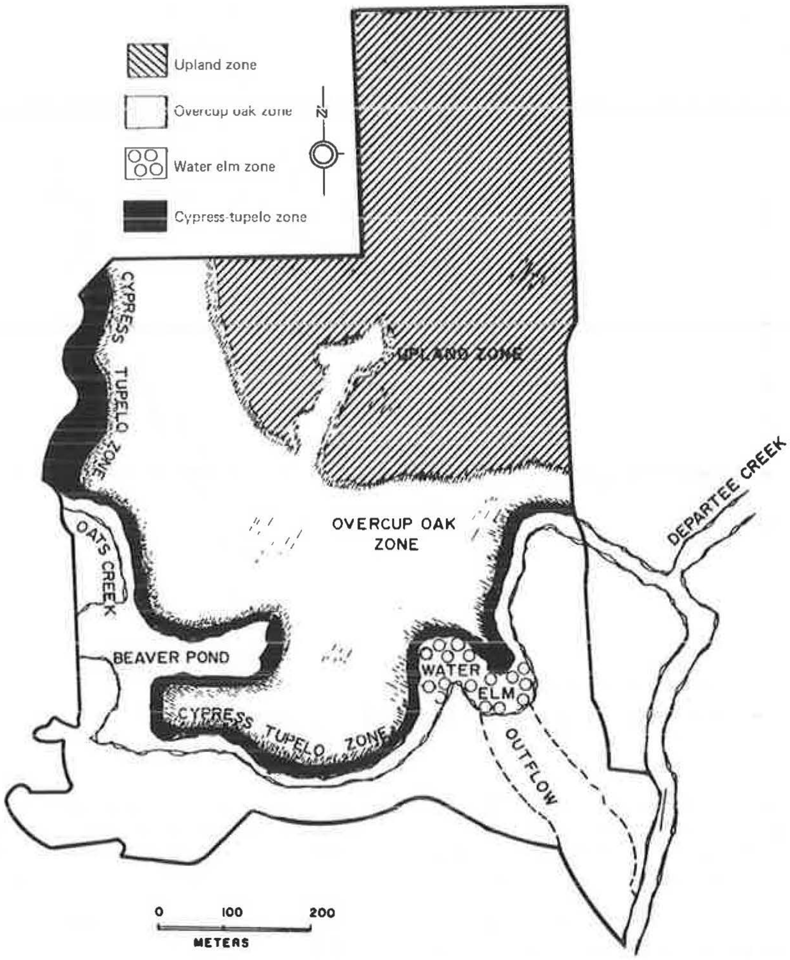

FIGURE 2 Vegetation dominance zones.

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

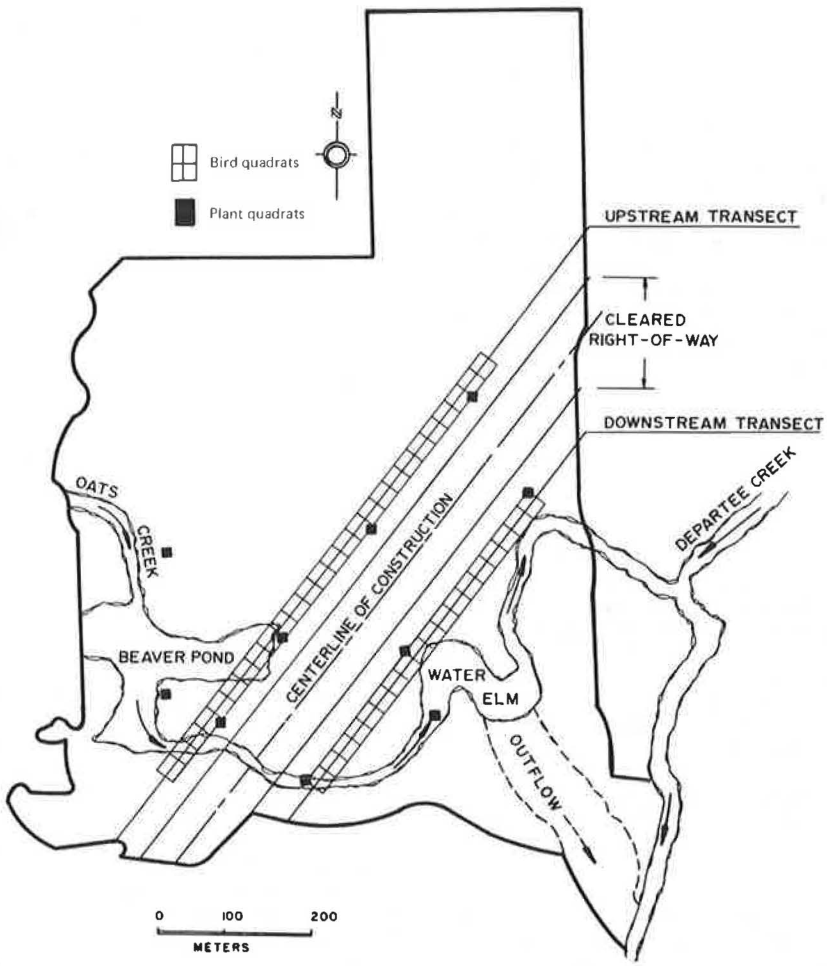

FIGURE 3 Plant and bird sample quadrats.

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.

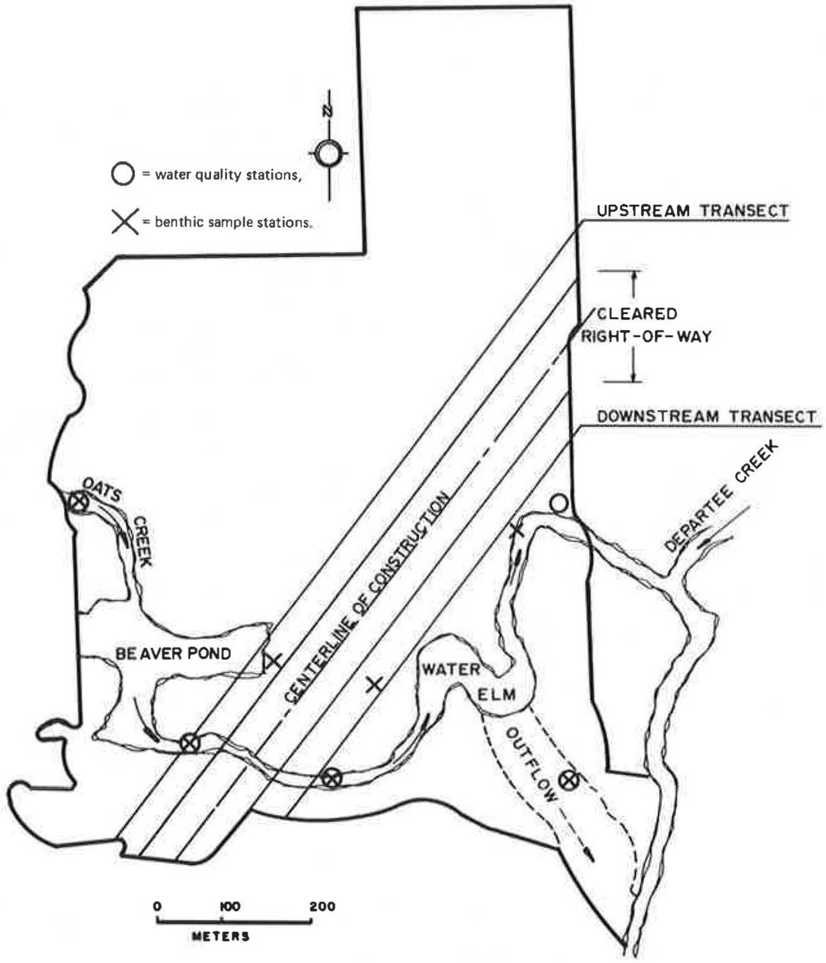

FIGURE 4 **Benthic invertebrate and water quality sampling stations.**

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.

General

Good, R.E., D.F. Whigham, and R.L. Simpson (eds), 1978. Freshwater wetlands: ecological processes and management potential. Academic Press, New York. 378 pp.

Greeson, P.E., J.R. Clark, and J.E. Clark (eds), 1979. Wetland functions and values: the state of our understanding. American Water Resources Association Publication TPS 79-2. 674 pp.

National Wetlands Newsletter. Irregular publication of Environmental Law Institute and the National Wetlands Technical Council.

Wharton, C.H., W.M. Kitchens, and T.W. Sipe, 1982. The ecology of bottomland hardwood swamps of the southeast: a community profile. U.S. Fish and Wildlife Biological Services Program FWS/OBS-81/37. 133 pp.

Wisconsin Department of Natural Resources, 1968. Bibliography of freshwater wetlands: ecology and management. Report 33. Madison, Wisconsin. 222 pp.

Materials and Methods

Research Design

Burns, J.W., 1972. Some effects of logging and associated road construction on northern California streams. Trans. Am Fish. Soc. 101:1-17.

Burke, R.C., II and J.A. Sherburne, 1982. Monitoring wildlife populations and activity along I-95 in northern Maine before, during, and after construction. Transportation Research Record 859:1-8.

Climatic Conditions

Barton, B.A., 1977. Short-term effects of highway construction on the limnology of a small stream in southern Ontario. Freshwater Biol. 7:99-108.

Brown, G.W. and J.T. Krygier, 1970. Effects of clear-cutting on stream temperatures. Water Resources Research 6:1133-1139.

Feller, M.C., 1981. Effects of clearcutting and slashburning on stream temperature in southwestern British Columbia. Water Research Bull. 17(5):863-867.

Rishel, G.B., J.B. Lynch, and E.S. Corbett, 1982. Seasonal stream temperature changes following forest harvesting. J. Env. Quality 11(1):112-116.

Shuldiner, P.W., D.F. Cope, and R.B. Newton, 1979. Ecological effects of highway fills on wetlands. Transportation Research Board. National Cooperative Highway Research Program Report 218A. 34 pp.

Stern, D.H. and M.S. Stern, 1980. Effects of bank stablization on the physical and chemical characteristics of streams and small rivers: a synthesis. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-80/11. 43 pp.

Stern, D.H. and M.S. Stern, 1980. Effects of bank stablization on the physical and chemical characteristics of streams and small rivers: an annotated bibliography. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-80/12. 77 pp.

Stern, E.M. and W.B. Stickle, 1978. Effects of turbidity and suspended materials in aquatic environments. U.S. Army Corps of Engineers Tech. Report D-78-21. 127 pp.

Hydraulics

Hemond, H.F., 1982. A low-cost multichannel recording piezometer system for wetland research. Water Resources Research 18(1):182-186.

Hemond, H.F. and R. Burke, 1981. A device for measurement of infiltration in intermittently flooded wetlands. Limnology and Oceanography 26(4):795-800.

Mather, J.R., 1981. Using computed stream flow in watershed analysis. Water Resources Bull. 17(3):474-482.

Novitzki, R.P., 1978. Hydrology of the Nevin Wetland near Madison, Wisconsin. U.S. Geological Survey Water Research Investigation 78-48. 25 pp.

O'Brien, A.L., 1977. Hydrology of two small wetland basins in eastern Massachusetts. Water Resources Bull. 13(2):325-340.

Shuldiner, P.W., D.F. Cope, and R.B. Newton, 1979. Ecological effects of highway fills on wetlands. Transportation Research Board. National Cooperative Highway Research Program Report 218A. 34 pp.

Swift, L.W. and W.T. Swank, 1981. Long-term responses to stream-flow following clearcutting and regrowth. Hydrological Sciences Bull. 26(3):245-256.

Physical Parameters

Barton, B.A., 1977. Short-term effects of highway construction on the limnology of a small stream in southern Ontario. Freshwater Biol. 7:99-108.

Bilby, R.E., 1981. Role of organic debris dams in regulating the export of dissolved and particulate matter from a forested watershed. Ecology 62(5):1234-1243.

Bilby, R.E. and G.E. Likens, 1980. Importance of organic debris dams in the structure and function of stream ecosystems. Ecology 61(5):1107-1113.

DePinto, J.V., T.C. Young, and S.C. Martin, 1982. Aquatic sediments. J. Water Pollution Control Fed. 54(6):855-862.

Hansen, E.A., 1971. Sediment in a Michigan trout stream, its source, movement and some effects on fish habitat. U.S. Dept. Agri. Forest Service Research Paper NC-59. 14 pp.

McLeese, R.L. and E.P. Whiteside, 1977. Ecological effects of highway construction upon Michigan woodlots and wetlands: soil relationships. J. Env. Qual. 6(4):467-471.

Murphy, M.L., C.P. Hawkins, and N.H. Anderson, 1981. Effects of canopy modification and accumulated sediment on stream communities. Trans. Am. Fish. Soc. 110:469-478.

Naiman, R.J., 1982. Characteristics of sediment and organic carbon export from pristine boreal forest watersheds. Can. J. Fish. Aq. Sci. 39(12):1699-1718.

O'Leary, S.J. and R.L. Beschta, 1981. Bedload transport in an Oregon coast range stream. Water Resources Bull. 17(5):886-894.

Reynolds, C.S. and B.M. Godfrey, 1983. Failure of a sediment-trapping device. Limnology and Oceanography 28(1):172-176.

Shuldiner, P.W., D.F. Cope, and R.B. Newton, 1979. Ecological effects of highway fills on wetlands. Transportation Research Board. National Cooperative Highway Research Program Report 218A. 34 pp.

Chemical Parameters

Cramer, G.H., II and W.C. Hopkins, Jr. 1981. The effects of elevated highway construction on water quality in Louisiana wetlands. FHWA Research Rept. No. 75-4G. 31 pp.

Hirsch, R.M., J.R. Slack, and R.A. Smith, 1982. Techniques of trend analysis for monthly water quality data. Water Resources Research 18(1):107-121.

Hobbie, J.E. and G.E. Likens, 1973. Output of phosphorus, dissolved organic carbon, and fine particulate carbon from Hubbard Brook watersheds. Limnology and Oceanography 18:734-742.

Karr, J.R. and I.J. Schlosser, 1978. Water resources and the land-water interface. Science 201:229-234.

Likens, G.E. and F.H. Bormann, 1974. Linkages between terrestrial and aquatic ecosystems. Bioscience 24:447-456.

Peverly, J.H., 1982. Stream transport of nutrients through a wetland. J. Env. Quality 11(1):38-43.

Schlesinger, W.H., 1978. Community structure, dynamics, and nutrient cycling in the Okefenokee cypress swamp forest. Ecol. Monogr. 48:43-65.

Van Belle, G. and J.P. Hughes, 1983. Monitoring for water quality: fixed stations versus intensive surveys. J. Water Poll. Control Fed. 55(4):400-404.

Vitousek, V., 1982. Nutrient cycling and nutrient use efficiency. Am. Naturalist 119(4):553-572.

Biological Parameters

Plants

Bedinger, M.S., 1979. Forests and flooding with special reference to the White River and Ouachita River basins, Arkansas. USGS Water Resources Investigations Rept. 79-68. 27 pp.

Fritts, H.C., 1971. Dendroclimatology and dendroecology. Quaternary Res. 1:419-449.

Kaushik, N.K. and H.B.N. Hynes, 1968. Experimental study of the role of autumn-shed leaves in aquatic environments. J. Ecology 56:229-243.

Larson, J.S. (ed.), 1973. A guide to important characteristics and values of freshwater wetlands in the northeast. U. of Massachusetts Water Resources Research Center Publ. No. 31. 31 pp.

Lonard, R.I., E.J. Clairain, Jr., R.T. Huffman, J.W.

Hardy, L.D. Brown, P.E. Ballard, and J.W. Watts, 1981. Analysis of methodologies used for the assessment of wetlands values. Technical Report, U.S. Water Resources Council. 68 pp.
Lovvorn, J.R. and C.M. Kirkpatrick, 1982. Analysis of freshwater wetland vegetation with large-scale color infrared aerial photography. J. Wildlife Management 46(1):61-70.
Mitsch, W.J., C.L. Dorge, and J.R. Wiemhoff, 1979. Ecosystem dynamics and a phosphorus budget of an alluvial cypress swamp in southern Illinois. Ecology 60(6):1116-1124.
Phillips, D.R. and J.R. Saucier, 1982. Estimating understory biomass. Southern J. of Applied Forestry 6(1):25-27.
Rice, E.L., 1967. A statistical method for determining quadrat size and adequacy of sampling. Ecology 48:1047-1049.
Shuldiner, P.W., D.F. Cope, and R.B. Newton, 1979. Ecological effects of highway fills on wetlands. Transportation Research Board. National Cooperative Highway Research Program Report 218A. 34 pp.
Wolda, H., 1981. Similarity indices, sample size and diversity. Oecologia 50:296-302.

Benthic Invertebrates

Barber, W.E. and N.R. Kevern, 1973. Ecological factors influencing macroinvertebrate standing crop distribution. Hydrobiol. 43:53-75.
Buikema, A.L., E.F. Benfield, and B.R. Niederlehner, 1982. Effects of water pollution on freshwater invertebrates. J. Water Pollution Control Fed. 54(6):862-868.
Cummins, K.W. and G.H. Lauff, 1969. The influence of substrate particle size on the microdistribution of stream macrobenthos. Hybrobiol. 34:145-181.
Huish, M.T. and G.B. Pardue, 1978. Ecological studies of one channelized and two unchannelized wooded coastal swamp streams in North Carolina. U.S. Fish and Wildlife Service Biological Services Program Publ. FWS 10BS-78/85. 72 pp.
Karr, J.R. and I.J. Schlosser, 1977. Impact of near-stream vegetation and stream morphology on water quality and stream biota. EPA-600/3-77-097. Athens, Ga. 90 pp.
Lemly, A.D., 1982. Modification of benthic insect communities in polluted streams: combined effects of sedimentation and nutrient enrichment. Hydrobiologia 87:229-245.
Newbold, J.D., D.C. Erman, and K.B. Roby, 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. Can. J. Fish. Aq. Sci. 37:1076-1085.
Quigley, M.A., 1982. Freshwater macroinvertebrates. J. Water Poll. Control Fed. 54(6):868-877.
Resh, V.H. and J.D. Unzicker, 1975. Water quality monitoring and aquatic organisms: the importance of species identification. J. Water Poll. Control Fed. 47(1):9-19.
Wynes, D.L. and T.E. Wissing, 1981. Effects of water quality on fish and macroinvertebrate communities of the Little Miami River. Ohio Acad. Sci. 81(6):259-267.

Fish

Hocutt, C.H., 1981. Fish as indicators of biological integrity. Fisheries 6(6):28-31.
Huish, M.T. and G.B. Pardue, 1978. Ecological studies of one channelized and two unchannelized wooded coastal swamp streams in North Carolina. U.S. Fish and Wildlife Service Biological Services Program Publ. FWS 10BS-78/85. 72 pp.
Karr, J.R., 1981. Assessment of biotic integrity using fish communities. Fisheries 6(6):21-27.
Marais, J.F.K., 1981. Seasonal abundance, distribution, and catch per unit effort using gill nets, of fishes in the Sundays Estuary. S. African J. Zool. 16(3):144-150.
Schlosser, I.J., 1982. Trophic structure, reproductive success, and growth rate of fishes in a natural and modified headwater stream. Can. J. Fish. Aq. Sci. 39(7):968-978.
Spehar, R.L., G.M. Christensen, C. Curtis, A.E. Lemke, T.J. Norberg, and Q.H. Pickering, 1982. Effects of pollution of freshwater fish. J. Water Poll. Control Fed. 54(6):877-922.
Wynes, D.L. and T.E. Wissing, 1981. Effects of water quality on fish and macroinvertebrate communities of the Little Miami River. Ohio Acad. Sci. 81(6):259-267.

Reptiles and Amphibians

Gibbons, J.W. and R.D. Semlitsch. 1981. Terrestrial drift fences with pitfall traps: an effective technique for quantitative sampling of animal populations. Brimleyana 7:1-16.
Strang, C.A., 1983. Spatial and temporal activity patterns in two terrestrial turtles. J. Herp. 17(1):43-47.

Birds

Best, L.B., 1975. Interpretational errors in the "Mapping Method" as a census technique. Auk 72:452-460.
Brewer, R., 1978. A comparison of three methods of estimating winter bird populations. Bird Banding 49(3):252-261.
Emlen, J.T., 1971. Population densities of birds derived from transect counts. Auk 88:323-342.
Emlen, J.T., 1977. Estimating breeding season bird densities from transect counts. Auk 94:455-468.
Williamson, K., 1964. Bird census work in woodland. Bird Study 11(1):1-22.

Mammals

Geier, A.R. and L.B. Best, 1980. Habitat selection by small mammals of riparian communities: evaluating effects of habitat alterations. J. Wildlife Management 44:16-24.
Sealander, J.A., 1979. A Guide to Arkansas Mammals. River Road Press. Conway, Ark. 313 pp.

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.

ACKNOWLEDGMENT

Many people have contributed to the research program and to mention all would take volumes. The authors must thank those who were instrumental in getting this project off the ground. These include AHTD employees J. Gaither and M. Harris, Environmental Division; T. Black, K. Flynn, and C. Lindstrom, Hydraulics Section; K. Carson, Surveys Division; L. Bryant and G. Green, Chemistry Section; and R. Gruver, Materials and Research Division.

B. Pell and B. Shepherd of the Arkansas Natural Heritage Commission and T. Lamb of the USGS greatly aided in the early stages of design.

Special thanks go to P. Gee and K. Williamson for typing the many drafts of this manuscript and to E. Sullivan for preparation of the figures.

REFERENCES

1. Environmental Impact Statement: Bald Knob-Newport. Arkansas State Highway and Transportation Department, Little Rock, 1974.
2. L.M. Cowardin, V. Carter, F.C. Golet, and E.T. LaRoe. Classification of Wetlands and Deepwater Habitats of the United States. Document FWS/OBS-79/31. Biological Services Program, U.S. Fish and Wildlife Service, 1979.
3. Arkansas Natural Area Plan. Arkansas State Department of Planning, Little Rock, 1974.
4. W.A. Gore and C. Harris. Soil Survey of White County, Arkansas. Soil Conservation Service, U.S. Department of Agriculture, 1981.
5. Methods for Chemical Analysis of Water and Wastes. Environmental Monitoring and Support Laboratory, Environmental Protection Agency, Cincinnati, Ohio, 1979.
6. Standard Methods for the Examination of Waste and Wastewater. American Public Health Association, Washington, D.C., 1975.

Publication of this paper sponsored by Committee on Landscape and Environmental Design.

Method for Wetland Functional Assessment

DOUGLAS L. SMITH

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, new construction in wetlands unless there is no practicable alternative and that any construction undertaken shall include all practicable measures to minimize harm to the wetland. In making decisions, an agency may take into account economic, environmental, and other pertinent factors [Section 2(a)].

Until recently, wetlands were viewed as unproductive wastelands, sources of mosquitoes, and impediments to development and travel. By the mid-1950s, almost 40 percent of our nation's wetlands had been lost to drainage, fill, and construction (2). In the mid-1950s there were 43.8 million hectares of wetlands. By the mid-1970s there were 40.1 million hectares (3). By the late 1960s and early 1970s the perception of wetlands began to change as more was learned about their importance. Since 1969 there have been a number of federal and state laws and regulations that mandate the protection of wetlands (Table 1).

The problem that now faces the FHWA and the states is how to comply with these regulations and still fulfill the charge of providing safe and efficient transportation at a reasonable cost. States need a method to determine

1. The value of a wetland,
2. The significance of any impact, and
3. How to mitigate impacts or find practicable alternatives.

FHWA policy on Mitigation of Environmental Impacts to Privately Owned Wetlands (4) states that the extent of federal-aid participation in mitigating adverse impacts should be related to the importance of the wetland and the significance of the impact. Evaluation of the importance of the wetland should consider the primary functions of the wetland, the relative importance of these functions to the total wetland resources of the region, and other factors such as uniqueness and aesthetics (Section 777.7). Until the development of the FHWA method for wetland functional assessment (5,6) there was no systematic method of evaluating the importance of a wetland or determining whether mitigation is warrented and, if so, to what extent.

WETLANDS RESEARCH PROGRAMS

To assist states and provide the information they need, FHWA initiated its wetlands research program in 1976. One of the first products of the FHWA research and development program was the development of interim guidelines for construction through wetlands (7-9). These guidelines were intended as an interim measure to aid states until more specific information on highway impacts on wetlands could be obtained.

The FHWA also initiated research on the values of tidal flats (10-12). Wetland protection has usually focused on emergent systems often at the expense of tidal flats. Highways have been rerouted through flats to avoid other systems, or tidal flat elevations have been raised and the area planted with emergents to create marsh systems as mitigation. When this has been done, it has been without full understanding of the values being lost. The tidal flats research has provided some of this needed understanding.

In addition to the FHWA research program, studies are being conducted by state highway agencies and through the National Cooperative Highway Research Program. These studies address topics such as the effects on wetlands of highway fills, end-on construction, and highway runoff; and the development of methods for the creation and restoration of wetlands. These research efforts are coordinated by FHWA.

All of this information on wetlands has been incorporated in a wetlands training course for state highway personnel. Almost half of the course is devoted, however, to instruction on the use of the newly developed FHWA method for wetland functional assessment. This is the subject of the remainder of this paper.

APPROACH

As was said before, the main problems facing the states are determining the values associated with a particular wetland and then translating this information into practical alternatives. The determination of values is most often accomplished through consultation with regulatory agencies such as the U.S. Fish and Wildlife Service (FWS) or the U.S. Army Corps of Engineers (Corps). Such determinations are frequently based on a subjective "expert" opinion about the wetland's value. Methods that consider only a limited number of functions, such as the FWS Habitat Evaluation Procedures, are also being used increasingly.

In developing its method, FHWA was looking for a procedure that would concisely and accurately determine functional values attributable to wetlands, be applicable for all wetland types, and use the FWS wetland classification system. These criteria were what was believed was needed to solve a real problem that faces not only highway agencies but everyone involved in wetland management and protection.

About the time FHWA began its work, the Water Resources Council (WRC) was sponsoring a study to evaluate wetland assessment methods. The work was conducted by the Corps. The FHWA used the Corps' work to avoid duplication of effort.

TABLE 1 Representative Federal Legislation and Regulations that Directly or Indirectly Provide Wetland Protection

	Citation
Legislation	
Transportation Act of 1966 [Section 4(f)]	49 U.S.C. Section 1653(f) 23 U.S.C. Section 138
National Environmental Policy Act of 1969	42 U.S.C. Sections 4321-4347
Clean Water Act as Amended (especially Section 404)	33 U.S.C. Sections 1251-1376, 1344
Fish and Wildlife Coordination Act	16 U.S.C. Sections 661-666
Water Bank Act	16 U.S.C. Sections 1301-1311
Endangered Species Act	16 U.S.C. Sections 1531-1543
Regulations and orders	
Protection of Wetlands	Executive Order 11990
Preservation of the Nation's Wetlands	U.S. Department of Transportation Regulation 5660.1A
Mitigation of Environmental Impacts to Privately Owned Wetlands	23 C.F.R. Section 777

The WRC study identified methods that assess wetland functional values. The merits and limitations of each method was identified and the results of the study were published by WRC (13). Table 2 gives the 20 methods reviewed in the study, plus the FHWA method, and one of the functions each considers. Table 3 gives some of the geographic features of each method. The basic approach taken by FHWA in developing the assessment method recognized that although there is a large amount of information lacking for certain functions, a lot is also known. Because of time and monetary constraints, it was decided that the study would rely on existing data to develop the method. The method has been field tested to a limited extent and is being used on highway projects in several states.

THE METHOD

The FHWA method is presented in a two-volume report (5,6). The method is a rapid assessment procedure for screening the functional values of wetlands. The functions covered are groundwater recharge, flood storage and desynchronization, shoreline anchoring and dissipation of erosive forces, sediment trapping, nutrient retention and removal, food chain support (detrital export), habitat for fish and wildlife, and active and passive recreation. The method can be used for all wetland types in the 48 coterminous states, and uses the FWS wetland classification system (14).

Other features of the method are that it is qualitative and results are not based on a series of scores; it can be used to evaluate the importance of a single wetland or compare two or more wetlands; it can be used to assist in selecting practicable mitigative alternatives; and it incorporates social as well as scientific factors into the overall assessment. Assessments can be made using three levels of data: data available in the office, data from cursory field visits, and detailed field data.

Volume I

Volume I is an important and major component of the overall method. In it are background material on the assumptions and decisions used in Volume II. In Volume I the validity of claims regarding the functions of wetlands is examined and what is actually known about each function is discussed. The trade-offs among wetland functions are also described. Conditions that are optimal for one function may not be so for another.

Wetland types are ranked according to their importance to various functions. These rankings are based on a synthesis of the literature and are qualified to reflect regional differences or the scarcity of support data. Cause-and-effect relationships that link potential changes in each wetland function to specific highway activities are identified. There is a discussion of the variable sensitivity of different wetland types to the impacts of construction.

A thorough understanding of the material in Volume I is important. It will enhance the value of the assessment and help ensure that management decisions based on an evaluation are practical and realistic.

Volume II

Volume II contains the assessment method. This method is made up of three separate procedures: threshold analysis (procedure I), comparative analysis (procedure II), and mitigative analysis (procedure III). The threshold analysis is used in all assessments using the method. The other two procedures are used if further assessment is desired.

The threshold analysis is used to estimate the relative functional value of a specific wetland. If more than one wetland is being assessed, the method is used to evaluate each wetland separately. Procedure I needs to be completed before procedure II or III is conducted. Procedure II is used after procedure I has been applied to compare, more closely, two or more wetlands.

A wetland's value, as reflected in procedures I and II, has three major components: opportunity, effectiveness, and significance. The result of the interaction of these is termed "functional significance." Opportunity is the chance a wetland stands of fulfilling a particular function. Effectiveness is the probability of a wetland being able to maxi-

TABLE 2 Functional Assessment Methods and Criteria Measured[a]

Method	Citerion				
	Habitat	Hydrology	Recreation	Agriculture/ Silviculture	Heritage
A. Brown et al., 1974	Yes	NA	NA	NA	NA
N. Dee et al., 1973	Yes, IT	Yes, IT	NA	Yes, IT	Yes, IT
E. Fried, 1974	Yes	NA	NA	NA	NA
G. E. Galloway, 1978	Yes, IT	Yes, IT	NA	NA	Yes, IT
F. C. Golet, 1973	Yes	NA	NA	NA	NA
T. R. Gupta and J. H. Foster, 1973	NA	NA	NA	NA	Yes (scenic)
H. V. Kibby, 1973	NA	Yes, WQ, PP	NA	NA	NA
J. S. Larson, Ed., 1976	Yes	Yes	NA	NA	Yes
Maryland Department of National Resources, undated	Yes	NA	NA	NA	NA
R. T. Reppert et al., 1979	Yes	Yes	PJ	PJ	PJ
P. W. Shuldiner et al., 1979	Yes	Yes	NA	NA	NA
Stearns, Conrad, and Schmidt, 1972	NA	Yes	NA	NA	NA
R. C. Smardon, 1972	NA	NA	Yes (rec. c.c.)	NA	NA
R. C. Solomon et al., 1977	Yes, IT	Yes, IT	Yes, IT	NA	Yes, IT
U.S. Army Corps of Engineers, 1980	Yes	NA	NA	NA	NA
U.S. Army Corps of Engineers, 1972	Yes, IT	Yes	Yes (day use)	Yes, IT	Yes, IT
U.S. Department of Agriculture, 1978	Yes	Yes (flood control)	Yes	Yes (forest management)	Yes
U.S. Fish and Wildlife Service, 1980 (HEP)	Yes	NA	NA	NA	NA
Virginia Institute of Marine Sciences, undated	Yes	NA	NA	NA	NA
B. H. Winchester and L. D. Harris, 1979	Yes	Yes	NA	NA	NA

Note: NA = not addressed, IT = interdisciplinary team, WQ = water quality, PP = primary productivity, PJ = professional judgment, and rec. c.c. = recreational carrying capacity.

[a]Adapted from Frayer et al. (3).

TABLE 3 Summary of Geographic Features of 20 Wetland Evaluation Procedures and the FHWA Method [adapted from Lonard et al. *(13)*]

Citation	Inland[a]	Coastal[b]	Regional Application[c]	Widespread Application[d]	Use
A. Brown et al., 1974	Yes; a variety of inland wetland types	NA	Developed for wetlands in Arkansas	Must be modified for widespread application	Can be used to assess a single wetland site; can be used to rank similar or dissimilar wetland types
N. Dee et al., 1976	Used for water resource development projects on rivers or river systems; could be modified for wetlands	NA	Applicable	Applicable	More useful for an assessment of a single wetland area
E. Fried, 1974	Applicable to freshwater wetlands and wetland restoration projects	Developed for tidal wetlands but has not been used for that purpose	Developed for wetland acquisition studies in New York	Must be modified for use in other regions	More useful for ranking wetlands
G. E. Galloway, 1978	Applicable to a variety of wetland types	Applicable to coastal wetlands and estuaries	Applicable	Applicable	Applicable for use in inland and coastal areas
F. C. Golet, 1973	Applicable to a variety of wetland types	NA	Developed for Massachusetts and useful in the general region	Applicable but must be modified for use outside the Northeast	Applicable for use in inland and coastal areas
T. R. Gupta and J. H. Foster, 1973	Applicable	NA	Developed for Massachusetts and useful in the general region	Applicable but must be modified for use outside the Northeast	Applicable for use in inland and coastal areas
H. V. Kibby, 1978	Applicable to wetlands adjacent to rivers	NA	Applicable	Applicable	More useful for a narrative evaluation of a single wetland site
J. S. Larson, Ed., 1976	Applicable	NA	Developed for Massachusetts and useful in the general region	Applicable but must be modified for use outside the Northeast	Applicable for both requirements; comparison of wetlands in same general region
Maryland Department of Natural Resources, undated	NA	Applicable	Developed for Maryland and useful in the general region	Must be modified for use in coastal zones outside the region	Applicable for both requirements, but comparisons must be made of wetlands in the same salinity regime
R. T. Reppert et al., 1979	Applicable	Applicable	Applicable	Applicable	Applicable for use in inland and coastal areas
P. Schuldiner et al., 1979	Applicable	Applicable	Applicable	Applicable	Applicable for an assessment of a single wetland
Stearns, Conrad, and Schmidt, 1979	Applicable	Applicable	Applicable	Applicable	Applicable for use in inland and coastal areas
R. C. Smardon et al., 1972	Applicable	NA	Developed for Massachusetts and useful in the general region	Applicable but must be modified for use outside the Northeast	Applicable for use in inland and coastal areas
R. C. Solomon et al., 1977	Applicable, but developed for Water Resources projects	Possibly applicable, but developed for Water Resources projects	Applicable	Applicable	Applicable for use in inland and coastal areas
U.S. Army Engineer Division, Lower Mississippi Valley (HES), 1980	Applicable, but developed for Water Resources planning projects	NA, but salt marshes will be evaluated in future revision of procedure	Ecosystems in the lower Mississippi River Valley	Can be modified for use in other regions	Developed to be used in comparing project impacts or alternatives on existing and future "without"
U.S. Army Engineer Division, New England, 1972	Applicable, but unique to eastern Massachusetts	NA	Applicable for specific study site in eastern Massachusetts	NA	Not easily modified to assess and rank several wetlands
U.S. Department of Agriculture, 1978	Applicable	Applicable	Developed for Massachusetts and useful in general region	Can be modified for use in other regions	Applicable for use in inland and coastal areas
U.S. Fish and Wildlife Service, 1980	Developed for inland terrestrial and aquatic habitats	Not extensively applied to estuarine systems, but concepts may be applicable	Applicable	Applicable	Useful for evaluating baseline conditions and impacts in a single wetland; also designed to rank habitats according to wildlife values
Virginia Institute of Marine Science, undated	NA	Applicable to tidal wetlands	Developed for tidal wetlands in Virginia	May be difficult to modify for use in other coastal regions	Applicable for use in inland and coastal areas
B. H. Winchester and L. D. Harris, 1979	Applicable	NA	Developed for freshwater wetlands in Florida	Could be modified and used in noncoastal wetlands of the southeastern coastal plain	Applicable for use in noncoastal wetlands
P. Adamus, 1983	Applicable	Applicable	Developed for use nationally	Applicable	Can be used to assess a single wetland site; can be used to compare two or more wetlands; can be used to assess mitigative measures

Note: NA = Not addressed.

[a]Can the procedure be used to evaluate a variety of inland wetland types?

[b]Can the procedure be used to evaluate a variety of coastal wetland types?

[c]Was the procedure developed for regional use?

[d]Was the procedure developed for widespread application?

mize the opportunity given it to fulfill that function. Significance considers the degree to which the performed function is valued by society. Figure 1 shows the relationship of these components within the method.

There are two basic steps in procedures I and II. First, the evaluator answers three series of questions or "predictor inventories." One series is used to evaluate opportunity and effectiveness, the second addresses significance, and the third reviews impact-related factors. Second, the responses to the predictor inventories are evaluated using interpretation keys to arrive at a rating for functional significance. Figure 2 shows a flow diagram of procedures I and II.

Procedure III is more of a bookkeeping method for evaluating mitigative alternatives. The procedure requires that a functional effectiveness rating for each wetland be determined for both preconstruction and postconstruction conditions, with and without each mitigative alternative. It also requires data describing the projected cost of each alternative. The procedure provides a means of comparing various mitigative alternatives to allow selection of the alternative that accomplishes the mitigation desired at the least cost. It also provides a way of making informed trade-offs between functional and mitigation costs.

Use of the Method

Two of the major questions that have come up concerning the method are: what does the method really tell you, and how and when do you use the method?

The method does not provide "the" answer or make decisions. Figure 3 shows a completed "Summary Sheet D" for a wetland evaluation. This is the final distillation of the assessments in procedure I or II. It provides an assessment of the wetlands functional significance for each function and the sensitivity that would be affected. On the basis of this information decisions can be made concerning the functional values of that wetland, its potential for impact, and the practicable alternatives for mitigation. The decision, however, about what must be done is made by the individuals or agency using the method not by the method. The method only helps ensure that all aspects of the wetland have been considered.

The method should be used as early in a project as possible. It is an excellent tool to aid in coordinating with other agencies. The method can be used by highway and regulatory agencies as a rapid screening process for sensitive areas and areas that are of special concern.

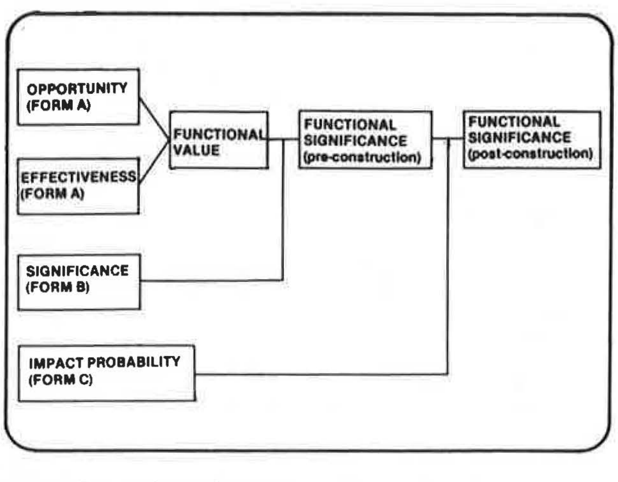

FIGURE 1 Relationships among concepts that determine wetland value *(6)*.

Summary

The FHWA method provides a flexible way of assessing the functional values of wetlands using a variety of data types that best suit the situation. The method may look imposing when first encountered but, if the user takes time to become familiar with it, the method becomes relatively easy to use.

The method is not perfect. Problems range from correcting typographical errors to possibly changing some of the assumptions made in areas where specific information may be lacking (e.g., groundwater). The FHWA and the Corps are working together to make many of these needed changes. In addition, long-range research needed to help answer some of the more difficult question is being assessed by the Corps and others. When FHWA first began the development of the method, it was considered a first step and not a one-time effort.

FUTURE DEVELOPMENT AND IMPLEMENTATION

Updating the method is already under way. Before the method went to print, draft copies were reviewed by state highway agencies, other state and federal agencies, and individual experts. A major result of the review process is that the FWS and the Corps have become interested in using the FHWA method as a basis for what may become a national assessment method. Agencies such as FWS and the Corps recognize the FHWA method as the best available tool.

In May 1983 several agencies jointly sponsored a workshop to review the method. As a result of the workshop an interagency coordinating committee was established to coordinate the future development of a national assessment method and other wetlands research issues.

It is too soon to know exactly how the future updating of the method will progress. The FHWA and the Corps will be working together during the next 2 years in an effort to update and refine the method. It is hoped that other agencies and private organizations will actively participate in the future development of the method and in the needed long-term research.

Developmental Needs

There are both long- and short-term modifications that need to be made. Some of the short-term modifications include

1. Rewriting ambiguous questions,
2. Conducting a sensitivity analysis of questions and throwing out unnecessary questions,
3. Adding questions to address areas not adequately covered, and
4. Computerizing the method.

The main long-term effort is to continue updating technical areas for which information is lacking.

Implementation

It is not the intent of FHWA to mandate the use of this or any other procedure for impact assessment.

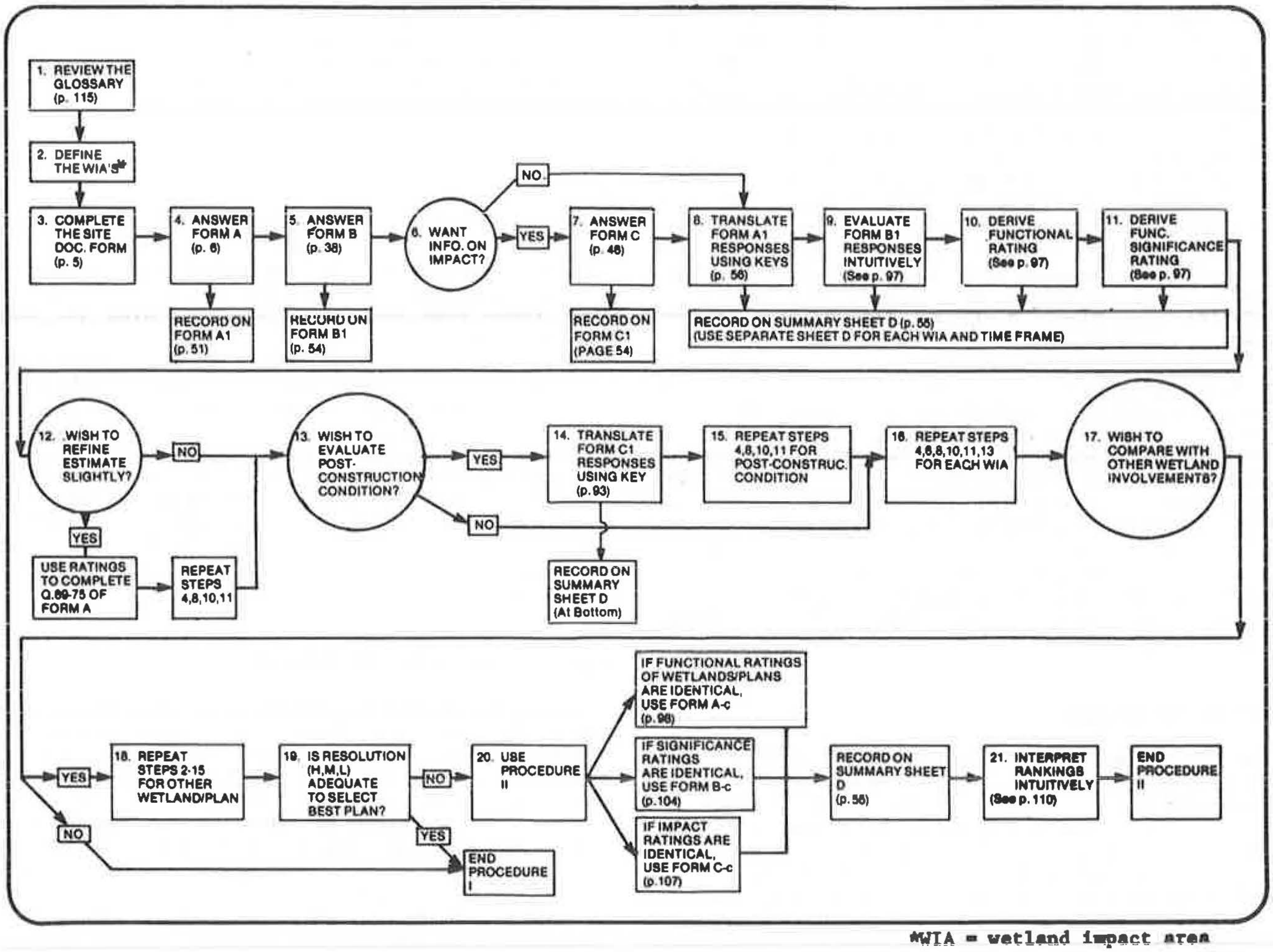

FIGURE 2 Flowchart for procedures I and II *(6)*.

In the development of the method, FHWA is providing assistance to the state highway agencies. Therefore, the method is offered to the states as a tool for their use. The FHWA is offering training courses to help the states begin to use the method.

Two state conservation agencies are adapting the method for use. Several other states have expressed an interest in using the method. Through the increased use of the method and its adoption by other agencies, and the interagency coordination of its future development, it is hoped that a national method for wetland functional assessment will emerge within 5 years.

Copies of the FHWA two-volume method are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. The cost of Volume I (stock number 050-001-00266-3) is $6.50, Volume II (stock number 050-001-00267-1) costs $6.00.

REFERENCES

1. J. Carter. Protecting Wetlands. 101 Fed. Reg. May 25, 1977.
2. Protecting Wetlands: What You Should Know. American Littoral Society, Highlands, N.J., n.d.
3. W.E. Frayer, T.J. Monahan, D.C. Bowden, and F.A. Graybill. Status and Trends of Wetlands and Deepwater Habitats in the Coterminous United States, 1950's to 1970's. Colorado State University, Fort Collins, 1983.
4. Mitigation of Environmental Impacts to Privately Owned Wetlands. FHWA, U.S. Department of Transportation, 45 Fed. Reg. 149, July 31, 1980.
5. P. Adamus and L.T. Stockwell. A Method for Wetland Functional Assessment: Vol. I, Critical Review and Evaluation Concepts. FHWA-IP-82-23. FHWA, U.S. Department of Transportation, 1983.
6. P. Adamus. A Method for Wetland Functional Assessment: Vol. II, FHWA Assessment Method. FHWA-IP-82-24. FHWA, U.S. Department of Transportation, 1983.
7. P.A. Erickson and G. Camougis. Highways and Wetlands: Vol. 1, Interim Procedural Guidelines. FHWA-IP-80-11. FHWA, U.S. Department of Transportation, 1980.
8. P.A. Erickson, G. Camougis, and N. Miner. Highways and Wetlands: Vol. 2, Impact Assessment, Mitigation, and Enhancement Measures. FHWA-IP-80-11. FHWA, U.S. Department of Transportation, 1980.
9. P.A. Erickson and G. Camougis. Highways and Wetlands: Vol. 3, Annotated Bibliography. FHWA-IP-80-11. FHWA, U.S. Department of Transportation, 1980.
10. R.J. Diaz, G. Markwith, R.J. Orth, W. Rizzo, and R. Wetzel. Examination of Tidal Flats: Vol.

BASIN Interior Drainage Area WIA ______ PROJECT I-284

EVALUATION TIME FRAME (PRE/POST) Pre MITIGATION PLAN # ______

FUNCTION	EFFECTIVENESS	OPPORTUNITY	FUNCTIONAL RATING	SIGNIFICANCE	FUNCTIONAL SIGNIFICANCE
GROUND WATER RECHARGE	HIGH	HIGH	HIGH	MODERATE	HIGH
GROUND WATER DISCHARGE	LOW		LOW	MODERATE	LOW
FLOOD STORAGE	HIGH	HIGH	HIGH	HIGH	VERY HIGH
SHORELINE ANCHORING	HIGH	LOW	MODERATE	MODERATE	MODERATE
SEDIMENT TRAPPING	HIGH	HIGH	HIGH	MODERATE	HIGH
NUTRIENT RETENTION				MODERATE	
LONG-TERM	HIGH	HIGH	HIGH		HIGH
SEASONAL	MODERATE	HIGH	HIGH		HIGH
FOOD CHAIN SUPPORT				MODERATE	
DOWNSTREAM	LOW		LOW		LOW
IN-BASIN	MODERATE		MODERATE		MODERATE
FISHERY HABITAT				MODERATE	
WARMWATER	MODERATE		MODERATE		MODERATE
COLDWATER	LOW		LOW		LOW
COLDW.RIVERINE	LOW		LOW		LOW
ANADROMOUS RIV.	LOW		LOW		LOW
SPECIES ______					
WILDLIFE HABITAT				HIGH	
GENERAL DIVERSITY	MODERATE		MODERATE		HIGH
WATERFOWL GP.	MODERATE		MODERATE		HIGH
WATERFOWL GP.	MODERATE		MODERATE		HIGH
SPECIES Gt. Blue Heron	MODERATE +		MODERATE +		HIGH +
SPECIES Pied Bill	LOW		LOW		LOW
SPECIES Grebe					
ACTIVE RECREATION			LOW	MODERATE	LOW
SWIMMING	LOW				
BOAT LAUNCHING	LOW				
POWER BOATING	LOW				
CANOEING	LOW				
SAILING	LOW				
PASSIVE RECREATION AND HERITAGE				MODERATE	MODERATE
IMPACT VECTOR RATING	HIGH				

FIGURE 3 Completed Summary Sheet D *(6)*.

1, Research Report. FHWA/RD-80/181. FHWA, U.S. Department of Transportation, 1982.

11. R.J. Diaz, R.J. Orth, G. Markwith, W. Rizzo, R. Wetzel, and K. Story. Examination of Tidal Flats: Vol. 2, Identified Values Review. FHWA/RD-80/182. FHWA, U.S. Department of Transportation, 1982.
12. R.J. Diaz. Examination of Tidal Flats: Vol. 3, Evaluation Methodology. FHWA/RD-80/183. FHWA, U.S. Department of Transportation, 1982.
13. R.I. Lonard, E.J. Clairian, Jr., R.T. Huffman, J.W. Hardy, L.D. Brown, P.E. Ballard, and J.W. Watts. Analysis of Methodologies Used for the Assessment of Wetlands Values. U.S. Water Resources Council, Washington, D.C., 1981.
14. L.M. Cowardin, V. Carter, F.C. Golet, and E.T. LaRoe. Classification of Wetlands and Deepwater Habitats of the United States. FWS/OBS-79/31. U.S. Fish and Wildlife Service, Dec. 1979.

Publication of this paper sponsored by Committee on Landscape and Environmental Design.

Plant Materials and Establishment Techniques for Revegetation of California Desert Highways

RAIMOND F. CLARY, JR., and ROBERT D. SLAYBACK

ABSTRACT

Soil erosion can be severe along desert roadsides, especially after new construction. Container plantings and direct seedings of available plant materials have not always provided needed long-term erosion control. In 1978 the California Department of Transportation contracted with the U.S. Department of Agriculture, Soil Conservation Service, to test new plant materials for roadside revegetation in the desert environment. Direct seedings of herbaceous perennials were largely unsuccessful. Red brome (Bromus rubens), an annual grass, showed potential. Seedings of woody plants were more successful. Desert saltbush (Atriplex polycarpa), Marana fourwing saltbush (Atriplex canescens) and Casa quailbush (Atriplex lentiformis) established good stands at three of the five planting sites. Desert encelia (Encelia farinosa), big sagebrush (Artemisia tridentata), California buckwheat (Eriogonum fasciculatum), and Dorado bladderpod (Isomeris arborea) grew well at two of the five sites. These seven shrubs also performed well in container plantings. Woody plants that grew successfully from containers but not from direct seedings were desert broom (Baccharis sarothroides), shadscale (Atriplex confertifolia), bursage (Ambrosia dumosa), creosoto bush (Larrea tridentata), and rubber rabbitbrush (Chrysothamnus nauseosus). Wildlife depredation was the greatest cause of shrub mortality.

Survival of nonirrigated perennial vegetation planted along California highways has often been lower than expected. This is particularly true in the desert environment where little, if any, precipitation occurs during the hot summer months. In 1978, the California Department of Transportation (Caltrans), in cooperation with the FHWA, entered into a 5-year agreement with the U.S. Department of Agriculture, Soil Conservation Service (SCS), to gain information that could improve survival of seeded and planted material. Several problems were investigated under the agreement; however, only the portion of the project that dealt with the testing of plant materials and establishment methods along highways in the desert environment will be discussed.

Sites in the Mojave Desert were selected to adequately test plant materials within different rainfall areas as well as on representative desert soils. Plantings were made at five locations. A site along CA-14 near Lancaster is within the 8-in. (20.3-cm) mean annual precipitation (MAP) zone and the soil type is a coarse sandy loam. The Edwards Air Force Base site, approximately 20 miles (32 km) northeast of the Lancaster site, lies in the 5.5-in. (14-cm) MAP zone and the soils consist of fine sandy loams. A third location 7 miles (11.3 km) west of Ridgecrest on US-395 is on a sandy loam within the 5.5-in. (14-cm) MAP zone. The fourth site, also along US-395, is 22 miles (35.2 km) north of the Ridgecrest site within the 7.5-in. (19.0-cm) MAP zone and situated on decomposed granite. The fifth and driest site is 41 miles (55 km) east of Barstow on gravelly sandy loam in the 4-in. (10.2-cm) MAP zone. Temperatures throughout the desert range from a low of about 20°F (7°C) in January to over 110°F (43°C plus) during the summer.

The work consisted of two phases: (a) direct seedings of herbaceous and woody plants and (b) establishment of vegetation from container stock. More than 300 seeded plots and 2,000 container-grown shrubs were planted during the project.

METHODS

Standard planting techniques were used throughout the study with few variations (1). Any nonstandard system would have to show exceptionally good results to be incorporated into the Caltrans revegetation program. Plots were seeded at a rate of 20 lb/acre (22.5 kg/ha). Initially mixtures of shrub and herbaceous species were seeded together to observe what effect one species might have on another after germination. Because success of this method was limited, this procedure was abandoned and all species were subsequently seeded in individual plots.

Seed was both drilled and broadcast. At the start of the project, seedbed preparation consisted of disking and harrowing. Later when only single species plots were established, slope surfaces were roughened by a modified harrow. Straw was applied at a rate of 4,000 lb/acre (4490 kg/ha) and wood fiber and paper product at a rate of 2,000 lb/acre (2245 kg/ha). Fertilizer (16-20-0) at a rate of 250 lb/acre (280 kg/ha) was either broadcast with the seed before strawing or applied with the slurry of wood fiber or paper mulch. Plots were generally 10 x 20 ft (3 x 6 m) in size.

Seed of commercially available grass varieties was purchased. Early in the program shrub seed was purchased from native seed collectors, but as the study progressed seed was collected by project personnel. The main emphasis was on native plant materials. Some nonnative species were included for comparisons. Container stock was purchased during the first year of the study. In following years, container plants were raised from seed collected as part of the study (2,3). Propagation was done at the Antelope Valley Resource Conservation District Nursery near Lancaster and the SCS Plant Materials Center in Lockeford (4). Most desert shrub seed does not need treatment to encourage germination. For those few species that do, however, seeds were given appropriate hot water and cold stratification as recommended (5).

Two types of containers were tested: gallon-can size and bookplanters [1.5 x 8 in. (3.8 x 20.3 cm) folding plastic plant bands]. When possible 20 shrubs of each accession were planted, 10 of each container type. For ease of evaluation, 10 shrubs were planted in each row. Plants were spaced 3 ft (0.91 m) apart and rows 5 ft (1.5 m) apart. Two ounces (57 g) of slow-release fertilizer (7-40-6) were mixed with backfill material at the time of planting. All shrubs were watered immediately after planting. A portion of each shrub accession was irrigated monthly from May through October with one gallon (4.2 L) of water per plant. Holes approximately 12 in. (30.5 cm) deep were dug with soil augers or other common garden implements. Rodent protectors made of plastic mesh 3 in. (7.6 cm) in diameter and 15 in. (38.1 cm) high were placed around all shrubs planted in the second through fifth years because loss to rodents was high during the first year.

RESULTS

Except for some of the annual grasses, direct seedings of herbaceous plant material proved to be unsuccessful. Most of the more common annual and perennial grass varieties adapted to low-rainfall areas were tested. In 1979-1980, a year of abnormally high precipitation [13 in. (33 cm)], most grasses germinated. Annual grasses are opportunistic and take advantage of precipitation. Red brome (Bromus rubens), an annual grass, showed potential for revegetation. Perennial vegetation is preferred; however, a good reseeding annual grass has revegetative uses in the desert environment. Table 1 gives some of the grass varieties and their success.

TABLE 1 Herbaceous Plant Materials Established by Direct Seeding

Species	Ground Cover (%) 1st Year	2nd Year	5th Year
Agropyron elongatum (Largo tall wheatgrass) (P)	Trace	2	Trace
Bromus rubens (red brome) (A)	60	30	5
Bromus mollis (Blando brome) (A)	20	2	Trace
Lolium rigidum (Wimmera 62 ryegrass) (A)	30	0	0
Trifolium hirtum (rose clover) (A)	50	0	0
Vulpia myuros (Zorro annual fescue) (A)	80	30	Trace

Note: P = perennial, A = annual.

Several perennial grass species were planted as container stock. This technique has been used with some success to establish Indian ricegrass in the Great Basin (6). As part of this study several plants of each grass species were irrigated. No significant differences were seen between irrigated and nonirrigated plants. Container plants were tested to observe survival, seed production, and rhizome activity. Grasses survived better when planted from containers than when seeded directly. Performance, however, was not good enough to recommend the procedure as a standard practice. Grasses planted as container plants are given in Table 2.

Direct seedings of woody plants were much more successful than seedings of herbaceous species. On slopes where soils were deep or parent material fragmented, woody plants did become established. Indigenous woody species generally did best. Species classified as invaders were not easily established. Many climax species were also difficult to establish. Most successful were shrubs appearing naturally in an intermediate stage of succession.

Many invader or pioneer species are of the sunflower (Compositae) family. Plants of this family are prolific seed producers, but seed viability is short. Because seed germination of many composites is low, proper seedbed preparation is important.

TABLE 2 Herbaceous Plant Materials Established from Container Stock

Species	Survival (%) 2nd Year I	2nd Year NI	5th Year I	5th Year NI
Agropyron elongatum (Largo tall wheatgrass)	33	0	33	0
Agropyron intermedium trichophorum (Luna pubescent wheatgrass)	33	0	33	0
Dactylis glomerata (Berber orchardgrass)	0	0	0	0
Dactylis glomerata (Palestine orchardgrass)	0	0	0	0
Oryzopsis hymenoides (Paloma Indian ricegrass)	20	0	20	0
Oryzopsis miliacea (smilo)	100	100	50	50
Sporobolus airoides (alkali sacaton)	67	100	67	50
Stipa speciosa (desert stipa)	33	0	0	0

Note: I = irrigated, NI = nonirrigated.

Rough seedbeds often provide favorable environments for light seed to lodge and germinate. If conditions are not right (old seed, smooth hard seedbed, or late precipitation) germination may not occur.

The saltbushes (Atriplex sp.) of the family Chenopodiaceae have been the most consistent and successful of all woody plants seeded. The seeds remain viable for several years and are large enough to be easily planted. Desert saltbush (Atriplex polycarpa) has consistently established stands at the Little Lake, Ridgecrest, and Lavic Road sites. Marana fourwing saltbush (Atriplex canescens) and Casa quailbush (Atriplex lentiformis) produced fair to good stands at the same locations. Desert encelia (Encelia farinosa) and big sagebrush (Artemisia tridentata), both members of the sunflower family, grew well at the Little Lake and Ridgecrest sites. Desert encelia has a large seed that is easily planted. Big sagebrush, however, has a small, light seed that is difficult to handle. California buckwheat (Eriogonum fasciculatum) and Dorado bladderpod (Isomeris arborea) grew well from seed at both the Little Lake and Ridgecrest sites. Of approximately 80 woody plant accessions seeded, only a few germinated and developed into matue shrubs. Table 3 gives the more successful species.

TABLE 3 Woody Plants Established from Direct Seedings

Species	Avg No. of Plants/Plot[a] 2nd Year	5th Year
Artemisia tridentata (big sagebrush)	2	2
Atriplex canescens (Marana fourwing saltbush)	11	10
Atriplex polycarpa (desert saltbush)	110	75
Atriplex lentiformis (Casa quailbush)	3	3
Isomeris arborea (Dorado bladderpod)	20	15
Encelia farinosa (desert encelia)	3	3
Eriogonum fasciculatum (California buckwheat)	4	3

[a]Plot size = 10 x 20 ft (3 x 6 m).

A number of factors must be taken into account when considering a new plant for use in revegetation. If the goal is to establish vegetation by direct seeding, it is important that the plant selected possess seed of sufficient size to be harvested, cleaned, stored, and planted easily. Plants that do not have this characteristic must be outstanding to warrant the development of specialized handling equipment. Physical characteristics of the seed are not as important when container plants are used. Large volumes of seed are not needed to produce container-grown stock. During this study native species were the most successful from containers. Several woody species that did not become established from direct seedings did well from container stock. The most economical way to establish vegetation is definitely through direct seeding. However, there are instances where the greater certainty of obtaining an established plant through the use of container stock will offset the cost.

Only 10 percent of the shrubs planted during the first year of the study survived. Rodents were primarily responsible for the high mortality. Other investigators have also experienced setbacks due to wildlife depredation (7). All plantings made after the first year were shielded by protectors. The devices used were constructed so that they could be quickly slipped over a plant and held in place by a wooden lath. Plant survival increased to about 75 percent overall. Rodents do some harm to the plastic protectors and shrubs, but damage is slight.

Of all shrub species planted from containers, the saltbush species showed the best growth and survival. Desert saltbush, Marana fourwing saltbush, and Casa quailbush were the outstanding shrub species planted. Fair to good performance was shown by several other woody species as well (Table 4).

TABLE 4 Woody Plants Established from Container Stock (Ridgecrest Site)

	Average Survival (%)			
	2nd Year		5th Year	
Species	I	NI	I	NI
Artemisia cana (silver sage)	67	0	33	0
Artemisia frigida (fringed sage)	33	0	33	0
Artemisia tridentata (big sagebrush)	33	0	33	0
Atriplex canescens (Marana fourwing saltbush)	100	100	100	100
Atriplex confertifolia (shadscale)	100	100	80	80
Atriplex lentiformis (Casa quailbush)	67	100	33	50
Atriplex nummularia (Oldman saltbush)	100	100	67	50
Atriplex polycarpa (desert saltbush)	67	100	67	100
Atriplex torreyi (Torrey saltbush)	100	100	67	50
Baccharis sarothroides (desert broom)	100	100	100	100
Chrysothamnus nauseosus (rubber rabbitbrush)	100	67	100	67
Ephedra nevadensis (Nevada ephedra)	67	100	67	100
Ephedra viridis (green ephedra)	100	100	67	100
Eriogonum fasciculatum (California buckwheat)	33	50	33	50
Ambrosia dumosa (bursage)	67	100	67	50
Grayia spinosa (spiny hopsage)	67	0	0	0
Lycium andersonii (wolfberry)	100	50	33	50
Larrea tridentata (creosote bush)	100	75	100	75

Note: I = irrigated, NI = nonirrigated.

At the beginning of the study, container plantings were made in both the fall and late winter. Fall plantings were severely hurt by winter snows. Even though hard winters do not always occur, late winter or early spring plantings are less of a risk than fall plantings. Plantings after the first year were made in late winter.

CONCLUSIONS

No perennial grass performed well enough to recommend its use in a seeding mixture for the Mojave Desert. Several seeded perennial grasses germinated, but none could tolerate the droughty soil and intense heat. Annual grass and legume species, such as red brome, Zorro annual fescue, and Hykon rose clover, are the preferred herbaceous plants to seed because they are opportunistic and take advantage of moisture when it is available. For long-term erosion control it is best to revegetate with woody plants. The Atriplex sp. (Table 3) consistently produced good stands.

Direct seedings should be drilled wherever possible. Seeds broadcast onto the soil surface and covered with mulch have less chance of germinating than seeds incorporated in the soil. Fertilizer, such as ammonium phosphate sulfate 16-20-0, at a rate of 250 lb/acre (273 kg/ha) should accompany the seed.

Wood fiber and paper mulch products do not provide as effective a mulch as straw (8). Straw, however, can be readily blown from the site if it is not secured. Applying hydromulched wood fiber or paper product over the straw at a rate of 750 lb/acre (818 kg/ha) will hold the straw in place. Straw applied at a rate of 2 tons/acre (1.96 metric tons) has proved satisfactory. Container-grown shrub plantings usually become established more quickly than direct seedings. Several species (Table 4) can be planted with a high probability of success. The type of treatment (irrigation, container size, and so forth) at the time of planting is less important than the condition and vigor of the plant material. Rodent protectors are necessary and should be included as a part of any planting.

Irrigation did not increase the survival of most shrub species. It might, however, be helpful during the establishment year if precipitation is abnormally low. Shrubs that performed best were those naturally adapted to the desert environment. Plantings should be made in late winter or early spring. Shrubs that are planted during this period will have sufficient time to acclimate themselves before the onset of the hot summer.

REFERENCES

1. G.C. Edmunson. Plant Materials Study. USDA Soil Conservation Service, Davis, Calif., 1976.
2. Collecting, Processing, and Germinating Seeds of Western Wildland Plants. Agricultural Reviews and Manuals, ARM-W-3. USDA Science and Education Administration, 1978, 38 pp.
3. Seeds of Woody Plants in the United States. Agriculture Handbook 450. USDA Forest Service, 1974.
4. K.F. Baker, ed. The U.C. System for Producing Healthy Container-Grown Plants. Manual 23. California Agricultural Experiment Station Extension Service, Berkeley, 1957.
5. D. Emory. Seed Propagation of Native California Plants. Leaflets of the Santa Ana Botanic Garden, Vol. 1, No. 10, 1964, pp. 81-96.
6. A.P. Plummer, D.R. Christensen, and S.B. Mosen. Restoring Big Game Range in Utah. Publication 68-3. Utah Division of Fish Game, Ephraim, 1968.
7. W.L. Graves. Revegetation of Disturbed Sites with Native Shrub Species in the Western Mojave Desert. In Test of Seeds of Mojave Desert Shrubs, B.L. Kay, ed. Progress report BLM contract 53500-CT4-2(N), 1976, pp. 11-31.
8. B.L. Kay. Mulches for Erosion Control and Plant Establishment on Disturbed Sites. Agronomy Progress Report 87. University of California, Cooperative Extension, 1978, 20 pp.

Publication of this paper sponsored by Committee on Landscape and Environmental Design.

Allelopathy and Its Potential Applications in Right-of-Way Management

RICHARD E. FOSTER, JR.

ABSTRACT

The use of herbicides for control of undesirable vegetation along highway, railroad, and utility rights-of-way has been a valuable tool for many years. As energy and labor have become more expensive so have mowing and hand clearing of brush, and a greater dependence on herbicide use has been created. Today, however, environmental concerns about herbicides are threatening their usefulness for the future. Herbicide programs as they exist today will undoubtedly be cut substantially or eliminated completely in many states. It is becoming increasingly urgent that alternatives to long-standing vegetation maintenance practices be developed. A greater understanding of chemical ecology, and more specifically allelopathy, may well lead to the development of more economical and environmentally sound right-of-way maintenance practices. Allelopathy is defined as any direct or indirect harmful effect by one plant on another through production of chemical compounds that escape into the environment. It is hypothesized that if allelopathy is a wide-ranging phenomenon involving many plant species, it will be possible to find individual plants that can be used to establish stable communities capable of preventing the encroachment of undersirable species.

The term allelopathy has been defined by Rice (1, pp. 1-2) as any direct or indirect harmful effect by one plant, including microorganisms, on another through production of chemical compounds that escape into the environment. This definition differs slightly from that of Molisch [see Rice (2)], who first coined the term in 1937, in that Rice's definition deals only with the harmful effects, whereas Molisch used the term to describe both beneficial and harmful biochemical interactions between microorganisms and plants. Rice's use of the term may be more technically accurate in that allelopathy was derived from two Greek words meaning "mutual harm." The elimination of beneficial effects from consideration, however, has been shown to be very artificial by such researchers as Khailov [see Rice (2)] who demonstrated conclusively that the effects of any given compound may be inhibitory or stimulatory depending on the concentration of the compound in the surrounding medium. In fact, most researchers in Europe and Asia use the term as defined by Molisch. The point is that many important ecological roles of allelopathy are probably overlooked because of the concern with just the detrimental effects of added chemicals.

The effects of allelopathy depend on a chemical compound being added to the environment by an allelopathic agent. This essentially separates allelopathy from competition involving the removal or reduction of an environmental factor (e.g., water, light, or minerals) that is required by some other plant sharing the habitat. Confusion in this respect has hindered the development of research in allelopathy for years. Muller (3) suggests that, to lessen this confusion, the term "interference" be used whenever the causes of mutual inhibition are not clearly separated. Szczypanski [see Putnam and Duke (4),p. 432] recently described three possible mechanisms for plant interference: (a) allelospoly--the competition for necessary growth factors, (b) allelomediation--the possession of herbivore toxicant or repellant substances that prevent grazing, and (c) allelopathy--the addition of toxic factors to the environment. Interference is thus defined to encompass both allelopathy and competition.

In further defining allelopathy, it is important to understand that this specific phenomenon is only one of many classes of interactions termed allelochemics, which involves chemicals used by organisms of one species, which affect the growth, health, behavior, or populations biology of organisms of another species. Many interactions of attack, defense, and behavioral response involve not physical force but chemical agents. The study of these interactions and the array of chemicals involved is the subject of chemical ecology. Chemical ecology, in turn, is only one of many subjects covered under what is undoubtedly the most important scientific basis for rights-of-way (ROW) vegetation management, plant ecology.

Plant ecology is the science that treats the reciprocal relationship between plants and their environment. For example, a plant may directly affect wildlife and wildlife, in turn, may directly affect the plant. Witch hobble may furnish food for deer and hare; conversely, deer and hare may destroy witch hobble through excessive browsing.

An understanding of these ecological relationships is basic to sound ROW management. One must realize that ROW vegetation is in a dynamic state of reaction and adjustment to habitat conditions. Climate, water, soil, physiography, wildlife, man, and other plants all make for a complicated situation on ROWs.

To simplify and make something useful and understandable out of the complex ROW situation is the most difficult task in the application of ecology to management. Often, to help in this task, the theory of limiting factors is used to explain cause and effect. For example, animal destruction of weeds has been used to explain why trees do not reproduce in a scrub oak community. When this one factor was controlled, pine was established. In such a community on a ROW, a thriving small mammal population could be a limiting factor of value.

Similarly, allelopathy has been used recently to explain why black cherry does not reproduce on certain sites of the Allegheny plateau where open orchardlike stands had persisted for 50 years before they burned. For years the cause was attributed to heavy browsing by deer and hare, to frosts, and to herbaceous competition. Now it is known that an allelopathic effect, from dominant goldenrod, grass, asters, and fern, is the limiting factor.

OVERVIEW

In a review of scientific literature concerning allelopathy, several general observations can be made which, without getting into excessive detail about any one area, can yield an acceptable overview of the phenomenon and a sound basis for practical applications.

Widespread Occurrence

Allelopathic effects have been recorded for agricultural and wild species of most types of plants from forest trees to desert shrubs. Although most of the research in the field has been done within the last 20 years, reports of the phenomenon and its influence on agriculture were made as early as the fifth and third centuries B.C. by Democritus and Theophrastus. A 300-year-old document by Banzan Kumazawa, written in Japanese and found by Lee and Monsi in 1963, described the effects of rain and dew washing the foliage of red pine and inhibiting crop production under the pine. DeCandalle researched and described the effects of allelopathy in 1832.

In general, allelopathy has been related to problems with crop production on certain types of soil, with stubble-mulch farming, with certain types of crop rotation, with orchard replanting on old orchard land, with crop monoculture, and with forest site replanting. In more recent times, effects on old field succession, plankton succession, and range land and pasture management have been investigated. Investigations have been broadened in horticulture, forestry, and agronomy.

From all of the research done on such a wide array of plant types, it is quite obvious that the occurrence of allelopathy in the environment is common. Furthermore, it is reasonable to judge that the observed cases of allelopathic effects stand out from a background of more widespread, less conspicuous effects on plant growth and populations.

Significance in Plant Communities

Allelopathy, therefore, is undoubtedly of widespread significance in plant communities. In plant succession in old fields, a dominant species may, by allelopathic suppression, speed its invasion of a preceding community and delay its replacement by other species. In both successional and climax communities strongly dominated by a single species, chemical effects of that species on the soil may limit the number of other species able to occur. In communities in which a number of canopy species are mixed together, these may form a mosaic of differing chemical effects on the soil, which may contribute to the patterning and species diversity of the undergrowth.

> One observes in the forest patches of one species here and another species there, a few meters apart in environments not visibly different. Ecologists believe that light differences, root competition, wood decay remnants, differences in fungal biota, microrelief, dispersal accidents, and clonal history may all, in varied combinations, affect these intracommunity patterns. One should allow also for chemical relations among plants, broadening concern from allelopathics to leachates, exudated, and decay products in general (5, p. 51).

Autotoxicity

Allelopathic self-inhibition in many types of plants has been reported by many researchers. Although some of these plants (e.g., eucalyptus) are considered climax species, most are successional species, such as brome grass, asters, brambles, sunflower species, and ferns. In the case of successional species, self-toxicity may be no serious disadvantage because these species are generally transient populations that dominate a community for only a short period of time. Species of ferns, however, such as bracken fern, might have value in a ROW, but, because of this trait, they would have to be ruled out as a desirable species for a stable community.

In many cases, the cause of self-inhibition is the toxicity of products from their own decay. Heavy accumulations of terpenes in the soil have been attributed to self-toxicity. Self-toxicity has been described as an evolutionary paradox in that one would presume that the allelopathic substances have some adaptive advantage that outweighs the apparent selective disadvantage of autotoxicity.

Chemical Nature of Allelopathic Substances

Grummer [cited by Rice (1)] suggested in 1951 that special terms be used for the chemical agents involved in allelopathy based on the type of plant producing the agent and the type of plant affected. They are

1. Antibiotic--a chemical inhibitor produced by a microorganism and effective against a microorganism,
2. Phytoncide--an inhibitor produced by a higher plant and effective against a microorganism,
3. Marasmins--compounds produced by microorganisms and harmful to higher plants, and
4. Kolines--chemical inhibitors produced by higher plants and effective against higher plants.

Most antibiotics, marasmins, phytoncides, and kolines that have been identified fit into 14 categories as delineated by Rice. A diagram of probable major biosynthetic pathways leading to the production of these various categories is shown in Figure 1. Before Rice's system, Whittaker and Feeney (6) stated that, in general, the chemicals associated with allelopathy belong among the secondary substances and that these compounds could be classified into five major groups: phenylpropanes, acetogenins, terpenoids, steroids, and alkaloids. A diagram of the biosynthetic pathways associated with these is shown in Figure 2. In comparing the two figures it is obvious that Rice merely expanded on Feeney and Whittaker's work. Perhaps the most outstanding characteristic of these compounds shown by the figures is their diversity.

In characterizing these compounds, it is important to note that, as far as is known, they are not essential to the basic protoplasmic metabolism of the plant. As Whittaker stated, "There is, in most cases, no evident reason why the plant should produce them at all" (5, p. 53). This is true when a plant is considered free from interaction with other organisms, for, in many cases, the secondary compounds associated with allelopathy have been reported to be involved in protective or defensive functions of plants. Simple phenolic acids, for example, have been implicated in allelopathic interactions. These same compounds are associated with the lipid layer at the plant surface and may be

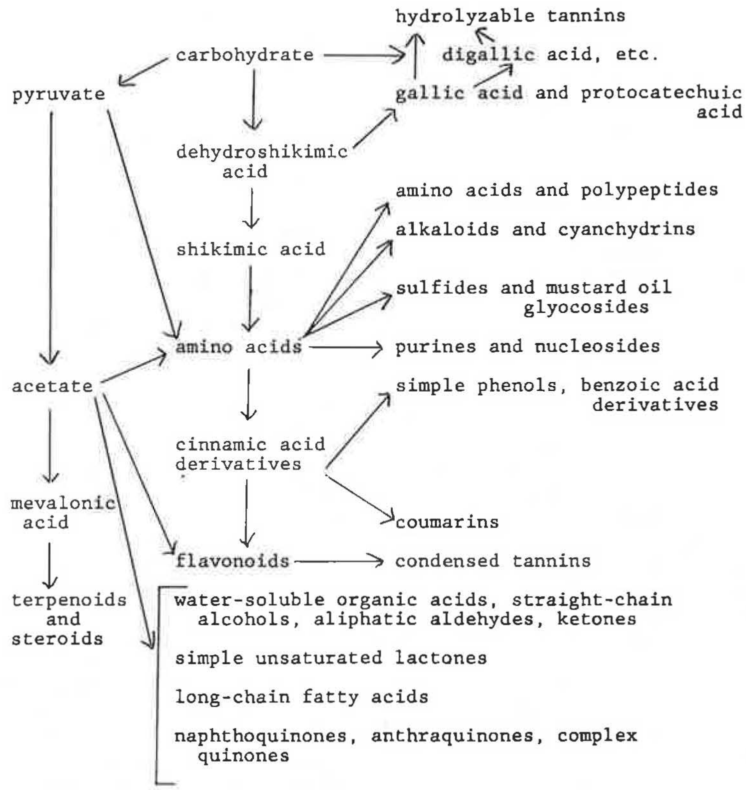

FIGURE 1 Probable major biosynthetic pathways, based on Rice *(1)*.

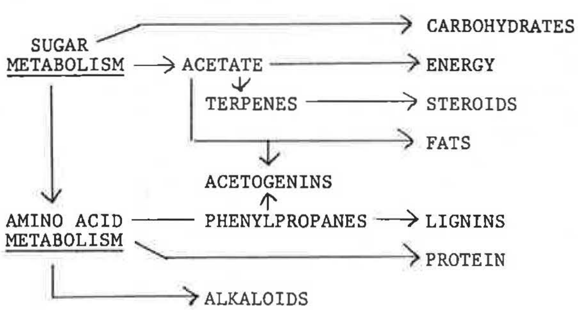

FIGURE 2 Probable major biosynthetic pathways, based on Whittaker and Feeney *(6)*.

involved in epidermal resistance to attack by plant pathogens. Chlorogenic acid, caffeic acid, and other similar common phenols are toxic to selected pathogens after building up at a more rapid rate in resistant plants than in sensitive ones in response to infections, and they are the same materials most often cited as the toxic chemicals in allelopathic reactions. There are, of course, exceptions to this; for example, the phenolic quinone, juglone, associated with black walnut, which is one of a few apparently specialized allelopathic compounds. Other quinones, however, are associated with disease resistance.

It should be understood that the roles of these compounds often depend more on their particular concentration at a given site than on their chemistry.

Routes of Release

Allelopathic materials are released from plants in a variety of ways. Discharge of secondary compounds into the environment may occur as a result of exudation of volatile chemicals (e.g., volatile terpenes such as camphor and cinede) that are released from leaves into the air and then absorbed by soil particles. This was illustrated by Muller (3) in the soft chaparral areas of southern California: Water-soluble toxins from above-ground parts are leached in response to the action of rain, fog, or dew. For example, p-hydroxybenzoic acid, vanillic acid, and furic acid were identified as kolines that were washed from the leaves of Camelina sp. and that inhibit flax. The exudation of water-soluble toxins from below-ground parts (e.g., release of juglone from roots of black walnut) inhibits many plant species. Toxins are released from nonliving plant parts through leaching from litter or sloughed root cells and microbial by-products result from little decomposition (e.g., flavonoids, such as agolycones, which are only very slightly soluble in water, are released by decomposition and are highly inhibitory).

When these secondary substances are released into the immediate environment, they must accumulate in sufficient quantity to affect other plants, persist for some period of time, or be constantly released in order to have lasting effects.

The salient point about the release of inhibitory compounds by plants is that no matter what the role of the compound in the plant may be, and regardless of its location in the plant, the substance will eventually escape into the environment through one means or another.

Treatment in the Plant

In general allelopathic compounds and other secondary substances occur in plants in ways that protect the plant against their effects. Many of these compounds occur as glycosides, in which case the substance that might be toxic is combined with a sugar and thereby rendered innocuous within the plant. Despite the innocuous nature of the substance, the glycosides are commonly in solution in vacuoles of cells and, consequently, further separated from protoplasmic functions of the plant.

Other secondary substances occur as polymers (tannins, lignins, resins, and rubbers) or as crystals (calcium oxalate raphids). Many of the substances are deposited outside living cells in the dead heartwood, in dead cells, in spaces between cells, in ducts, or in the glandular hairs found on the surface of many plants. Still other substances are discharged from the plant by leaching, exudation, or volatization as previously mentioned. Secondary substances, as this illustrates, are treated as toxic wastes to be inactivated within the plant or excreted from the plant. The evolutionary interpretation of why plants produce copious amounts of substances against which they must protect themselves was addressed by Whittaker:

> Plants have need for various specialty compounds--as pigments, regulatory substances, skeletal materials, etc. Many of these are compounds of the major secondary substance groupings. Protoplasm is the most complex and highly perfected system we know, but it cannot be quite perfect. An enormous number of transformations, rate controls, and enzymes are involved. It is impossible that protoplasmic function should provide enough of every metabolite needed and not too much of some, should exclude metabolic byways yielding some unneeded materials and recycle every product, and should do this in the face of changing environmental conditions. There is not enough selective advantage to have brought evolution of enzymes and controls for the use or recycling of ever metabolite produced (5,p.61).

In summary it can be said that allelopathy is not a peculiarity of a few plants but a widespread and normal, although not always conspicuous, phenomenon of natural plant communities and that allelopathic substances are not significant only to the functioning of plant communities, they are part of the extensive traffic in chemical influences relating organisms of all the major groups to one another.

POTENTIAL APPLICATIONS

The main thrust of research involving allelopathy has been in the field of agriculture. This, of course, is understandable because feeding the people of the world has been and still is the greatest challenge facing plant scientists. In doing this, however, scientists have approached allelopathy in terms of minimizing its effects. Only in the last 15 years have scientists looked at allelopathy as a phenomenon that might be of significant value in assisting farmers in the production of food.

This change of attitude is due in part to the expanded knowledge in the field of allelochemics and a more thorough understanding of plant interaction. A more profound influence, however, has been exerted by ecologists who have pointed out both the long- and short-term effects on the environment of continued pesticide use.

The need to develop alternatives to chemical pesticides has led researchers to investigate the possibility of exploiting naturally occurring events. In entomology, for example, pheromones are now being used to disrupt the mating cycles of insects, and the result is a decline in their population in a given area. The beauty of this kind of control is that, first, only a very small amount of pheromone need be used, which reduces the amount of chemical substances released into the environment, and second, the control is specific to the target because a pheromone is insect specific.

In addition to the previously mentioned factors affecting the accelerated interest in allelopathy, economy has played a significant role. The use of traditional techniques, commonly associated with vegetation control, is rapidly becoming too expensive. Mowing has been reduced along most highway ROWs because of the increasing costs of fuel and equipment. Labor-intensive means have been virtually eliminated because of high labor costs. The use of herbicides and growth regulators is also being restricted by increases in manufacturing and application costs. Use of the allelopathic advantage of some plants would be of great value in reducing the need for these expensive control measures. Extending a herbicide spray cycle, for example, from 3 to 10 years represents a tremendous saving to a utility. The use of herbicides, of course, could not be completely abandoned because there are situations where these tools must be used.

Despite the significance of the various factors influencing the development of allelopathy, one has to look hard and long to find a single example of its use by man. Perhaps the only agronomic advantage gained from direct use of allelopathy is the interim "smoother crops" such as Hordeum vulgare and Avena sativa. The benefits of using such practices have long been known, but not until recent times was it discovered that the benefit was due to exudations of a mixture of compounds, including scopoletin. Although plant breeders have successfully incorporated both insect and disease resistance into cultivars of many crops, not until 1974 was there a concerted effort by Putnam and Duke (4) to develop crops with competitive ability superior to that of weeds. Putnam and Duke hypothesized that predecessors of many species now grown for food and fiber, when growing in their wild habitat, may have possessed allelopathic substances that allowed them to compete effectively in their native plant community. This characteristic may have been reduced or lost as plants were bred and selected for other desirable characteristics in a weed-free environment. Screening the germplasm collection of Cucumis sativas and related Cucumis species, they found several accessions that demonstrated allelopathic activity. Avena sativa varieties also showed exception lines for inhibiting growth of weeds, suggesting a genetic basis for allelopathy: some varieties could reduce weed growth and others could not.

Allelopathic chemicals are usually assigned a very secondary role, as pointed out earlier, because compounds can be both repellents and phytoncides and will be allelopathic only if circumstances are favorable for their accumulation. The allelopathic properties are, therefore, labeled secondary effects of the secondary compounds. Despite the natural advantages of allelopathy, selection for this trait is not obvious in nature.

Contrary to this, however, it has been reported that secondary chemicals are rapidly synthesized and that their production may be genetically controlled.

Evidence is not available to show whether allelopathic agents are produced by chance or specifically for an effect on other plants to ensure survival of successional species. Logically one should assume genetic control of the amounts of inhibitors in plants.

Consequently, even though nature may not have selected plants that produce amounts of secondary compounds necessary for allelopathic effects, perhaps these effects can be brought about by genetic manipulation similar to that by which plants have been selected and improved for production of other secondary compounds involved in defense against disease.

A number of approaches could be taken. One might be that desirable plant species could be developed that would release kolines as natural herbicides to provide satisfactory weed control. Another approach could be to develop plants that would be used as companion plants that are selectively allelopathic but do not interfere with desirable species.

One of the main factors involved in the encroachment of undesirable species into an area is the gemination of weed seeds. Two of the major functions of allelopathic compounds, as described by Rice (1), are to prevent seed decay and to control germination. Methods of increasing weed-seed decay and methods of stimulating or inhibiting weed-seed germination would aid dramatically in stabilizing a plant community. The use of microorganisms able to destroy weed seeds and the inactivation of inhibitors that protect the seed from decay are two possible ways of accomplishing this. To a limited extent, this is already being done: ethylene is administered by soil injection to achieve suicidal germination of *Striga asiatica*. There are undoubtedly many other compounds that could be used in this manner.

CONCLUSION

In summary, the significance of allelopathy in the plant community is apparent and the potential for practical, environmentally sound applications is tremendous. As investigators continue to unravel the fabric of plant ecology, the role of allelopathy and its influence will continue to grow.

At present, a number of possible applications of allelopathy are available to ROW managers in the Northeast. Several indigenous shrub species are known to possess allelopathic properties. When used on proper sites these plants can effectively establish stable communities inhibiting the encroachment of undesirable species for extended periods of time. Such plants as low-bush and high-bush blueberry, barberry, maple leaf viburnum, hobble bush, witherod, narrow-leaf goldenrod, sweet fern, loosestrife, and American cranberry bush could be used to this end. Selective use of herbicides to help establish these species would hasten the effect. Development of an inventory of indigeneous species in a particular section of a ROW and attention to soil and climatic conditions in an area will also aid in establishing these plant communities. Allelopathy may well be the most potentially valuable means to sound vegetation control for the ROW manger.

REFERENCES

1. E.L. Rice. Allelopathy. Academic Press, New York, 1974.
2. E.L. Rice. Allelopathy--An Update. The Botanical Review, Vol. 14, 1979, pp. 15-109.
3. C.H. Muller. Allelopathy as a Factor in Ecological Process. Vegetatio, Vol. 18, 1968, pp. 348-357.
4. A.R. Putnam and W.B. Duke. Allelopathy in Agrosystems. Annual Review of Phytopathology, Vol. 16, 1978, pp. 431-451.
5. R.H. Whittaker. The Biochemical Ecology of Higher Plants. *In* Chemical Ecology, E. Sondheimer and J.B. Simone, eds., Academic Press, New York, 1970.
6. R.H. Whittaker and P.P. Feeney. Allelochemics: Chemical Interactions Between Species. Science, Vol. 171, 1971, pp. 757-770.

Publication of this paper sponsored by Committee on Landscape and Environmental Design.

Ground Covers for Louisiana Highways

R. J. STADTHERR, V. J. MANNINO, and D. W. NEWSOM

ABSTRACT

More than 200 different plants were investigated during 8 years for their adaptability; hardiness; propagation; maintenance; and general suitability for use as ground covers on slopes, medians, and flat areas along highways in Louisiana. Eight different plantings were made. Ratings for overall appearance, weed presence, and establishment over a 13-month period indicated that the liriope rated highest by far. Lonicera japonica 'Pupurea', Trachelospermum asiaticum, and Wedelia trilobata also rated high.

Because limited information on the use of ground covers along highways in the South was available, this research requested by the Louisiana Highway Department was conducted by the Department of Horticulture at Louisiana State University, Baton Rouge, Louisiana. The primary purpose was to learn about and observe low-growing plant materials that could enhance safety, give beauty, prevent erosion, and reduce maintenance costs on problem areas.

The objectives were

1. To research literature on ground covers and their use and adaptability to Louisiana;
2. To obtain, select, propagate, and learn of sources of plants for trials in the immediate area;
3. To learn best propagation and production methods for selected types and determine their availability commercially;
4. To set up field trials, screen plant materials, and then replicate trials to learn about establishment and performance;
5. To meet problems such as drought or weeds and learn how to cope with them; and
6. To make recommendations for future plantings based on information obtained.

DISCUSSION

Phase 1 (1974) gave a review of the literature on the use of ground covers with emphasis on highway use (1). Low-growing plants of 60 cm or less that tended to propagate readily were stressed. Original plants were grown under 50 percent shade in a lath house. Bugleweed (Ajuga reptans L.), mock strawberry [Duchesnia indica (Andr.) Focke], and moneywort (Lysimmachia nummularia L.) completely covered plots within a 3-month period. In a previous report (2) the 32 plants that showed the most promise are listed and remarks given about their performance.

Most trial plants were transferred to 0.003 m^3 containers from 7.6 cm pots after they were well established but before they were pot bound. The medium was composed of 85 percent shredded pine bark, 4.72 percent washed builder's sand, 9.4 percent gravelite, 0.472 percent 18-6-12 osmocote, 0.201 percent dolomitic lime, 0.08 percent hydrated lime, and 0.007 percent fritted trace elements.

Liners and plants that were divided and placed in containers for finishing were fertilized with soluble 20-20-20 fertilizer at 100 ppm every 2 weeks while in the lath house. About 5 weeks later they were moved to full sunlight until they were planted along the highways. Osmocote (18-6-12) at 42 g per container was applied after 4 weeks and thereafter every 12 weeks.

In an unreplicated trial along LA-415 underneath the US-190 overpass at Lobdell, Algerian ivy (Hedera canariensis Willd.) and trailing lantana [Lantana montevidensis (K. Spreng.) Briq.] spread rapidly and made a dense cover. The heavy shade also seemed best for the cast-iron plant (Aspidistra elatior Blume).

The first planting was made in November-December 1973; the second in March 1974; the third in March 1975; the fourth, on the Hill Farm of Louisiana State University (LSU), in June 1975; the fifth in August 1975 on Florida-Airline property; the sixth on the Essen Lane median in March 1976; the seventh, an extension of the Florida-Airline planting, in March 1977; and the eighth on Dalrymple, Fuqua, and Bluebonnet sites on April 20, 1980. Early spring plantings were considered best because plants need an entire growing season to become well established. Many species showed no growth late in the season, whereas asparagus fern [Asparagus densiflorus (Konth) Jessop], lantana hybrids, and wedelia [Wedelia trilobata (L.) A.S. Hitchc.] were killed by frosts and regrowth did not recur until soils warmed up again the following spring.

In the first planting, most rapid covering occurred with bronze bugleweed, moneywort, and mock strawberry. In the next growing season, the dwarf Confederate jasmine [Trachelospermum asiaticum (Siebold & Zucc.) Nakai], big blue liriope [Liriope muscari (Decne.) L.H. Bailey], bronze wintercreeper [Euonymus fortunei (Turcz.) Hand-Mazz. 'Colorata'], memorial rose (Rosa wichuriana Crep.], stonecrop (Sedum acre L.), and variegated eulalia (Miscanthus sinensis Anderss. 'Variegatus') covered the areas well. Bugleweed and moneywort were susceptible to southern wilt. The bugleweed was very susceptible to root-knot nematodes. In the second planting in full shade, Algerian ivy and trailing lantana made the best cover. Other plants that persisted included the cast-iron plant, creeping liriope (Liriope spicata Lour.), mondo grass [Ophiopogon japonicus (Thunb.) Ker-Gawl], and ground ivy (Glechoma hederacea L.).

None of these except ground ivy spread to any extent. The ground ivy grew best when temperatures were below 50°F. An extended hot, dry period in 1975 severely damaged plants in full sunlight; however, the next winter the area was covered and plants had spread along the embankment. Weed growth was excessive in the third planting at Lobdell. Inability to get labor until June and frequent rains in early spring allowed weeds to become excessively established. More aggressive species also infiltrated. Moneywort, mock strawberry, big periwinkle (Vinca major L.), ground ivy, and wedelia, because of long vines, tolerated hand weeding only. Pilferage was extensive at this site especially of the narrow-leaf evergreens, liriope, and roses. The entire area was mowed on October 25, 1975, which caused considerable damage to the woody plants; however the memorial rose, dwarf Confederate jasmine, and Algerian ivy plants tended to branch more and thus covered the area more rapidly.

Bermuda and Johnson grasses were the two main weeds. Because there were so many missing plants, no statistical analyses were made. Species remaining to date were day lilies (Hemerocallis fulva L.) and sunproof liriope on the southern exposure and day lilies, big periwinkle, Algerian ivy, and dwarf Confederate jasmine on the northern side. Liriope and day lilies persisted in full sunlight under annual highway department mowings and herbicide sprayings. The fourth planting was made in June 1975 on the Hill Farm, LSU campus, in full sunlight on raised rows that could be cultivated. Plants that grow best under full sunlight were tried. Those that rated excellent included dwarf bamboo [Arundinaria pygmaea (Miq.) Asch. & Graebn, 'Nana'], dwarf coreopsis (Coreopsis auriculata L.), variegated eulalia, lantanas, dwarf rosemary (Rosmarinus officinalis L.), St. Paul Verbena [Verbena pervriana (L.) Britt], dwarf Confederate jasmine, purple-leaved honeysuckle (Lonicera japonica, Thunb. 'Purpurea'), liriope, and mondo. The planting was discontinued in 1976 to allow develop- ment of a rose garden.

The Florida-Airline planting was made in August 1975. Glyphosate was applied twice at 2-week intervals and all existing vegetation appeared to be dead before planting. Spot treatment with 2,4-D was made on dewberries to kill those in the plots. Plantings were replicated on either side of the bridge with two exposures, one a slope with more sunlight and the other a north-facing slope where direct sunlight hit only a short time during the day. Wedelia and lantanas made the fastest coverage. The lantana, wedelia, stonecrop, yarrow (Achillea millefolium L.), and day lilies gave attractive flowers. The lantana bloomed for months. On the north-facing slope, the big perwinkle, dwarf Confederate jasmine, memorial rose, variegated liriope, and variegated eulalia looked best. On the south slope, stonecrop, lantana, mondo, wedelia, and lantanas gave the best coverage in the first year.

Two replications were made on a median strip on Essen Lane in early March 1977. Unfortunately underlying this area was a hardpan because cement had been mixed here when the road was paved. The only plants that grew well were the liriopes, mondo, and dwarf Confederate jasmine. This planting was mowed frequently, thus most plants except liriope never became well established.

A seventh planting was completed on March 18, 1977, and was an extension of the previous Florida-Airline planting. The akebia [Akebia quinata (Houtt.) Decne.], bronze wintercreeper, dwarf bamboo, and thimbleberry (Rubus parviflorus Nutt.) grew well. Unfortunately the entire planting was run over by a rotary mower on October 4, 1978, and many plants were uprooted. Heavy clippings caused smothering and rotting of plants. Duff was removed by lifting with forks and by raking, but heavy damage had occurred. An inadvertent herbicide spraying occurred the same fall. The next spring, the wedelia had not survived, but the day lilies, lantana, yarrow, and wintercreeper came back well on the south side and the big periwinkle, thimbleberry, memorial rose, and ground ivy on the north side. Verbena was substituted for the wedelias.

Stock was increased in the summer of 1979 for three replicated trials along the Interstate including dwarf Confederate jasmine, purple-leaved honeysuckle, bronze wintercreeper, dwarf coreopsis, dwarf compact sprengeri fern, St. Paul verbena, and wedelia.

Highway department glyphosate sprayings were to be made at the rate of 16 cm^3/L over the three areas at least twice in the fall. If a third spraying had been necessary it was to have been made 2 weeks after the second spraying. The first and only spraying was made in October. To learn what weed growth to expect, sod was taken from each site and placed in flats in a greenhouse. The Bluebonnet sample showed regrowth of Bermuda grass but the Johnson grass, which has just about 2 cm of root, did not grow. The Dalrymple area showed primarily Bermuda grass. The Fuqua area showed growth of dallis grass and winter annuals. A second spraying was made on February 21, 1980, but temperatures at this time were too low and weeds were not actively growing.

Soil tests indicated low phosphate so treble superphosphate was applied to all plots at 4.5 kg/ha before planting. Because finished plants were available, planting could not be delayed and was started in late February. Many weeds were present; the worst were Bermuda and Johnson grass.

A complete randomized planting was made at each location with individual plantings from top to bottom of the slope. Individual plantings varied in size depending on available plant materials and spacings required. Spacings were from center to center of the plants. The smallest plots were of asparagus fern that were almost 141 m^2. Plantings, starting with Fuqua and ending on Bluebonnet, were completed on April 20, 1980.

Approximately 1,440 man-hours were required to plant about 35,000 plants in the 0.64-ha area. Weed control started as soon as plantings were completed. Ratings were made monthly by six judges starting in June 1980 for overall crop appearance, weed presence, and crop establishment. An extended period of drought from May 20 to June 19, 1980, and in August took its toll on plants. Most of the dwarf coreopsis and verbena were lost and were replanted. The asparagus fern on Fuqua were planted in February before plants could be checked to see if they were alive and many were dead. Both asparagus fern and wedelia will kill in containers if the medium freezes. Roughly 70 percent never came up in spring. Replanting, which was done from December through February, took about 900 man-hours for all replications. Weed control began in April 1980 and continued thereafter. Directed sprays and hand weeding around plants were used initially. Glyphosate was used at the rate of 10 mL/L over the dwarf Confederate jasmine after plants became established and at the rate of 5 mL/L over the honeysuckle and wintercreeper. No visible damage occurred to the crop plants and the jasmine exhibited an increased number of shoots per plant. Terminal buds were killed and axillary buds were induced to break. Glyphosate could not be used on the asparagus fern, coreopsis, eulalia, or verbena, all of which are highly susceptible to injury. Glyphosate at 5 mL/L over liriope did not appear to damage the plants. When plants were small, covering with plastic containers and spraying between and within rows prevented the plants being touched. Paraquat was used in the two first sprayings. Thereafter glyphosate (4 sprayings) was used in the first growing season and subsequently. Crops that were not treated with herbicides were hand weeded.

In 1981 glyphosate was used twice over tolerant crops and a quickbar was used overall once. Quickdraw, a liquid application from a bar containing glyphosate solution, was used to control tall weeds, mainly Johnson grass. Crops were considerably shorter than many weeds. Honeysuckle, a vine, crawled up the weeds; thus the bar could not be used on it. The bar had a solution of 2 parts glyphosate to 1 part water on a volume basis. It was used three times during the growing season.

To estimate what yearly maintenance would cost, a record of man-hours was kept from April 1, 1980, through March 31, 1981. The project took 1,400 man-hours of labor. A commercial lawn maintenance company charged $180 to put 46 kL water over the 0.64-ha area. Four waterings were made; however, double that number should have been made. About 26.5 L of glyphosate and 15 L of paraquat were used to control weeds. Fertilizer costs were roughly $300. Service station charges averaged $50 per month, and miscellaneous expenses totaled about $350. The total expense was $10,680 for the 0.64-ha planting.

Irrigation, when needed, was always a problem. In May and June just 3.35 cm of rain was recorded. Plants suffered immensely and added moisture seemed necessary at least once every 2 weeks. Average temperatures were 13°C with full sunlight and more wind than usual; many plants died.

The first frost occurred on November 19, 1980; however, the wedelia was not killed until a low of -16.5°C was recorded. The lantana showed injury; however, they were not killed until the temperature dropped to -18°C. All plantings made excellent recovery the next spring. The lowest recorded temperature was -22°C on January 13, 1981.

SUMMARY

Ratings were made monthly by six judges on the three replicated plots for overall appearance of the crop, presence of weeds, and crop establishment using a scale of 1-9 with 9 indicating the largest number of plants. Analyses of variance were run monthly and for the 13-month period. Duncan's multiple range tests were run on the means (Table 1). Only six species were rated because the dwarf coreopsis and St. Paul verbena were severely damaged by drought in May, June, and August.

On the first date, liriope had the best rating followed by wedelia and honeysuckle. Closer spacing in liriope contributed to the high rating because fewer weeds were present. The same relative order was shown in crop establishment.

Considering the summary analysis of variance (2), the overall ratings were highest for the Dalrymple site. Weeds were easier to control here because much less Bermuda and Johnson grass was present. Plots here were more protected from winds. A pH closer to neutral might also have favored the crop plants. The same order was shown in crop establishment and significantly fewer weeds were present.

The overall rating for liriope was significantly better than that for all other species. The honeysuckle, wedelia, and jasmine were not significantly different, yet they were better than the wintercreeper. In previous trials wintercreeper was slower to become established but in time made a dense cover.

For crop establishment the same general pattern was exhibited among species means. Significantly more weeds were found in the wintercreeper than in all other species. The honeysuckle and wedelia had significantly more weeds than the jasmine and liriope. No herbicides were applied to the wedelia plots, and the reduced rate and more open nature of honeysuckle gave the appearance of more weeds. The honeysuckle at Bluebonnet had the greatest amount of Johnson grass. Tall grasses in the wedelia at Fuqua tended to compete with the crop. The fern was hand weeded at Dalrymple but herbicides were used between plants that could be covered to avoid contact with herbicides. Weed kill was greater among this species because a higher concentration of herbicide could be used. In general, the fewest weeds were found in liriope; however weed populations were not significantly less than in the jasmine, which had periodic herbicide applications over the entire plots. Whether these sprays will have a long-term effect on the crop was not determined.

In conclusion, the liriope appeared to be the best species for highway plantings followed by honeysuckle, jasmine, and wedelia. Wintercreeper and fern required more time for establishment.

RECOMMENDATIONS FOR IMPLEMENTATION

1. All vegetation should be killed before planting is started. Fumigants that can be watered down into the ground might be used. If glyphosate and 2,4-D are used, at least three sprayings spaced a minimum of 2 weeks apart should be made to kill all grasses and weeds. Weeds should be in active growth when herbicides are applied, and temperatures should be 70°F or above. Soil tests should be run and fertilizers added as needed. The pH should be close to 6.5. If a big adjustment is needed in pH, tests and lime or sulfur additions should be made 6 months before planting.

2. If the area to be planted is bare, soil tests should be made, fertilizers added as needed, and the area rototilled to 20 to 30 cm before fumigation. On slopes, erosion control would be necessary. Using established plants in 0.003-m³ or larger containers for planting and staggering plants from row to row would reduce erosion considerably. Straw might possibly be used between plants on very steep sites. Shredded bark such as used in nursery media is too coarse and will float or be carried away by rains. Erosion net could be used between rows where erosion might be a problem but only after plantings were completed. The netting would make using a post-hole digger difficult. A mulching anchoring tool or tracking with a tracked-type vehicle with cleats penetrating to about 6 cm might be used to

TABLE 1 Duncan Multiple Range Tests for Rating Means for Overall Appearance[a]

	Overall Appearance		Crop Establishment		Weed Presence	
Species	$\bar{X}$[b]	Letters[c]	$\bar{X}$	Letters	$\bar{X}$	Letters
Liriope	7.21	a	8.23	a	3.65	d
Honeysuckle	6.34	b	7.75	b	4.76	b
Jasmine	6.11	b	7.56	b	3.89	cd
Wedelia	6.16	b	7.43	b	4.60	b
Fern	5.55	c	6.68	c	4.38	bc
Creeper	3.91	d	5.86	d	6.82	a

[a]Crop establishment and weed presence for six ground cover species on three sites during 13 months rated by six judges.

[b]$\bar{X}$ = Mean.

[c]All with the same letter are not significantly different.

prevent erosion on very steep slopes. Straw and fertilizers could be incorporated into the soil by this method.

3. Obtaining finished plants in containers in the numbers needed will be difficult unless plants are grown on consignment. This would mean that at least one growing season would be necessary to produce most plants except the very fast-growing herbaceous types. Using two or three rooted cuttings per container would also speed maturity. Most of the woody plants, with the exception of akebia, grow relatively slowly from liners. Although many nurseries grow ground covers, few produce them in quantity unless assured they will have a market when plants are well established. The dwarf Confederate jasmine was sold by most of the nurseries consulted, but usually in numbers not exceeding a few thousand plants. The liriopes could be obtained best as liners; however, getting the creeping liriope was difficult. A number of nurseries carried the purple-leaved honeysuckle but finished stock was very limited. Other materials were in exceedingly short supply.

4. Stock produced in the same hardiness zone in which it will be used would be best; however, for asparagus fern, wedelia, and lantana, or those plants that are injured by freezing temperatures during the winter if they are in containers, only plants produced and planted before freezing temperatures occur would be reliable. Some problems also occurred with plants in containers in which a very fine medium with very poor internal drainage was used especially during very rainy periods. The only solution to obtaining large numbers of finished plants when needed is to buy on consignment and this must be done at least a year before the plants are wanted.

5. Plants should be maintained by the planter at least through the first growing season. If weeds are not controlled before planting, maintenance should be contracted for at least two growing seasons. Irrigation when necessary would be essential to establishment. Possibly at least 2.54 cm of water per week might be necessary during periods of drought when plants are newly planted and before they have become well established. When plants are established, bimonthly checking might be sufficient and irrigation used only if needed. Plantings should be made from mid-November through February.

6. Fertilization, using a slow-release nitrogen carrier like urea-formaldehyde, should be done shortly after planting at the rate of at least 48 kg of actual nitrogen per hectare. After the first year, fertilization at the rate of 1,465-2,000 kg/ha of 8-8-8 would be suggested to keep plants growing well.

7. Herbicides might be used in the first season after plants become established although certain herbicides can be used when the plants are planted. Systemic herbicides like glyphosate have affected growth of certain woody crop plants for several seasons after applications. Long-range effects would have to be learned as well as effects of repeated applications of small concentrations.

FURTHER INVESTIGATIONS

Peculiar problems encountered in conducting this research and time limitations made full investigation of certain practices impossible. Further work would be of great value in the following areas.

1. More extended tests over at least 3 years of many different plant materials are needed. Certain plants that showed promise were unobtainable or could not be produced in sufficient numbers for trials (e.g., akebia, dwarf bamboo, and kumasaca). Testing of more native materials like Coreopsis lanceolata L., Achillea millefolium L., Rudbeckia sp., and others is needed. Many of these plants have wide adaptability and persist with no care along highways.

2. Companion plantings should be tried. For example, ground ivy grew rampantly when temperatures were cool and soil was moist; thus it could be planted with memorial rose. Memorial rose is slow establishing and has strong apical dominance in the shoots. Planting ground ivy with memorial rose would give a fast cover to prevent weed infiltration and erosion stresses. Leaf drop, which often occurs in the roses due to diseases or low temperatures in winter, would permit the ground ivy to grow because it tolerates full sunlight well at this time of year. The big periwinkle, with other plants giving a good cover at the Florida-Airline site, is another example of plant partners. Native dewberries make an excellent solid cover; however, their thorniness is objectionable. There is a thornless selection that is not available. Although a dwarf form of the pampas grass [Cortaderia selloana (Schult & Schult. f.) Asch. & Graebn.], which is an ornamental grass used along highways and which has very low maintenance and excellent persistence, has been reported, efforts to obtain it were futile. Such a selection could be invaluable for highway use if it were very dwarf.

3. Use of smaller plants in tube-type containers, liners as in sprigging, and mats developed from planting liners to develop like sod should be tried to ascertain if a quicker cover could be obtained without erosion and with reductions in cost. Equipment developed to facilitate mechanical planting of these plants might greatly reduce costs for labor needed in planting, which was next to plant costs in amount.

4. Further studies are needed on ways to kill existing vegetation before ground covers are planted. Maintenance costs are prohibitive and weed competition is excessive and detrimental to establishment if weed kill is not completed before planting. Fumigants and herbicides that can be used to achieve this need to be researched. A thorough testing of new material is needed.

5. High mowing, at least annually until a solid stand occurs, is needed to improve appearance of the plants by removing dead stems and seedheads. Tall weeds, if present, might be weakened enough to allow crop plants to take over. Only the narrow-leaf evergreens did not tolerate inadvertent mowings over trial plantings. Possibly for herbaceous materials, which have tall seedheads that become unattractive, mowing could be done at least once annually. Plants that exceeded 60 cm might be kept down by an annual mowing.

6. For those plants that have annual tops, herbicides might be tried to control weeds without danger of injury to the crop when tops have died back.

7. Research to determine best fertilizer rates and formulations to maintain excellent growth for each species should be initiated.

8. Chemicals to induce lateral buds to break are needed for those plants that show strong apical dominance (e.g., dwarf Confederate jasmine, Algerian and English ivies, and memorial rose). This would mean a faster complete coverage of an area. Growth-retarding chemicals might also be tried.

ACKNOWLEDGMENTS

Credit is due to the Louisiana Department of Transportation and Development and FHWA for their financial support of and continued interest in the project. Special appreciation is extended to O.M. Pourciau, Sidney J. Babin, Jr., Sheldon M. Law, J.W. Lyons, Jr., and J.C. Franklin of the Louisiana Department of Transportation and Development and to Charles C. Carr, area engineer, FHWA. Much credit is also due to Louisiana State University and the Department of Horticulture faculty and staff.

Deep appreciation is extended to Sidney J. Babin, Jr., Claude Blackwell, Vincent J. Mannino, O.M. Pourciau, and T.J. Raiford who judged the plots each month. Statistical analyses were conducted under K. Koonce and his help is very much appreciated.

REFERENCES

1. R.J. Stadtherr, D.W. Newsom, and T.J. Raiford. Establishment of Ground Covers for Non-Mowable and Locked-in Areas on Louisiana Interstate Highways. State Research Project 72-3M, Phase 1. Louisiana State University, Baton Rouge, June 1974, 25 pp.
2. R.J. Stadtherr, V.J. Mannino, and D.W. Newsom. Establishment of Ground Covers for Nonmowable and Locked-in Areas on Louisiana Interstate Highways. Final Report. Horticulture Department, Louisiana State University, Baton Rouge, July 1981, 52 pp.

Publication of this paper sponsored by Committee on Landscape and Environmental Design.

Roadside Deicing Chemical Accumulation After 10 Years

MARTHA T. HSU

ABSTRACT

Soil and plant samples were collected along the northbound lane of I-95 between Alton and Howland, Maine, from sites identical to those used in a similar study in 1972-1973. The sodium and chloride content of the samples was determined; the values were averaged and treated statistically. The mean values were then compared with values obtained in 1972- 1973. The following conclusions could be drawn. Sodium ion concentration exhibited a general cumulative trend due to application of road salt, sodium chloride (NaCl). However, accumulation was far below exchangeable sodium levels that are considered damaging. The chloride ions leached out of the soil fairly rapidly and had no pronounced accumulative effect. The effect of deicing salt on the sodium and chloride content of hemlock needle tissues was insignificant. The NaCl content of accumulated snow, which is caused by snow plow and blow action during the application of the road salt in the winter season, diminished as the distance from the highway increased. The alkalinity (or acidity) of soil appeared to have a direct relationship with the sodium content of the soil. The present study is generally applicable to areas adjacent to four-lane divided Interstate highways in the northeastern United States.

The use of deicing salt, sodium chloride (NaCl), to remove snow and ice from highways during the winter months has been an environmental concern for more than two decades. Highway maintenance agencies struggle constantly to balance the benefit of highway safety versus the possible harm of the salt to nearby soil and plants. Numerous studies have been carried out to determine the extent of the contamination including the effect of deicing chemicals on soil and plants (1,2) and the effect of deicing chemicals on groundwater (3). The economic aspects of highway snow and ice control are also a subject of much concern (4,5); the cost of damage to the environment and automobiles is compared with the financial benefit derived from road safety and travel convenience. Studies of alternative deicing methods for winter maintenance have also been carried out by many researchers (6,7).

It is generally agreed that most salt vacates the roadside environment via surface runoff and leaching after the winter season. In particular, chloride ions leach out quite rapidly. However, the interaction between the salt and the soil is of great complexity, depending on weather conditions, amount of snowfall, depth of the water table, soil texture, and soil chemistry (8). Therefore, it requires a considerable amount of data to reach a conclusion.

A recent publication by Hudler (9) summarized the effect of salt injury to roadside plants by listing various plants according to their tolerance of deicing salt. Among the highly tolerant plants were Norway maple, yellow birch, mulberry, and mountain ash. Some plants of low tolerance, among others, were balsam fir, red maple, black walnut, Norway spruce, and eastern hemlock.

As early as 1965 concern over pollution caused by deicing chemicals along Maine highways prompted the investigation of soil and water in areas contiguous to the highway under the direction of F.E. Hutchinson of the University of Maine at Orono (10,11). It was found that there was no significant increase in sodium or chloride content of river water during the spring when snowmelt was at its maximum. However, some of the wells along the highway showed an increase in sodium and chloride content. These contents increased as distance from the highway decreased. Additional information was collected that showed an increase in sodium content along the Maine Turnpike and I-95 as the number of years of salt application increased.

In the summer of 1972 construction on a portion of I-95 near Alton, Maine, was planned for that fall. A study was then initiated by the Maine Department of Transportation (DOT) with the cooperation of the Maine Agricultural Experimental Station under the supervision of A.R. Langille of the University of Maine at Orono (12,13). The study compared methods of salt application in relation to severity of toxicity symptoms in conifers of differential salt tolerance. Soil and plant samples were collected along the newly constructed highway before and after one season of deicing operation and analyzed for sodium and chloride content. The results showed a significant increase of both ions in the soil and in the plant tissues after one deicing season.

With this study as a source for the initial data, it was thought that a comparison of the sodium and chloride levels in 1972-1973 with those in 1981-1982 would give an indication of the accumulative effect of those ions attributable to deicing through the years. The U.S. Department of Transportation, FHWA, approved such an undertaking in 1981 as part of the Maine Department of Transportation Work Program TQX HPR-PR-1(18).

METHODOLOGY

Collection of Samples

Soil samples were collected on five dates, August 13, 1981; September 29, 1981; November 20, 1981; April 15, 1982; and May 26, 1982. It should be noted that the last snowstorm during the 1981-1982 winter season occurred on April 7, 1982, after which most of the snow melted rather quickly. The samples were taken from six sites along northbound I-95 between Alton and Howland, Maine (Maine mileage numbers 195 to 205). These sites were the same as those used in the 1972-1973 study (12). At each site single soil samples were collected at the distances of 20, 40, 80, 160, and 200 ft from the edge of the highway. Soil sampling was done with a steel sampling tube 1 ft long and 3/4 in. in diameter, but only the top 6 in. of soil were collected.

Hemlock branches were cut with a pruning pole. Samples were collected on the last three dates mentioned. The sites were the same as those for soil sampling, but samples at distances of 80, 160, and 200 ft only were collected. At each site there was a cleared area with tall trees (mostly evergreen) growing on both sides. There was a drainage ditch at the vicinity of 40 ft and the ground sloped down on both sides.

The winter of 1981-1982 was relatively severe. Total snowfall in the Bangor area was around 100 in. As a consequence the application of road salt was extensive. The average amount of salt applied during the winter of 1981-1982 was 6.5 tons per lane-mile. To gain some information on the effect of the snow plow and salt and sand drift, samples of the accumulated snow were collected on March 11, 1982. Sampling was done with a metal tube 30 in. long and 2 in. in diameter. The samples were brought to the laboratory immediately, melted, and allowed to reach room temperature.

Analysis of Samples

All the soil samples were air dried and sieved through a No. 10 sieve before testing. The sodium concentration was determined by extracting the soil sample with 1N ammonium acetate (pH = 7) (laboratory procedures used by Department of Plant and Soil Sciences Analytical Laboratory, University of Maine at Orono). Subsequently the extracted solution was analyzed for sodium by atomic emission spectrophotometry (Perkin Elmer Model 403). The chloride was extracted from the soil by mixing 25 g of the soil sample with 50 mL of water for 1 hr. The solution was adjusted for ionic strength and was measured for Cl^- concentration by a specific chloride ion electrode, using Orion Specific Ion Meter, Model 407A. A series of standard chloride solutions with the same ionic strength was used to establish a calibration curve for the determination.

The hemlock branches were air dried and only the needles were collected for analysis. The needles were ashed before testing for sodium and chloride (laboratory procedures used by Department of Plant and Soil Sciences Analytical Laboratory, University of Maine at Orono). The sodium ions were extracted from the ashed samples by a 20 percent hydrochloric acid (HCl) solution (Analytical Methods for Atomic Absorption Spectrophotometer, Perkin-Elmer Corp.) and subsequently analyzed using atomic emission spectrophotometry. The chloride was extracted by a calcium oxide (CaO) paste (laboratory procedures used by Department of Plant and Soil Sciences Analytical Laboratory, University of Maine at Orono) and dissolved in a nitric acid (HNO_3) solution. It was then titrated with 0.0100N silver nitrate ($AgNO_3$) solution by the Gran Plot Method (14,15).

The sample from the snowmelt was filtered and analyzed for sodium and chloride content by atomic emission spectrophotometry and the Gran Plot Method, respectively.

The pH of the soil samples collected at these locations on November 20, 1981, was determined with a combination pH electrode in connection with the Orion Specific Ion Meter, Model 407A.

These data were analyzed statistically by the Waller-Duncan K-ratio t-test method, which is a standard program within the Maine DOT Computer System, SAS ANOVA program.

RESULTS AND DISCUSSION

Sodium Content of Soil

The sodium contents of the soil samples collected on various dates and averaged at each distance for the six locations are given in Table 1. It is apparent that the sodium content at the 20- and 40-ft distances was much higher than that at the 80-, 160-, and 200-ft distances. This was due to the closeness to the salt spray operation at these distances. Al-

TABLE 1 Sodium Content (ppm) of Soil Samples from Various Locations

Distance from Highway (ft)	Date Sampled				
	8/31/81	9/29/81	11/20/81	4/15/82	5/26/82
20	59.7 A[a]	50.0 A,B	50.3 A	70.6 A	68.3 A
40	63.4 A	61.0 A	53.5 A	59.8 A,B	70.8 A
80	16.4 B	16.9 C	18.2 A	18.0 C	27.7 B
160	21.8 B	22.4 B,C	32.2 A	36.9 B,C	19.4 B
200	24.4 B	28.5 B,C	30.9 A	20.1 C	17.3 B

[a] A,B,C: Within the same column, the same letter denotes that there were no significant differences among the means according to the Waller-Duncan K-ratio t-test.

though statistically there were no significant differences between the values at 20 ft and those at 40 ft, the general tendency was for the latter to be slightly higher than the former, which showed that the sodium ion did leach out toward the lower ground near the 40-ft distance, where the drainage ditch was located.

Deicing salt spray during the snow season definitely affects the sodium content of the soil as is demonstrated when the data from November 20, 1981, are compared with those from April 15, 1982, and May 26, 1982. The increase was more obvious for the 20- and 40-ft distances than for the other three distances.

To evaluate the accumulative effect of the deicing salt, the data from the 1972-1973 season (12) are given in Tables 2 and 3. When the data given in Table 1 for November 20, 1981, and those given in Table 2 for November 13, 1971 (before construction) are compared, values from 1981 show a marked increase in sodium content at the 20- and 40-ft distances, but only a slight increases was observed at the 80-, 160-, and 200-ft distances.

This confirms the effectiveness of the drainage ditch. At the same time the accumulative nature of the sodium ion at locations near the highway was evident and should not be overlooked. Samples obtained after the first winter season and after the ninth (i.e., July 10, 1973, and August 13, 1981) indicate in general that the sodium content has not changed over that period of time, with the exception of a reduction of nearly 50 percent in the sodium content at the 20-ft distance.

It must be emphasized here, however, that even for the highest value in Table 1 the exchangeable sodium level is far below those that may be considered damaging. This was also evident from the healthy appearance of the hemlock and other vegetation at the test sites.

Chloride Content of Soil

The chloride content of the soil samples collected at various dates is given in Table 4. Statistically there were no significant differences among the means as the distances from the edge of the highway varied. However, on close examination, there appeared to be a significant increase in chloride content after the snow season at the 40-ft distance, the site closest to the drainage ditch. The data from other locations showed that chloride ions were leached out quite rapidly.

Comparison of the chloride ion content of the soil samples collected in November 1981 with that of those obtained in November 1972 indicated no significant change due to accumulation.

Sodium and Chloride Content of Hemlock Needle Tissue

The sodium and chloride content of hemlock needle tissue was determined from samples collected on November 11, 1981, April 15, 1982, and May 26, 1982. The data are given in Table 5. The influence of road salt application was evident from the increase in the values shown by samples collected in November 1981 and those collected in April 1982. Between April and May 1982 the sodium content in the tissue samples decreased, and chloride levels differed insignificantly.

Comparison of the data obtained in November 1981 with those obtained in November 1972 (Tables 3 and 5) shows the sodium content was at nearly the same level, but the chloride level of the present study was considerably lower. In any case, the increase of the sodium in soil due to the accumulative effect appeared to have no influence on the sodium and chloride content of plant tissue.

TABLE 2 Sodium and Chloride Content of Soil Samples Collected Along a Newly Opened Section of I-95 Before and After the First Winter of Road Salt Application[a b]

Distance from Highway (ft)	Sodium (ppm)		Chloride (ppm)	
	11/13/72	7/10/73	11/13/72	7/10/73
20	13.82 A	112.67 A[c]	22.17 A	75.75 AB[c]
40	17.87 A	67.83 AB[c]	22.50 A	101.33 A[c]
80	15.82 A	21.33 B	8.83 B	47.17 B[c]
160	14.38 A	23.00 B	11.67 B	51.00 B[c]
200	20.87 A	24.83 B	10.33 B	58.33 B[c]

[a]Based on Langille (12).

[b]Within columns, means followed by the same letter were not significantly different by Bayes L.S.D.

[c]For a particular distance and element, means were significantly different by F-test (p = .01).

TABLE 3 Sodium and Chloride Content of Hemlock Needle Tissue Collected Along a Newly Opened Section of I-95 Before and After the First Winter of Road Salt Application[a b]

Distance from Highway (ft)	Sodium (ppm)		Chloride (ppm)	
	11/13/72	7/10/73	11/13/72	7/10/73
80	106.85 B	290.00 A	154.00 C	861.50 A
160	112.72 B	282.67 A	126.83 C	613.67 B
200	109.34 B	173.60 A	143.00 C	551.40 B

[a]Based on Langille (12).

[b]For each element, means followed by the same letter were not significantly different by Bayes L.S.D.

TABLE 4 Chloride Content (ppm) of Soil Samples from Various Locations

Distance from Highway (ft)	Date Sampled				
	8/13/81	9/29/81	11/20/81	4/15/82	5/26/82
20	7.3 A[a]	6.0 A	12.2 A	13.3 A	13.3 A
40	10.0 A	6.8 A	10.7 A	23.3 A	57.0 A
80	7.0 A	7.0 A	6.5 A	9.5 A	9.3 A
160	8.4 A	10.5 A	14.6 A	33.1 A	14.1 A
200	11.4 A	16.6 A	13.6 A	19.0 A	19.0 A

[a]Within the same column, the same letter denotes that there were no significant differences among the means according to Waller-Duncan K-ratio t-test.

Sodium and Chloride Content of the Snowmelt

On March 11, 1982, before the snow began to melt in the spring, snow samples were collected and brought to the laboratory for sodium and chloride analysis. The results are shown in Figure 1 in which black circles represent chloride and open circles represent sodium. It is apparent that the deicing salt application by the plow and blow action had the most effect on the areas close to the highway--up to 80 ft away. Trees planted beyond this distance should be fairly safe from damage caused by road salt application.

Soil pH

It has been found that the higher the pH of the soil, the more detrimental the presence of excessive

TABLE 5 Sodium and Chloride Content (ppm) of Hemlock Needle Tissue at Various Locations

Distance from Highway (ft)	Sodium			Chloride		
	11/20/81	4/15/82	5/26/82	11/20/81	4/15/82	5/26/82
80	102.2 A[a]	218.5 A	97.3 A	38.0 A	126.8 A	144.0 A
160	93.5 A	87.7 B	85.3 A	38.6 A	123.8 A	111.8 A,B
200	98.6 A	102.4 B	86.7 A	22.0 A	64.8 A	80.8 B

[a]Within the same column, the same letter denotes that there were no significant differences among the means according to the Waller-Duncan K-ratio t-test.

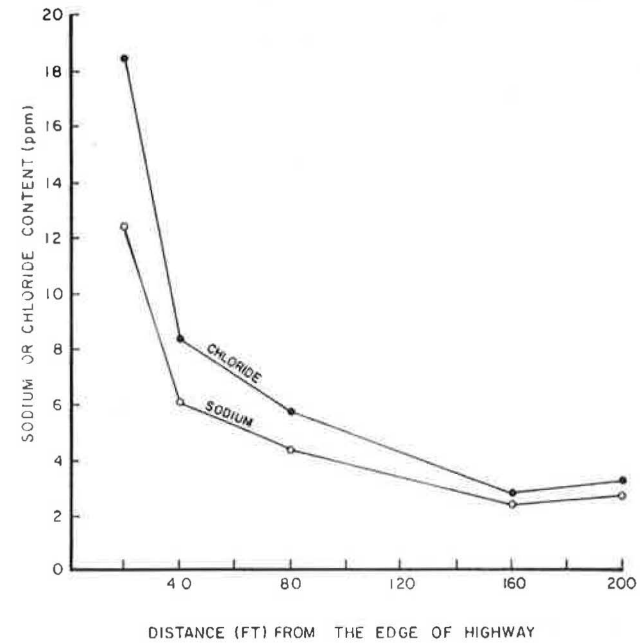

FIGURE 1 Sodium and chloride content of showmelt samples from various locations (collected March 11, 1982).

sodium in soil will be for plant growth (16, pp. 221-222). An increase in a sodium salt, such as sodium carbonate, may cause the pH of the soil to rise, that is, become more alkaline. Therefore, the pH of the soil samples in the test area was determined for samples collected on November 20, 1981, according to the distances from the edge of the highway.

The results are given in Table 6. It is interesting to note that the pH of the soil samples closest to the highway (20- and 40-ft distances) was about one unit higher than that of samples from the other distances. This is about 10-fold higher in terms of the concentration of the OH^- ion.

CONCLUSIONS

Sodium ion concentration exhibited a general cumulative trend due to application of road salt, sodium chloride. However, accumulation was far below exchangeable sodium levels that are considered damaging. The chloride ions leached out of the soil fairly rapidly and thus had no accumulative effect.

The effect of deicing salt on the sodium and chloride content of hemlock needle tissue was insignificant.

The NaCl content of accumulated snow caused by the snow plow and blow action during the application of road salt in the winter season diminished as the distance from the highway increased. The effect became insignificant at locations further than 80 ft from the highway.

The alkalinity (or acidity) of soil appeared to have a direct relationship with the sodium content of the soil. A further study should be made on this point to see if pH measurements could be used as a tool to check the extent of sodium accumulation. It would be beneficial to check the sodium and chloride content of soil and plants 5 or 10 years from now to evaluate the rate of accumulation of sodium in soil.

TABLE 6 pH of Soil Samples Collected November 20, 1981

	Distance from Highway Edge (ft)				
	20	40	80	160	200
pH	5.6 A[a]	5.6 A	4.5 B	4.8 B	4.4 B

[a]The same letter denotes that there were no significant differences among the means according to the Waller-Duncan K-ratio t-test.

REFERENCES

1. E.F. Button and D.E. Peaslee. The Effect of Rock Salt upon Roadside Sugar Maple in Connecticut. In Highway Research Record 161, HRB, National Research Council, Washington, D.C., 1967, pp. 121-131.
2. R.E. Hanes, L.W. Zelazny, K.G. Verghese, R.P. Bosshart, E.W. Carson, Jr., R.E. Blasser, and D.D. Wolf. Effects of Deicing Salts on Plant Biota and Soil. NCHRP Report 170. TRB, National Research Council, Washington, D.C., 1976, 94 pp.
3. S.J. Pollock and L.G. Toler. Effect of Highway Deicing Salts on Groundwater and Water Supplies in Massachusetts. In Highway Research Record 425, HRB, National Research Council, Washington, D.C., 1973, pp. 17-22.
4. D.M. Murray. Economic Analysis of the Environment Impact of Highway Deicing Salts. In Transportation Research Record 647, TRB, National Research Council, Washington, D.C., 1977, pp. 29-39.
5. J.C. McBridge. Economic Impact of the Highway Snow and Ice Control. In Transportation Research Record 674, TRB, National Research Council, Washington, D.C., 1978, pp. 58-63.
6. R.F. Strafull, D.L. Spellman, and J.A. Halterman. Further Evaluation of Deicing Chemicals. In Transportation Research Record 506, TRB, National Research Council, Washington, D.C., 1974, pp. 56-64.
7. S.A. Dunn and R.U. Schenk. Alternative Highway Deicing Chemicals. FHWA-RD-79-109. FHWA, U.S. Department of Transportation, 1980.
8. A.H. Westing. Plants and Salt in Roadside Environment. Phytopathology, Vol. 59, No. 9, 1969, pp. 1174-1181.

9. G. Hudler. Salt Injury to Roadside Plants. Ground Maintenance, Vol. 16, No. 2, 1981, pp. 80-84.
10. F.E. Hutchinson. Effect of Deicing Salts Applied to Highways on the Contiguous Environment. Fourth Symposium on Salt, Vol. 1, Northern Ohio Geological Society, Inc., Cleveland, Ohio, pp. 427-433.
11. F.E. Hutchinson and B.E. Olson. The Relationship of Road Salt Application to Sodium and Chloride Ion Levels in the Soil Bordering Major Highways. In Highway Research Record 193, HRB, National Research Council, Washington, D.C., 1967, pp. 1-7.
12. A.R. Langille. Salt Toxicity of Conifers. Technical Paper 74-5. Maine Department of Transportation, Augusta, 1974.
13. A.R. Langille. One Season's Salt Accumulation in Soil and Trees Adjacent to a Highway. Horticultural Science, Vol. 11, No. 6, 1976, pp. 575-576.
14. G. Gran. Determination of the Equivalent Point in Potentiometric Titration. The Analyst, Part II, Vol. 77, No. 11, 1952, pp. 661-671.
15. Gran Plots and Other Schemes. Orion Research Newsletter: Specific Ion Electrode Technology, Vol. 11, 1970, pp. 49-56.
16. H.D. Foth. Fundamentals of Soil Science. 6th ed. Wiley, New York, 1978.

Publication of this paper sponsored by Committee on Landscape and Environmental Design.

Current Practices of Harvesting Hay on Highway Rights-of-Way

KUMARES C. SINHA, KANG HU, and JOHN D.N. RIVERSON

ABSTRACT

The harvesting of hay on highway rights-of-way has recently received attention by state highway departments. Several states have already implemented a harvesting program. However, concern has been expressed about traffic safety, lead poisoning, and other problems. The pros and cons of a harvesting program are examined, and current practices of the state highway departments are reviewed. The various aspects considered include legal problems, geographic condition, traffic safety, economic benefit, contamination of hay, and aesthetic and environmental concerns. Although the economics of a hay-harvesting program may not make such a program implementable in most states at the present time, changes in the local demand for hay and in labor and administrative costs for roadside mowing programs may make such programs feasible in the future.

Mowing is one of the major tasks of roadside maintenance. Mowing is done to maintain adequate sight distance and drainage and to provide a safe and neat highway environment for the public. However, because of limited maintenance budgets, mowing is not receiving the funding priority it once had. Many state highway departments are looking for ways to reduce their mowing programs by restricting the frequency of mowing as well as the total area mowed. In addition, growth retardants are being suggested to reduce mowing needs.

Recently a program designed to eliminate highway mowing with highway department resources and to allow private individuals and companies to harvest hay on highway rights-of-way has received attention by many states. The hay from the highway right-of-way is, in fact, a usable resource and should not be wasted. If the hay can be cut and used by private interests, it would benefit both the state and the harvester. Several states have already implemented such a program. South Dakota, for example, has been harvesting hay along its highways since 1940 (1). However, a lot of concern has been expressed about safety, lead poisoning, and other problems.

The purpose of this paper is to present the findings of a nationwide survey of current practices of state highway departments regarding highway hay harvesting. Various aspects considered include geographic condition, legal problems, economic benefits, traffic safety, contamination of the hay, and aesthetic and environmental concerns.

TYPE AND SOURCES OF DATA

The Indiana Department of Highways obtained information from 11 states on the practice of harvesting roadside hay in 1976. An inquiry was made of the remaining 39 states in April 1983. Thirty-five states responded with either the details of their haying program or the reasons why they do not allow such practices. Subsequently, telephone interviews were conducted with the highway maintenance engineers of the initial 11 states as well as with representatives of those states that did not respond to the inquiry. Current data are now available for all the states except Alaska.

SUMMARY OF CURRENT PRACTICES

The policies of state highway departments concerning the harvesting of hay along highways, as of summer 1983, are shown in Figure 1. Thirty-one states currently do not have such a program. Among these states, however, California has a few isolated areas where harvesting is allowed under permit. Washington allows owners of abutting property to harvest native grasses for hay on non-limited access highways. Eighteen states reported that a harvesting program has been in force for years. South Dakota, Missouri, Wyoming, and Iowa considered the program successful.

Summaries of the major reasons for not allowing harvesting of hay are given in Table 1. Geographic condition is the most common reason, followed by economic, safety, contamination, and legal aspects. In addition, aesthetic and environmental concerns were cited as reasons for not allowing hay harvesting.

Geographic Conditions

Certain topographic conditions of highway rights-of-way are required to make hay harvesting possible. The terrain must be flat enough to accommodate conventional harvesting equipment and an adequate stand of palatable grass must exist. For geographic reasons, none of the states in New England and the Middle Atlantic regions allow hay harvesting along highways. New Jersey, Massachusetts, and Rhode Island are highly urbanized and narrow rights-of-way make it economically and technically infeasible to harvest hay. Maine does not have a haying program primarily because the major part of its Interstate system is located in wooded areas where grass is hard to mow. Pennsylvania has a hilly terrain that makes it difficult to carry out hay-mowing operations. In the mountain region, most states, except in Montana and Wyoming, do not provide a harvesting program.

On the other hand, most of the states in the West North Central and West South Central regions permit such practices. The climate, moisture, and flat terrain of these regions are conducive to harvesting hay.

Legal Aspects

Most state laws on access control and federal highway regulations require that state highway departments maintain control of rights-of-way. A question has been raised about whether it is legal to allow private citizens to work on the highway right-of-way for any commercial purpose. Arizona statutes preclude the use of highway right-of-way for any commercial activity. Colorado prohibits the movement of nonofficial machinery within the right-of-way. As a result, the harvesting of hay cannot be legally permitted in these states.

However, this barrier was removed in Texas by a state statute (Art. 6673f Sec. 1) enacted in 1977, which stipultes that

> A district engineer of the State Department of Highways and Public Transportation may grant permission to a person, at his request, to mow, bale, shred, or hoe the right-of-way of any designated portion of a highway that is in the state highway system and is within the district supervised by the engineer.

In Tennessee, a state statute enacted in 1978 provides that a local farmer may petition the de-

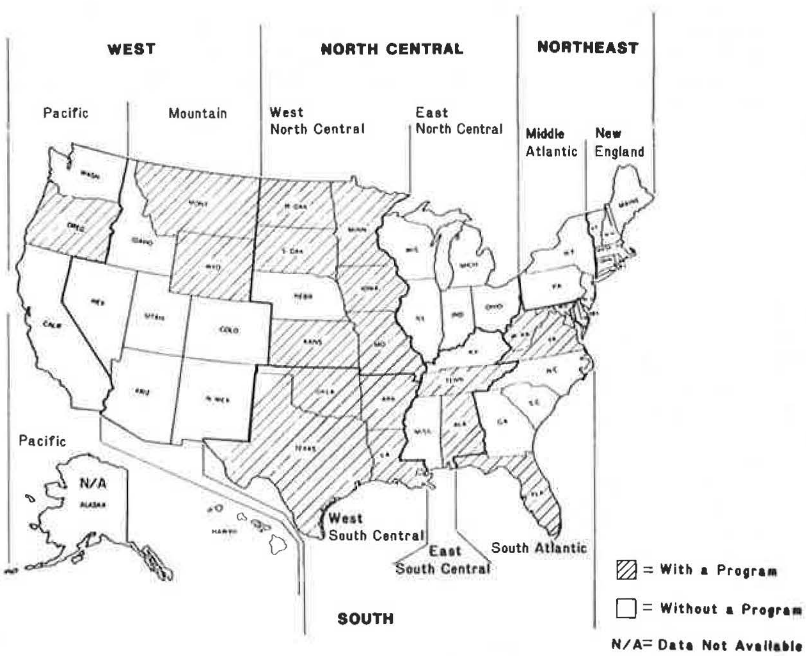

FIGURE 1 Geographic distribution of states with hay-harvesting programs.

TABLE 1 Summary of Reasons for Not Allowing Hay Harvesting

	Reason					
State	Geographic Condition	Legal Problem	Economically Infeasible	Traffic Safety Concern	Contamination Concern	Other
Arizona	X	X	X			
California	X			X	X	
Colorado		X				
Connecticut	X		X			
Delaware	X					
Georgia	X			X	X	
Hawaii	X					
Idaho				X		Complaints about issuance of permit
Illinois				X	X	Union problem
Indiana			X		X	
Kentucky				X		
Maine	X			X		
Maryland	X			X		
Massachusetts	X		X		X	
Michigan			X			
Mississippi		X				
Nebraska			X			Wildlife concern
Nevada	X					
New Hampshire	X		X		X	
New Jersey	X					
New Mexico				X		
New York	X		X			
North Carolina		X		X	X	
Ohio			X	X		
Pennsylvania	X		X	X		
Rhode Island	X			X		
South Carolina				X	X	Aesthetic concern
Utah			X			
Vermont			X			
Washington			X			
Wisconsin				X		

partment of transportation for permission to cut and bale hay along the right-of-way of Interstate highways within the state for personal farming only. Several other states have also enacted similar regulations to administer such programs.

Under current practices, most states give adjacent property owners the first right to mow and bale hay on secondary roads where most of the right-of-way was obtained by easement. For the Interstate system, where the right-of-way is possessed in fee simple, the most popular approach for granting permits is on a first-come-first-served basis. In areas of high demand, bids are received.

Considerable legal precedent exists for permitting the harvesting of hay along highways. When the demand for access to cut hay on rights-of-way is sufficient, states need to review current practices or seek legislative relief.

Economic Benefits

The most direct benefit to a state from allowing harvesting of hay is the savings in highway mowing costs. Currently, mowing in many states is performed by state maintenance forces or contractors. Even though a number of states are reducing their mowing budget, there is still a significant amount of money expended on highway mowing each year. For instance, the Indiana Department of Highways spent $1 million hiring private contractors to mow 44,000 acres of right-of-way in 1982. It took $308,000 for the state of Washington to mow more than 7,000 miles of highways right-of-way in 1982. It may be possible to reduce these costs if a large portion of the highway system can be mowed free of charge.

Mowing costs have increased rapidly in the past few years. Figure 2 shows the trend of mowing costs per acre of highway right-of-way by contractor and state forces in Indiana. The mowing cost per acre was $24.80 by contractor in 1982 (2). (It should be noted that the actual mowing cost was $22.64 in 1982. The $24.80 figure includes a 10 percent addition for highway department inspection costs.) If the harvesting of hay is done along the 1,150 miles of Interstate highway in Indiana with a conservative estimate of 10 acres per mile, the state can save up to $285,000 per year.

The other possible benefit to a state is compensation from the harvesters. In Missouri, haying is done on a share basis with the state receiving one-third of the hay harvested by farmers. If the hay is not needed by the state, the one-third share

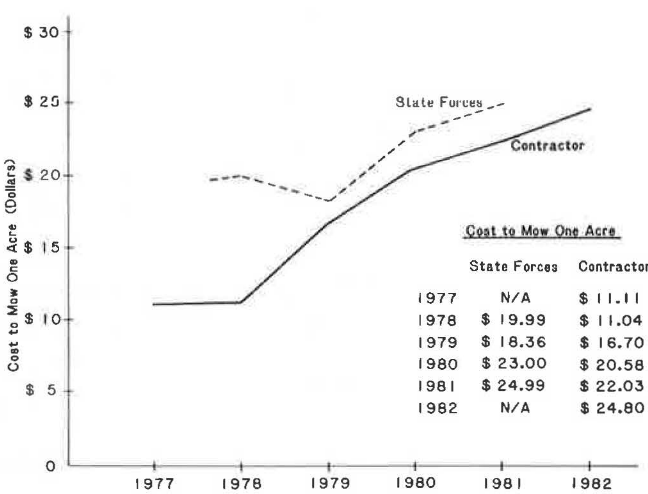

FIGURE 2 Cost comparison for mowing 1 acre by contract and by state forces in Indiana *(2)*.

may be sold to the harvester at the established rate of $30-$40 per ton. It was estimated that the average yield of hay per acre of right-of-way is 2-4 tons. If 10,000 acres are to be hayed, the state government can expect about $350,000 in compensation each year.

Obviously the economic benefits that state highway agencies can receive depend on the acreage available for haying. The Utah Department of Highways pointed out that the right-of-way area there is not sufficiently large to support a profitable hay-harvesting program. In Washington, it was estimated in 1976 that only 1,602 of the 110,350 acres of highway right-of-way may be suitable for the harvesting of hay. With such a small portion of highway right-of-way available for haying, the savings or compensation for the state would be limited.

Another factor that affects economic benefit is the demand for highway hay. If there are very few requests from harvesters for hay baling even though a good program is in place and a large amount of right-of-way is available, the savings in operation cost for the state would be very minor. As a matter of fact, this is exactly the case for some states including Oregon, Tennessee, West Virginia, and Florida. Efforts have been made by these states to encourage the private sector to use highway hay. However, little interest has been expressed by farmers and private citizens. It is worth noting that Nebraska had such a program several years ago. But because the bids received were extremely sparse, it was decided that it was not worthwhile to continue this program.

In addition to the possible economic benefits, there are extra costs incurred. These costs include administrative expenses, cost of establishing right-of-way in the field, traffic control, refertilization, performance bond, and so on. A group of states including Washington, Utah, Pennsylvania, and Ohio fear that the benefit of savings they might receive from such a program would not make up for the extra costs and that such a program would not be worth the effort, especially when very few requests are received to harvest the hay.

Traffic Safety

Many states expressed concern about traffic safety problems that may be associated with hay harvesting along the highways by private citizens. The appearance of an unexpected slow-moving machine on a major highway right-of-way would probably increase the risk of accident from the standpoint of both sight distance at interchanges and potential hazards related to the harvesting operation. Further, it is more difficult to regulate operations carried out by private interests than those of state maintenance forces. According to the survey, more than 10 states consider harvesting of hay along roadside dangerous and therefore prohibit if.

Although concern about traffic safety is high, the safety records associated with hay harvesting in several other states do not indicate any cause for alarm. South Dakota has had very few problems with traffic safety since the implementation of their program. Wyoming and Missouri have not encountered any major safety problem so far. A detailed examination of the bid specifications for these states leads to the conclusion that well-defined safety regulations are necessary to ensure safe operation.

First, liability insurance is required for the harvester in most of the states. Two hundred fifty thousand dollars for property damage and five hundred thousand dollars in personal liability are most common. In addition, the harvester is required to file a bond to cover the cost of fertilizing the harvested area and guarantee restoration of the right-of-way in Arkansas and Iowa.

Next is the requirement of appropriate sign installation in working areas. The harvester is required to furnish and maintain advance warning signs that conform to either the federal or the state manual on uniform traffic control devices.

Most states do not allow mowing in the median and the interchange areas of Interstates to avoid unsafe operation. In West Virginia, Tennessee, and Illinois, mowing in the median and the interchange is allowed under special arrangement.

Several other regulations for safe operation include access control to the working area, working time constraint, parking of equipment, and so on. It is probable that traffic hazards can be reduced to a minimum when harvesters abide by the regulations.

Contamination of Hay

The hay on highway rights-of-way is subject to contamination by traveling vehicles. The lead and cadmium content as well as litter, debris, and other pollutants in the hay could create problems for cattle feeding and eventually result in a severe public health problem.

This concern is one of the major reasons cited by states for not permitting harvesting of hay along highways. Georgia Department of Transportation indicated that the lead content of grass grown near heavily traveled roads is high enough to be of concern. In Massachusetts, it was feared the amount of chloride in the hay resulting from snow and ice controlling operation could be unhealthy for animals. North Carolina expressed concern not only about lead poisoning but also about broken glass and large debris found in the hay; these would certainly be hazardous to animal life. South Carolina mentioned that a certain amount of the herbicides used for grass and weed control along the Interstate route could be harmful to cattle.

The experiences of those states where harvesting hay along highways is in practice, however, are not discouraging. No state has yet received claims about lead poisoning. Nor has any known disease of or harm to cattle fed on highway hay been reported. However, no claim does not necessarily mean no problem, and the lead content of the hay needs to be tested and analyzed.

In a study conducted in Oregon (3), a number of grass samples collected along various highway locations were tested to check their lead content. It was found that the lead concentration in roadside soil and grass decreases rapidly with distance from traffic or edge of pavement. The highest lead level, which occurred at the edge of shoulder, was less than 40 ppm and it decreased to 10 ppm when the distance from the edge of pavement reached 40 ft. The weighted average of lead concentration was 12-14 ppm. The safe level of lead content, as Buck (4) pointed out, is approximately 100-200 ppm. Consequently the lead content of roadside grass is well below the safety standard. To reduce the chance of any possible contamination hazard, the Oregon program mows the first 15 ft from the highway edge with highway department forces and allows the grass beyond 15 ft to be harvested for livestock forage.

Another study done in Illinois (5) reported a similar result of decreasing lead concentrations of plants with increasing distance from pavement edge. It was found that, within 65.6 ft (20 m) of heavily traveled roads, the lead content in and on various plants was about 30 ppm. At a distance of 98.4 ft (30 m) and more from the pavement, the lead in and on crops was not significantly different from the field average of 8 ppm. On lesser traveled roads, the traffic produced no observable influence on crop lead concentrations.

A laboratory experiment conducted with randomly selected samples of forage from highway right-of-way in Indiana (6) indicated that the concentration of lead, nickel, cadmium, and zinc in the forage is below toxic levels. Table 2 gives the concentrations

TABLE 2 Concentration Levels (ppm) of Pb, Ni, Cd, and Zn in Forage Sampled at Different Locations *(8)*

	Element (ppm)			
Position Along Highway	Pb	Ni	Cd	Zn
25 ft beyond shoulder edge W of I-65 or S of I-70	22.86	2.01	0.37	24.62
Next to shoulder edge W of I-65 or S of I-70	17.48	3.10	0.42	33.34
Median closest to I-65 S or I-70 E	15.94	3.14	0.39	35.39
Next to shoulder edge E of I-65 or N of I-70	19.97	3.50	0.44	37.20
25 ft beyond shoulder edge E of I-65 or N of I-70	23.10	2.53	0.38	27.53
$\bar{x}$	17.83	2.75	0.39	30.81
P[a]	NS	<.01	NS	.07

[a]Probability of a larger F-value due to chance.

of lead, nickel, cadmium, and zinc in forage sampled from different locations. In particular, the overall mean concentration level of lead obtained in this study was approximately 18 ppm, well below the concern level for livestock consuming roadside hay.

Some animal scientists do not regard debris as a problem (7). A preliminary check before mowing can be made to remove large debris, such as muffler or tire pieces, that has fallen from vehicles.

In most states, herbicides will not be sprayed on areas where hay is harvested. A careful coordination between the administration of the spraying program and hay harvesting would possibly reduce the level of contamination due to herbicides.

Although the public health problem may not be significant, the nutritional quality of the hay is generally not very high. Highway hay is mainly rye grass and fescue and some bluegrass and volunteer clover. These are not the best hay for livestock. In states such as Ohio and Virginia where hays are in abundant supply, the private sector would not be interested in cutting highway grass. A number of states reported that, because of the poor quality of highway hay, there have been very few requests to harvest hay along highways.

Aesthetic and Environmental Concerns

In general, the public views a mowed roadside as aesthetically pleasing and an unmowed roadside as less attractive. In regions where mowing has been reduced, complaints about unsightly appearance of the highways are often voiced. Harvesting of hay can help the state maintain a neat appearance of highways. However, some operators do a very poor job of mowing and leave the roadside in an unsightly condition. Furthermore, some states found it difficult to get private harvesters to remove their hay from the right-of-way within the specified time. Thus, adverse aesthetic impact could also be caused by such a program.

From the standpoints of ecology and environment, mowing can potentially disrupt the native flora and fauna growing along a roadside. Unmowed roadside will provide good nesting cover for wild animals and birds. For this reason, reduction in mowing or even no mowing is advocated by some environmental groups. Consequently, a number of states, including Minnesota and South Dakota, have received complaints from environmental groups about hay harvesting. As a result, the Minnesota Highway Department discourages adjacent landowners from mowing roadsides controlled by easement until after July 31 to protect nesting wildlife.

OTHER CONSIDERATIONS

Not only can highway hay be used as forage for livestock, this hay can be applied as a mulch material for construction or maintenance purposes. In Florida, a hay-baling study in two of six districts is currently under way. The hay is being cut from the highways, baled, and delivered using the department's own equipment and forces. The purpose of that study is to determine if it is feasible to use the hay as mulch material for shoulder reworking projects.

There is a positive as well as a negative impact on drainage blockages and fire hazard along highways due to harvesting of hay. Well-mowed rights-of-way would reduce possible fire hazards caused by standing dry grass and facilitate the passage of drainage water. However, the time between mowing of hay and removal of hay would create an ideal situation for fire starts. Besides, failure to remove cut hay from drainage areas could result in even more severe blockages.

Some states do not allow harvesting of hay except in a severe drought season. The hay provided along the highways would be a valuable resource in time of demand. For example, in 1975 Wisconsin and Minnesota experienced a drought condition, and the state governments authorized the cropping of hay free of charge by adjacent farmers from state trunk highway rights-of-way on an emergency basis.

CONCLUSIONS

Traditionally, highway mowing is performed by state maintenance forces or contracted out to private contractors with the state paying the cost. Due to economic constraints, a number of states are tightening their budgets for highway mowing and reducing the frequency. There is a possibility that highway mowing may be partly replaced by private harvesting of hay. Under this program, the state would allow private interests to cut grass on highway rights-of-way and bale it for hay for little or no fee. A possible program may offer haying as an alternative to regular mowing contracts. This would require mowing to minimum standards with harvesting regulated to specific times or locations. This might result in lower bid prices per acre than standard mowing contracts with the difference made up by the value of the hay obtained. It might be more attractive to potential harvesters because there would be some revenue paid by the state for the mowing portion.

In this paper, a review has been made of the current practices of state highway departments. The pros and cons of various aspects of highway hay harvesting have been discussed. It can be concluded that the harvesting of hay on highway rights-of-way is feasible only under certain conditions. First, a suitable geographic condition must exist: the terrain must be flat enough and the areas available for haying must be large enough for possible operation. Next, there must be appropriate legal authority for a highway department to allow such a practice. Most important, there must be sufficient demand for highway hay. Without the interest of farmers and private contractors in mowing the grass, any program would be in vain. The demand for highway hay would depend on its quality as well as on the price and availability of hay in the region. Experience reveals that traffic safety can be maintained with proper regulations and administration of the hay-harvesting program.

The concern about contamination of roadside vegetation by such pollutants as lead and cadmium is a serious one. However, the available information suggests that the level of contamination may not be significant enough to cause any public health problem, particularly if the harvesting is done some distance from the highway edge and along low-volume roads.

Although the economics of a hay-harvesting program may not make such a program implementable in most states at the present time, changes in local demand for hay and in labor and administrative costs of roadside mowing programs may cause the hay-harvesting program to be feasible in the future. The relative success of existing hay-harvesting programs in several states suggests that their potential cost-effectiveness for both state governments and private citizens should be subject to periodic review and consideration.

ACKNOWLEDGMENTS

This paper is based on research conducted by the Joint Highway Research Project of Purdue University in cooperation with the Indiana Department of Highways. The authors are thankful to the various highway departments for furnishing the requested information. This assistance of Joseph Sudol, Barry Partridge, and John Burkhardt of the Indiana Department of Highways and Keith Johnson, David Petritz, and Jerry Cherney of Purdue University is gratefully acknowledged. The authors are also thankful to the reviewers of TRB Committee A3C07 for their helpful comments. The authors are, however, solely responsible for the contents of the paper.

REFERENCES

1. W.M. Gere. South Dakota's Harvesting of Crops in Highway Rights-of-Way. In Transportation Research Record 647, TRB, National Research Council, Washington, D.C., 1977, pp. 25-26.
2. Cost Comparison Study of Roadside Mowing. Research and Training Center, Indiana Department of Highways, West Lafayette, Nov. 1982.
3. J. Hay. Roadside Grass Lead Content. Maintenance Section, Oregon State Highway Division, Jan. 1977.
4. W.B. Buck. Toxic Materials and Neurologic Disease in Cattle. Journal of the American Veterinary Medical Association, Vol. 166, No. 3, Feb. 1975.
5. G.L. Rolfe and A. Haney. An Ecosystem Analysis of Environmental Contamination by Lead. Institute for Environmental Studies, University of Illinois at Champaign-Urbana, Aug. 1975.
6. K.C. Sinha, K.D. Johnson, C.H. Cherney, D.C. Pefritz, K. Hu, J.A. Mullen, and W. Jacobs. Yield, Quality and Lead Content of Forage Along Indiana Highways. Report JHRP-84-6. School of Civil Engineering, Purdue University, West Lafayette, Ind., May 1984.

Publication of this paper sponsored by Committee on Roadside Maintenance.