antecedent moisture is highest in summer (solid line) for pine and broomsedge. In comparing vegetative covers, the highest frequency of dry moisture conditions is maintained by pine followed by broomsedge and barren. Pine cover exhibits the greatest range of antecedent moisture. The greatest difference between winter and summer antecedent moisture for the full range of frequencies was observed under the pine cover.

The objective of drainage design is to size facilities to handle some T-year runoff peak. This study and others have shown that the best antecedent soil moisture assumption for predicting the T-year runoff peak from a T-year rainfall is seasonal antecedent moisture.

The risk analysis has shown, by using probability theory, that cover types that have high evapotranspiration rates (e.g., pine) can provide a drier antecedent soil moisture more frequently than can cover types that have lower evapotranspiration rates (e.g., broomsedge). In addition, seasonal antecedent soil moisture data probably fit a lognormal distribution for Piedmont cover types in other basins where soil and climatic conditions are similar to those found at the Calhoun Forest. Finally, the risk of experiencing a level of $EMC_a > \overline{EMC_a}$ when a design rainfall occurs does not represent a risk of a design failure but simply describes antecedent moisture probability.

CONCLUSIONS

1. Future drainage design work should incorporate source control of runoff through the management of postdevelopment soils and vegetation. This practice will reduce runoff peaks and thereby decrease the need for constructed detention facilities and other costly flood control measures.

2. The design storm concept of sizing drainage facilities is a valid technique only when used with hydrologic assumptions that will facilitate prediction of the T-year runoff peak from the T-year design rainfall. In locations where flood peaks are strongly seasonal, the seasonal rainfall frequency should be used for design. Flood peaks are seasonal if the annual frequency analysis yields the same frequency relation as one of the seasonal frequency analyses. If antecedent soil moisture is a parameter of the method for design peak-flow estimation and flood peaks in the watershed are seasonal, then the seasonal average antecedent moisture should be used for design. If flood peaks in the watershed are not typically seasonal, then the annual average antecedent moisture should be used in design.

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Effects of Dredged Highway Construction on Water Quality in a Louisiana Wetland

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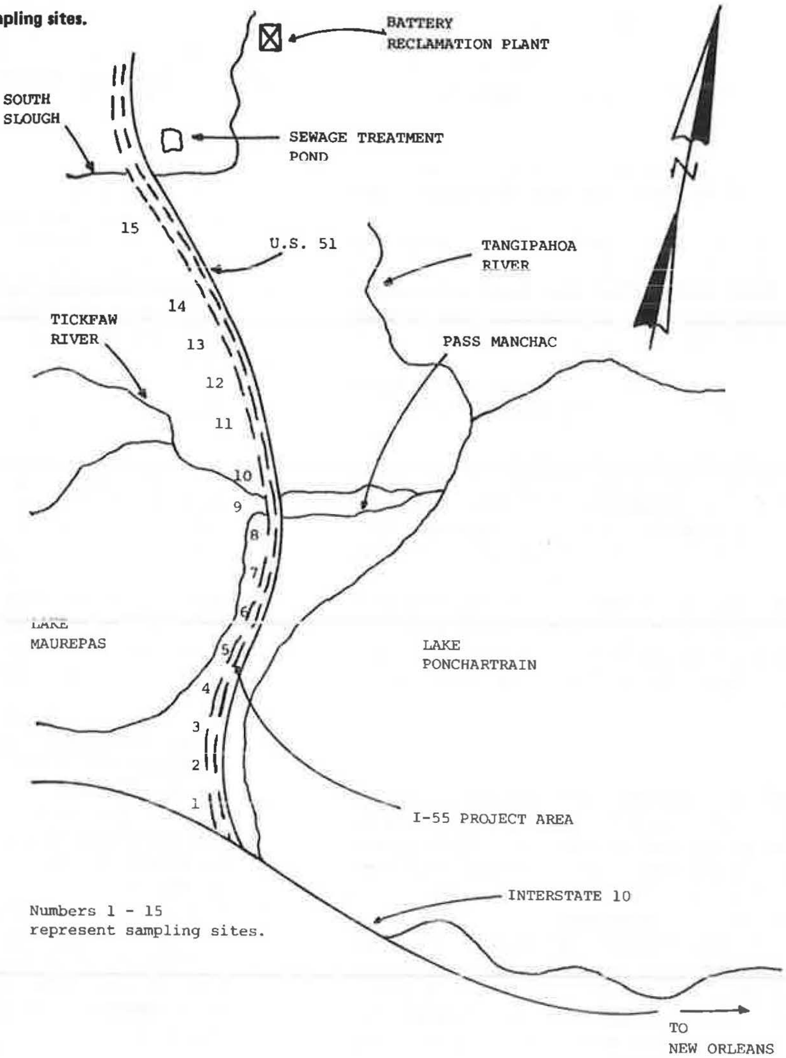
A research effort to determine, by physical and chemical means, the effect of current bridged highway construction techniques on water quality in a wetland is summarized. Selected water-quality parameters were monitored before, during, and after construction activities. The data show increases in turbidity and color during construction and a gradual returning to the preconstruction ambient in areas where construction was completed. Other parameters also followed this trend, but these changes were not as directly related to the construction activities as were turbidity and color. Local isolated activities other than highway construction were shown to produce more severe and longer-lasting effects on water quality. The information obtained may be useful in predicting the degree and duration of impacts of future construction projects on wetland environments.

The effects of highway construction on the water quality of wetland areas have been studied only to a limited degree. The apparent signs of water degradation, such as siltation and sedimentation, have

Figure 1. I-55 project area showing 15 sampling sites.



been seen many times in similar construction situations. The degree of degradation depends on construction techniques and watershed characteristics. Knowledge of the sedimentation process is necessary to assess the effects on the aquatic ecosystem. Chabreck (1) observed that sedimentation and the resulting turbidity depend on the vegetative cover and the soil type for a particular area. Hopkins (2) concluded that highway construction near watercourses should be watched very closely for silting and sedimentation.

The primary objectives of this research were as follows:

1. To provide a baseline or ambient condition for existing water quality.
2. To determine the changes in wetland water quality due to the dredging and construction of an elevated roadway.
3. To determine any residual effect on water quality due to the construction and the time rate of change caused by the construction.

STUDY PLAN

Description of Study Area

The area selected as a typical wetland was the new alignment for Interstate 55 beginning at the Interstate 10 junction north of LaPlace, Louisiana, and ending a few miles north of Pass Manchac between Lake Maurepas and Lake Pontchartrain (see Figure 1). This corridor offered an excellent opportunity for study because it contained areas not yet under construction, areas where construction was in process, and areas where construction was complete.

The area is located in the Mississippi River deltaic plain. Formation of the lakes occurred when two former deltas of the Mississippi River, St. Bernard and Cocodrie, filled in a formerly open bay with clay and silt from high water flows.

The wetlands of the area have undergone a number of changes in the past. In the late 1800s to early 1900s, logging and the Illinois Central Gulf Railroad posed two of the first man-made threats to this sensitive area. The railroad was built along the shores of Lake Pontchartrain and formed a barrier that limited the flushing action of the wetland ecosystem. Cypress logging activities from approximately 1910 to approximately 1935 left scars that can be seen even now when the area is viewed from the air. In 1954, the muck-fill construction of US-51 added to the problem of water movement within this marsh system. These alterations of the drainage patterns have contributed to the spread of the now overabundant water hyacinth (Eichhornia crassipes).

Table 1. Water-quality data.

		Turbidity			Color			Salinity			Dissolved Oxygen			pH		
Phase	Site	N	$\bar{x}$ (NTU)	σ (NTU)	N	$\bar{x}$ (PCU)	σ (PCU)	N	$\bar{x}$ (ppt)	σ (ppt)	N	$\bar{x}$ (ppm)	σ (ppm)	N	$\bar{x}$	σ
Preconstruction	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2	17	15.82	7.61	16	100.94	29.56	16	0.43	0.27	16	3.91	1.48	16	7.09	0.28
	3	37	18.62	12.68	37	84.11	38.82	33	0.36	0.32	26	5.03	2.18	38	7.26	0.23
	4	40	15.30	18.00	40	96.73	41.41	33	0.44	0.54	27	3.84	1.84	40	7.05	0.30
	5	19	8.37	8.62	19	98.15	48.51	19	0.46	0.73	9	3.88	2.43	18	6.73	0.39
Construction	1	33	20.71	20.67	27	101.10	38.86	28	0.33	0.41	23	3.14	2.05	27	7.19	0.30
	2	23	15.57	11.28	23	79.22	31.09	17	0.81	1.35	13	5.53	2.30	23	7.29	0.28
	3	23	19.30	18.89	23	113.29	91.54	14	1.37	1.43	14	6.37	1.85	21	6.89	0.63
	4	17	18.66	16.04	16	190.63	89.40	11	0.50	0.39	10	3.81	2.72	16	6.20	0.57
	5	27	21.39	20.44	27	164.81	52.85	15	0.28	0.31	14	3.19	2.13	27	6.82	0.30
Postconstruction	1	60	6.17	6.11	59	75.29	23.29	49	0.63	0.35	49	4.88	2.82	59	7.21	0.36
	2	51	23.92	31.17	48	140.39	108.04	42	0.52	0.37	42	5.38	2.45	48	7.13	0.38
	3	33	37.24	36.95	32	119.47	79.07	32	0.94	0.62	33	7.15	2.22	33	7.37	0.29
	4	33	22.46	33.91	33	134.61	50.08	32	0.21	0.32	33	4.71	2.03	33	7.12	0.48
	5	27	15.11	18.33	26	133.15	36.77	27	0.09	0.22	28	4.48	2.43	27	6.82	0.30

Note: NTU = nephelometric turbidity units, PCU = platinum cobalt units, ppt = parts per thousand, and ppm = parts per million.

Performed Work

The construction technique used in this construction project consisted of using a dredge barge to dig an access canal between the existing borrow canal for US-51 and the US-51 roadway. This canal provided access for construction of the new bridged highway supported by concrete piles. In later years, the canal will provide access for maintenance of the structure as well as an area for a new aquatic habitat.

Two mitigation techniques were used on this construction project. The first technique required the spoil from the canal excavation to be placed in spoil areas so that water runoff from the dredging operation returned to the channel being excavated. The second technique was the use of earth plugs to minimize exchange of water along the new construction canal. By this means, increased sedimentation due to dredging was restricted to a specific area and not allowed to migrate the length of the new construction canal.

Hydrology

The major tidal flows and currents in the lakes are east-west in direction. Normal tidal fluctuations are 1-2 ft with storm tides of 3-4 ft. The borrow canal being studied generally travels in a north-south direction. Therefore, the tidal actions and currents from Lake Pontchartrain and Lake Maurepas exert a minimal effect on the study waterway. Data on the volume of water flowing through the Pontchartrain Basin and the study area are not readily available.

Sampling

Sampling sites were established in three different areas: one area not yet under construction, one area under construction, and one area where construction was completed. The number of sites originally selected for the monitoring study was 15 (Figure 1), but this was later reduced to 5 for better control. Sites that exhibited the stream characteristics most "typical" or representative of the area were chosen. Stream characteristics include depth, velocity of flow, stream bottom substrate, vegetation, and aquatic and wildlife habitat. Other factors used in site selection were the type of construction in the area and the accessibility of the site.

The sampling program was set up so that samples could be taken and processed within a one-week period. The sampling frequency was based on seasonal and climatic factors and construction activities. The schedule was adjusted for major events that affect runoff, such as heavy rains or unusual tides.

Construction

For the purposes of the study, "construction" was defined as any activity preparatory to or a part of the actual erection of the superstructure. This included clearing, grubbing, grading, filling, embankment development, and all structural work on the superstructure. It did not include finish work such as barrier rails, signs, and safety markers.

"Nonconstruction" was used to indicate that none of the above activities was in progress at the time of sampling. Due to variations in the work schedule based on the contractor's own time frame, the only separable parts of the construction activities were the dredging and structural work within these two categories; the various activities at each site were mixed up and followed no predictable sequence. Therefore, it is impossible to be any more specific about these activities.

Measured Parameters

The parameters selected for monitoring in this study were grouped into two categories. The first category included all parameters measured in the field study, such as temperature, salinity, pH, conductivity, and dissolved oxygen. The second category was the laboratory study in which turbidity, color, nutrients, and periodic oil and grease samples were evaluated. All laboratory tests were run at the Louisiana Department of Transportation and Development Materials Laboratory.

DATA ANALYSIS AND INTERPRETATION

The results of sampling and testing at each site for all parameters are summarized in Table 1. For each parameter, this table gives the total number of samples taken at each of the five final sites for the period of May 1975 to March 1980, the mean for each site, and the standard deviation of the samples taken during this period of time for each site. The data have been divided and analyzed in relation to preconstruction, construction, and postconstruction time frames. The variability of the data is expressed as sigma, the standard deviation of the observations. The magnitude of the standard deviation should be considered as a measure of the variability associated with material, sampling, and testing. The following is a brief description of the findings for each of the major parameters.

Turbidity

Turbidity is the term used to describe the degree of opaqueness produced in the water by suspended particulate matter. The major effects of high turbidity are (a) the quenching of light penetration, which inhibits photosynthesis and the production of oxygen by plants; (b) the building of zones of mud, silt, other sediments, and detritus; and (c) depletion of the dissolved oxygen as a result of respiration in the breaking down of suspended organic materials. The turbidity test data indicated that there were localized effects of construction on turbidity at site 1. The data also indicate that the turbidity began to decrease after completion of construction activities. Day and Boucher (3) indicated that this is the normal sequence of events with the parameter in relation to construction activities. There is a trend toward greater turbidity in the waters at sites 9 and 15. This is indicated by the preconstruction and postconstruction test data, which show overall increases in turbidity. At site 9, the most probable cause is the result of increased currents and tidal changes. At site 15, the increased turbidity is the result of off-site water pollution and low flows.

The effects of the construction were as predicted by Day and Boucher (3)--that is, minimal, controllable, and not of long duration.

Color

Color is defined as a quality of a visible phenomenon distinct from form and from light and shade. The standard test used in this project is the platinum cobalt spectrophotometric procedure of the U.S. Environmental Protection Agency (5). The color results indicated that there was an overall trend for the color to increase at the north end of the project. The data also indicate that construction activities at sites 12 and 15 increased the color content and, once the construction was completed, the trend was for the color to return to the ambient level.

Salinity

Salinity is a measure of the concentration of dissolved salts in water, expressed in parts per thousand. According to Cole (4), "Salinity affects the numbers and kinds of animals that can live in the area. Salinity also affects the amount of oxygen that can be dissolved in the water."

Significant changes in salinity occurred at sites 1, 9, 12, and 15. The data for sites 1 and 9 indicate that the salinity changes were due to natural phenomena rather than to construction activities. Sites 12 and 15 were subject to pollution from a used automobile battery plant. The effects of this are indicated by the decrease in salinity after the pollution of the project area by the battery junkyard was reduced.

Dissolved Oxygen

The amount of oxygen found in the water and available for use by aquatic flora and fauna is termed dissolved oxygen (DO). All of the significant test data indicate that the DO content was continuously increasing at sites 1, 5, and 9 throughout the duration of the project. The remainder of the sites showed no significant changes. The cause or causes of this were not determined in the study.

pH

The symbol pH represents the concentration of hydrogen ions (H^+)--i.e., the intensity of the acid. The pH of most inland waters varies from 6.0 to 9.0 depending on the amount and type of organic and/or mineral loads. The waters of the project area are subject to heavy organic loading from the marshes and swamp, which are the source of many organic acids.

The only effects of the construction were shown as a general trend to varying degrees at sites 1, 5, and 9. There the pH became more acidic during construction and then returned to the more alkaline ambient. Sites 12 and 15 showed the same tendency; however, because of pollution with battery acid during the project, the effect cannot be definitely attributed to the construction activities.

Solids

The solids category includes total, suspended, dissolved, and volatile solids. The tests on the various categories of solids produced few significant results. The parameter of volatile solids was deleted due to excess variability. The dissolved residue data indicated no significant change. The suspended residue showed increases at sites 12 and 15 during construction and a return toward the ambient after completion of construction.

The only significant change in total solids was a decrease at site 15 between the preconstruction data and postconstruction conditions. Although the data indicate that the decline in total solids continued through the construction activities, the initiation of the decline before and the continuation of it after construction make it doubtful that this improvement in water quality is related to the construction activities.

CONCLUSIONS

Review of all the data and external conditions affecting the various parameters leads to the identification of three highly significant trends within the study:

1. Elevated highway construction with environmental controls has minimal effects on the quality of the surrounding water.
2. Any effects produced by the construction tend to be temporary in nature and, once the construction is completed, the water quality tends to return toward the preconstruction ambient.
3. Local activities other than highway construction may produce greater and longer-lasting adverse effects on water quality.

It is recommended that future projects for this type of evaluation select research areas that absolutely minimize the influences of activities other than highway construction. These future projects should be designed very carefully to ensure a proper sampling program, a thorough evaluation of preconstruction (ambient) water-quality conditions, and a sufficient postconstruction period of evaluation to determine definitely whether the changes in water quality due to elevated highway construction are indeed reversible.

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Management of Drainage Systems from Highway Bridges for Pollution Control

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Pollutants associated with runoff water from highway bridges were characterized and quantified. These pollutants are directly discharged through scupper drains to adjacent water bodies and floodplains or detained in ponds before being released to lakes and streams. Selected heavy metals, such as lead, zinc, copper, chromium, iron, nickel, and cadmium, were of particular concern because of their potential enrichment in biota. Results show significant differences in heavy metal concentrations between water samples from bridge runoff and adjacent streams. Heavy metals tend to concentrate in bottom sediments, floodplains, and adjacent soils. For example, bottom sediment samples from Lake Ivanhoe, north of Orlando, Florida, collected beneath bridges with scupper drains showed significantly higher concentrations of heavy metals than did samples collected beneath bridges without scupper drains. In addition, concentrations of heavy metals in the sediments of detention ponds receiving bridge drainage were higher than concentrations in sediments from adjacent lakes. It appears that management and careful design consideration of highway bridge drainage systems could result in significant reduction of the amount of pollutants released to adjacent water bodies.

In a 1979 National Cooperative Highway Research Program report, Shuldiner, Cope, and Newton (1) recognized the need for environmental impact assessment studies to satisfy guidelines for state and local agencies, U.S. Army Corps of Engineers permit procedures, and Section 4(F) of the U.S. Department of Transportation Act of 1966, as amended. They developed a user's manual and listed possible physical, chemical, and biological impacts from pile-supported roadway or bridging construction, maintenance, and use. These activities could result in major or variable impacts on turbidity, sedimentation, and chemical pollution. Biological responses may include changes in plant species composition, changes in primary and secondary productivity, and, in some cases, sudden mortality of aquatic species. The quantity and significance of these impacts have not been determined.

Many investigators, including Pitt and Amy (2), Sartor and Boyd (3), and Shaheen (4), had determined pollutant loadings, particularly lead (Pb), iron (Fe), zinc (Zn), cobalt (Co), chromium (Cr), nickel (Ni), and cadmium (Cd), associated with highway surfaces. Wanielista, Yousef, and Christopher (5) investigated pollutants from highway bridge runoff. Bell and Wanielista (6) investigated the transport of heavy metals by overland flow. They detected relatively high concentrations in adjacent soils.

This paper reports on pollutants detected in bridge drainage and associated impacts on the receiving land and/or freshwater environment.

RUNOFF FROM HIGHWAY BRIDGES

Lake Ivanhoe is a 125-acre freshwater lake located just north of the downtown section of the City of Orlando, Florida. A section of the central portion of the lake was filled in 1965 during the construction of Interstate 4, and the central island created was connected to the northern and southern shores by means of two bridges, as shown in Figure 1. The north bridge at Lake Ivanhoe consists of two sections, one for westbound traffic and one for eastbound traffic, each carrying three lanes of through traffic. Water on the bridge drains toward the adjacent land on either side since there are no scupper drains on the bridges. The south bridge also consists of two sections. Water is drained by a set of 4-in-diameter plastic pipe scupper drains set at 8-ft centers running along the eastern edge of the bridge. The average daily traffic (ADT) volume across Lake Ivanhoe, as provided by the Florida Department of Transportation (FDOT) during 1980, was approximately 45 000 to 50 000 eastbound and 48 000 to 58 000 westbound.

Samples were taken from beneath the northern bridges, from beneath two sets of scuppers on the southern bridges, and from the main body of the western portion of the lake, to serve as a control section. Direct runoff samples were collected directly from the scupper drains during three storm events in mid-August 1979. A total of 11 separate runoff samples were collected by taking samples from four different drains during each storm event.

The total concentrations of Zn, Pb, Ni, and Fe in runoff water averaged 4.7, 20.8, 3.5, and 12.6 times higher, respectively, than the average concentrations in Lake Ivanhoe, as given in Table 1. It is difficult to assess the relative impact of the bridge runoff due to a lack of specific information about the location and loadings from other sources and mixing zones within the lake.

Lead in the scupper drain runoff water was of special interest because it was detected in the highest concentrations of all the toxic heavy metals. The average lead concentration in the waters of Lake Ivanhoe (75 μg/L total Pb) and in the scupper drain runoff water (1558 μg/L total Pb) violates the maximum permissible concentration recommended by the Florida Department of Environmental Regulation. The rules specify that concen-