Louisiana Agricultural Experiment Station, Baton Rouge, Bull. 664, 1972, 72 pp.
2. H.T. Hopkins and others. Processes, Procedures and Methods to Control Pollution Resulting from All Construction Activity. Office of Air and Water Programs, U.S. Environmental Protection Agency, 1973, pp. 2-169.
3. P.B. Day and R.J. Boucher. Turbidity Study: Final Report. Materials and Research Division, Bureau of Highways, Maine Department of Transportation, Bangor, 1980, 26 pp.
4. G.A. Cole. Texbook of Limnology. C.V. Mosby Co., St. Louis, 1975, 225 pp.

Publication of this paper sponsored by Committee on Hydrology, Hydraulics, and Water Quality.

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-

Figure 1. Sampling locations for bridge runoff at Lake Ivanhoe.

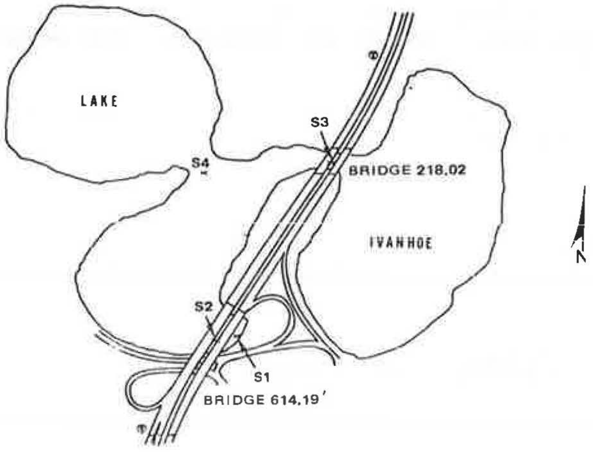

Table 1. Comparison of heavy metal concentrations in bridge runoff and Lake Ivanhoe water samples.

		Avg Concentration (μg/L)		Dissolved (%)		
Element	Form	Lake Ivanhoe	Bridge Runoff	Lake Ivanhoe	Bridge Runoff	Runoff/Lake Ratio
Zn	Total	104	498			4.7:1.0
	Dissolved	57	336	55	67	5.9:1.0
Pb	Total	75	1558			20.8:1.0
	Dissolved	55	187	73	12	3.4:1.0
Ni	Total	15	53			3.4:1.0
	Dissolved	9	49	60	92	5.4:1.0
Fe	Total	192	2427			12.6:1.0
	Dissolved	68	287	35	12	4.2:1.0

trations of Pb in all surface waters should not exceed 50 μg/L.

The heavy metals released into Lake Ivanhoe through the scupper drains can be estimated by assuming an average yearly rainfall of 50 in/year on the 73 440 ft^2 of bridge surface and the average concentrations determined in the runoff water from the south bridges during this study. The loadings based on these assumptions were 13.5 kg/year total and 1.6 kg/year dissolved lead, 4.3 kg/year total and 2.9 kg/year dissolved nickel, and 0.1 kg/year dissolved chromium. These loadings are probably conservative estimates of pollutants released to Lake Ivanhoe because dust fall and bulk precipitation have not been considered.

The fate of the heavy metals released into the waters of Lake Ivanhoe could not be completely predicted. Lead, which had the highest average concentration of the toxic heavy metals in the scupper runoff water, was shown to be primarily in the particulate form, 88 percent of the total lead. The exact fate of this particulate matter is not fully known; however, as reported by Olson and Skogerboe (7), lead compounds have generally been associated with the most dense fractions of the soil and should settle out of the water close to the point of release.

BOTTOM SEDIMENTS

Sediment samples were collected from several locations of each of the principal sampling sites in Lake Ivanhoe and measured for extractible metals. A statistical analysis was performed to compare the concentrations of heavy metals in the sediments collected underneath the south bridges with scupper drains and the north bridges without scupper drains. The results of the test analysis comparing the samples are presented in Table 2. The concentrations of Zn, Pb, Ni, and Fe were found to be significantly greater in the sediments underneath the south bridges with scuppers at the 99 percent confidence level. Lead concentrations were significantly different at the 99.9 percent confidence level and were more than three times higher in the sediments beneath the bridges with scuppers. Statistical analysis shows that there is significant heavy metal enrichment in the sediment underneath the bridges with scuppers. It supports the conclusion that heavy metals associated with particulates, especially lead, which was 88 percent in the particulate form in the runoff samples, will settle out and become immobilized in the sediments near the point of release.

RETENTION-DETENTION PONDS

The Maitland interchange north of Orlando was constructed in 1976. Maitland Boulevard crosses over I-4 by means of a bridge overpass created during construction of the interchange. The traffic lanes on the Interstate are separated by a 20-ft grassy median as they approach the interchange. The median widens to 44 ft through the interchange. Stormwater coming off the Interstate is delivered by overland flow over a good grass cover to storm-drain inlets or receiving waters. Three borrow pits that were dug to provide fill for the construction of the overpass remain in existence, serving as stormwater retention-detention facilities. Stormwater runoff from the Maitland Boulevard bridge crossing over I-4 is conveyed directly off the roadway surface through storm-water inlets to culverts that discharge directly into the ponds. The ponds are interconnected so that the two northernmost ponds flow into the southwest pond (referred to hereafter as the west pond) when they reach a certain design level. The water from the west pond flows over a wooden weir at its southern end, which is connected to Lake Lucien by means of a culvert and a short, densely vegetated ditch (see Figure 2). Runoff to the ponds is essentially all from the roadway environment, and flow to Lake Lucien is a combination of natural, highway, and citrus runoff. Lake Lucien is a 57-acre freshwater lake, and the lack of significant development on its shores has left it in a relatively clean condition.

The Maitland Boulevard bridge consists of two sections, one that carries two lanes of eastbound traffic plus one exit lane and another that carries two lanes of westbound traffic plus one exit lane. ADT on Maitland Boulevard was approximately 11 000 eastbound and 10 000 westbound during the early period. I-4 has three lanes of through traffic eastbound and westbound through the Maitland interchange. ADT on I-4 through the Maitland interchange was approximately 32 000 to 40 000 eastbound and westbound.

Three sets of samples were collected from the Maitland interchange site--one from the west pond, one opposite the outfall of the west pond into Lake Lucien, and one from the center of Lake Lucien to serve as a control.

The statistical comparison of the west pond and Lake Lucien (Table 3) showed that concentrations of dissolved and total lead, total chromium, and total iron were significantly greater in the west pond at the 95 percent confidence level. The west pond was also noted to be highly turbid, with many fine particulates in suspension, which would help to

Table 2. Significance of differences in heavy metal concentrations of bottom sediments from Lake Ivanhoe (t-test analysis).

	Mean Dry Weight (μg/g)		
Element	South Bridges With Scuppers[a]	North Bridges Without Scuppers[b]	Probability (%)
Zn	96.9	42.0	99.60
Pb	423.0	132.0	99.99
Cr	23.9	11.0	97.07
Ni	7.2	2.8	99.60
Cu	80.1	29.2	98.71
Fe	1689.0	643.0	99.85

[a]Eight samples were collected. [b]Seven samples were collected.

Figure 2. Sampling locations for bridge runoff at Maitland Interchange.

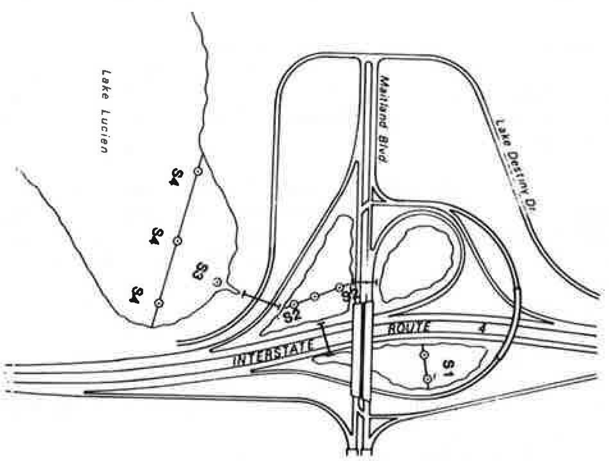

Table 3. Significance of differences in heavy metal concentrations in water samples from Maitland Interchange.

	Avg Concentration (μg/L)					
	Total		Dissolved		Probability (%)	
Element	Lake Lucien	West Pond	Lake Lucien	West Pond	Total	Dissolved
Zn	56	64	34	43	45.9	75.6
Pb	33	92	19	66	99.9	98.6
Cr	8.6	17	5.4	7	94.9	70.4
Ni	7.3	15	3.4	5	80.8	53.6
Cu	36	38	19	21	29.2	34.9
Fe	182	414	82	128	98.4	52.4

explain the higher total concentrations reported there.

A comparison of sediments from the west pond and sediments from the center of Lake Lucien (see Table 4) showed that concentrations of Pb, Cr, Ni, Cu, Fe, and Cd were 3-22 times greater in the sediments of the west pond. The analysis of Pb, Cr, Ni, Fe, and Cd showed significant difference at the >95 percent confidence level. A comparison between the west pond and the outfall area into Lake Lucien did not exhibit similar results (5). The sediments from the downstream area of the outfall were similar in concentration levels to those found in the west pond. These concentrations may be due in part to the high organic content of these sediments and flow leakage through the wooden slats of the exit weir from the west pond to the outfall area during periods of no flow over the weir. The use of a control structure that prevents leakage and the installation of underdrains or a simple filtration device to remove heavy metals by adsorption and filtration can significantly reduce the amount of heavy metals leaving the west pond.

Table 4. Significance of differences in heavy metal concentrations in bottom sediments from Maitland Interchange (t-test analysis).

	Mean Dry Weight (μg/g)		
Element	Lake Lucien	West Pond	Probability (%)
Zn	21.1	35.2	80.27
Pb	3.4	76.0	97.51
Cr	2.5	33.9	98.87
Ni	1.2	10.7	97.64
Cu	5.0	15.2	93.17
Fe	421.4	3264.7	98.62
Cd	0.1	0.7	96.05

FLOODPLAINS

Floodplains may filter out nutrients, heavy metals, sediments, and other pollutants and store them within the ecosystem. It is possible to use these floodplains for treatment of controlled highway bridge runoff without damaging their habitat. Odum (8) stated that wetlands are natural water management and treatment systems that operate on solar energy. The extent of their tolerance to heavy metals and highway-related activities is not well defined.

Soil and plant samples were collected from floodplains beneath highway bridges located at US-17-92 and Shingle Creek, US-192 and Shingle Creek, and I-4 and Padgett Creek in central Florida. These bridge areas receive direct runoff water through scupper drains or curb-and-gutter drainage systems. Control areas were selected upstream and downstream from the bridge areas. Preliminary results of heavy metal concentrations in soil and plant samples collected from bridge areas and control areas were analyzed.

The data indicated higher concentrations of heavy metals, particularly lead, in soil samples collected from bridge areas than were found in samples collected from control areas (see Table 5). Lead concentrations in soil samples from bridge areas were 78, 3.3, and 23.4 times higher than control samples from US-17-92 and Shingle Creek, US-192 and Shingle Creek, and I-4 and Padgett Creek, respectively. Plant samples exhibited similar trends, but the difference between plant samples from bridge areas and control areas was not as high as the difference in the soil samples. The work is continuing, and no obvious differences have been observed in the diversity of plants located in various areas surrounding the bridges. However, bioassay experiments in the laboratory tend to show increased plant productivity as a result of discharging runoff from highway bridges to adjacent streams (9).

CONCLUSIONS AND RECOMMENDATIONS

This paper has presented various examples of the management of bridge runoff. They include direct discharge of storm water through scupper drains to Lake Ivanhoe and I-4. Heavy metals, particularly lead and iron, in the scupper drain runoff were mainly in the particulate form, since an average of only 12 percent of the total concentration was in the dissolved form. These particulate fractions were most likely to settle out from the water column in the immediate vicinity of the point of release and become immobilized by the sediments. This may have resulted in the concentrations of Pb, Cr, Fe,

Table 5. Statistical analysis of extractable heavy metals in soil samples collected from floodplains receiving highway bridge runoff.

Location	Element	Control: No. of Samples	Control: Oven Dry Weight (μg/g) x	Control: Oven Dry Weight (μg/g) σ	Bridge Area: No. of Samples	Bridge Area: Oven Dry Weight (μg/g) x	Bridge Area: Oven Dry Weight (μg/g) σ
US-17-92 and Shingle Creek	Zn	9	2.1	0.8	14	46	40
	Fe	9	487	108	14	1213	689
	Pb	9	3.5	1.3	14	273	339
	Cr	9	1.3	0.7	14	5.7	4.3
US-192 and Shingle Creek	Zn	4	17	14	12	7.7	0.4
	Fe	4	302	94	12	607	164
	Pb	4	11	7.4	12	36	4.7
	Cr	4	1.7	2	12	3.6	3.1
I-4 and Padgett Creek	Zn	4	50	13	8	253	159
	Fe	4	3392	1485	8	5738	1202
	Pb	4	93	40	8	2174	2128
	Cr	4	16	6.8	8	17	4.0

Ni, and Zn in the sediments underneath the scupper drains being significantly higher than concentrations in the sediments collected from areas beneath the bridges without scupper drains.

Most of the heavy metals released to Lake Ivanhoe were concentrated in bottom sediments. On a mass balance basis, which estimated the average distribution of heavy metals per unit area among the dissolved fraction, the suspended fraction, and bottom sediments, it was shown that most of the heavy metals--typically 95-98 percent of the total--were associated with the bottom sediments (5). As a result, high concentrations of heavy metals in submerged plants and benthic organisms were detected.

Limited results from highway bridge sites that release runoff to floodplains demonstrated the capacity of soil to concentrate heavy metals. Floodplains are conjectured to be possible sinks of metals. The sorption-desorption capacities of floodplains are currently being investigated. It is also encouraging to notice no significant difference in plant diversity on soils located close to the bridge sites and control areas. Floodplains could become a feasible alternative to receive runoff from highway bridges.

The study conducted at the Maitland interchange was useful to illustrate the function of retention-detention ponds, which seemed to concentrate heavy metals associated with highway runoff and could be maintained to effectively minimize release of pollutants to adjacent Lake Lucien. Detention ponds retain an initial amount of runoff and release it into the lake at a controlled rate through the use of well-designed outlet structures. The outlet hydrograph depends on the type of control structure and the size of the detention pond. Detention reduces peak flows and suspended solids and can provide other pollutant removal efficiencies for storms of short duration (10,11).

When highways pass over bodies of water, especially land-locked impoundments where the effects of heavy metal pollution are more localized and where high traffic volumes are encountered, it is recommended that

1. The use of scupper drains in new construction be limited as much as possible,
2. Runoff from the bridge surface be directed off the bridge surface toward either side so that the runoff will experience the maximum overland flow to encourage percolation and removal of heavy metals by the soil before the runoff reaches the receiving body, and
3. Future research be conducted to determine the extent of the floodplain required adjacent to a bridge to create a desirable level of heavy metal removal.

Where detention-retention systems are used in conjunction with highways for the control and storage of runoff before the runoff is discharged into a receiving water body and where heavy metal removal is desired,

1. Control structures should be installed to ensure that heavy metals are not released to the receiving water body during periods of no flow by flow leakage between the ponds and the receiving waters,
2. Natural vegetation canals can be used to convey water from the detention-retention pond to the receiving water body to enhance additional settling out and adsorption of heavy metals before introduction of the runoff into the main body of the receiving water, and
3. Further research should be conducted to develop construction practices and management schemes for these detention-retention ponds to maximize removal of heavy metals, and consideration should be given to the types of sediments that afford the greatest degree of removal and the role and best types of plants that might be introduced to increase heavy metal removal.

ACKNOWLEDGMENT

We wish to acknowledge with gratitude the financial support and technical assistance received from the Federal Highway Administration and FDOT. The interest and assistance of Gary Evink and Larry Barfield of FDOT are most gratefully appreciated.

REFERENCES

1. P.W. Shuldiner, D.F. Cope, and R.B. Newton. Ecological Effects of Highway Fills on Wetlands. NCHRP, Rept. 218A, Dec. 1979.
2. R.E. Pitt and G. Amy. Toxic Material Analysis of Street Surface Contaminants. U.S. Environmental Protection Agency, Rept. RZ-73-283, Aug. 1973.
3. J.D. Sartor and C.B. Boyd. Water Pollution Aspects of Street Surface Contaminants. U.S. Environmental Protection Agency, Rept. RZ-72-081, Nov. 1972.
4. D.C. Shaheen. Contribution of Urban Roadway Usage to Water Pollution. U.S. Environmental Protection Agency, Rept. 600/2-75-004, 1975.
5. M.P. Wanielista, Y.A. Yousef, and J.E. Christopher. Management of Runoff from Highway Bridges. Florida Department of Transportation, Tallahassee, Final Rept., Oct. 1980, 140 pp.
6. J.H. Bell and M.P. Wanielista. Use of Overland Flow in Storm-Water Management on Interstate

Highways. TRB, Transportation Research Record 736, 1979, pp. 13-21.
7. K.W. Olson and R.K. Skogerboe. Identification of Soil Lead Compounds from Automotive Sources. Environmental Science and Technology, Vol. 9, March 1975, pp. 227-230.
8. H.T. Odum. Proceedings of the National Wetland Protection Symposium, Reston, Virginia, June 6-8, 1974. U.S. Department of Interior, FWS/OBS-78/79, 1979, pp. 9-18.
9. Y.A. Yousef and H.H. Harper. Effects of Bridging on Biological Productivity and Diversity in the Flood Plain. Univ. of Central Florida, Orlando, STAR Project 80-074 (in preparation).
10. W. Whipple, Jr. Dual Purpose Detention Basins. Journal of Water Resources Planning and Management Division, ASCE, Vol. 105, No. WR2, Sept. 1979, pp. 403-412.
11. R.H. McCuen. Water Quality Trap Efficiency of Stormwater Management Basins. Journal of AWWA, Vol. 16, No. 1, 1980, pp. 15-21.

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

Field Instrumentation for Monitoring Water-Quality Effects of Storm-Water Runoff from Highways

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Storm-water runoff from operating highways can carry considerable quantities of pollutants, especially petroleum hydrocarbons and solids and metals, into the nation's receiving waters. The Federal Highway Administration, charged with the responsibility of protecting the environment from pollution from highway sources, has approached the problem in a multiphase research effort. The objective of the first phase was to identify and quantify the constituents of highway runoff. The next phase sought to identify sources and migration paths of these pollutants from the highways to receiving waters. The third phase, currently in progress, is analyzing actual impacts of highway runoff on receiving water. A wide variety of instrumentation has been used in the field monitoring portions of the investigation. Physical, chemical, and biological characterizations have been made. A general description of the types of equipment used in all three phases of the research program is presented. Included are brief observations on the effectiveness of certain types of specialized equipment not common to most water-quality surveys. It is hoped that this information will be of assistance to the highway community in planning and conducting environmental monitoring programs.

The highway system is a potential source of many possible pollutants to surrounding surface and subsurface waters. The National Environmental Policy Act of 1969 (NEPA) mandates that, for all federal projects that affect the environment, government agencies shall use a systematic, interdisciplinary approach that will ensure integrated use of the natural and social sciences and the environmental design arts in planning and decisionmaking. The Federal Water Pollution Control Act amendments of 1972 set a national goal of restoring and maintaining the chemical, physical, and biological integrity of the nation's water resources. In addition, many states either have already enacted or are in the process of enacting legislation similar to NEPA that may be more stringent than the federal laws in controlling various point and nonpoint discharges. Thus, consideration of the effects of a highway system on the environment plays an increasingly important role in the planning, design, construction, and operation of a transportation system.

Millions of roadway miles across the country pass over or near a variety of receiving waters. Thus, large volumes of highway storm-water runoff from highway right-of-way drainage areas are eventually discharged to a variety of large and small watersheds. The roadway contaminants contained in runoff might exert significant impact on receiving waters due to both chronic and acute loadings. However, there is currently very little information in the available literature on impacts on receiving water from highway runoff. Therefore, it is necessary to develop information on these impacts in order to properly address the need to protect the quality of receiving water from degradation.

The Federal Highway Administration, charged with responsibility for protecting the environment from pollution from operating highways, has approached the problem in a multiphase research effort that has the following objectives:

1. To identify and quantify the constituents of highway runoff,
2. To identify the sources and the migration paths of these pollutants from the highways to the receiving water,
3. To analyze the effects of these pollutants on receiving waters and on specific aquatic biota, and
4. To develop the necessary abatement and treatment methodology for objectionable constituents.

To date, studies designed to fulfill the first two research objectives have been effectively completed. A study of actual impacts on receiving water (objective 3) is currently under way. It should be noted that the scope of the research program is nationwide. Six sites located in different geographic regions of the contiguous United States were monitored in the phase 1 study. Four sites are to be used for both the phase 2 and phase 3 evaluations.

The objective of this paper is to describe instrumentation requirements for conduct of such a comprehensive field monitoring program. The scope is limited to types of equipment actually used in the program but includes physical, chemical, and biological techniques. To date, only lotic (flowing water) receiving water systems have been studied in the phase 3 research and only instrumentation pertinent to these types of systems is included in this discussion.

METEOROLOGICAL MONITORING

The meteorological parameters of most importance in this type of water-quality study include precipita-