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EFFECTS OF HIGHWAY RUNOFF ON RECEIVING WATERS

Vol. V: Guidelines for Conducting Field Studies

Final Report

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16. Abstract

Guidelines for conducting comprehensive field monitoring programs are provided in this volume. Included are detailed descriptions of site selection, planning aspects, station location, equipment installation and maintenance, sampling methodology, physical/chemical analytical methods, data analyses and glossary. All aspects of field practices are covered for surface water impact evaluation including hydrologic, chemical, sediment and biological components.

The titles of the volumes of this report are:

FHWA-RD-	Volume	Title
84/062	I	Executive Summary
84/063	II	Results of Field Monitoring Program
84/064	III	Resource Document for Environmental Assessments
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METRIC CONVERSION FACTORS

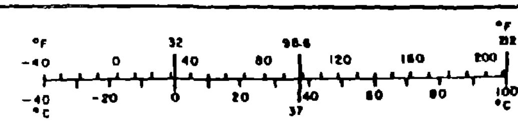
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF TABLES

LIST OF TABLES (continued)

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SECTION 1
INTRODUCTION

As a result of federal and state legislation passed in the last decade (National Environmental Policy Act (NEPA), 1969 and Water Pollution Control Act 1972, Clean Water Act, 1977), highway agencies are obligated to assess the potential for environmental impact of any proposed highway project. One vital aspect of this assessment is that of potential impact from stormwater runoff from operating highways.

In response to this need, the Federal Highway Administration embarked upon a multiphase research program to determine the nature and magnitude of stormwater runoff effects on surface water resources. The first phase quantified the characteristics of these discharges and developed a predictive statistical model to estimate pollutant loadings (1). The second phase identified the sources of these pollutants and their mode of migration and fate from right-of-way to receiving water (2). The third phase, from which this report volume derives, investigated the potential for actual impacts upon receiving waters.

Extensive field studies were conducted at three receiving water/highway sites. These studies involved detailed monitoring of hydrologic, chemical, biological and sediment regimes of the receiving water and direct tributary basins. The results of these studies can be found in Volume II of this report.

The objective of this manual is to provide state highway agencies (HA) with information on methods for field monitoring of highway runoff impacts on surface waters. The manual is designed, through detailed descriptions and references, to allow the user to either conduct such a field study in-house or to effectively review proposals from extramural investigators. Standardized techniques are referenced as much as possible, especially those developed by the United States Geological Survey. This will insure comparability of data collected by diverse agencies. The manual emphasizes procedures for more comprehensive programs including continuous data collection and coverage of all aquatic impact components (physical, chemical and biological). It is recognized that many programs will not require this degree of analysis (as discussed below in more detail). However, the same basic sampling methodologies will have to be used regardless of the program complexity. The only difference would be in duration and scope. Obviously, the HA will have to tailor the program to meet both objectives and available funds.

The scope of the manual includes the following areas:

1. Planning a monitoring program,
2. Site selection criteria,
3. Instrumentation requirements,
4. Field monitoring strategies for:
    a. Collection of background meteorological data,
    b. Hydrological characterization,
    c. Water quality assessment,
    d. Sediment quality assessment,
    e. Analytical methods,
    f. Biological assessments, and
    g. Bioassay testing, and
5. Data evaluation and impact assessment.

FIELD MONITORING PROGRAM SCOPE AND OBJECTIVES

Several circumstances could prompt a state highway agency to conduct (or fund) a field monitoring program to determine water quality effects. These include:

1. Data support for NEPA related documents, including pre-construction and post-construction monitoring,

2. Monitoring required by conditions placed in permits issued by state or federal agency (eg., Section 404, NPDES, CAMA).

3. Fulfillment of agency research objectives, including in-house state HA projects, interagency programs, and federal programs.

The required scope of the program of course relates to both the objective and the available funds. The most common circumstance would be the need to provide data to answer general or specific questions raised by agencies reviewing draft environmental impact statements. Most of the general questions concerning highway runoff quality and receiving water impacts can be answered by utilizing results from previously completed research efforts funded by FHWA and state agencies (See Volumes II and III). However, some agencies may not consider these data pertinent to their state or region or the receiving water in question and a new field monitoring study may be required. If the issue is the overall ecological effect of runoff (including chemical, physical and biological components), then obviously a more comprehensive effort will be necessary.

More frequently, the state highway agency will be faced with questions very specific to the proposed project. For these types of questions, it is quite possible that previous research did not provide the needed specificity. For most of these cases, fortunately, the field monitoring program could be more narrowly focused on addressing the specific issue and the scope and costs would be more limited than for a comprehensive program.

When a field monitoring program is conducted in response to EIS considerations, it is possible that the program will involve pre-construction and post-construction sampling to validate the conclusions reached during the EIS process. One highway (though not runoff) related example is that of the proposed construction of I-64 through Greenbriar County in West Virginia (3). The study is being conducted by the West Virginia DNR but is being funded by the State DOT. It includes both pre-construction and post-construction monitoring of wetland hydrology, flora and fauna along the proposed alignment. A report was prepared by USGS which discusses the values and methodologies for post-EIS monitoring (4). Values include advanced warning, documentation and control of potential impacts. Although NEPA does not require monitoring, it was suggested in this USGS report that it could become more commonplace in the future to "insure that appropriate and practical adjustments will be made during the life of the project and that insight gained can be applied to improvement of future ecological predictions" (4).

It is now becoming fairly commonplace for regulatory agencies to place conditions in permits which stipulate that special or regular field monitoring be performed to ensure that a given project does not cause water quality violations. Examples of permits which could trigger a monitoring condition for highway projects include:

1. NPDES permit issued by the state environmental agency or U.S. EPA when the project includes a rest area waste treatment facility. Some states (eg., Florida) require NPDES or state permits for stormwater discharges as well and there are some indications that EPA will provide further encouragement to permit stormwater facilities in the future.

2. Section 401 water quality certification for a Section 404 dredge and fill permit.

3. Coastal Area Management Act (CAMA) permit issued by the state CAMA agency for all major projects in coastal areas.

Finally, a monitoring program could be undertaken to fulfill basic research objectives. Such programs can fulfill specific needs of the state HA. Examples include comprehensive road salt impact projects conducted by the

State of Wisconsin (5) and the State of Maine (6). Other programs are undertaken in partnership with other state agencies. One example is a study performed jointly by the North Carolina Department of Transportation and Department of Natural Resources and Community Development (Division of Environmental Management) to evaluate the water quality affects of bridge maintenance activities such as sandblasting and painting (7). Of course, a number of field monitoring efforts have been sponsored by FHWA, often in conjunction with state HA's, private consultants and universities. Another good example of an interagency program is the National Cooperative Highway Research Program.

SECTION 2

PLANNING A MONITORING PROGRAM

Once the need and scope of a field monitoring program has been established a detailed field study plan needs to be developed. Most vital to the eventual success of the field program is comprehensive initial planning prior to equipment installation and actual field monitoring. Included in this initial analysis is determination of study period duration, procurement and review of site background information, selection of monitoring station locations, and determination of equipment, manpower and analytical needs.

DURATION OF STUDY PERIOD

Selection of appropriate study period duration is contingent upon available funding, climatic factors, and desired monitoring complexity. Assuming that funding is available for optimum results, climatic factors, most notably annual precipitation frequency distribution, and desired monitoring complexity, especially the need for biological monitoring, are the dominant factors. If extensive biological monitoring is planned, a minimum duration of one year is recommended to ensure documentation of seasonal variation in organism distribution and response. It is possible, in geographic regions where precipitation is generally confined to one or two seasons, that field efforts in runoff documentation and water quality effects be confined only to this period. But in general, a one year program is recommended as the minimum to provide statistical data reliability and a sufficient number of storm events to document seasonal variability.

PROCUREMENT AND REVIEW OF ADDITIONAL SITE BACKGROUND INFORMATION

Although a certain amount of specific site information will have already been obtained during the site selection process, more detailed information will be required. This can include information on both highway and receiving water characteristics.

General highway characteristics such as average daily traffic, maintenance practices, and overall design and materials information will have been obtained during site selection. However, detailed elucidation of highway drainage patterns and sub-basin, boundry definition must usually be deferred until the site has been selected due to the level of effort required in this analysis. The highway right-of-way should be broken down into paved and unpaved area, and tributary drainage outside but tributary to the right-of-way must also be broken down into general land use classifications. This type of highway information can generally be obtained from state highway agencies and includes plans and profiles, aerial photographs, detailed topographic maps, and if possible hydraulic design information. If this information is not available from highway agencies, as is often the case for older highway systems, other local agencies might have to be contacted. These include local soil conservation districts; local, county, or regional planning commissions; or private map services. This is especially true for characterization of drainage areas outside the highway right-of-way.

County tax departments will usually provide quartermaps or plot maps and associated information which identify private property owners in areas adjacent to the monitoring site. This is of critical importance in terms of both obtaining access permission to monitoring stations and enlisting local cooperation for equipment protection or as rainfall observers.

The amount of background information available on receiving water characteristics will vary greatly from state to state and even locality to locality. If the state highway department does not have an ongoing in-house environmental monitoring program for the receiving water in question, then alternate sources must be sought. Water Resources Data for each state and each water year are compiled and published by the U.S. Geological Survey and includes both hydraulic and water quality data for selected receiving waters. Unfortunately, these data can generally serve only as rough watershed background information since USGS gauging stations will in all probability not correspond to the microscale monitoring requirements of the highway study. Other sources of receiving water information are state water quality regulatory agencies, area-wide planning commissions, and local university environmental departments. It should be kept in mind, however, that if site specific, detailed and up-to-date data were available, the need for the field monitoring portion of the water quality study would not be as great.

Background information on local official climatological conditions can be obtained from the National Climatic Center at the following address:

National Climatic Center
National Oceanic and Atmospheric Administration
U.S. Department of Commerce
Asheville, NC 28801

These monthly and annual summaries include wind speed and direction, relative humidity, air temperature, precipitation, soil temperature and snowfall accumulation. This is useful information to obtain during site monitoring to supplement field data and serve as back-up in case of site equipment failure.

LOCATION OF MONITORING STATIONS

The selection of monitoring station location is one of the most critical steps in the planning process. Depending on the desired complexity of the monitoring program, these stations can encompass the following types:

1. Receiving water stations
    a. Water quality
    b. Sediment
    c. Biological
2. Runoff stations
3. Climatological and hydrological stations
    a. Precipitation
    b. Atmospheric deposition
    c. Meteorological parameters
    d. Receiving water hydrological characterization.

Receiving Water Stations

Within the selected site, activities at specific receiving water stations might include documentation of water quality, sediment and biological effects. For all three general categories, both control and highway runoff influenced stations will usually be employed. If the entire receiving water system in question is affected by highway runoff, then the basis for impact evaluation will be either the use of another receiving water with similar watershed characteristics to serve as control or comparison of dry weather with wet weather conditions and the spatial and temporal impact patterns of the highway runoff influenced receiving water. It is certainly preferable to select control and influenced stations of such proximity to minimize input of other confounding intermediate pollutants. This is achieved in lotic water series (i.e., streams and rivers) by moving the control station upstream of highway runoff inputs. It is a more complicated task to select control regions within a lentic series (lake or wetland) due to uncertainties in hydraulic transport mechanisms.

To the highest practical degree, both water quality, sediment and biological stations should be located to provide interstation uniformity in morphology, hydraulic regime, and bottom substrate. This will allow a more valid comparison of control versus highway influenced station differences.

For example, hydraulic differences can affect water quality through variations in degree of sediment scour or deposition. Hydraulic differences also influence dissolved oxygen budgets due to reaeration and sediment uptake variation. Hydraulic differences largely determine bottom substrate composition differences which in turn affect distribution patterns of benthic organisms. In addition, hydraulic gradient differences directly affect substrate colonization by periphyton and invertebrates through shearing actions and organism drift.

Other factors which influence the selection of receiving water stations include:

1. Accessibility,
2. Degree of canopy coverage,
3. Spatial distribution factors for water quality sampling.

Water quality sampling stations should be located to provide information on the spatial extent of runoff impacts. This is normally accomplished through establishment of transect lines either downstream for lotic series or radially from the runoff source for lentic series.

Runoff Monitoring Stations

The complexity of the highway runoff station selection task is obviously contingent upon the complexity of highway drainage patterns; ranging all the way from a single sole-source highway runoff discharge point to a number of discharge points, some of which may have tributary drainage area beyond the highway right-of-way. It is important to attempt to isolate highway runoff from other drainage basin runoff sources. This might require continuous or intermittent monitoring of sources tributary but extraneous to the highway runoff conveyance system.

For sites with multiple discharge points, the number of stations chosen for monitoring is often determined by available funds. In many cases, all discharge points cannot be continuously monitored and several representative stations should be selected.

Climatological and Hydrological Stations

Precipitation--

The number and location of precipitation measurement stations depends on site surface area and topography. For small sites, less than 2 km in length (8), a single station is sufficient, but for larger sites with significant topographic extremes, several stations will be required. Poor characterization of uniformity in precipitation distribution can seriously detract from the validity of the site hydrologic balance.

In general, precipitation measurement stations should be located on level ground away from or above large obstructions such as trees or buildings. In addition, stations should not be located in areas where ground elevation decreases sharply towards the predominant wind direction (9).

Atmospheric Deposition--

Since highway related atmospheric particulate deposition will be indirectly measured in conjunction with stormwater runoff, location of these stations in background areas is most critical to differentiate between highway and nonhighway related loadings. Stations for quantification of background total atmospheric deposition (also referred to as bulk precipitation which includes both wet and dry deposition processes) should be located a minimum of 35 m (115 ft) from the highway right-of-way (2) and away from or above obstructions such as buildings, signs, etc (10). Notes should be made on direction and distance from stacks, parking lots, materials storage piles or other potential sources of atmospheric particulates.

Meteorological Parameters--

If an existing climatological station is not in the immediate vicinity of the site, then selection of a suitable station for measurement of such parameters as wind speed, direction and air temperature will be required. Again, care must be exercised to locate instrumentation to minimize air flow disturbances caused by nearby obstructions. If such obstructions cannot be avoided entirely, one general rule of thumb would be to locate the station 5-10 times the height of the obstruction in the downwind distance and at least one height of the obstruction in the upwind direction (11). Another recommendation is to mount the instrument sensors 20 feet above ground or at least 12 feet above any obstruction within 100 feet horizontal distance and at least as high as any obstruction between 100 to 200 feet from the unit (12).

Receiving Water Hydrologic Characterization--

An indepth knowledge of stream discharges and lake circulation patterns is critical to the overall evaluation of receiving water to impacts. The most important parameter in the hydrologic evaluation is stream or lake stage which is defined as the height of the water surface above an established datum. The datum can be arbitrarily chosen for convenience or related to some recognized plane such as mean sea level. Stage (also referred to as gage height) levels are recorded at appropriately selected gaging stations.

For lakes and wetlands, accessibility and stilling well structural stability are the most important parameters for locating the gaging station. Carter and Davidian (13) suggest the following considerations for selection of gaging stations for streams and rivers:

1. Permanent channel bed profiles are preferable to changing profiles due to deposition or scour. As such, rock riffle or falls make ideal stations. Sandy beds should be avoided if possible. Areas upstream of obstructions, such as bridges, should be avoided due to the constant deposition and infrequent scour during storm flows. However, areas downstream of such obstructions serve as good stations for reasons described in points 3, 5 and 7 below.

2. Avoid areas where backwater effects occur. Such backwater effects can be caused by downstream tributary inflow, dam gate manipulation, natural channel constriction, and tidal influence. If such conditions cannot be avoided, an auxiliary gage will have to be placed downstream for computation of slope-stage-discharge relationships. This is discussed in Section 5.

3. Easily accessible stream crosssection for discharge measurements should be available. During high-flow periods, this might require use of existing bridges or necessitate installation of a cableway.

4. Areas where access roads are frequently flooded should also be avoided.

5. Avoid stations where the possibility exists for flow to bypass through groundwater infiltration or in flood channels.

6. If electrical instruments are to be used, the availability of power is a major consideration.

7. Opportunity for installation of artificial control structures such as weirs, flumes and low dams can make a station more desirable. Such structures influence the liquid level or energy gradient and tend to stabilize the stage-discharge relationship. Even the presence of natural bed formations, such as riffle areas, can provide a similar benefit.

The number of gaging stations required at a given site will depend upon hydraulic complexity of the system and degree of subbasin characterization desired. The simplest case would be a stream site with a single highway runoff inflow. In this case a single gaging station downstream of the runoff inflow is required. Control flow can be determined by difference. A more complex, and more common, situation is several or many runoff inputs (both highway and other sources) and tributary inflows dispersed along the site. In this case, the minimum number of gaging stations would be two; one each at the entrance and exit of the study site. The number of intermediate gages which can be utilized for intersite comparison will depend on project needs or funds.

Biological Monitoring Stations

Following a "desk top" analysis of available background data and other information related to the problem in question, a reconnaissance survey is indicated of the reach of waterway to be studied, as well as principal contributing pollution sources. During the biological reconnaissance survey a judgment is reached on the potential effects on water quality of individual pollutional sources, the reach or reaches of waterway that are of potentially greatest concern in the particular investigation, and possible sampling sites and actual points of access. Observations should be made at various points of access on stream width, depth if ascertainable, nature and type of stream bed, relative flow, as well as any other morphometric features that would seem to contribute towards a better organized sampling procedure when biological samples are collected. It is extremely important to know where boats and other equipment may be lowered into the waterway and possible difficulties that may be encountered when this is done. It is equally important to ascertain that proportion of the samples that may be collected by wading or by some means other than by boat. Observations should be made that may later relate to the use of such gear as conventional biological sampling dredges, square foot stream samplers, and various types of fish nets or seines. During the reconnaissance survey contacts can be made with local officials or local investigators who may have an interest in the investigation. Arrangements should be made with land owners to cross private lands, should this be necessary.

Concurrently, water samples for chemical analyses should be collected from access points along the waterway during the reconnaissance survey to ascertain the relative magnitude of pollution at various points, and to aid in the judgment of selecting sampling stations. The aquatic organisms that can be observed qualitatively on rocks and other submerged objects should be noted and recorded.

Following the completion of a reconnaissance or pilot survey, and subject to modification or change during the course of field sampling, decisions can be made on the following:

1. Types of samples necessary to point to a solution to the problem (i.e. plankton, periphyton, benthos, vascular plants or fish)

2. Sampling points for each of the selected types of samples
3. Periodicity of sampling and approximate collection time for a specific sample type and

4. Approximate number of samples necessary to complete the study.

Preliminary to the collection of a sample, the investigator must firmly establish the location of sampling stations. Station selection varies with the physical features of the waterway and this discussion will relate to streams, lakes, reservoirs, and estuaries.

Biological sampling stations for the stream environment should be routinely located close to or at those sampling stations selected for chemical and microbiological analyses to enhance interpretation through the use of interrelated data. Sampling stations should be located upstream and downstream from suspected pollution sources, and from major tributary streams, and at appropriate intervals throughout the stream reach under investigation. The upstream stations should depict conditions unaffected by a pollution source or tributary. The nearest downstream station to the pollution source or tributary should be so located that it leaves no doubt that conditions depicted by the sample can be related to the cause of any environmental change. The minimum number of downstream stations from this point should be located in the most severe area of the zone of active decomposition, downstream in an area depicting less severe conditions within this zone, near the upstream reach of the zone of recovery, near the downstream reach of the recovery zone, and in the downstream reach that first shows no effect from the suspected pollution source. Precise station location will depend on the flow, the strength, volume and type of pollution entering at the source, and entrance of additional sources of pollution to complicate the stream recovery picture. When water in tributary streams is found to be polluted or to influence water quality in the primary stream, these streams should be similarily investigated.

A stream usually is composed of riffles and pools. These areas will vary in depth, velocity of flow, and types of substrate that form the stream bed. Because the biologist seeks to determine changes that occur in water quality as depicted by aquatic organisms and to relate these changes to particular station with observations and findings from an upstream station, as well as a station within the stream reach that is unaffected by a suspected source. To accomplish this an effort should be made to collect samples from habitat types that are morphometrically similar. Riffle samples should be compared with riffle samples and pool samples compared with pool samples. Both should be studied where feasible.

Plankton samples are collected usually at one point within the study station, most commonly at midstream, 1 to 2 feet below the surface. Samples for bottom associated organisms should be collected at a number of points on a transection line between the stream banks. These samples should be collected at a minimum of three points across the stream (mid- and one-third points); more than one sample may, at times, be collected from each point and retained separately. Realistically the objectives of a particular survey and the number of stations at which bottom fauna are collected may dictate the number of samples from a particular station. Attached growths are sampled wherever they occur.

Within the lake or reservoir, a number of sampling sites may be chosen depending on the problem under investigation and the conditions to be studied. An investigation of the kinds and relative abundance of aquatic vegetation would naturally be limited to the littoral area. A mapping of aquatic plants often proves useful for future comparisons.

The use of transections in sampling a lake bottom is of particular value because there are changes in depth and because benthos concentration zones usually occur. Unless sampling is done systematically and at relatively close intervals along transections, especially those that extend across the zone between the weed beds and the upper extent of the hypolimnion, concentration zones may be missed entirely or inadequately represented. Maximum benthic productivity may occur in the profundal region. Because depth is an important factor in the distribution of bottom organisms, productivity is often compared on the basis of samples collected from similar depth zones. Collections from a transection will sample all depth zones, and a sufficient number of samples must be taken to make the data meaningful.

FIELD INSTRUMENTATION REQUIREMENTS

Meteorological Monitoring

Meteorological parameters of most importance for these types of water quality studies include quantity and type precipitation of (rain, snow, sheet, hail, etc.), wind speed and direction, air temperature and total atmospheric particulate deposition (TAD).

Precipitation--

Precipitation gages can be of either the non-recording or recording type. Non-recording gages provide only total precipitation volume and include graduated measuring cylinders, graduated dipsticks, storage gages, snowboards and snowstakes (12). Recording gages provide continuous record of precipitation and are preferred for runoff investigations where precipitation intensity and duration are of critical importance. The most common recording gage types are:

1. Weighing,
2. Tipping-bucket, and
3. Float and counterweight.

Weighing systems can be used with all types of precipitation whereas the tipping-bucket and float types generally record only rainfall. Standard tipping-bucket and float type gages can be retrofit to record solid precipitation forms by using electrical heat tape or a propane flame to heat metal collection trays and meet snow and ice (14).

Weighing type gages use a spring mechanism or a system of balance weights and directly translate precipitation weight into volume for continuous record. Figure 1 is an example of the weighing type gage. Collection buckets are usually manually emptied, but provision is made for the recording pen to traverse the cumulative chart two or more times. Evaporative losses for long term charts (one week or more) can cause chart reading problems, but these losses are usually discernible. Oscillation of the balance in strong winds can be simply corrected by locating the gage in a box or other wind-breaking enclosure such as the Alter type. This type of windshield has thirty-two free-swinging galvanized sheet metal leaves (each 16 inches long, 3 inches wide at the top and two inches wide at the bottom) mounted on a 48 inch diameter hoop. The hoop is mounted parallel to the ground and at a height such that the top of the leaves is slightly above the gage orifice. This design not only prevents strong updrafts which can distort precipitation trajectory, but also breaks up streamlines over the gage orifice and improves the catch.

The tipping-bucket gage works by sequential filling and emptying of a two compartment tipping bucket. As each compartment is filled [usually a volume of 0.01 inches (1)], the bucket tips for emptying of that compartment and filling of the adjacent compartment. The tipping action causes electrical contact for cumulative recording purposes.

The float type recording raingage was used by USGS at the Efland, NC site (See Volume II). Rain is conducted from a collector tray to a stand pipe (Figure 2). A float and counterweight system translates the rainfall accumulation in the pipe to standard rainfall volume through the use of an

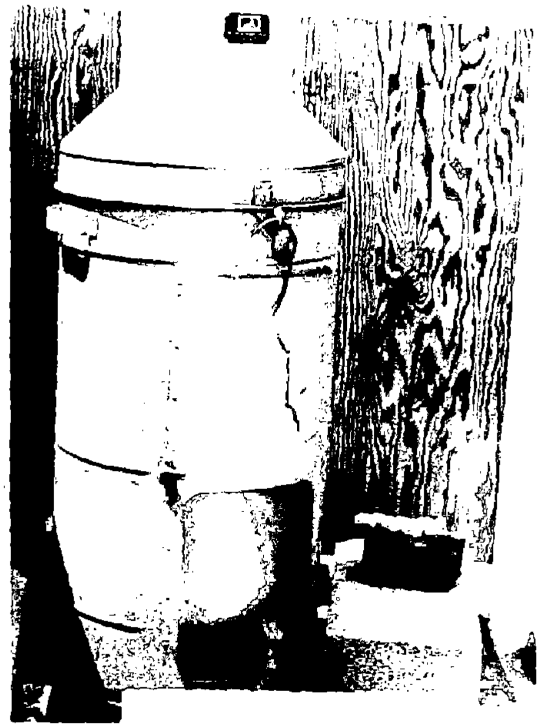


Figure 1. External housing of weighing raingage (Belfort).

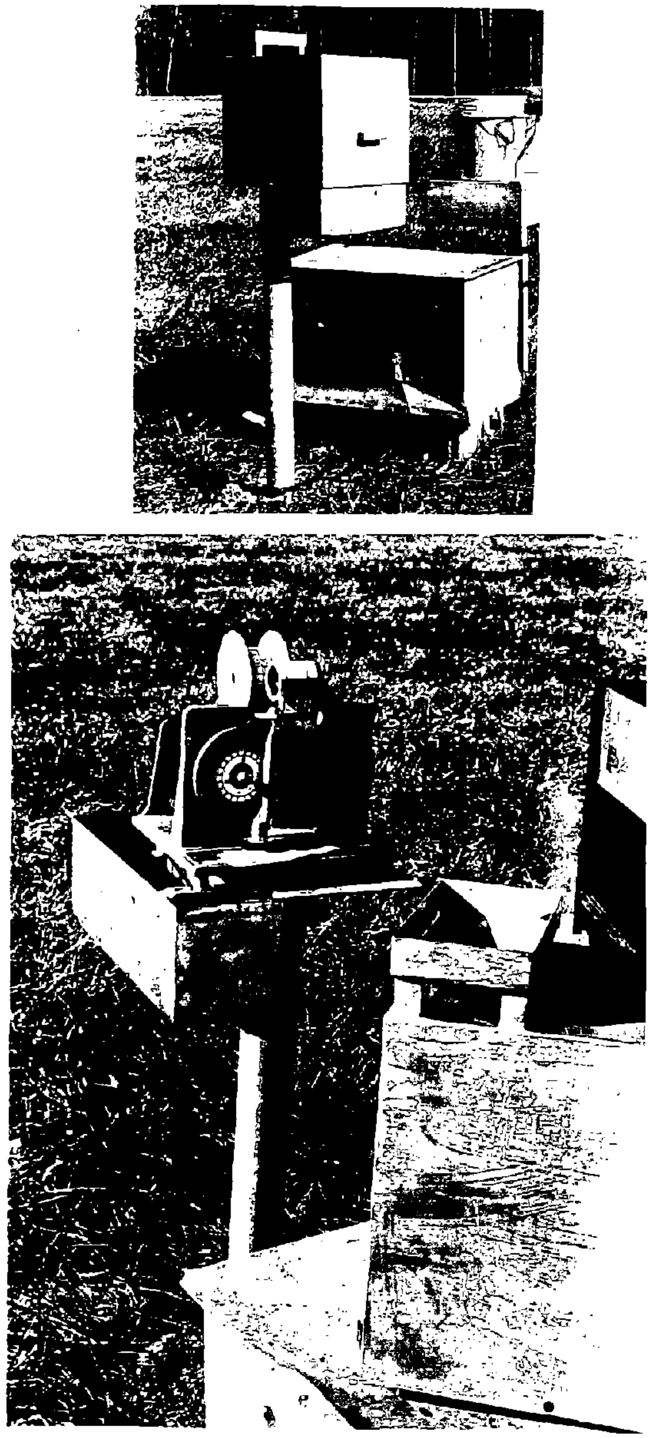


Figure 2. Float-type digital recording raingage.

automatic digital recorder (ADR). A small battery-powered pump periodically (level actuated) empties the stand pipe of accumulated rainfall. This provides a digital punched tape recording of rainfall volume per discrete time interval, greatly reducing manpower requirements for chart reading. Diurnal thermal expansion of metallic stand pipes can produce minor apparent fluctuations in precipitation volume, but these can be readily accounted for as tapes are entered into computer file.

Dustfall--

Dustfall buckets are often used to provide estimates of background or highway right-of-way pollutant loadings due to atmospheric deposition. ASTM D-1739-62 (15) specifications on dustfall bucket locations, size and analytical procedures should be followed. A standard 8 in. (20.3 cm) diameter by 10 in. (24.4 cm) deep tapered plastic (polyethylene) bucket equipped with bird-ring support is specified. These hold up well under all climatic conditions. In addition, separation of atmospheric deposition into precipitation related and dry dustfall components can be achieved with the use of wet/dry collectors (16) (Figure 3). These units consist of two side-by-side polyethylene 11.3 in. (23.6 cm) diameter by 9.1 in. (23.2 cm) deep buckets. One bucket serves as wet and the other as a dry collector, with a mechanical cover shifting from one to the other depending upon climatic conditions. A heated sensor detects rainfall (or any other form of precipitation) and activates the movement of the cover from wet to dry bucket, and back again.

Wind Speed and Direction and Air Temperature--

Supplemental meteorological measurements such as wind speed and direction are useful (though often not critical) for hydrologic characterization of lake sites. Lake circulation patterns and stratification are largely contingent upon wind energy and direction. This information also is useful if atmospheric transport of pollutants from the highway site is being monitored with dustfall buckets or saltation catchers (2). Air temperature is of

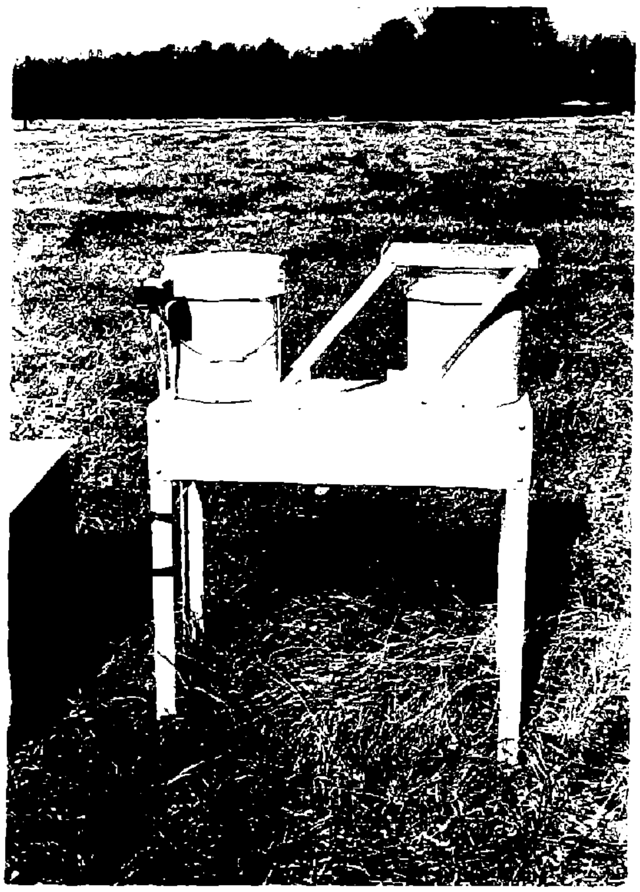


Figure 3. Wet/dry collector.

importance relative to snowmelt runoff. Detailed descriptions of available types of anemometers and thermometers for respective surface wind and air measurements are given in the National Handbook of Recommended Methods of Water Data Acquisition (12). For the field monitoring phase of this contract (See Volume II) a single Meteorology Research Institute (MRI) instrument provided continuous record of wind magnitude and direction and air temperature on a one-month duration strip chart.

Quantitative Highway Runoff Monitoring

To quantify stormwater runoff volume and intensity, a variety of instrumentation can be employed. Two basic categories of runoff flow instrumentation are:

1. Primary measurement devices, and
2. Level recording devices.

Primary recording devices are calibrated flow restrictions which artificially control the liquid level or energy gradient of an open-channel flow system. Most common control devices are weirs. Figures 4 and 5 illustrate sharp-crested weir and flume types used in this research program (See Volume II). Selection of weir or flume, or specific weir or flume type, is contingent upon both basin hydrologic characteristics, runoff measurement sensitivity requirements, and other specific study needs.

For example, weirs are generally cheaper and easier to install than flumes, but promote a relatively higher headloss, are not always self-cleaning and can have their accuracy more easily affected by excessive approach velocities (17). More detailed discussions of primary measuring device selection and calibration can be found in the literature (8, 17, 18, 19, 20).

The second component is the liquid level sensing and recording instrumentation. Primary control devices are calibrated to provide volumetric

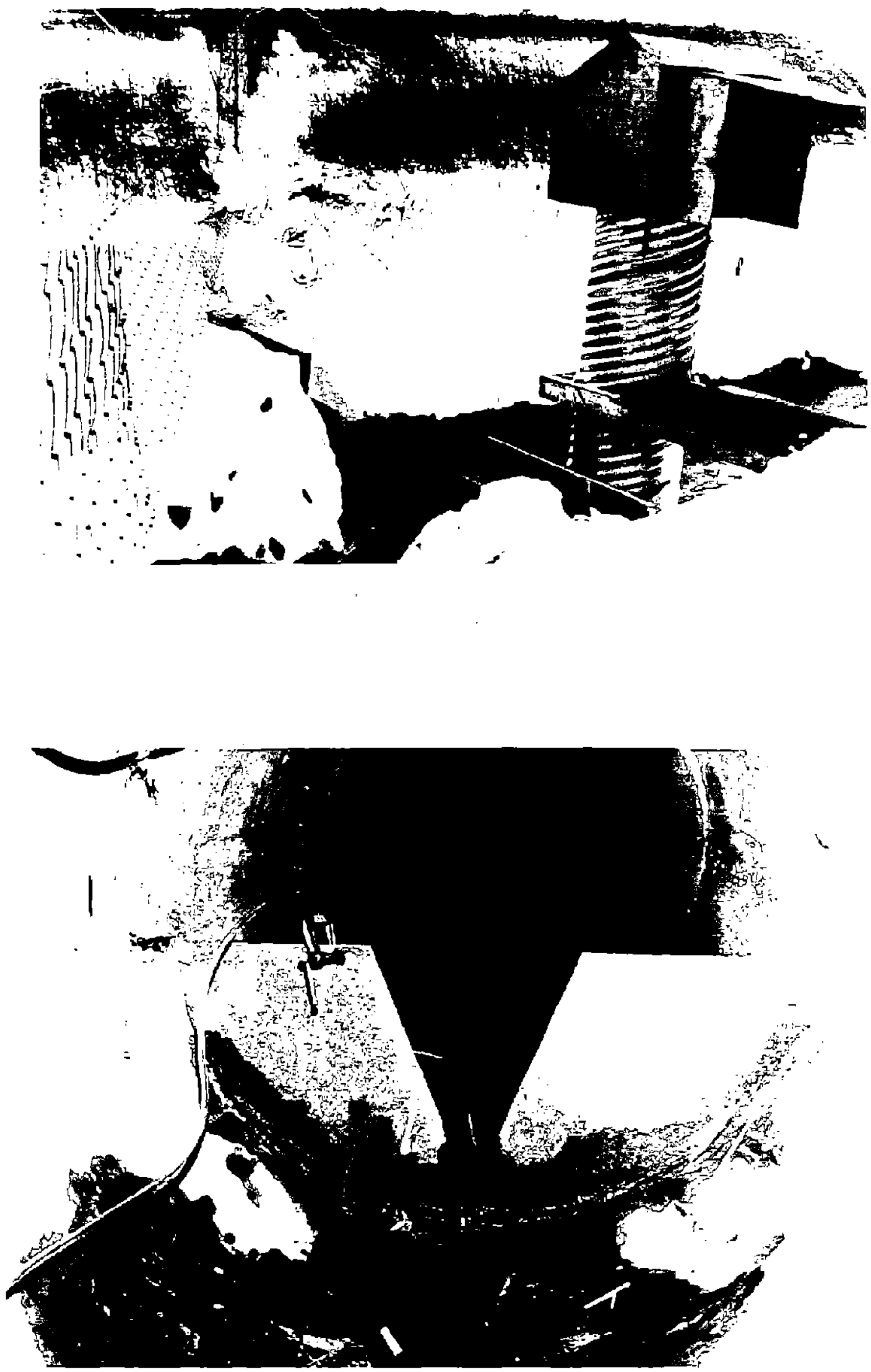


Figure 4. Typical weir installations. a) Combination V-notch and rectangular; b) V-notch.

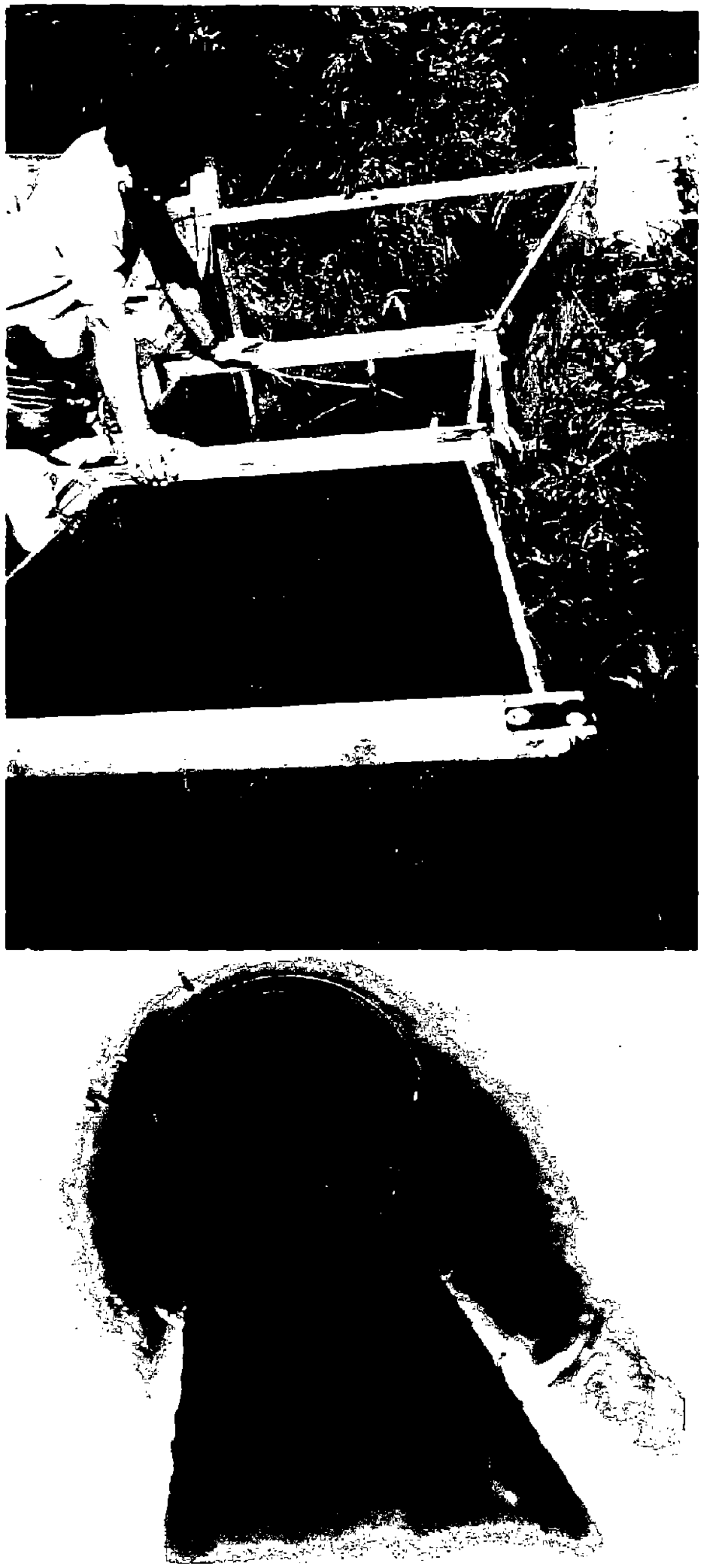


Figure 5. Typical flume installations. a) 30-inch wooden parshall flume; b) Palmer-Bowlus flume in sewer.

flow rates as a function of liquid level. Some secondary instruments measure and record only liquid level while others provide direct conversion of liquid level to flow rate. The latter is especially useful if automatic water sampling requires flow integrated samples. Two varieties of level sensing devices are commonly used:

1. Mechanical surface floats, and
2. Bubble-gages.

Surface floats are attached to a cable with counterweight. The liquid level is thereby recorded in conjunction with the angular position of a shaft. Bubble-gages discharge compressed gas (air or nitrogen) into the flow stream at a fixed depth and gas flow rate. The pressure required to maintain a constant gas flow rate is proportional to liquid level. It is preferable to enclose both surface floats and bubble-gages in attached stilling wells to dampen out minor perturbations in liquid level caused by turbulence. Recording instrumentation includes simple graphic inking systems on both circular, drum, and strip charts; printed totalized strip charts; punched tape for digital recorded systems; and even complex telemetry systems. These will be discussed in more detail in the following section.

Receiving Water Hydrologic Characterization

For all receiving water types, the single most important hydrologic measurement is liquid level. For lentic series, liquid level combined with morphological characteristics and other water sources and sinks (surface and groundwater outflows and inflows, precipitation and evapotranspiration) provides a complete water budget. For lotic series, liquid level combined with periodic velocity measurements provide a stage-discharge curve covering a wide range of volumetric flow rates.

General equipment categories for surface water hydrologic measurements include (19, 21):

1. Level sensors,
2. Water stage recorders,
3. Stilling wells,
4. Instrument shelters,
5. Non-recording gages, and
6. Current meters.

Level Sensors--

Two general varieties of level sensors are available:

1. Float sensors, and
2. Bubble-gage sensors.

These systems are identical to those described in the previous section on quantitative highway runoff monitoring. The advantage of bubble-gages is that they can be used without necessarily being enclosed in a stilling well. This can eliminate the need for costly excavation and external structural support and is especially suitable for short term installations. However, if bubble-gage systems are to be used in streams or rivers of high current velocity or turbulence, then stilling wells or other special installation precautions should be utilized (21).

Water-Stage Recorders--

A variety of stage recording instrument types are available. The most common of these are:

1. Graphic Recorders - These units provide ink or pressure sensitive graphic traces of water stage versus time on either circular, drum or strip charts. Such recorders can be integrated with both level sensing devices through strictly mechanical components or by incorporation of electronics. As previously discussed, some types record only liquid level while others directly convert level to

discharge through microprocessor or analog-based systems. Of course, the latter is only applicable where stage-discharge relationships have been established or a primary control device is used.

2. Digital Recorders - These instruments translate angular shaft positions and bubble-gage pressure through both mechanical and electronic processes. A commonly used digital recorder mechanically punches paper-tape strip charts. These punched charts are later input to digital computer through the use of electronic translators. This greatly reduces manpower requirements for data reduction. Microprocessor controlled digital recorders provide printed record of stage or flow volume on paper strip charts.

3. Telemetering Systems - In general, these systems receive information from conventional level sensing devices and transmit these data to remote recorders either through internal transmitters (achieving distances of up to 40 miles) or over leased telephone lines or other metallic circuits. These systems have merit for sites where frequents trips are either impossible or not cost-effective (21).

Stilling Wells and Instrument Shelters--

Stilling wells protect float sensor systems and provide dampening action to smooth out extraneous fluctuations in surface level due to wind or turbulence. They are usually installed in the bank of the receiving water but can also be attached to bridge piers, abutments, or other structures. The size (ie., diameter) of the stilling well depends upon whether the instrumentation is to be located on a shelf within the stilling well or an attached shelter. Corrugated metal pipe is generally suitable for semipermanent installations. Figure 6 shows a typical stream stilling well installation. More involved stilling well constructions for permanent installations can be found in Buchanon and Somers (21) and U.S. Department of Interior Water Measurement Manual (19).

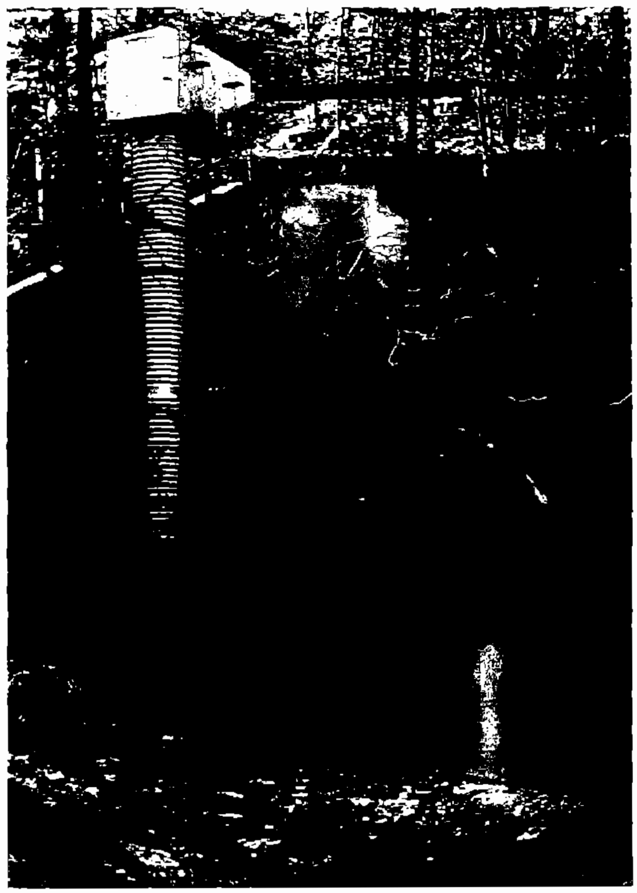


Figure 6. Typical stream stilling well installation.

Non-Recording Gages--

The main function of non-recording gages in detailed water quality investigations is to provide reference levels both inside and outside the stilling well for verification/calibration of continuous level recorders. Gages are required both inside and outside the stilling well to ensure that intake lines are not plugged. Common types of nonrecording gages are (21):

1. Staff Gage - Standard USGS gages consist of vertical or inclined calibrated iron staffs with porcelain enamel coating.

2. Wire Weight Gage - A single layer of cable, wound around a drum, is lowered with an attached weight to the water surface. The distance over which the weight is lowered is measured by the combination of a graduated disc connected to the drum shaft and Veeder counter. This distance can then be related to the reference datum. The drum is enclosed in a protective box which is usually mounted on a bridge rail or similar support structure.

3. Float-Tape Gage - A calibrated metal tape connects a float and counterweight and provides direct measurement of the water surface level.

4. Electric-Tape Gage - A weight, which is attached to a calibrated metal tape, is lowered to the water surface. When the weight touches the water surface, an electrical circuit is closed between the weight, tape, tape reel and frame, battery, voltmeter and ground. Again, this provides a direct measure of the water surface relative to the reference datum.

Current Meters--

Current meters are used to measure volumetric flow rates at given stage levels. The stream is divided into a number of cross sections. The sum of the products of velocity and area over the entire stream width then represents the total discharge at the gaging station. This procedure will be described in more detail in Section 3.

Most current meters operate by relating the proportionality of rotor angular velocity to stream velocity. Very commonly used for stream discharge ratings are the Price AA and pygmy style current meters. The AA model is shown in Figure 7 and can be used in either a bridge suspension mode or hand held with a wading rod. The pygmy variety is only two-fifths the size of the AA model and is therefore suitable for very shallow streams. It can be used only with a wading rod. These vertical-axis meters work in the following fashion: as the cups are rotated by liquid flow, electrical pulses are sent to a headset worn by field personnel. The number of clicks heard per unit time can later be accurately related to flow velocity rating tables. Due to design simplicity, these meters are quite effective in terms of both operational and maintenance reliability. An attachment for determining current direction is also available for the type AA units.

Also used for current velocity measurement are horizontal-axis meters (eg., OH, Neyrpic, Haskell and Hoff meters) and an optical current meter which operates on stroboscopic principles (22).

Water Quality Determinations

Sampling for Laboratory Chemical Analysis--

Both automatic and manual water quality sampling procedures will have to be employed. A number of automatic water quality samplers are commercially available, and relative merits of each should be investigated. A summary and review of this equipment was provided by ASTM (23).

An innovative automatic highway runoff sample compositing system was designed, tested and extensively utilized by the University of Washington (24). It consists of a rectangular open-channel box with longitudinal vertical flow splitters which transfer a volume of runoff proportional to flow into a sample storage tank. The researchers contend that the system can be

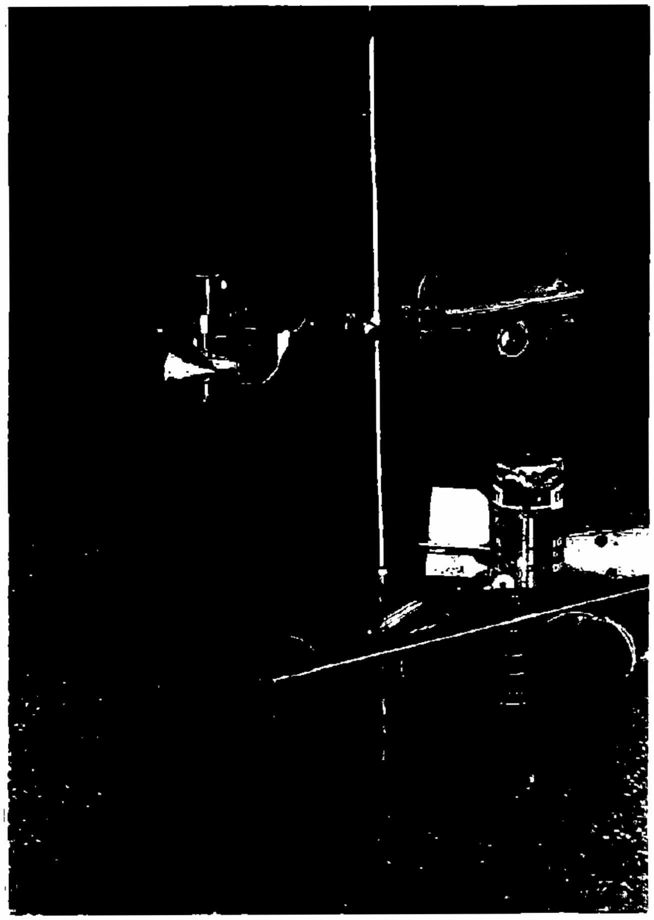


Figure 7. Illustrations of Price AA Gurley-type flowmeter.

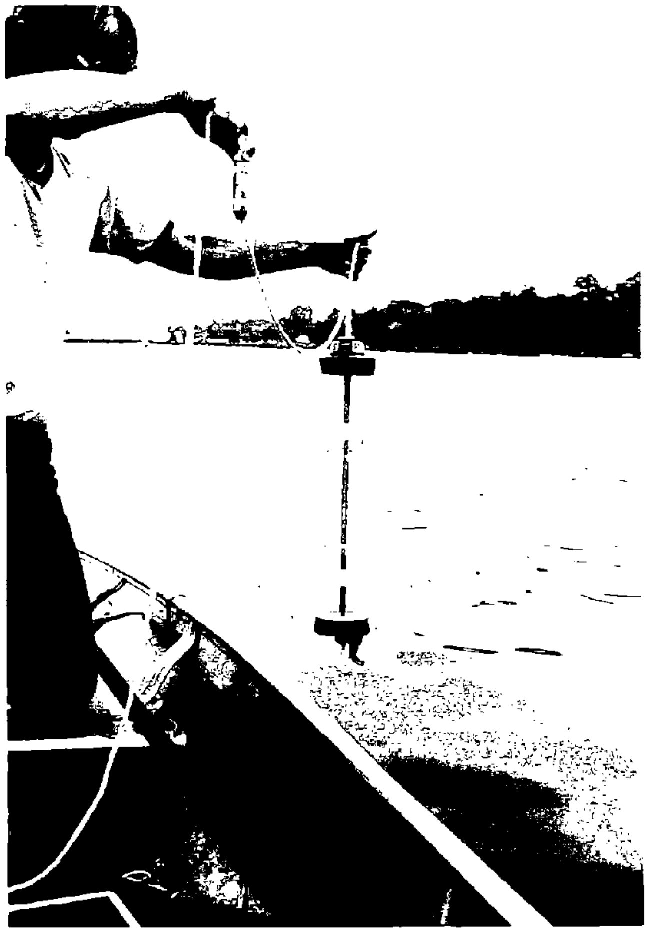
installed at less than 10 percent the cost of other runoff monitoring systems, is easier to operate and potentially more accurate than discrete sampling.

Manual water quality sampling at discrete depths in either lentic or lotic series can be accomplished with a variety of equipment. Most common are four general design types:

1. Kemmerer style,
2. Alpha style,
3. Beta style, and
4. Zobell-type.

Kemmerer, Alpha and Beta style samplers all operate on basically the same principle. They consist of open-ended cylindrical sampling chambers. After being lowered to the desired depth, a messenger activates closure of end seals. Kemmerer samplers have the cylinder aligned in a vertical configuration with neoprene or silicon rubber stoppers for end seals. Alpha and Beta styles are available in both vertical and horizontal configurations. Vertical designs are used for multiple bottle or series sampling. End seals for the Alpha style are made of conical semirigid molded rubber. End seals for the Beta style consist of gasketed rigid machined plastic. Figure 8 shows examples of the Kemmerer and horizontal Alpha style samplers in the open and cocked position.

Zobell-type samplers (25) obtain uncontaminated samples from any discrete depth for bacteriological analyses. A glass bottle is autoclaved with rubber stopper and open-ended glass tube in place. After autoclaving, while the bottle is still hot, the outside end of the glass tube is sealed by melting. During cooling a vacuum is created within the bottle. The bottle is then strapped into the metal frame and lowered to the desired depth. A messenger triggers the action of a lever which breaks the glass tube and prompts rapid vacuum filling of the bottle. If series sampling is being performed the first messenger will activate the release of the second messenger and so on down the line.



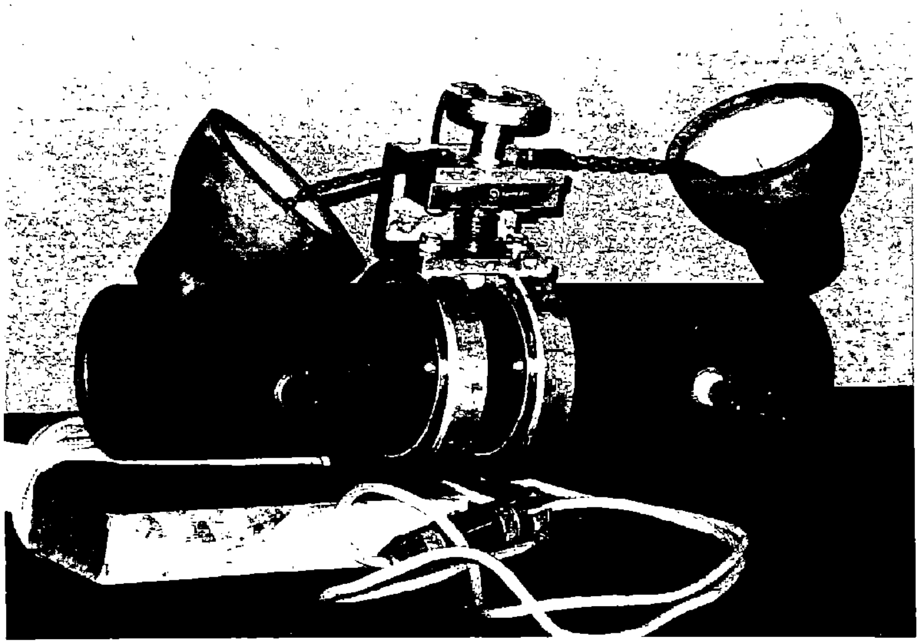


Figure 8. Discrete depth water quality samplers. a) Kemmerer-type; b) Horizontal alpha-type.

In-Situ Water Quality Measurements--

In situ measurement of such water quality parameters as pH, temperature, dissolved oxygen, and specific conductivity is accomplished with the use of common, commercially available instrumentation. Membrane-covered polarographic sensors are used for dissolved oxygen (DO) determinations (generally gold/silver or platinum/lead electrodes through which a small measured voltage is applied; chemical reduction of oxygen passing through the membrane generates an electrical current at the anode). Potentiometric determination of pH (using a glass and calomel reference electrode; the voltage across these electrodes is a measure of hydrogen ion concentration) is most common, and thermistors are generally used for temperature measurement. Conductivity measurements are generally made with Wheatstone bridge-type recorders and conductivity cells with platinum coated electrodes firmly enclosed in plastic or glass insulation. These instruments are generally quite reliable when properly calibrated with standard solutions or field titrations. Calibration procedures will be discussed in Section 3. DO measurements can be difficult in very cold climates due to frozen membranes. Under these conditions, field titrations might have to be performed.

Continuous measurement of several water quality parameters (especially conductivity and temperature) is often performed by USGS. A "Servo Programmer" has been used in conjunction with the previously described automated digital recorder. The "Servo Programmer" sequentially converts the outputs of resistance-type sensors (wheatstone bridge or thermistor types) into angular positions which are input to the digital recorder. A Chelsea clock is used to repeat this process on a regular time interval. Although the "Servo Programmer" is no longer available, it has been replaced by the "USGS Mini Monitor", which serves the same function (26).

Sediment Sampling

Sediment/water interactions have come to be recognized as crucial elements in determining overall fate and impact of pollutants in receiving waters. Sediments can serve as either a source or sink of most pollutants contingent upon such factors as oxidation/reduction potentials, pH and turbulence.

Consolidated sediments (often referred to as bed-material) can be sampled with core tubes, dredges, and special US-series bed-material samplers. Core sampling can be performed manually, or in soft sediments, with a Jenkins-type automatic corer (27). This is a spring-loaded corer which, when sunk into soft sediments and activated with a messenger, simultaneously covers both ends of the tube. This allows withdrawal of a relatively undisturbed core. Manual core samplers include the ballcheck corer, which provides check-valve positive sealing to keep the core in place during withdrawal, hand-held piston-core samplers (12) and Phleger, KB and stovepipe samplers (14).

Disturbed sediment samplers (grab samplers) consist of both dredges and some US-series bed-material samplers. Dredges operate by being sunk into soft sediments either manually or through an attached weight and enclosing the sample with spring-loaded and messenger-activated or mechanically operated jaws. Most common is the Ekman dredge (Figure 9) although a number of variations are available including the Shipek, Ponar, Petersen, Orange-Peel and Smith-McIntyre dredges (14, 28). These samplers were developed largely for characterization of benthic faunal communities and their ability to retain the fine fraction of sediments during sampler retrieval is questionable.

Disturbed sediment samples can also be obtained with special rotating bucket US-series bed-material samplers developed by and available from the Federal InterAgency Sedimentation Project (29). These involve the 180° upward rotation of a spring-loaded circular bucket which collects the bed sample and seals the cutting edge for sample retention.

The dynamics of sediment transport within receiving waters is an important monitoring area given the high association of highway pollutants

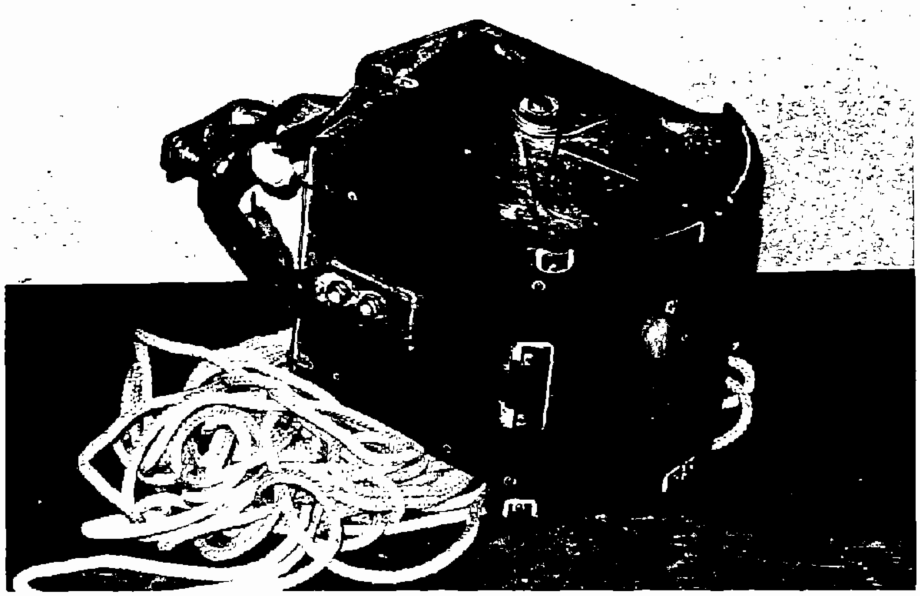


Figure 9. Ekman sediment/benthic organism grab sampler.

with particulates (2). Sediment transport compartments include suspended sediment, bedload and sedimentary particles, each of which can be sampled separately.

Specially designed depth or point-integrating samplers should be used to measure suspended sediment loads (12). Due to density differences between suspended particles and the water medium, and the attendant variation in response to attend hydraulic regimes great care must be exercised to use isokinetic samplers (i.e., intake systems which are not significantly different from the ambient flow velocity). Table 1 summarizes the variety of depth and point integrating samplers developed by the Federal Inter-Agency Sedimentation Project (12) which meet rigorous design specifications. Sampler selection will depend on receiving water current velocity, depth, and desired sampling mode (i.e., cable or wading rod suspension).

Depth-integrating samplers collect a sediment-water mixture integrated over the entire water column proportional to flow velocity. This is accomplished by lowering and raising the sampler at a constant rate over the entire depth. Point-integrating samplers collect samples at discrete depths through the opening and closing of an intake valve. Depth-integrated composites can thus be obtained from point-integrating samplers.

Bedload samplers are designed to collect sediments which are transported along the receiving water bed in a rolling motion or series of jumps. The most common bedload samplers include basket and tray types, especially the Helley-Smith bedload sampler (29). However, since most bedload samplers were developed for specific ranges in particulate size and transport rate, no single sampler type is currently recommended (12).

Another recent approach to characterize impacts of pollutants on sediment composition is the use of sediment traps. These are distinguished from bedload samplers in that they are designed to collect only those sediments

Table 1. Physical characteristics of US-series depth-integrating and point-integrating samplers for collecting samples of water-suspended sediment mixtures **(12)**.

Name	Type of sampler	Method of suspension	Mass (kg)	Overall length (m)	Available nozzle size	Sample container size (mL)	Maximum allowable depth (m)	Maximum calibrated velocity (m/s)	Remarks
US DH-48	DI	Rod	2.0	0.33	A, B	473	c	2.7	For wading.
US DH-59	DI	Cable	10.2	.42	A, B, C	473	c	1.5	For hand-line operation.
US DH-75P	DI	Rod	.4	.26	B	500	c	2.0	For sampling only in subfreezing temperatures.
US DH-75Q	DI	Rod	.4	.29	B	1,000	c	2.0	Similar to US DH-75P.
US DH-76	DI	Cable	10.9	.47	A, B, C	946	c	2.0	Similar to US DH-59.
US D-49	DI	Cable	28.0	.61	A, B, C	473	c	2.1	
US D-49AL	DI	Cable	18.0	.61	A, B, C	473	c	2.0	Similar to US D-49.
US D-74	DI	Cable	28.2	.66	A, B, C	473 or 946	c	2.0	Similar to US D-49.
US D-74AL	DI	Cable	11.4	.66	A, B, C	473 or 946	c	1.8	Similar to US D-74.
US P-50	PI	Cable	135.6	1.12	B	473 or 946	61.0[a] 41.0[b]	3.0	
US P-61-A1	PI	Cable	47.5	.71	B	473 or 946	54.9[a] 36.6[b]	2.0	
US P-63	PI	Cable	90.4	.86 .71	B	473 or 946	54.9[a] 36.6[b]	2.0	
US P-72	PI	Cable	17.7	.71	B		22.0[a] 15.5[b]	1.6	Similar to P-61-A1 but for hand-line operation.

a. With 473-mL container.
b. With 946-mL container.
c. Varies with nozzle and container sizes as follows:

Nozzle size	Container size 473 mL	Container size 946 mL
C	5.8 m	4.9 m
B	4.9 m	4.9 m
A	2.7 m	4.9 m

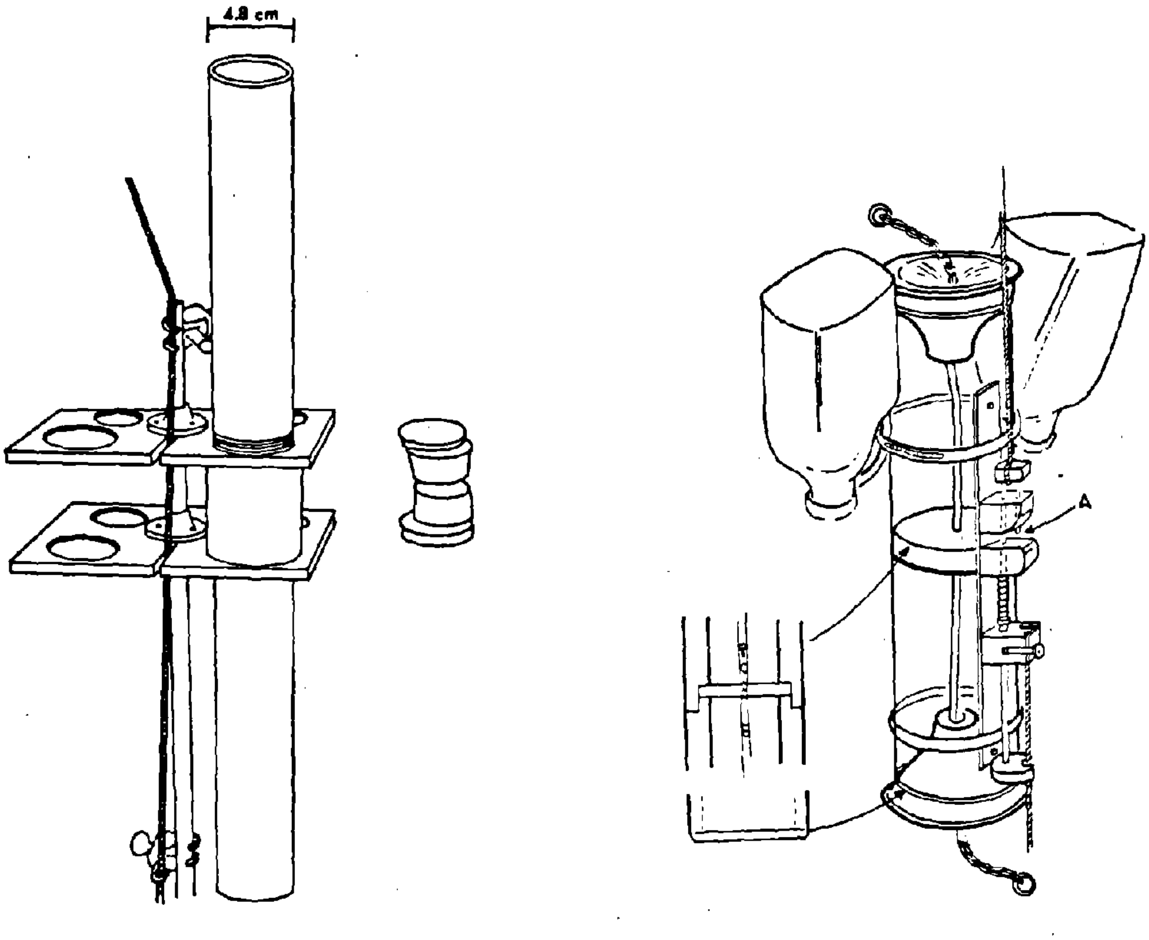
Note: [Type: DI, depth-integrating; PI, point-integrating. Available nozzle size: A, 6.4mm; B, 4.8mm; C, 3.2mm].

which are actively settling to the bottom. The upper horizontal edge of the orifice in bedload samplers is located just above the sediment surface to collect rolling or jumping particulates, while traps are located high enough to avoid collection of such particulates.

Most sediment traps have been used in lentic series, although there have been reports of their application in streams and rivers (30). Funnel-type collectors with a variety of attached sediment reservoirs have often been used (31, 32, 33, 34) but are not recommended. Pennington (35) found that funnel-type collectors catch 2 to 3 times less material than those with straight, vertical sides with an unrestricted opening. It was hypothesized that this was due to removal of accumulated material on the conical surface by water currents. Trap mouth surface area does not appear to be critical to trap efficiency on a unit area basis (32, 36); nor does the trap depth to mouth diameter ratio assuming that some minimum depth is used. Fuhs (37) simply stated that trap depths of 20 cm should be sufficient to retain more than 95 percent of the collected material. One recent refinement in trap design which is of significance is the use of dual collectors (36, 37). One collector should open upwards and other downwards. The downward facing collector is used as a reference chamber so that zooplankton and peripyton growth can be subtracted from the total material collected in the upward facing trap. This provides a more accurate measurement of settling material. White and Wetzel (36) recommended the use of opaque PVC for trap construction to minimize the negative phototactic migration of zooplankton from the downward facing collector. Several acceptable trap configurations found in the literature are shown in Figure 10. Figure 11 is a photograph of the traps used in the field monitoring phase of this contract at Lower Nemahbin Lake, WI (See Volume II). Note that submerged floats should be used to minimize the transfer of surface wave action to the bottom trap.

Biological Monitoring

The biological integrity of a receiving water is perhaps the best indicator of the pollutional effect of stormwater runoff. Numerous collecting



a) White and Wetzel (36) b) Fuhs (37)

Figure 10. Dual-chamber sediment trap designs.

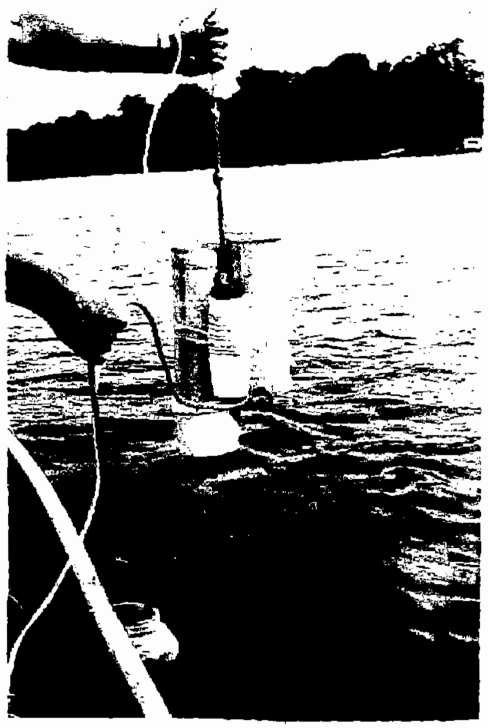


Figure 11. Dual-chamber sediment trap configuration used at I-94/Lower Nemahbin Lake site.

devices and techniques are available for sampling stream and lake biota. These include grab samples, sieving devices, artificial substrates, drift nets, periphyton samplers, and qualitative devices.

Grab Samplers--

Grabs are devices designed to penetrate the substrate by virtue of their own weight and leverage, and have spring- or gravity-activated closing mechanisms. In shallow waters, some of these devices may be rigged on poles or rods and physically pushed into the substrate to a predetermined depth. Grabs with spring-activated closing devices include the Ekman, Shipek, and Smith-McIntyre; gravity-closing grabs include the Petersen, Ponar, and Orange Peel. Excellent descriptions of these devices are given in Standard Methods (28). Grabs are useful for sampling at all depths in lakes, estuaries, and rivers in substrates ranging from soft muds through gravel. Disadvantages which can affect the reliability of these devices are as follows:

1. Depth of penetration is not always uniform because of restrictions or error,

2. Angle of closure is not always uniform,

3. Closure of the jaws is not always complete with consequent loss of sample material during retrieval,

4. Creation of a "shock" wave and consequent "wash-out" of near-surface organisms,

5. Lack of stability of sampler at the high-flow velocities often encountered in rivers.

Sieving devices--

For quantitative sampling, the well known Surber square-foot sampler is the most commonly used sieving device. This device can be used only in flowing water having depths not greater than 18 inches and preferably less than 12 inches. It is commonly used for sampling the rubble and gravel riffles of small streams and may be used in pools where the water depth is not too great.

When using a sieving-type device for quantitative estimates, reliability may be affected by:

1. Adequacy of seating of the frame on the substrate,
2. Backwash resulting from resistance of the net to water flow; at high velocity of flow this may be significant,
3. Care used in recovering the organisms from the substrate materials,
4. Depth to which the substrate is worked, and
5. Drift of organisms from areas upstream of the sample site.

To reduce the possibility of bias resulting from upstream disturbance of the substrate, always stand on the downstream side of a sieving device and take replicates in an upstream or lateral direction. Never start in the upstream portion of a pool or riffle and work in a downstream direction.

The precision of estimates of standing crops of macrobenthos obtained with Surber-type sieving devices varies widely and depends on a number of factors including the uniformity of substrate and distribution of organisms therein, the care used in collecting samples, and level of sample replication.

Artificial substrates--

The basic multiple-plate sampler and rock-filled basket sampler have been modified by numerous workers and are widely used for investigating the macroinvertebrate community. Both samplers may be suspended from a surface flow or may be modified for use in shallow streams by placing them on a rod that is driven into the stream bottom or anchored in a piece of concrete.

A multiple-plate sampler similar to that described by Fullner (38), except with circular plates and spacers, is recommended for use by EPA biologists (39). This sampler is constructed of 0.3-cm tempered hardboard cut into 7.5-cm diameter circular plates and 2.5-cm circular spacers. A total of 14 plates and 24 spacers are required for each sampler. The hardboard plates and spacers are placed on a 1/4-inch (0.625 cm) eyebolt so that there are eight single spaces, two triple spaces, and two quadruple spaces between the plates. This sampler has an effective surface area (excluding the bolt) of 0.13 square meter and conveniently fits into a wide-mouth glass or plastic jar for shipment and storage. Caution should be exercised in the reuse of samplers that may have been subjected to contamination by toxicants, oils, etc.

The rock basket sampler is a highly effective device for studying the macroinvertebrate community. A cylindrical, chromeplated basket or comparable enclosure filled with 30, 5- to 8-cm diameter rocks or rock-like material is recommended for use by EPA biologists (39).

To reduce the number of organisms that escape when the samplers are retrieved, the multiple-plate sampler and the rock-filled basket sampler should be enclosed by a dip net constructed of 10-mesh or finer grit bolting cloth.

In some situations, artificial substrate methods are the best means of conducting quantitative studies of the ability of an aquatic environment to support a diverse assemblage of macroinvertebrate organisms. Advantages of the method are:

1. The confounding effects of substrate differences are reduced.

2. A higher level of precision is obtained than with other sampling devices (Table 2).

3. Quantitatively comparable data can be obtained in environments from which it is virtually impossible to obtain samples with conventional devices.

4. Samples usually contain negligible amounts of extraneous material, permitting quick laboratory processing.

Limitations of artificial substrate samplers are:

1. The need for a long exposure period makes the samplers unsuited for short term studies.

2. Samplers and floats are sometimes difficult to anchor in place and may present a navigation hazard.

3. Samplers are vulnerable to vandalism and are often lost.

4. Samplers provide no measure of the condition of the natural substrate at a station or of the effect of pollution on the substrate, including settled solids.

5. Samplers only record the community that develops during the sampling period, thus reducing the value of the collected fauna as indicators of prior conditions.

Drift nets--

Nets having a 15 by 30-cm upstream opening and a bag length of 1.3 m (No. 40 mesh netting) are recommended for small, swift streams. In large, deep

Table 2. Mean and modal values for coefficients of variation (%) for numbers of individuals and numbers of taxa of macroinvertebrates collected by various devices.

Sampling device	Individuals		Taxa	
	Mean	Mode†	Mean	Mode‡
Rock-filled barbeque basket	32	21-30	20	11-20
Ponar	46	41-50	28	11-20
Petersen	48	51-60	36	21-30
Ekman	50	41-50	46	31-40
Surber	50	41-50		
Corer†	50			
Stovepipe	56	31-40	38	21-30

*Coefficient of variation = (standard deviation x 100)/mean.
†Frequency distribution based on 10% increments.
‡Oligochaetes only.

rivers with a current of approximately 0.03 meters per second (mps), nets having an opening of 0.093 m^2 are recommended. Anchor the nets in flowing water (current not less than 0.015 mps) for from 1 to 24 hours, depending on the density of bottom fauna and hydrologic conditions. Place the top of the nets just below the surface of the water to permit calculation of the flow through the nets and to lessen the chance for collection of floating terrestrial insects. Do not permit the nets to touch bottom. In large rivers, maximum catches are obtained 0.3 to 0.6 meter above the bottom in the shoreline zone at depths not exceeding 3 meters.

Drift nets are useful for collecting macroinvertebrates that migrate or are dislodged from the substrate; they are particularly well-suited for synoptic surveys because they are lightweight and easily transported. Thousands of organisms, including larvae of stoneflies, mayflies, caddisflies, and midges and other Diptera, may be collected in a sampling period of only a few hours. Maximum drift intensity occurs between sunset and midnight (40). Elliot (41) presents an excellent synopsis of drift net methodology.

Periphyton samplers--

The standard glass microscope slide (plain, 25 x 75 mm) is the most suitable artificial substrate for quantitative sampling. If less fragile material is preferred, strips of Plexiglass may be used in place of glass slides.

Devices for exposing the substrates can be modified to suit a particular situation, keeping in mind that the depth of exposure must be consistent for all sampling sites. In large rivers or lakes, a floating sampler is advantageous when turbidities are high and the substrates must be exposed near the surface. In small, shallow streams or littoral areas of lakes where turbidity is not a critical factor, substrates may be exposed by attachment to a metal stake which is driven into the stream bed (42).

The number of substrates to be exposed at each sampling site depends on the type and number of analyses to be performed. Because of unexpected fluctuations in water levels, currents, wave action, and the threat of vandalism, duplicate samplers should be used. A minimum of four replicate substrates should be taken for each type of analysis.

Qualitative devices--

The investigator has an unlimited choice of gear for collecting qualitative samples. Any of the quantitative devices discussed previously, plus handheld screens, dip nets, rakes, tongs, posthole diggers, bare hands, and forceps can be used. For deep-water collecting, some of the conventional grabs described earlier are normally required. In water less than 2 meters deep, a variety of gear may be used for sampling the sediments including long-handled dip nets and posthole diggers. Collections from vascular plants and filamentous algae may be made with a dip net, common garden rake, potato fork, or oyster tongs. Collections from floating debris and rocks may be made by hand, using forceps to catch the smaller organisms.

In shallow streams, short sections of common window screen may be fastened between two poles and held in place at right angles to the water flow to collect organisms dislodged from upstream materials that have been agitated.

ESTIMATING MANPOWER REQUIREMENTS

Field tasks will require manpower investment for site preparation, equipment installation, routine maintenance and specific field surveys. Estimating manpower requirements for these tasks is necessary for the highway agency both to determine in-house needs and to verify the reasonableness of proposals from potential extramural contractors. Evaluation of staffing qualifications for both in-house and extramural water quality projects is also an important task. Extensive discussions of personnel qualifications necessary are provided in Gupta, et al., (8) and Shirley, et al., (43). Obviously, a multidisciplinary team is essential for the conduct of a comprehensive field monitoring program. Important areas of expertise include terrestrial and aquatic biology, hydraulics, hydrology, and environmental engineering. In addition, field personnel need experience in equipment installation and maintenance, thereby requiring above-average mechanical aptitude.

General recommendations on labor commitments are difficult to make. The number of man-days required for the various tasks depends on site complexity (number of stations and type of monitoring being conducted at each station), accessibility (hiking time to remote stations), distance to the site, frequency of required equipment maintenance, number of wet weather events to be monitored, type of receiving water (stream, river, lake or wetland), etc. Estimates of labor requirements similar to those in Gupta, et al., (8) could be provided here but due to extreme variability in specific site requirements, it is recommended to determine these on a case-by-case basis.

ESTIMATING ANALYTICAL REQUIREMENTS

One of the more vital aspects of the planning program for water quality studies is the selection of physical, chemical and biological parameters to measure. Some constituents in highway runoff emanate directly from vehicular and maintenance activities, while others are derived from background atmospheric deposition or other non-highway related runoff sources tributary to the highway system. Table 3 qualitatively describes the sources of a wide range of pollutants found in highway runoff. It is clear that the entire range of parameters given in Table 3 cannot be comprehensively measured for all discrete samples taken over the course of the field monitoring program. This is usually prohibitive from the perspective of both financial and sample volume constraints. The number of specific analyses must therefore be tailored according to study goals, complexity of the monitoring site, and insights into expected impact pollutants. The numbers of analytical determinations can also be reduced through sample compositing techniques and

Table 3. Listing of common contaminants on roadways.

Classification	Examples	Primary sources
Particulates	Dust and dirt, stones, sand, gravel, grain, glass, plastics, metals, fine residue.	Pavement, vehicle, atmosphere, litter, maintenance.
Heavy metals	Lead, zinc, iron, copper, nickel, chromium, mercury.	Vehicle, atmospheric washout.
PCB, pesticides	Chlorinated hydrocarbons, organo-phosphorus.	Spraying of highway right-of-way vegetation.
Inorganic salts	$CaCl_2$, NaCl, SO_4, Br.	Deicing salts, atmospheric washout, vehicle.
Organic matter	Vegetation, dust and dirt, humus, roadway accumulations, oil, fuels.	Roadside vegetation, vehicle, litter, aerosols.
Nutrients	Nitrogen, phosphorus.	Fertilizer, atmospheric deposition.
Pathogenic bacteria (indicators)	Coliforms.	Soil, litter, bird droppings, livestock trucks.
Other	Rubber, special compounds.	Vehicle, specific additives.

statistical correlation between certain indicator or carrier pollutants such as total or suspended solids or conductivity (44). These techniques as well as sample handling, preservation and analysis methods will be discussed in more detail in Section 3 and 6.

Provisions must also be made for inclusion of samples for laboratory quality control checks. These types of quality control sample submittals include spiked, duplicate and blank samples and should be incorporated into both in-house and extramural water quality projects. These should be used in addition to routine laboratories quality assurance programs which should include:

1. Analysis of reference samples (Alpha-Trol, EPA, ERA or other reference samples),
2. Performance audits,
3. Replication of analyses,
4. Instrumental checks, and
5. Method comparability checks.

Collecting and analyzing a sufficient number of samples over a range of events to provide statistically meaningful comparisons of runoff impacts is important. This will be discussed in more detail in Section 6.

SECTION 3
FIELD MONITORING STRATEGIES

INTRODUCTION

Strategies for the actual conduct of the field monitoring program are described in this section. Obviously, details of each individual program and site must be tailored to the specific needs and budgetary constraints. It is the objective of this section to acquaint the user with standard field monitoring procedures, where they exist, and provide insights into methods which can be used where standard procedures are lacking. Many of these latter insights were obtained during the course of field monitoring programs conducted under this same contract (see Volume II). Included in this section are:

1. Collection of background meteorological data,
2. Hydrologic characterization,
3. Water quality investigations,
4. Sediment quality characterization,
5. *In-situ* biological methods, and
6. Bioassay testing.

COLLECTION OF BACKGROUND METEOROLOGICAL DATA

Precipitation

It is recommended that recording raingages be used for the comprehensive runoff program. The intensity, duration, and real-time data are of critical importance in evaluating the impact of a given runoff event. Nonrecording gages can be used to provide supplemental information, such as to verify or provide back up for recording gages, or provide insights into the uniformity of rainfall distribution over large drainage areas.

The number of recording raingages required is contingent upon the size and topography of the basin being monitored and the history of rainfall distribution uniformity in the area. Such histories are seldom available for basin sizes which will normally be encountered in highway studies. Therefore, general rules of thumb and common sense principles must be used. Gupta, et al., (8) stated that small highway sites with lengths of 2 km or less will require only one gage.

Winter monitoring of precipitation in cold climates will require special effort. As a minimum, the precipitation collection device will have to be heated to melt snow and ice. Electrical heat tape usually works quite well for this, assuming of course that electrical power is available at the station. If power is not available, antifreeze added to the collector for some types of gages (weighing types) might be sufficient to melt snow and ice. In very severe cold, even the recording instrumentation will have to be heated to prevent freeze-up of mechanical parts. If a heated shed or shelter is at the station, a tube can be run from the tape heated collector to the recorder housed in the shed or shelter.

Atmospheric Deposition

For receiving water impact investigations, background atmospheric deposition is important. It can provide an order of magnitude type of comparison between highway runoff and background atmospheric loadings to the watershed and the highway right-of-way. If more detailed information is desired about the migration of highway pollutants within the right-of-way, including atmospheric processes, then a more complex arrangement of collectors in the highway vicinity will be required. A detailed description of such an application is provided in Kobriger, et al., (2).

Two basic types of collectors can be utilized. Bulk precipitation (combination of wet and dry deposition) and wet/dry collectors are most common. The number of collectors required will again depend on size and topography of the site.

It is critical for retention of deposited particulates that a slight liquid volume be maintained in the collection bucket. According to ASTM specification (15) distilled water should be used. A combination algicide/fungicide (mercuric chloride) or algicide alone (copper sulfate pentahydrate) might be required in warm months. In winter, methanol is usually added (to 50 percent) to prevent freezing. Due to its volatility, it must be replenished quite often (at least once per week). The duration of sample collection should be from four to six weeks to allow for adequate particulate accumulation for analytical needs. However, during periods of heavy rainfall, the buckets might have to be changed more frequently to prevent overflow.

The entire volume of the sample collected should be filtered to determine total particulate matter. Therefore, the volume of sample is not critical to the analysis. Prior to use, collector buckets should be acid washed with 5 percent HCl and then rinsed with deionized water.

Air Temperature, Wind Speed and Direction

The value of obtaining air temperature and wind speed and direction depends on the degree of complexity required in the study. Air temperature data can be important in evaluating snowmelt runoff events (given that some kind of solar radiation data are also available) and estimating evapotranspiration rates. Knowing evaporation rates is only critical if a water budget analysis is to be completed. Wind speed data are also often utilized for desk-top estimates of evaporation rates. Obviously, if pan evaporation rates are actually measured on site, the need for these data diminishes.

Wind speed and direction data can be useful for evaluating the effects of discrete highway runoff events on lakes and wetlands. The dynamics of lake circulation patterns, hence the fate of highway generated pollutants, are often contingent upon the season and magnitude and direction of wind forces. This is especially critical for stratified lakes. This topic will be discussed in more detail in the WATER QUALITY MONITORING portion of this section.

Wind speed and direction is also of importance if the scope of the project includes documentation of atmospheric transport of background or highway related pollutants. Kobriger, et al., (2) should be reviewed for a detailed discussion of atmospheric transport analyses.

HYDROLOGIC CHARACTERIZATION

Careful documentation of hydrologic conditions during the study period is critical to the ultimate evaluation of potential receiving water impacts. Stream discharges and associated hydraulic properties such as travel time, dispersion, velocity and reaeration affect pollutant dilution ratios, deposition of particulates, oxidation of organics, and biological colonization. Runoff intensities and durations, antecedent dry days, and runoff volumes affect the magnitude of pollutant loadings and receiving water dilution ratios. Similarly, lake and wetland water budgets, circulation patterns, and stratification are critical to understanding the fate and effects of highway runoff constituents.

Stream and River Hydrology

Discharge Measurement--

Stream gaging procedures have been meticulously derived by USGS over many years of practical experience. The best method is direct measurement of stream discharge (volume rate of flow of water) at a gaging station by current meters. A number of measurements made over a wide range of stages will allow compilation of a consistent stage/discharge rating curve as shown in Figure 12. This rating curve is then used in conjunction with a continuous recording of water stage to derive continuous discharge data.

Discharge is computed by multiplying the cross-sectional area of flow times the velocity (continuity equation). In practice, this is accomplished by dividing the river or stream into discrete partial discharge sections and summing the product of section area and section velocity according to the following equation (22):

$$q_x = v_x \left[\frac{(b_x - b_{(x-1)})}{2} + \frac{(b_{(x+1)} - b_x)}{2} \right] d_x$$

$$= v_x \left[\frac{b_{(x+1)} - b_{(x-1)}}{2} \right] d_x$$

Where:

q_x = discharge through partial section x,

v_x = mean velocity at location x,

b_x = distance from initial point to location x,

$b_{(x-1)}$ = distance from initial point to preceding location,

$b_{(x+1)}$ = distance from initial point to next location,

d_x = depth of water at location x.

Figure 13 provides a sketch of this method. As a general rule, each section should contain no more than 10 percent of the total flow (22). Uniform lateral spacing of partial sections seldom meets the 10 percent criterion. Spacings should therefore be wider near the banks and narrower at the deeper midchannel sections.

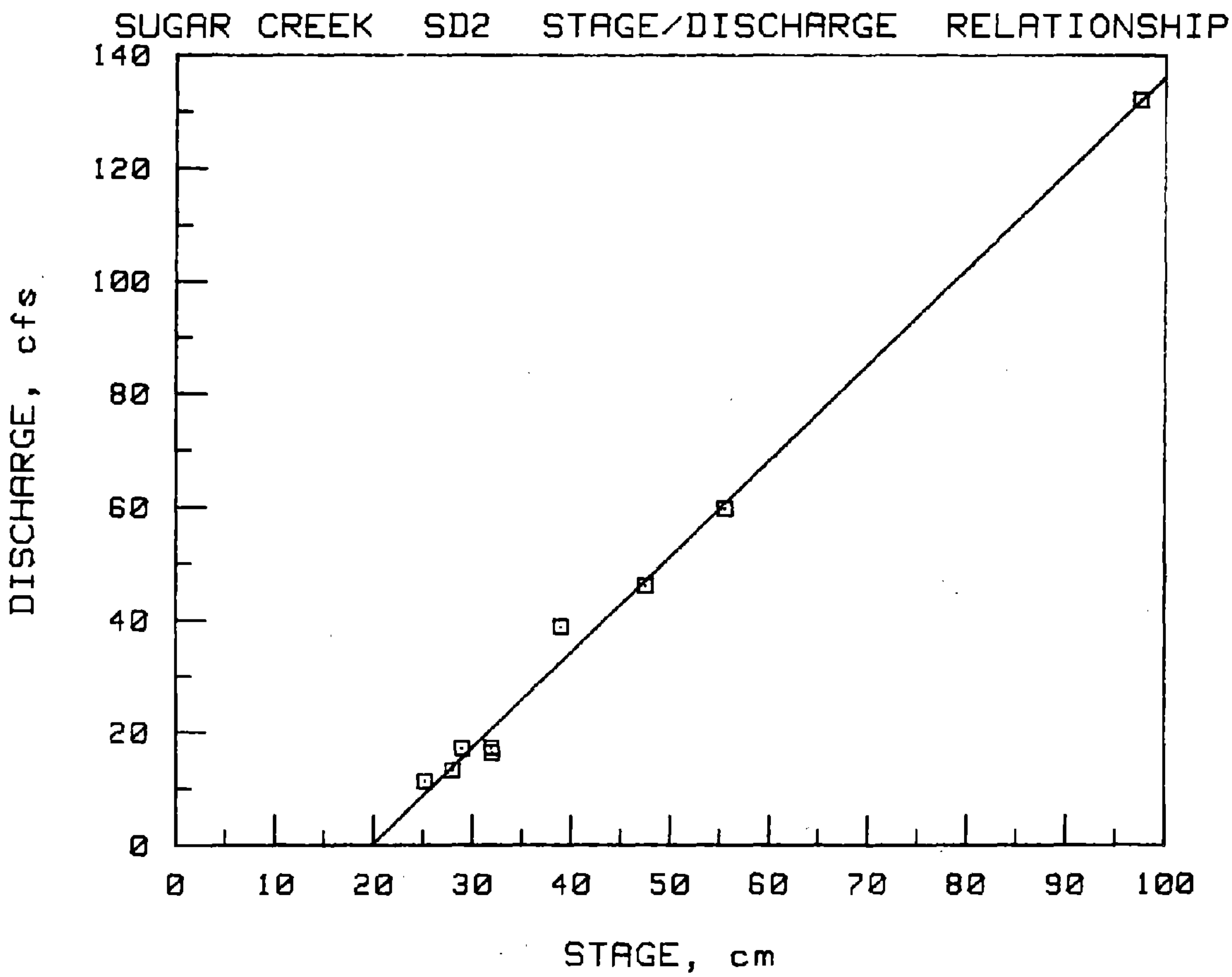
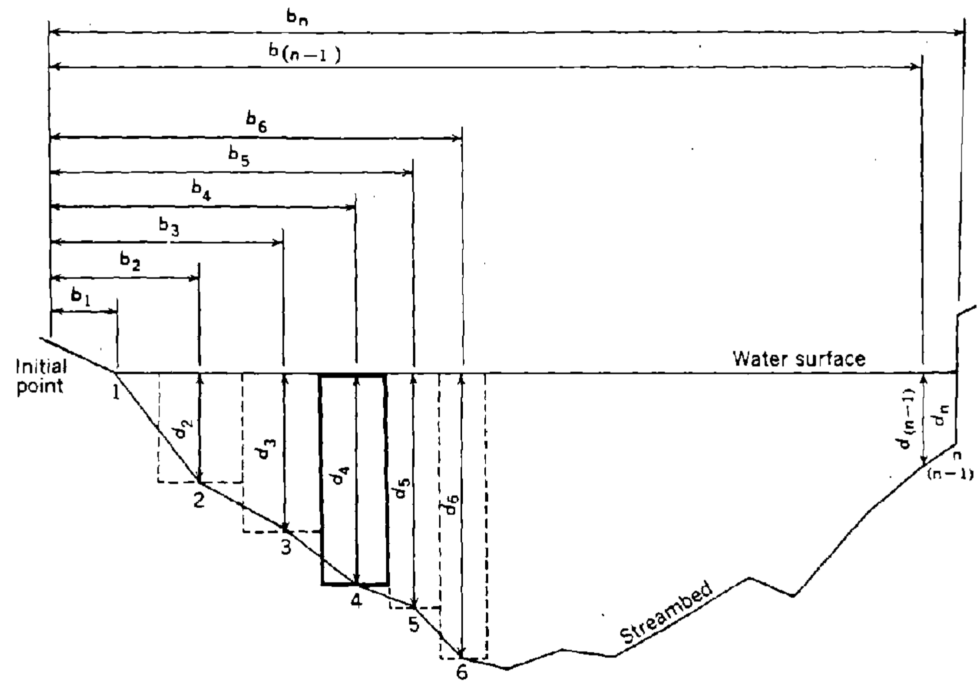


Figure 12. Stage/discharge relationship for Sugar Creek (WI) near Hodunk Road (station SD2).



EXPLANATION

1, 2, 3, ... n	Observation points
$b_1, b_2, b_3, \ldots\ldots b_n$	Distance, in feet, from the initial point to the observation point
$d_1, d_2, d_3, \ldots\ldots d_n$	Depth of water, in feet, at the observation point
Dashed lines	Boundary of partial sections; one heavily outlined discussed in text

Figure 13. Definition sketch of midsection method of computing cross-section area for discharge measurements (22).

Velocity measurements can be obtained by a variety of methods depending on the characteristics of the stream or river. These are (12, 22):

1. Vertical-velocity curve,
2. Two-point,
3. Six-tenths depth,
4. Two-tenths depth,
5. Three-point,
6. Subsurface.

The vertical velocity method is the most accurate and consists of measuring velocity at a number of vertical positions within each partial section as shown in Figure 14 (22). Due to the high cost of obtaining and analyzing these data, the vertical velocity method is normally used only to verify the results of other methods.

Velocity measurements are made at 0.2 and 0.8 of the depth below the water surface for each partial section in the two-point method. This method is advisable for streams or rivers greater than 2.5 ft deep. The six-tenths depth method is also frequently used, especially for stream depths less than 2.5 ft. Here the velocity is obtained only at the 0.6 depth below the surface. The other methods are used less frequently and are described in several references (12, 13, 22). Special techniques must also be employed for discharge measurement under ice cover in winter. These methods are detailed in Buchanon and Sommers (22).

Other less frequently used methods of direct measurement of discharge are volumetric measurement (only when discharges are small enough to be collected in a chamber of known volume) and dye-dilution where the dilution ratio of an injected conservative solution (of known volume and concentration) is a direct measure of the discharge volume. Rhodamine WT is the only dye currently recommended for surface water work. It has very low adsorptive losses and negligible photochemical decay.

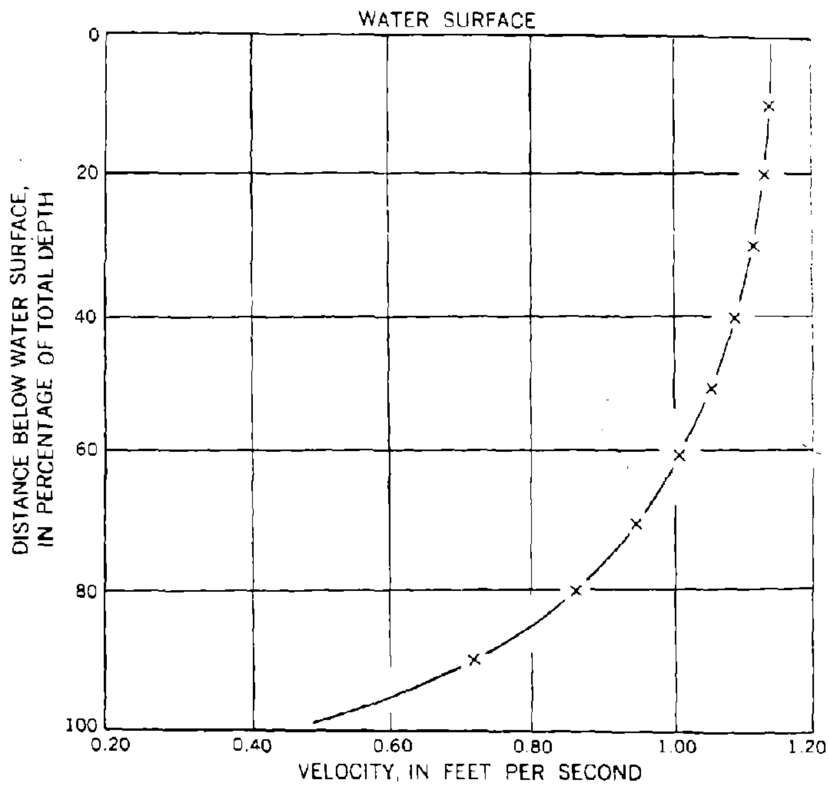


Figure 14. Typical vertical-velocity curve (22).

Indirect methods can also be used if project funds or abnormal field conditions (eg., extreme flooding) prohibit direct measurement. These are:

1. Slope-area,
2. Contracted-opening,
3. Flow through culvert,
4. Flow over dams and weirs,
5. Step-backwater.

Details of these methods can be found in the National Handbook of Recommended Methods for Water Data Acquisition (12).

Time-of-Travel and Dispersion Studies--

Time-of-travel studies are important not only to evaluate relative data from several stations along a stream but also to more effectively plan water quality surveys. This is especially true if synoptic surveys are to be used. (Water quality surveys are discussed in a later portion of this section). Dispersion studies are typically used to determine the downstream (longitudinal) attenuation of peak conservative pollutant concentrations. These are due to lateral hydraulic (mainly velocity) differences, especially for meandering stream sections. The way in which time-of-travel and dispersion information is integrated into the overall data analysis for a site is discussed in Section 6.

A single dye study will provide data for calculation of both travel time and longitudinal dispersion at one flow rate. At least one other study must be conducted at another flow rate in order to derive a relationship between travel time/dispersion and flow rate. It has been shown that this function is geometric for travel time according to the following equation (12):

$$t = kQ^{-a},$$

where:

t = travel time

Q = volume flow rate

k and a = coefficients of best fit.

Figure 15 illustrates this relationship for Sugar Creek in Wisconsin from station SD2 to SD3.

Dye is injected into the stream at some point upstream of the stations of interest. This injection point should be far enough upstream of the first station to allow complete lateral mixing of the dye. According to Hubbard, et al., (45), this distance can be calculated according to the following equation:

$$L_m = C \frac{v W^2}{E_z}$$

where:

L_m = upstream distance, m

C = coefficient, C = 0.1 for mid-channel single point injection and C = 0.4 for bank single point injection

v = mean reach velocity, m/s

W = average channel width, m

E_z = transverse mixing coefficient, m^{2}/S

$$E_z = 0.2\ dv_* = 0.2\ d\ (gds)^{1/2}$$

where:

d = mean depth, m

v_* = shear velocity, m/s

s = water surface slope, m/m

In order to eliminate the problem of lateral mixing, multiple point or line injections can also be made. Further discussion of these methods can be found in Hubbard, et al., (45).

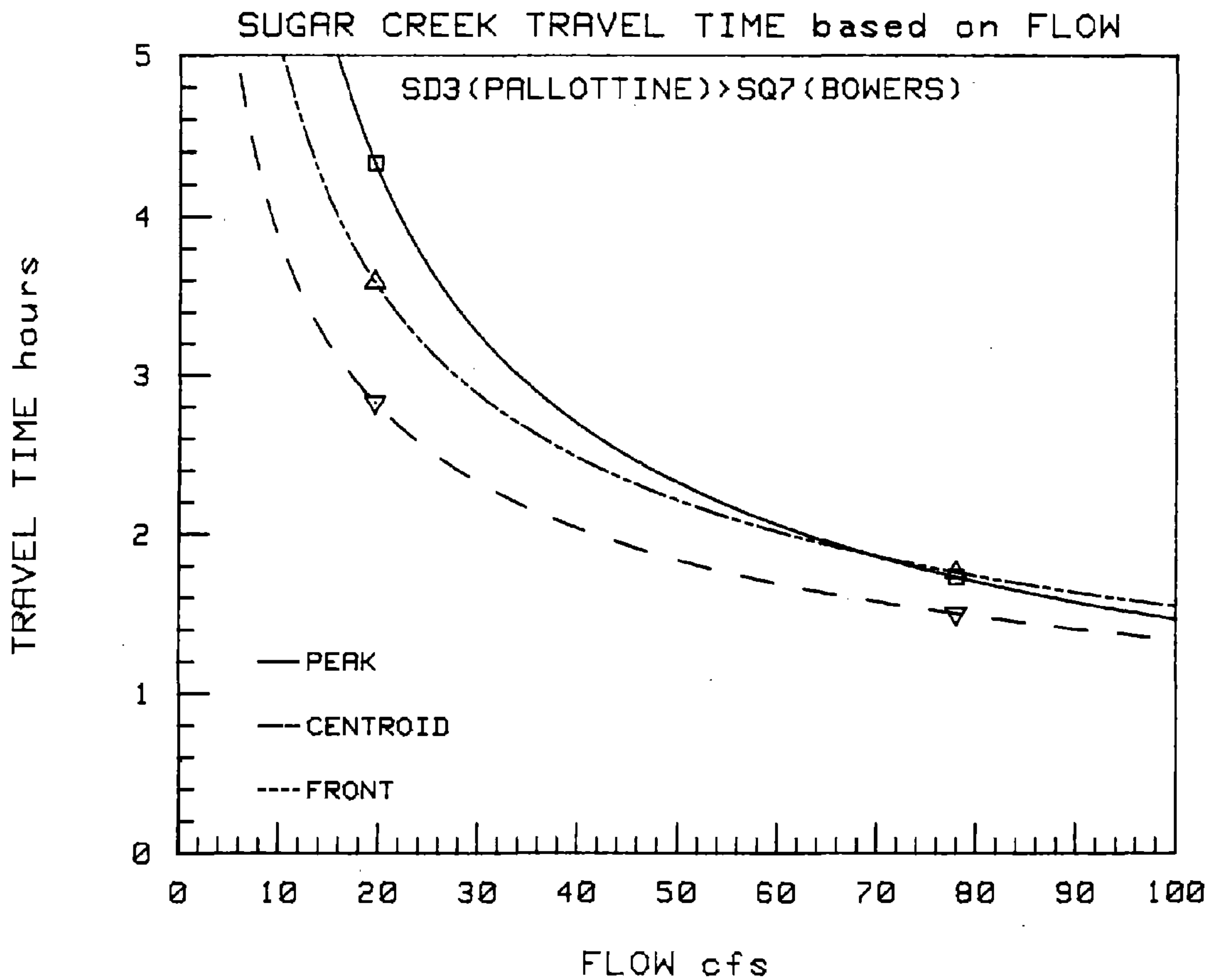


Figure 15. Travel time between two stations related to stream flow for a segment of Sugar Creek (WI).

The concentration profile as the dye cloud progresses downstream past several sampling stations (see Figure 16) is determined by in situ flourometric measurement or by collection of water samples followed by laboratory or field determination. Time-of-travel from station to station is calculated as the time between dye fronts, t_F, (ie., first measurable dye concentration), peak concentrations, t_P, or dye cloud centroid, t_C. Figure 16 demonstrates the difference between these travel times for a given stream (here, Sugar Creek). Generally, centroid travel times should be used unless there is a specific need for the other travel times. For example, peak concentrations are of most interest with regard to potential water quality standards compliance.

Rhodamine WT is presently the dye of choice for receiving water studies (45). The toxicity of Rhodamine B and the photochemical decay of fluorescein dyes preclude their use for this application. Dye can be injected either instantaneously or continuously at a known dilution and flow rate.

If a very long reach of stream is to be studied, it is best to break up the study into several subreaches and make several dye injections. If this is not done, dye concentrations at the furthest downstream monitoring stations will be below detection limits due to dispersion. Obviously, dye injections should be made at subreaches furthest downstream with subsequent subreaches injected moving upstream. This will prevent dye cloud overlap due to dispersion which would confound the analysis.

Details on equipment recommended for dye injection and sampling are given in Hubbard, et al., (45). Details on flourometric analyses are given in Wilson (46).

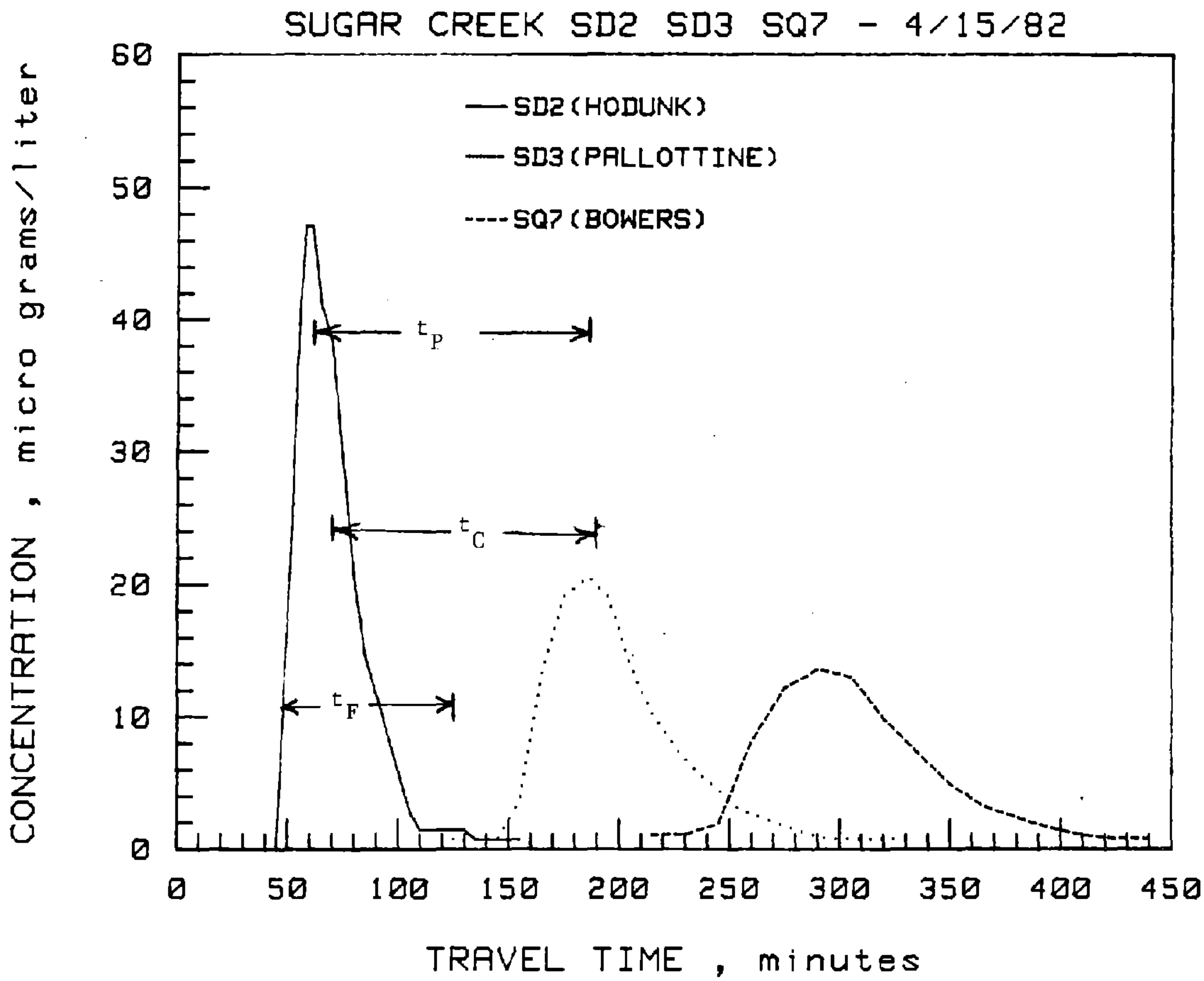


Figure 16. Rhodamine WT dye concentration curves for three stations on Sugar Creek (WI).

The quantity of dye which should be injected to ensure measurable flourometric concentrations can be calculated from the following formula (12, 45):

$$V_d = 2.0 \times 10^{-3} \left[\frac{(Q_m L)}{V} \right]^{0.93} Cp,$$

where:

Vd = volume of 20 percent Rhodamine WT dye, liters

Q_m = maximum discharge in reach, m^3/sec

L = length of reach, km

V = estimated mean velocity in reach, m/sec

Cp = peak dye concentration desired in downstream reach, μg/l
(NOTE: 25 μg/l is usually visually detectable, less than 5 μg/l is generally recommended for Cp).

Lake and Wetland Water Budget

The various components in a water budget for a lentic series can be summarized as follows:

$$\frac{dV}{dt} = I - O + (P \pm E),$$

where:

V = lake or wetland volume

t = time

I = net inflow rate

O = net outflow rate

P = precipitation

E = evapotranspiration.

The rate term, dV/dt is often referred to as the change in storage (ΔS). Inflows can be in the form of direct surface runoff, stream or river and groundwater inflows. Outflows are from stream or river outflow and groundwater seepage. Note that the evapotranspiration term which is usually negative becomes positive at times when condensation exceeds evaporation.

This happens, for example, when the water is considerably colder than the air, as can occur in spring.

Precipitation, evaporation, surface water inflows and outflows can be readily quantified by methods already described. Groundwater flows are quite difficult to measure accurately and it is common in actual practice to determine this component by difference. The change in storage is determined by combining data from continuous monitoring of lake level and detailed hydrographic mapping. Note that a slight change in lake level results in very significant changes in lake volume. This necessitates careful and accurate lake level recording.

Hydrographic mapping surveys are used to determine underwater bottom contours. Knowing the morphometric characteristics of the lake allows calculation of water volume at any level. The survey is conducted by establishing a grid or series of range lines and measuring water depth along each range at specified intervals. Points of equal depth are then connected when constructing the hydrographic map. A number of methods have been used for establishing range lines, maintaining datum control, determining position along the range line, and measuring depth. One commonly used technique is to travel by boat along the range line at constant speed. This allows the determination of distance and position as a function of time. Depth determination is usually accomplished either with a sounding pole for shallow lakes (less than 6.7 meters) or by using a sonic sounder. More details on hydrographic mapping can be found in the National Handbook of Recommended Methods for Water Data Acquisition (12). Although hydrographic maps are often available from state or regional agencies, they might not have contour intervals short enough for highly accurate volume determinations. A contour interval of 0.5 m (1.6 ft) or less is generally recommended for detailed reservoir surveys (12).

The relative importance of each of the terms in the water budget varies considerably between lakes and even for a given lake over the course of several seasons or years. Some closed lakes are dominated by atmospheric inputs and outputs while others are dominated by surface and/or groundwater flows.

Knowledge of the hydrodynamics (water circulation patterns) of lakes is also critical to effective water quality monitoring programs. For smaller lakes, this mainly involves wind induced motions. Under ice cover, water movements can still be quite extensive, even in the absence of inflows. A net heat flux from sediments to water column in winter will induce density currents. The upward or downward movement of this warmed water within the lake will initially depend upon the lake water temperature before ice-cover is established (47).

These types of motions influence the fate of pollutants within a lake and hence govern the sampling strategy during baseline and wet weather water quality surveys (discussed later in this section). Surface and groundwater inflows to a lake, including highway runoff, will move into density layers within the lake most similar to their oven density, which is a function of temperature and dissolved and suspended material.

Runoff Monitoring

Utilization of effective monitoring procedures for the runoff event(s) is critical for accurate assessment of receiving water impacts. Both the quantity and quality of highway stormwater runoff must be documented. Time synchronization between runoff and receiving water data collection must be accurate. The storm pollutant load and receiving water dilution potential (assimilative capacity) can only be determined if such data are available.

Components of a detailed runoff monitoring program are as follows:

1. Continuous measurement of volumetric runoff rate,
2. Automatic sampling for runoff quality,
3. Manual grab sampling for special pollutant classes such as oil and grease, pesticides, herbicides and bacteria,
4. Continuous or intermittent in situ measurement of water quality parameters such as temperature, pH or conductivity,
5. Record keeping, and
6. Sample handling, preservation, compositing and analyses.

Continuous measurement of volumetric flow rate can be determined by methods described in detail in Sections 3 and 4 and in Gupta, et al., (8). It should be emphasized that all primary control devices (weirs and flumes) should be field calibrated. Submergence effects on weirs and flumes and approach velocity effects on weirs can cause significant deviation from standard rating tables found in the literature (17, 18, 19). Field calibration should be accomplished by either the velocity-area (ie., current meter) or volumetric methods. Smaller pygmy-type current meters will be required for this application. Further discussion of calibration of submerged flow control structures can be found in Skogerboe (20).

Equipment and methods of automatic sequential sampling of runoff are discussed in Gupta, et al., (8) and U.S. EPA (48). Some automatic samplers can be operated in either a time or flow volume mode. The flow volume mode is beneficial when samples are to be flow volume composited prior to analysis. Liquid level actuated samplers are also beneficial, especially for remote sites where it is often difficult for field personnel to arrive prior to runoff.

Certain types of samples must be obtained manually. These are oil and grease, pesticides, herbicides and bacteriological samples. Hydrocarbon-based pollutants can adsorb to plastic tubing sidewalls, which is commonly used for intake sampling lines for automatic samplers. Bacteriological samples cannot be taken with a sequential sampler since the lines would require sterilization between samples. Manual grab sampling should be performed according to methods described in Gupta, et al., (8).

Recordkeeping is a critical part of any field monitoring program. Detailed field logs should be used. Pertinent field notes should be recorded as soon as possible; relying on memory can lead to gross errors. Specific information which should be recorded with respect to runoff monitoring includes:

1. Weather information,
2. Monitoring equipment maintenance tasks,
3. Condition of the highway right-of-way and observation of highway department maintenance activity such as road salting, herbicide or pesticides application, mowing, etc.
4. Details and times of sample collections or measurements.

Such notations are useful for documenting long term equipment maintenance and reliability trends and for synchronization of a variety of data after the event. Sorting out the particulars of a monitoring event several days later is virtually impossible without detailed field recordkeeping. This is especially true for surveys conducted during odd hours when monitoring personnel might be under unusual stress.

Sample handling, preservation, compositing and analyses are also of critical importance. Since these procedures are basically the same as for receiving water sampling, the discussion will be deferred to that section of this report.

WATER QUALITY

Approaches to water quality monitoring are quite different for each receiving water type. Stream and river responses to rainfall events demand a different monitoring approach than lakes or wetlands. For that reason, these receiving water types will be dealt with separately in this section.

Stream and River Surveys

Survey Types--

For the purpose of assessing potential highway stormwater runoff impact, it is necessary to conduct surveys during both dry and wet weather conditions. For streams and rivers, there is often no absolute demarcation between these conditions, especially for systems fed mostly by surface runoff. That is, between storm events, stream flow rates decrease continuously, even to drought, until the next event. For other systems, where groundwater flows are prevalent, the baseflow is more distinct, but will also vary according to long term precipitation and groundwater recharge patterns. Nonetheless, intuitive determinations can be made. For example, Figure 17 shows long term stream discharge for a station on Sugar Creek in Southeastern Wisconsin. Note that baseflow (roughly 15 cfs [0.45 m^3/s]) and stormflow conditions can be qualitatively distinguished. Quantitative separation of baseflow from stormflow is more complex, however, and is discussed in detail in Section 6.

The above discussion demonstrates the necessity of control station sampling. If quality comparisons between dry and wet conditions are difficult, then upstream control versus highway influenced water quality will form the basis for impact assessment. Such an assessment requires documentation of both pollutant concentration (mass/unit volume) and pollutant load (mass/unit time). Highway runoff might increase both the concentration and the load, or as has often been seen for road deicing salts, the load will increase but not the concentration due to increased stormwater dilution.

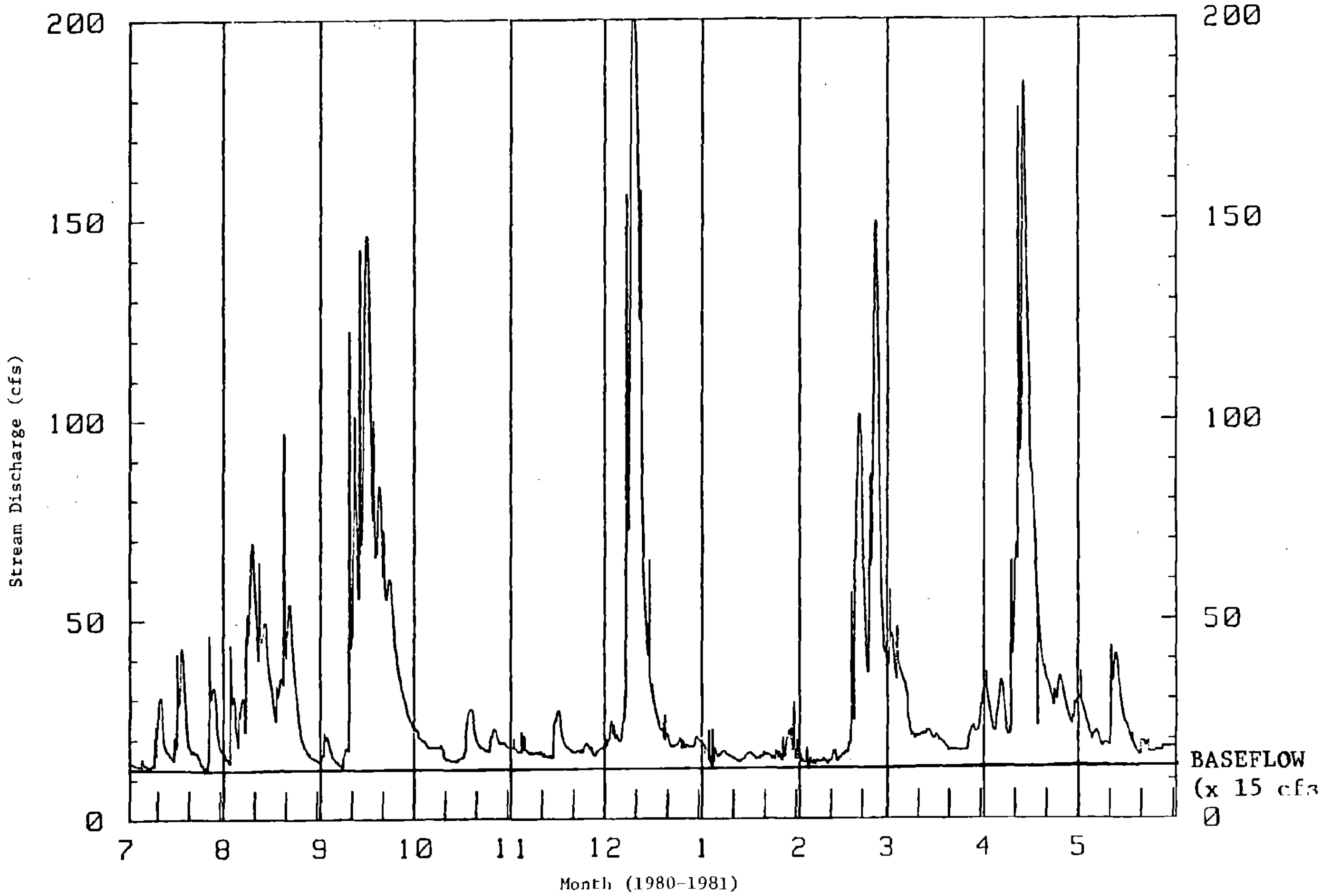


Figure 17. Stream discharge for station SD3 at WI Highway 15/Sugar Creek site.

Baseline water quality (ie., dry weather) sampling must include at least one control and one influenced station, even though no highway runoff inflows are present between these stations during the survey. Sediment fluxes of pollutants can affect water quality. For example, during summer low flows, when stream or river oxygen content is reduced, certain nutrients or even metals may be released from sediments into overlying waters.

Two basic approaches can be used for wet weather surveys:

1. Synoptic surveys, and
2. Hydrograph surveys.

Synoptic surveys attempt to follow a given "slug" of water mass as it moves downstream. This allows direct evaluation of both downstream sequential pollutant inputs and, if no additional pollutants are input, determination of non-conservative pollutant reaction rates (such as dissolved oxygen sag or bacterial die-off) and conservative pollutant (especially salts) dispersion or dilution. This approach is labor intensive since most sampling must be manual and requires detailed knowledge of stream hydraulics (ie., travel time, velocity) prior to the monitoring event. This type of survey would be useful if the highway agency is interested mostly in the downstream spatial and hydraulic characteristics of a discrete input of salt or spill of a conservative toxic substance.

A more useful method for most highway runoff studies is the hydrograph method. Here, samples are taken, either manually or automatically, at each station as a function of the hydrograph at that same station. Figure 18 shows typical sampling intervals over such a hydrograph. This allows determination of a station pollutograph (again see Figure 18). A flow-weighted composite sample can also be prepared from such a survey. This allows direct comparison between control and highway influenced station pollutant loads. The method is less labor intensive since automatic samplers can be used. Note that synoptic information can be obtained from the hydrograph survey, especially if sampling intervals are short enough. For remote sites, automatic sampling (level

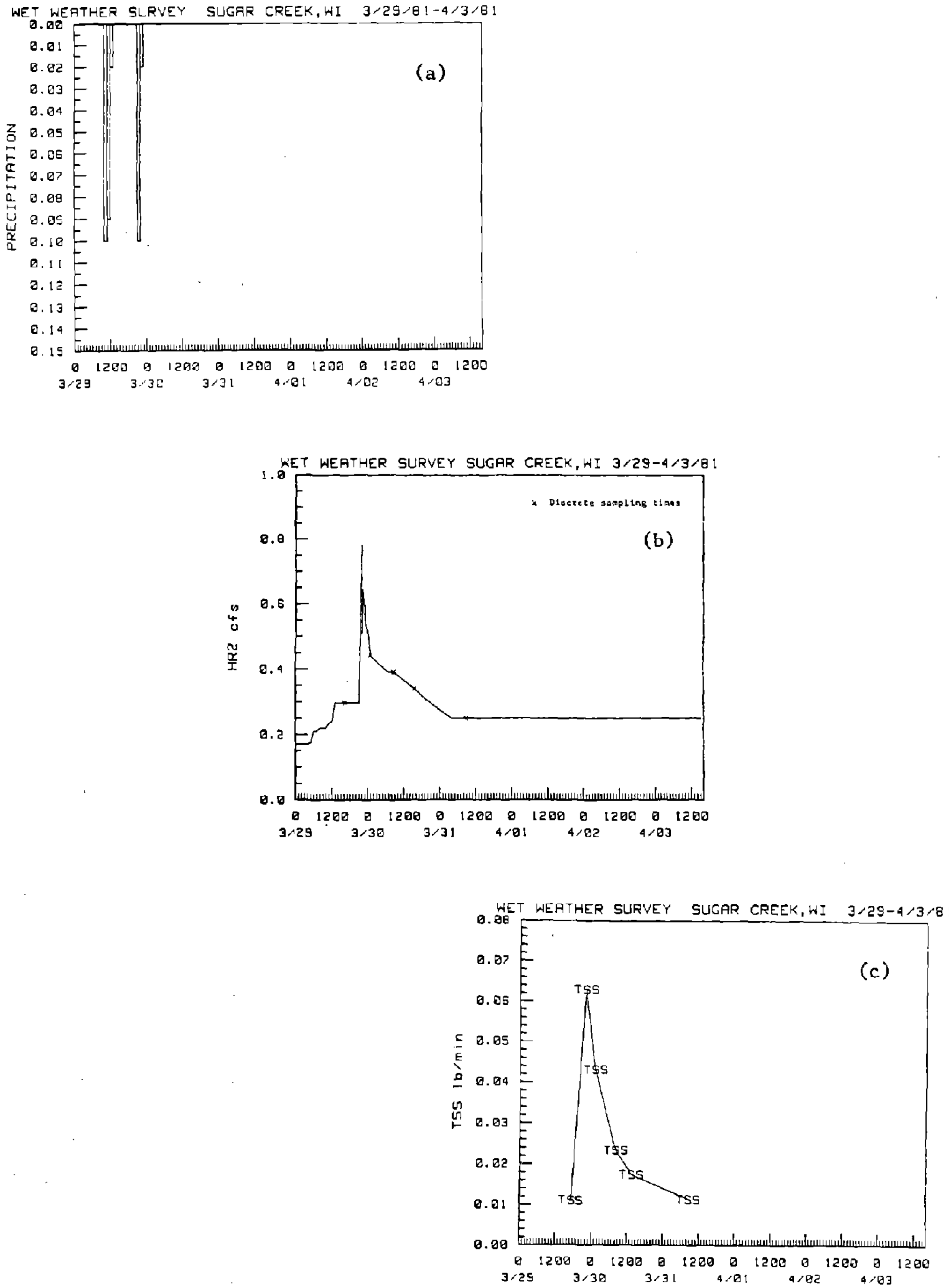


Figure 18. Rainfall distribution (a), hydrograph (b), and pollutograph (c) for storm event at Wisconsin Highway 15/Sugar Creek site.

actuated) minimizes incurred costs due to weather uncertainty. Drawbacks to the automated method include possible prestorm contamination of sampling probes, equipment failure and inability to get a baseline sample immediately prior to the precipitation event. The effect of these shortcomings is reduced by regular baseline monitoring and careful selection, placement and maintenance of intake probe and lines. Furthermore, the cost of aborted manual surveys (due to hard to predict weather conditions) is usually much more significant than lost surveys due to equipment failure.

Number of Events--

The number of events chosen for baseline and wet weather surveys should be sufficient to provide both statistically meaningful (see Section 6 for guidelines) and seasonally distributed water quality data. Practically, the number of events must be tailored to conform to project funds and objectives. Field studies should be at least one year in duration to cover all seasonal conditions. Exceptions could be made in geographical regions where the majority of precipitation events occur over a limited time of year.

The technical literature can provide guidelines on sampling network design, cost-effective monitoring strategies, and sampling frequency (48, 49 50, 51). Unfortunately, many of these guidelines deal with basin-wide water quality evaluations and not the microscale subbasin programs that will be required for most highway/receiving water impact studies. Monthly sampling should be sufficient for dry weather water quality assessment for most perennial streams and rivers. The number of wet weather surveys conducted should reflect the local variation in precipitation events. There should be a range in precipitation volume, intensity, duration and type; and antecedent conditions such as dry days. For example, in a northern climate, the following hypothetical wet weather matrix would comprehensively describe the entire range of potential events:

Rain volume:	low (<0.5"), high (>1.0")
Rain intensity:	low (<1.0 in/hr), high (>1.0 in/hr)
Precip. type:	rain, snow or ice
Antec. dry days:	low (3-5), high (>10)

However, to combine all the above variables would require a factorial experiment (2^4) of at least sixteen events. If the study duration is one year, it will be logistically impossible to conduct this many surveys, especially for a remote site. Experience has shown that six to ten surveys can be difficult in a one year period, depending on the complexity of the receiving water site. The most meaningful event conditions for highway runoff studies, given the nature of pollutant wash-off and transport, are as follows:

1. Low rain volume, high intensity, long antecedent dry period;
2. High rain volume, low intensity, long dry period;
3. High rain volume, high intensity, long dry days;
4. Any rain volume, high intensity, short dry days; and
5. Any snow or ice storm with road salting and melt runoff.

Since prediction of rainfall volume and intensity prior to the event is rather uncertain, it should be assumed that more than five events will be monitored to match these conditions. Other problems, such as equipment malfunction, will also necessitate that additional surveys be planned.

Sampling Procedures--

Specific types of equipment used in stream and river sampling have been previously described (Section 2). Basically these consist of suspended sediment samplers, simple subsurface manual grab bottles (wide mouth), Kemmerer or Alpha-type discrete depth samplers, and automatic sequential samplers with intake line and probe. Of major concern in this section are the spatial requirements for sampling. Specifically, how should a given station lateral transect be sampled to assure representativeness of the entire flow cross section?

Due to the often demonstrated affinity of highway related pollutants, especially hydrocarbons and metals, to particulates (1, 2), it is recommended that standard USGS suspended sediment sampling techniques be used (9, 12, 52, 53). These basically consist of taking vertical depth-integrated samples at several lateral positions along a stream or river transect. These vertical samples can be analyzed individually or combined into a single flow volume weighted sample (52). It may be possible for a given system to develop a statistical correlation between such a flow and depth integrated sample and a single subsurface grab sample. This will greatly reduce field sampling time for subsequent surveys. Figure 19 is an example of a point-sample to depth integrated sample correlation function for the I-85/Sevenmile Creek site (See Volume II).

Due to the labor intensive nature of the above sampling scheme, it has become fairly common practice to attempt to locate sampling stations far enough downstream to allow complete lateral mixing of pollutant inputs. In this case, a single depth-integrated sample and/or correlation function of a single grab sample will provide adequate quality data. Hem (54) has stated that in practice, small and medium sized streams generally have sufficiently uniform lateral and vertical quality to allow for a single sample taken at or near midstream. However, development of a correlation function with depth-integrated samples is recommended for highway studies where suspended particulate matter plays such a dominant role in pollutant transport. If sampling stations cannot be located far enough downstream to ensure uniform lateral mixing, then statistically valid plume sampling procedures such as those outlined by Adrian, et al., (49) or standard USGS suspended sediment sampling methods (9, 12, 52) should be used. As few as four grab samples across a transect may be sufficient to determine the lateral plume dispersion characteristics (49). But again, time consuming field verification of the method is required.

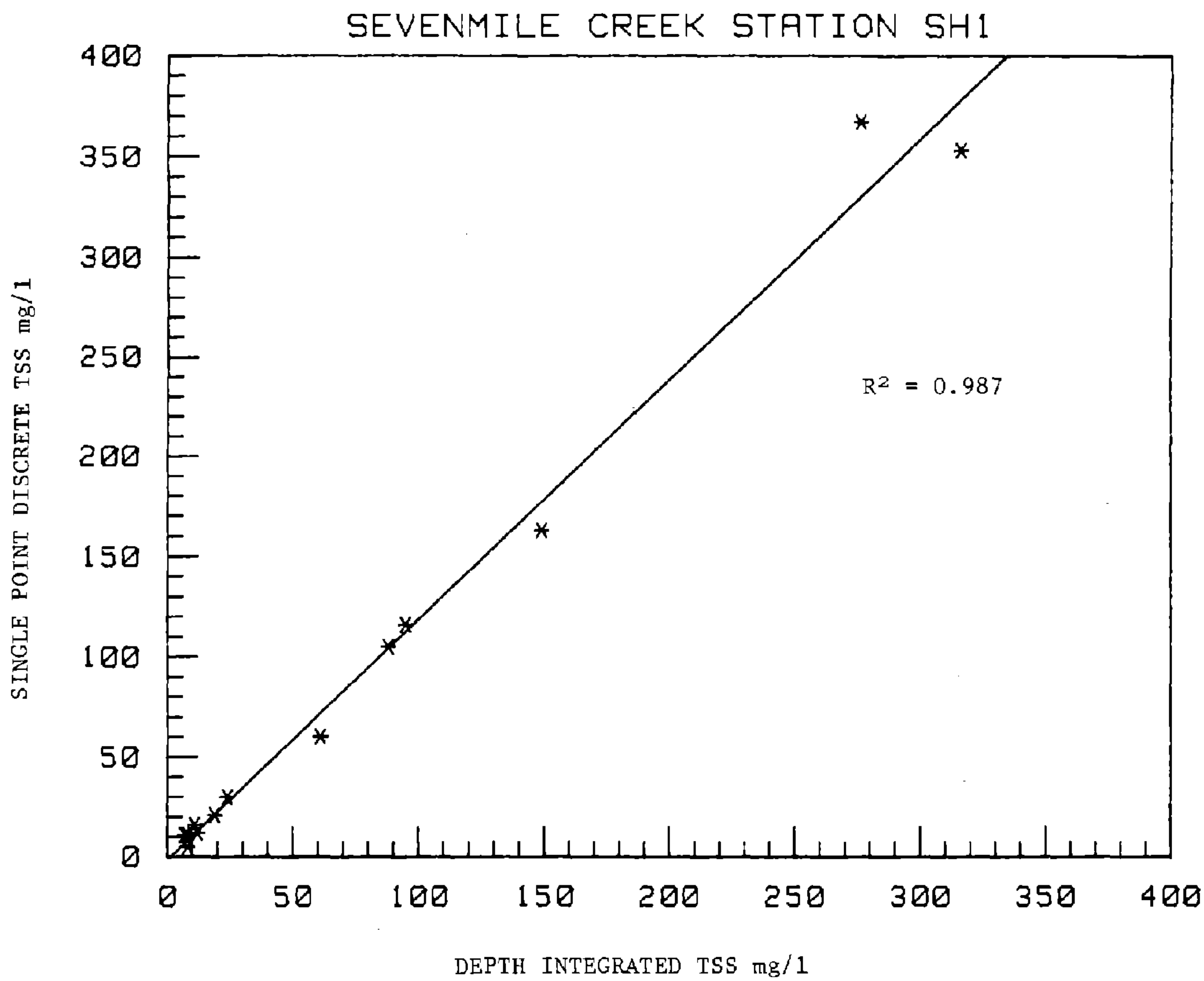


Figure 19. Depth-integrated and single point discrete sample total suspended solids concentration relationship for station SH1 at I-85/Sevenmile Creek site.

Lake and Wetland Surveys

Effective lake (including impoundments) and wetland monitoring will require not only generalized knowledge of hydrodynamics but also specific knowledge of frequently changing climatic and attendant hydrodynamic conditions. Although it is beyond the scope of this manual to serve as a detailed limnology text, basic principles which directly affect the monitoring approach will be elucidated. For more information, the user is referred to the excellent limnology text by Wetzel (47), or the three volume treatise by Hutchinson (55, 56, 57).

There are several key hydrodynamic concepts which will provide sufficient insight into required lake monitoring strategies:

1. Thermal stratification,
2. Wind induced mixing and circulation patterns, and
3. Density currents.

Many observed water quality changes are attributable to these hydrodynamic phenomena.

Thermal Stratification and Density Currents--

There are a number of types of thermal stratification which are used to characterize lakes. The type of stratification is typically a function of altitude and latitude as shown in Figure 20. Table 4 lists these lake types and simply defines the thermal conditions for each. Note that most lakes do not undergo thermal stratification. For small shallow lakes, wind induced mixing forces are able to overcome buoyancy (density related) forces created by solar warming of the lake water. Such stratification usually occurs for deeper lakes (or some shallow lakes under ice cover, referred to as inverse stratification). Unfortunately, no definitive depth can be stipulated at which thermal stratification will occur for a given climatic region. Other

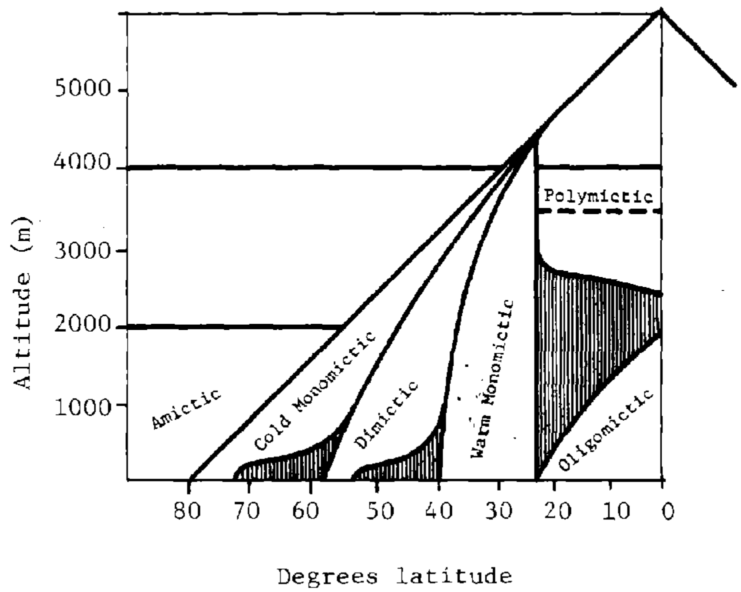


Figure 20. Schematic arrangement of thermal lake types with latitude and altitude (shaded areas represent transitional regions), (47).

Table 4. Types of thermal stratification common in the United States (after Wetzel (47)).

Lake type	Definition
Holomictic:	Seasonal circulations occur throughout the entire water column.
- Cold monomictic	Water temperature never exceeds 4°C; one turnover in summer; mostly found in Arctic or mountain regions.
- Warm monomictic	Water temperature never below 4°C; water circulates freely in winter and stratifies in summer only; most lakes in central, eastern and coastal regions of North America are warm monomictic.
- Dimictic	Two periods of overturn, one in fall and one in spring with thermal stratification in summer and inverse stratification in winter; found in cool temperate regions.
Meromictic:	Never undergo complete ciruclation, permanently stratified; usually caused by vertcial chemically induced density gradient, usually salinity infusion.

factors such as surface area, depth-volume relationships, prevailing wind direction and basin orientation, and topographical protection all affect the potential for a lake to stratify (47). Most wetlands are quite shallow and hence stratification is rarely encountered.

Lake stratification is the result of density layering; for holomictic lakes the density gradients are temperature related, for meromictic lakes the gradients are usually salinity related. Figure 21 shows the peculiar relationship between water temperature and density. Note that the maximum density of freshwater occurs at 3.94 °C, which explains why ice floats and inverse stratification occurs for dimictic lakes in winter. Also of importance is the fact that an increase in salt content of only 1 g/l will increase the density by around 0.00008 g/ml. Thus an increase in salt concentration of only 10 mg/l will bring about a density increase comparable to a temperature drop from 5 °C to 4 °C. Road salt laden runoff will seek the lake stratum of equal density. The implications of this phenomenon with respect to lake sampling is further discussed later.

Terms commonly used to define the three predominant density layers during summer stratification in dimictic and monomictic lakes are illustrated in Figure 22. Terms in parentheses are used for meromictic lakes. A typical seasonal progression of stratification and mixing for a dimictic lake in Michigan is shown in Figure 23. Note the inverse stratification in winter months under ice cover.

Any inflow to a stratified lake or impoundment will tend to gravitate to the layer of like density. If the density of the inflow is approximately equal to that of the epilimnion, then an overflow will occur. Underflow and interflow can also occur for inflows to the hypolimnion and metalimnion (thermocline), respectively.

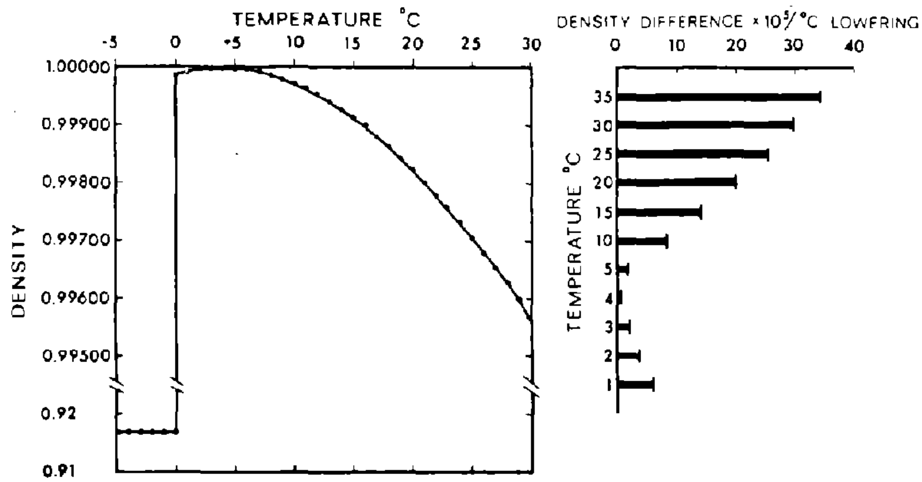


Figure 21. Density as a function of temperature for distilled water at 1 atm. The density difference per °C lowering is shown in the righthand portion of the figure at various temperatures (47).

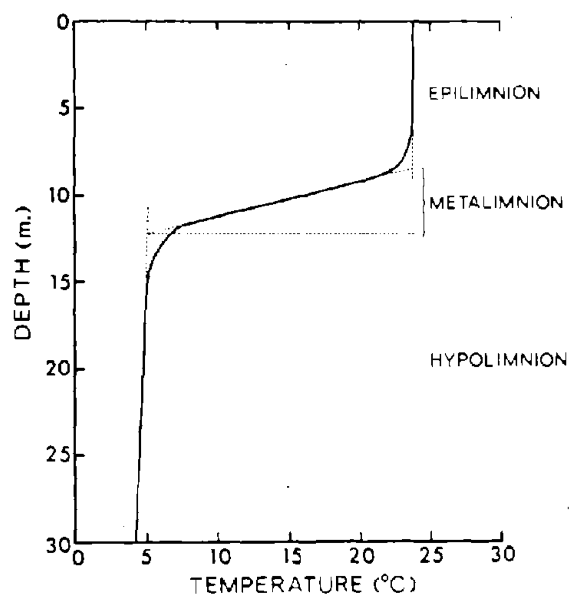


Figure 22. Typical thermal stratification of a lake into the epilimnetic, metalimnetic, and hypolimnetic water strata (47).

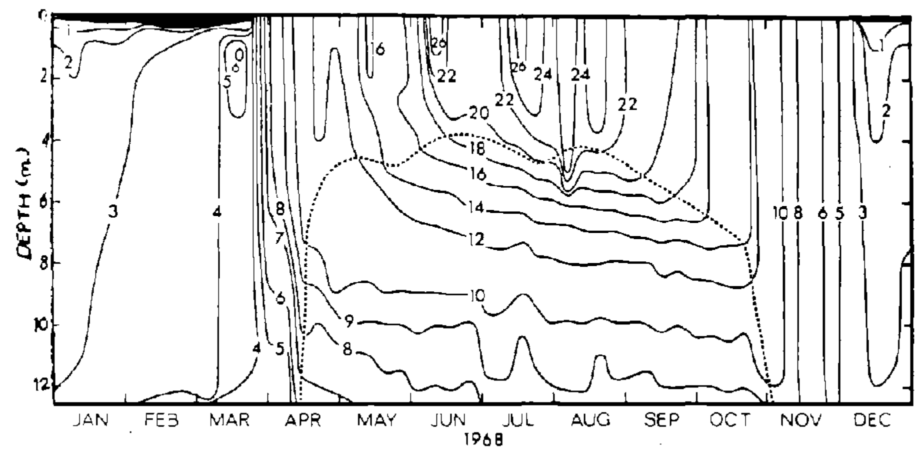


Figure 23. Depth-time diagram of isotherms (°C) in Lawrence Lake, Michigan, 1968. Dashed line indicates the upper metalimnetic-lower epilimnetic boundary. Ice-cover drawn to scale (47).

It is apparent that field monitoring efforts during stratified conditions will be enhanced if field personnel are aware of the stratum into which the runoff will most likely go. Sampling efforts, not ignoring other strata, should be concentrated in the most affected layer. This will require frequent field measurement of runoff temperature and density (approximated by correlations with specific conductivity for deicing agent laden runoff).

During summer stratification, the density function will be strictly temperature related. During winter or early spring in northern climates, both temperature and salt content will affect the density and flow distribution. Table 5 illustrates typical winter stratification for a dimictic lake (Lower Nemahbin Lake, WI, Station X4, January 1983). Typical surface water inflow to the lake was around 1.5 °C and would thus flow through the upper layer just below the ice to the overflow. However, if inflows have a significant salt content, the density at 1.5 °C would be considerably greater than existing lake water. Such concentrations are not atypical of winter snowmelt or spring thaw events. Table 6 shows the relationship for salt content, water temperature, specific conductivity, density and total dissolved solids for snowmelt runoff water collected from a bridge deck on I-94 near Delafield, WI (See Volume II). This salt laden runoff might sink to the bottom and flow through the hypolimnion or possibly accumulate as a relatively stagnant density layer until spring turnover, though these effects were not apparent during the winter of 1982-83 at Nemahbin Lake.

Wind Effects on Lake Circulation Patterns--

Even after the onset of stratification, lakes and impoundments are not static entities. Wind induced forces will thoroughly mix unstratified basins and the epilimnion (mixolimnion) of stratified basins. Even under ice cover, water circulation can be quite extensive due to density currents generated by heat input to lower waters from sediments.

Table 5. Inverse stratification of Lower Nemahbin Lake (station X4) near I-94, Delafield, WI - February 25, 1983.

Depth, feet	Water temperature, C°	Specific conductivity, µmhos/cm at 25°C
1.0	2.0	520
3.0	2.0	550
6.0	2.0	550
9.0	2.5	550
12.0	2.5	550
15.0	2.5	570
18.0	3.5	580
21.0	3.5	590
24.0	4.0	600
27.0	4.0	600
30.0	4.5	600

Table 6. Relationship between specific conductivity, specific gravity and salt content for bridge deck scupper drain runoff at I-94/Lower Nemahbin Lake site for January - February, 1983.

Date	2/14-18	2/2	1/22	2/2	2/10-14	1/15	2/2	1/14
Total solids, mg/ℓ	2,380	8,570	8,640	19,200	20,000	24,100	47,200	93,600
Total dissolved solids, mg/ℓ	2,280	8,430	8,550	19,100	19,900	23,900	47,140	93,100
Specific conductivity, μmhos/cm @ 25°C	3,800	13,000	14,500	22,000	20,000	30,000	25,000	60,000
Specific gravity, @ 25°C	NM	1.006	1.006	1.014	1.014	1.016	1.018	1.038
Salt content, mg/ℓ as NaCl	2,060	8,100	8,200	18,600	21,000	23,000	25,800	56,500

A schematic of wind induced currents for both stratified and unstratified lakes is shown in Figure 24. Upwelling and downwelling during the period of sustained wind action, and attendant circulation patterns, are transformed into oscillatory motions once the wind action ceases. These oscillatory motions are called seiches and they occur as surface seiches for unstratified and internal seiches for stratified basins. The seiche will continue, constantly dissipating in amplitude until wind forces again begin to act. An internal seiche, measured by the movement of the 9-11 °C layer of the metalimnion, is shown in Figure 25.

The importance of this phenomenon with respect to field monitoring is that stratification conditions are not static. For example, the metalimnion depth during a storm might not be the same as during prestorm baseline surveys or post storm monitoring. Field personnel will have to make repeated depth profile measurements to ascertain strata movements and ensure effective water quality sampling.

Although winter ice cover isolates lakes and reservoirs from wind stress, water currents beneath the ice can still be significant (47), even for closed lakes with no appreciable inflows or outflows. During summer and fall turnover, sediments accumulate heat which is gradually released into overlying waters during winter and spring. If the water temperature is greater than 4 °C, ascending buoyancy currents are generated by sediment heat efflux. If water temperatures are below 4 °C before establishment of ice cover, sediment heat efflux will create higher density water which will flow down into deeper lake regions. Such currents are usually quite weak, but can account for considerable dispersion of chemical constituents within a lake under ice-cover (47).

Normal Seasonal Variation in Lake Water Quality--

Due in part to the nature of lake circulation patterns, especially

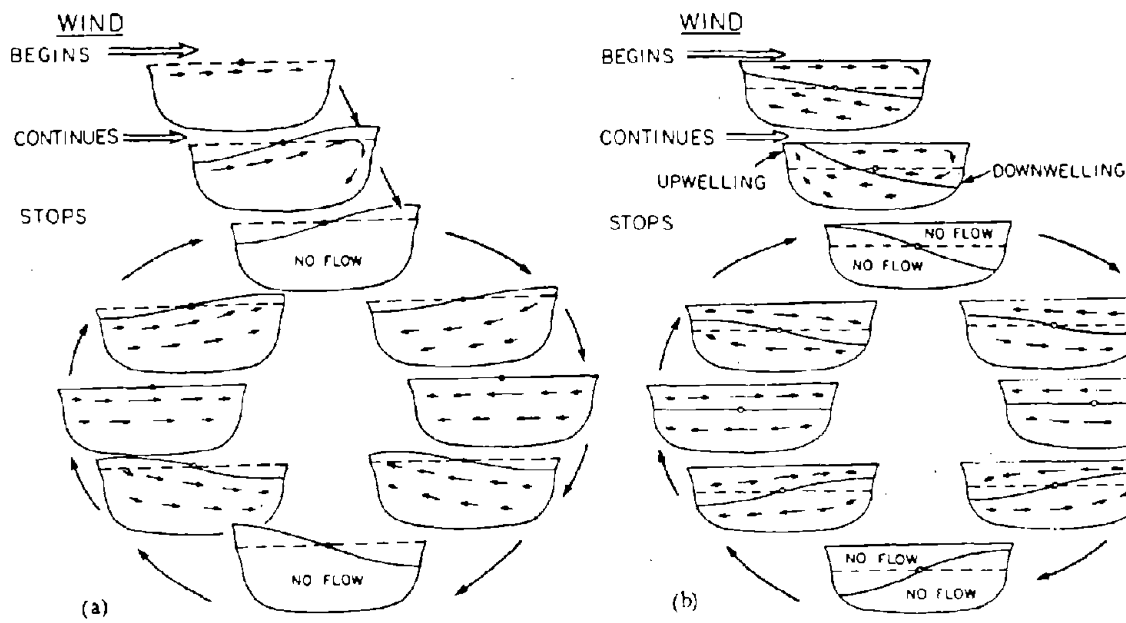


Figure 24. Models of (a) a surface seiche in a homogeneous lake and (b) an internal seiche in a two-layered lake. The initial action of the wind and one cycle of the ensuing oscillation is shown. The broken line represents the equilibrium position of the water surface in (a) and of the interface in (b).

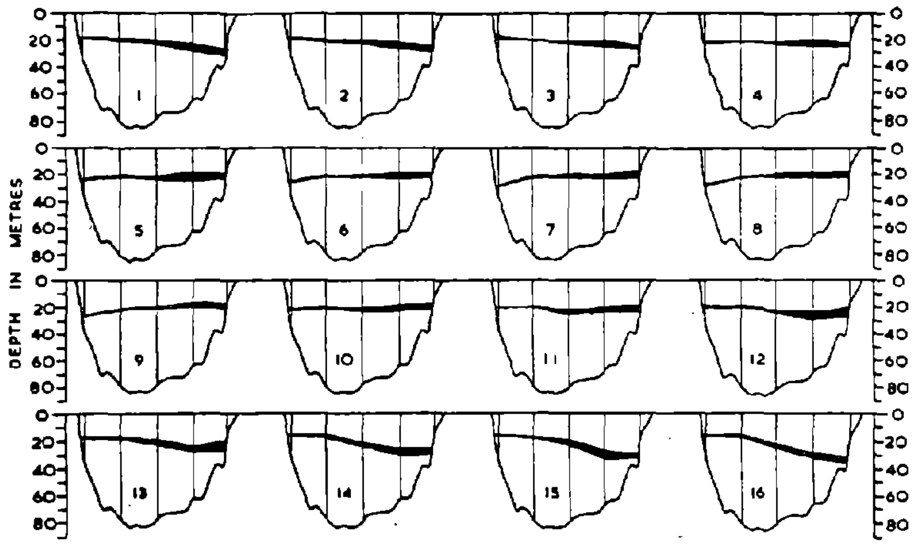


Figure 25. Successive hourly positions (0100 to 1600 hours, 9 August 1911) of the metalimnion bounded by the 9° and 11°C isotherms on a longitudinal section of Loch Earn, Scotland (47).

stratified lakes, considerable "normal" seasonal variation in water quality is encountered. It is important that these normal trends be documented (baseline water quality surveys) over the course of a monitoring program so that water quality changes can be attributed to their proper origin. Nutrient variability is a good example. During summer or winter stratification, reduced forms of phosphorus and nitrogen can be released from anoxic sediments into the stagnant hypolimnion. During the spring and fall overturns, these nutrients are then mixed over the entire water column. Furthermore, concentrations of nutrients, and the form of those nutrients (dissolved, organic, inorganic, particulate, etc) are determined by complex seasonal interactions with lake biota, especially bacterial and plankton communities. Nitrogen variability is illustrated in Figure 26 for Lake Mendota in Wisconsin (47).

Specific Lake Sampling Conditions--

Due to the nature of lake morphology, circulation patterns and variable inflow and outflow conditions, it is not possible to make specific recommendations on sampling approaches. Locations for transect sampling stations will be different for each lake and possibly even for each storm. In general, it is advisable to document potential localized and temporary water quality changes in areas of the lake in proximity to highway runoff discharges. Due to complete mixing in many small or shallow lakes, it will not be possible to find water quality control stations unaffected by runoff. However, zones or gradients of influence should be discernible for sediment or biological quality sampling.

Winter monitoring at a lake site presents some special problems and benefits. Extreme care must be exercised during ice formation in winter and break up in spring so that field personnel are not endangered. This usually means abandoning lake monitoring activities during these periods when the ice is too thin to walk on but too thick to break through with a boat hull. When the ice is thick enough, the water quality survey is facilitated because field

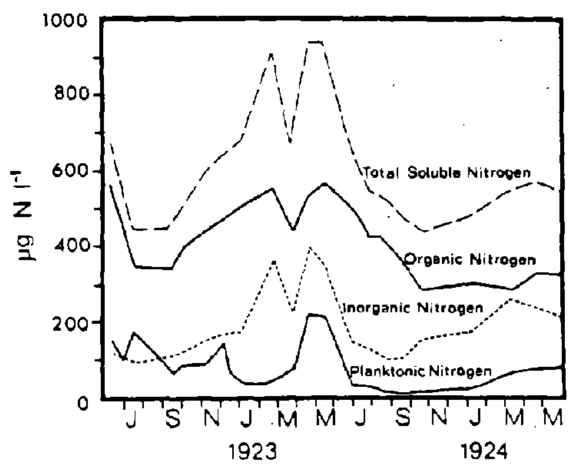


Figure 26. Average seasonal distribution of forms of nitrogen in Lake Mendota, Wisconsin, June 1922 through May 1924 (47).

personnel can walk (or snowmobile) from station-to-station, pulling samples and equipment on a sled. Obviously, manual or power augers or ice spuds will be required to obtain water samples.

Special safety precautions must be exercised to protect personnel when working on the ice. These include avoidance of "black ice" (often indicative of thin ice), never working alone, keeping enough distance between personnel, and carrying a small pointed object such as screwdriver, knife or nail with which to dig into the ice and pull oneself out of the water in case of an accident. Local agencies (especially the DNR) should be consulted before ice monitoring activities for additional ice safety precautions or verification of ice thickness.

SEDIMENT QUALITY

It has become increasingly apparent that examination of receiving water impacts must include sediment quality. The dynamic nature of sediments makes the segregation of sediments into consolidated, suspended and bedload fractions difficult. This section deals primarily with sediment sampling techniques which will provide insights into potential highway runoff impacts on the sediment regime rather than sediment loads caused by construction activity.

Bottom Sediments

As discussed in Section 2, a variety of sediment coring and dredging devices can be used. The purpose of this section is to discuss the temporal and spatial aspects of the surveys, assuming that appropriate equipment has been selected.

Of first concern is the depth to which bottom sediments should be sampled. With dredges, this depth is usually fixed as a function of dredge type or bottom material. The depth of the core sample is often up to the discretion of the investigators. The ideal way to determine sediment core sample depth at a particular station relative to other stations is to weight the depth according to measured sedimentation rates. This will ensure that comparisons between stations are normalized to a unit sedimentation load. Sites with a relatively low sedimentation load should have correspondingly shallower core sample depths so that samples represent comparable times of accumulation.

In practice, this approach is seldom used since a priori sedimentation rate data are rarely available. Two other approaches are possible. One is to merely select a depth and sample all stations to this depth. The other approach is to penetrate the core to a depth of some specified resistance. For automatic coring devices such as ball-check or Jenkins corers, this depth is equipment determined. For manual cores, this is more subjective but can often be related to a specific, definable substrata.

The uniform depth method is advisable for receiving waters where sedimentation rates will be comparable. Examples would be lakes of fairly uniform depth and hydraulic circulation patterns and rivers or streams where all stations are located in pools or riffles of similar depth and velocity profiles. The other method is more advisable for sites where there is little uniformity between stations.

Deep cores can be frozen and sliced into vertical sections. This can provide insight into time-related pollutant deposition patterns. If the slices are dated, using techniques such as ^{14}C, ^{137}Cs and ^{210}Pb (58) then the sedimentation chronology can be directly and quantitatively related to the operation of the highway.

Sediment sampling should be performed more than once per year whenever possible. For lakes it is necessary to sample during both stratified and unstratified conditions, especially when hypolimnetic oxygen deficits occur during stratification. Pollutant fluxes from sediments can be quite variable, but are primarily contingent upon the redox potential at the sediment/water interface. Seasonal, or more frequent, sampling will also reflect sediment impacts from seasonally variable highway runoff loadings. For long term studies, samples should only be compared when taken at the same time of year or hydrologic condition.

In streams and rivers, seasonal sampling is advisable not only because of varying redox potentials and seasonal highway loadings, but also because these sediments are more dynamic. Scour and resuspension during high flows and settling and decomposition at lower flows or velocities can substantially alter sediment pollutant concentrations at a given station.

Suspended Sediments

The emphasis of suspended sediment sampling for impact evaluation from operating highways is different from the typical experience of most highway engineers. The determination of annual sediment yield in control versus highway influenced regions is of some concern, but certainly less important than for impact assessment during highway construction. The need for suspended sediment sampling for impact assessment from operating highways is most critical for assuring representative general water quality sampling.

Due to the high association of highway pollutants with particulate material, it is important that suspended particulates be accurately quantified. Since the vertical suspended sediment concentration profile is not uniform, special sampling procedures should be used. Two approaches can be used. One is to employ suspended sediment sampling techniques for obtaining samples for all pollutant parameters (eg., metals, nutrients, petroleum hydrocarbons, etc). This is the recommended approach but is very time consuming. For medium to small sized streams, or larger streams and rivers with fairly uniform lateral quality, it might be possible to collect surface or subsurface grabs and develop a correlation function between these samples and depth and laterally integrated suspended sediment samples.

Standardized methods for suspended sediment sampling have been developed by USGS (9, 12, 48, 53, 59). Two depth-integrated methods are most common: the equal-width increment (EWI) and equal-discharge increment (EDI) methods. The EWI method is most simple and requires depth integrated (usually done with an equal vertical transit rate) samples at equal width increments across the transect of a stream or river. A more precise method is the EDI, which requires depth integrated sampling at equal discharge increments. This method obviously demands either beforehand knowledge of stream or river discharge profiles or actual discharge measurement during the sampling period.

Sediment Traps

The use of sediment traps is more common for lentic series, but they have also been used in streams and rivers (30). In general, traps should be located in the same area as bottom sediment sampling stations for comparative purposes. The required duration of trap exposure to yield sufficient sediment for chemical analyses depends on the type of receiving water system, number and size of traps used at each station, and the types of analyses which are to be run. For Costa, et al., (30) a small stream produced from 7.0 - 45.6 mg of settled solids greater than 0.45 um per unit cm^2 of trap area in only 11 days of exposure. Table 7 summarizes sediment trap accumulation data from the I-94 Lower Nemahbin Lake site (see also Volume II of this report).

Table 7. I-94/Lower Nemahbin Lake site - sediment trap data.

Parameter	Units	Exposure interval[b] 8/5/82 to 9/11/82	10/21/82 to 12/1/82		4/7/83 to 5/17/83		5/23/83 to 6/21/83	5/23/83 to 8/3/83	5/23/83 to 8/19/83
		S4	S3	S4	S3	S4	S2	S3	S4
Mass of solids	grams as total solids	2.33	3.58	3.12	9.30	6.10	0.133	3.16	10.9
Collection duration	days	36	41	41	40	40	29	72	88
Sediment flux[a]	g/m^2 - day	7.98	10.8	9.38	28.7	18.8	0.566	5.41	15.3
Sodium	mg/kg dry wt.	400	730	650	178	280	14,500	125	250
Chloride	mg/kg dry wt.	1,300	4,810	5,900	900	1,300	NA	93	180
Iron	mg/kg dry wt.	2,100	3,400	3,000	4,200	3,600	2,400	2,100	1,000
Lead	mg/kg dry wt.	43	65	60	61	54	110	60	43
Zinc	mg/kg dry wt.	75	74	60	101	56	140	37	39
Nickel	mg/kg dry wt.	15	18	20	11	13	37	14	12
Cadmium	mg/kg dry wt.	2.6	2.3	2.1	1.8	2.1	11	2.3	2.5
Chromium	mg/kg dry wt.	4.6	6.8	6.6	6.9	7.7	11	6.5	5.3
Copper	mg/kg dry wt.	21	19	19	17	18	41	16	12

a. Sediment trap area = 0.00811 m^2

b. Traps installed at station S2 were lost or stolen for the following exposure intervals:

10/21/82 - 12/1/82

4/7/83 - 5/17/83

6/23/83 - 8/19/83

SAMPLING HANDLING AND ANALYSES

Sample Handling, Preservation and Analytical Techniques for Water and Sediments

All samples obtained should be appropriately labeled in the field. As a minimum, the site, station, date, time, transect location, sample depth, field preservation type and lab number should be included on the label. Unique, pre-numbered stickers should be used for sample identification. These numbers should also be listed in sample log along with the appropriate descriptive information listed above for the label.

The required type of sample field preservation depends on the types of laboratory analyses which are to be run. Table 8 summarizes field preservation techniques, container material, and volume requirements for selected parameters in water samples. Table 9 provides a similar summary for sediments. Field preservation techniques consist of either keeping samples chilled (4 °C) or acidification to pH <2 with either sulfuric or nitric acid. Note that if a comprehensive list of analyses is to be run, it will be necessary to split the sample into three aliquots in the field. The volume requirements listed in Table 8 are the minimum volumes needed for each analysis.

Tables 8 and 9 also list analytical procedures commonly employed for parameters of interest in highway runoff pollution studies. These are not the only options available for analysis of these parameters, but were the methods used for samples analyzed for the field study portion of this contract (See Volume II). Several other EPA approved methods (64) are available for most parameters. The selection of method will depend upon the instrument and personnel capabilities of the lab. It is of critical importance to document the method of analysis used so that the comparability of data can be evaluated.

Table 8. Summary of sample preservation, handling, and analytical methods for selected parameters for water samples.

Parameter	Preservative[a]	Sample container material[a]	Required sample volume (ml)[a]	Analytical method[b]
Total solids	Cool, 4°C	Plastic (P) or Glass (G)	100	SM, Method 209A, p. 92 or EPA, Method 160.3
Total suspended solids	Cool, 4°C	P or G	100	SM, Method 209D, or EPA, Method 160.2
Volatile fractions of above	Cool, 4°C	P or G	100	SM, Method 209E, or EPA, Method 160.4
Total organic carbon	Cool, 4°C H_2SO_4 to pH<2	P or G	25	SM, Method 505, or EPA, Method 415.1
Chemical oxygen demand	H_2SO_4 to pH<2	P or G	50	SM, Method 508
Biochemical oxygen demand	Cool, 4°C	P or G	1000	SM, Method 507
Total Phosphorus	Cool, 4°C H_2SO_4 to pH<2	P or G	50	SM, Method 424 C(111). (persulfate digestion) followed by Method 424G; (automated ascorbic acid reduction) or EPA, Method 365.1
Total Kjeldahl nitrogen	Cool, 4°C H_2SO_4 to pH<2	P or G	500	EPA, Method 351.3
Ammonia nitrogen	Cool, 4°C H_2SO_4 to pH<2	P or G	400	EPA, Method 350.2
Nitrate + nitrite nitrogen	Cool, 4°C H_2SO_4 to pH<2	P or G	150	SM, Methods 418 & 419 or EPA, Method 353.2
Sulfate	Cool, 4°C	P or G	50	SM, Method 426, or EPA, Method 375.4
Mercury	HNO_3 to pH<2	P or G	100	SM, Method 320A, or EPA, Method 245.1
Chlorinated hydrocarbons (pesticides, herbicides and PCB's)	Cool, 4°C Formalin[d]	G only	Depends on analyses & concentrations	Analysis of chlorinated hydrocarbons in water
Oil and grease	Cool, 4°C H_2SO_4 to pH<2	G only	1000	SM, Method 503A

Table 8. Summary of sample preservation, handling, and analytical methods for selected parameters for water samples (continued).

Parameter	Preservative[a]	Sample container material[a]	Required sample volume (ml)[a]	Analytical method[b]
Alkalinity	Cool, 4°C	P or G	100	SM, Method 403
pH	Det. on site	P or G	25	SM, Method 423
Chlorides	None required	P or G	50	SM, Method 407B
Total coliforms	Cool, 4°C	G only[e]	Depends on required dilution	SM, Method 909A
Fecal coliforms	Cool, 4°C	G only[e]	Depends on required dilution	SM, Method 909C
Fecal streptococci	Cool, 4°C	G only[e]	Depends on required dilution	SM, Method 910B
Metals	HNO_3 to pH<2	P or G	100	Digestion, SM, Method 302 Lead: SM, 316A; EPA, 239.1 Iron: SM, 315A; EPA, 236.1 Zinc: SM, 312A; EPA, 289.1 Nickel: SM, 321A EPA, 249.1 Chromium: SM, 312A, EPA, 218.1 Copper: SM, 313A; EPA, 220.1 Cadmium: SM, 310A; EPA, 213.1

a. From: "Methods for Chemical Analyses of Water and Wastes" (60).
b. SM refers to "Standard Methods for the Examination of Water and Wastewater" (14). EPA refers to publication in footnote a.
c. "Method for Chlorinated Hydrocarbons in Water and Wastewater" (61).
d. Formalin increased PCB recovery (62).
e. Bottles must be sterilized and sealed air tight prior to use.

Table 9. Summary of sample preservation, handling, and analytical methods for selected parameters for sediment samples.

Parameter	Preservative[a]	Sample container material[a]	Analytical method[b] sediments
Total solids	Cool, 4°C	Plastic (P) or Glass (G)	SM, Method 209A, p. 92 or EPA, Method 160.3
Volatile total solids	Cool, 4°C	P or G	SM, Method 209E, or EPA, Method 160.4
Total organic carbon	Cool, 4°C H_2SO_4 to pH<2	P or G	SM, Method 505, or EPA, Method 415.1 (Dilute and homogenize prior to analysis)
Chemical oxygen demand	H_2SO_4 to pH<2	P or G	SM, Method 508
Biochemical oxygen demand	Cool, 4°C	P or G	SM, Method 507
Total phosphorus	Cool, 4°C H_2SO_4 to pH<2	P or G	SM, Method 424 C(111), (persulfate digestion) followed by Method 424G; (automated ascorbic acid reduction) or EPA, Method 365.1
Total Kjeldahl nitrogen	Cool, 4°C H_2SO_4 to pH<2	P or G	EPA, Method 351.3
Ammonia nitrogen	Cool, 4°C H_2SO_4 to pH<2	P or G	EPA, Method 350.2 (Interstitial water only)
Nitrate + nitrite nitrogen	Cool, 4°C H_2SO_4 to pH<2	P or G	SM, Method 418 & 419 or EPA, Method 353.2 (Dilute with Milli-Q water and remove solids by high speed centrifugation prior to analysis)
Sulfate	Cool, 4°C	P or G	SM, Method 426, or EPA, Method 375.4 (Dilute with Milli-Q water and remove solids by high speed centrifuge prior to analysis)
Mercury	HNO_3 to pH<2	P or G	EPA, Method 245.5
Chlorinated hydrocarbons (pesticides, herbicides and PCB's)	Cool, 4°C	G only	Analysis of priority pollutants in sediments and fish tissue[c]
Oil and grease	Cool, 4°C H_2SO_4 to pH<2	G only	SM, Method 503D
Alkalinity	Cool, 4°C	P or G	SM, Method 403 (Interstitial water only)
pH	Det. on site	P or G	SM, Method 423 (Interstitial water only)

Table 9. Summary of sample preservation, handling, and analytical methods for selected parameters for sediment samples (continued).

Parameter	Preservative[a]	Sample container material[a]	Analytical method[b] sediments
Chlorides	None required	P or G	SM, Method 407B (Interstitial water only)
Metals	HNO_3 to pH<2	P or G	Digestion, SM, Method 302 Lead: SM, 316A; EOA, 239.1 Iron: SM, 315A; EOA, 236.1 Zinc: SM, 328A; EPA, 289.1 Nickel: SM, 321A; EPA, 249.1 Chromium: SM, 312A; EPA, 218.1 Copper: SM, 313A; EPA, 220.1 Cadmium: SM, 310A: EPA, 213.1

a. From: "Methods for Chemical Analyses of Water and Wastes" (60).
b. SM refers to "Standard Methods for the Examination of Water and Wastewater" (14). EPA refers to publication in footnote a.
c. "Analysis of Sediments for Chlorinated Pesticides, Polychlorinated Biphenyls and Non-polar Neutrals" (63).

Note that in several cases, different analytical procedures are required for sediment samples (Table 9). In most cases, this involves only additional sample preparation prior to analysis. The reporting of sediment quality analyses requires different calculation procedures than liquid samples, however. Sediment parameter concentrations are usually recorded in mass of constituent per unit dry or wet weight of total solids (usually mg/kg dry weight).

Consideration also must be given to the proximity of the laboratory facility to the site. Bacteriological and BOD determinations should be initiated within 8-10 hours after sample collection. Other parameters can be run later, assuming proper field preservation techniques have been used. Therefore, if samples are to be shipped to a lab remote from the site, separate arrangements will have to be made for parameters which require immediate analysis.

Care should be taken to ensure that sample shipments conform to pertinent DOT or NEIC and state regulations. For example, if biological samples, preserved in a alcohol solution, are to be shipped by air transport, the outside of the shipment container must be labeled with a flammable liquid warning statement which also lists the flashpoint of the samples. In addition, the samples must also be packed with enough absorbent material to capture leakage in secondary sealed containers.

All samples should be checked for leakage prior to long distance shipping. This will prevent cross-contamination of multiple samples contained in one cooler. If glass sample bottles are being shipped, they should be cushioned to prevent breakage.

Quality Assurance in Sample Analyses

Laboratory Analyses--

In many cases the laboratory analyses will be performed by other than the highway agency. It is important that the agency responsible for the field study program verify the existence of a suitable quality assurance program by the laboratory contracted to do the analytical work. An ongoing comprehensive internal quality control program is essential to guarantee the validity of analytical results. A quality assurance program should consist of the following items (65):

1. Analyses of spiked and replicate samples,
2. Monitoring and calibration of equipment and instruments,
3. Blind analyses of externally prepared reference samples,
4. Conduct and report regular performance audits, and
5. Have in place a program for corrective action when quality control limits are exceeded.

Externally prepared reference samples can be obtained from EPA, Environmental Resource Associates (ERA) and Alpha-Trol. Laboratory participation in external quality control programs such as the Proficiency Analytical Testing Program (PAT) program of the National Institute of Occupational Safety and Health (NIOSH) or local lab round robin program is highly advisable (65). In many states, laboratories must obtain certification in order to perform analyses used in regulatory programs. The use of a state certified lab will generally ensure proper QA procedures, but it is still worth an inquiry.

Meter Calibrations--

Quality assurance objectives for field measurement of water quality (ie. - water temperature, specific conductance, dissolved oxygen, pH, and oxidation reduction potential) have been established cooperatively by several agencies of the U.S. Government and published in the National Handbook of Recommended

Methods for Water - Data Acquisition (12). Use of these objectives will ensure data comparability and representativeness. Table 10 summarizes the required precision and accuracy for field measurement equipment for these parameters as well as equipment calibration procedures.

BIOLOGICAL INVESTIGATIONS

Sampling Periodicity

Monthly samples of benthic constituents should be considered minimal except where otherwise indicated by objectives of the study. Insect representatives of the bottom organism community emerge from the water as adults periodically throughout the warm weather period; time of emergence depends on the species involved. Life histories of these organisms tend to overlap so that at no time is there a dearth of these organisms within the bottom associated community. Bottom fauna should be sampled during the annual seasons; the standing crop will be highest, however, during the fall and winter periods when insect emergence is minimal, and one of the sampling dates should reflect this period.

Data and Sample Collection

The collection of data and samples from a particular station involves making a number of scientific observations. On approaching a stream station observations must be made that will later be considered in interpreting the biological findings.

Observations are made on water depth; presence of riffles and pools; stream width; flow characteristics; bank cover; presence of slime growths, attached algae, scum algae, and other aquatic plants, as well as red sludge-worm masses; and unusual physical characteristics such as silt deposits, organic sludge deposits, iron precipitates, or various waste materials from manufacturing processes.

Table 10. Quality control procedures for field water quality monitoring (12).

Measurement parameter	Calibrated accuracy	Response time	Stability	Calibration method	Calibration points
Water temperature	$\leq$ 1% of full scale or $\pm$ 0.3°C, whichever is less	$\leq$ 2 minutes	$\leq$ 4 weeks with uncontaminated sensor	Comparison with high quality thermometer checked against NBS certified precision thermometer	3 points (high, medium, and low scale of constant temperature)
Specific conductance (normalized to 25°C)	$\leq$ 3% of full scale over temperature range of -2° - 40°C	$\leq$ 2 minutes	$\leq$ 4 weeks with uncontaminated sensor	Comparison with KCL standard solutions per Standard Methods	Each range will have 3 points (high, medium, and low scale) and be checked for temperature compensation
Dissolved oxygen (DO)	$\pm$ 0.2 mg/ℓ over temperature range of -2° - 40°C	$\leq$ 2 minutes	$\leq$ 4 weeks with uncontaminated sensor	Comparison with Alsterberg modification of the Winkler method in air-saturated distilled water	2 calibration points, one at zero DO ($COCl_2$ and Na_2SO_3 solution) and one at saturation
pH	$\pm$ 0.1 pH unit over temperature range of -2° - 40°C	$\leq$ 2 minutes	$\leq$ 4 weeks with uncontaminated sample	Comparison with NBS certified buffer solutions	3 points (high, medium and low)
Oxidation reduction potential (ORP)	$\pm$ 8 mv with standard buffer solutions	$\leq$ 2 minutes	$\leq$ 4 weeks with stable sensor	Comparison with standard pH buffer solutions as in Standard Methods to which quinhydrone crystals are added	2 points at nominal pH values of 4 and 7

Benthos Sampling--

Organisms associated with the stream bed are studied most often in the biological evaluation of water quality. These organisms are valuable to relate water quality because they are not equipped to move great distances through their own efforts and, thus, remain at fixed points to indicate water quality. Because the life history of many of these organisms extends through one year or longer, their presence or absence is indicative of water quality within the past, as well as the present. Bottom associated organisms are relatively easy to capture with conventional sampling equipment and the amount of time and effort devoted to their capture and interpretation is not as great as that required for other segments of the aquatic community.

The qualitative search for benthos should involve the collection of organisms from rocks, plants, submerged twigs or debris, or leaves of overhanging trees that become submerged and waterlogged. It is often convenient to scrape and wash organisms from these materials into a bucket or tub partially filled with water and then to pass this water through the sieve to concentrate and retain the organisms. The collected sample may be preserved for organism sorting and identification later. The investigator should search until he is certain that he has collected the majority of species that can tolerate the particular environment. In some environments it is possible only to collect qualitative samples because the physical nature of the waterway may be such that quantitative sampling is not feasible.

The basic principle in qualitative sampling is to collect as many different kinds of animals as practical. Obviously, because of the rarity of some forms, the probability of collecting a specimen of every kind is remote and a limit must be imposed on the collector's efforts. Two convenient limiting methods are:

1. Presetting a time limit on the collector's effort at each sampling point. A minimum of 30 minutes and a maximum of an hour is a

convenient range in which to establish this limit.

2. Sampling in an area until new forms are encountered so infrequently that "the law of diminishing returns" dictates abandoning the sampling point. This methods requires professional judgment - but if after 10 minutes only a single species or organism is found, the sampler can move to the next sampling site where he might continue to find new forms after searching more than an hour.

A number of tools readily obtained in any community are valuable in this type of sampling:

1. Pocket-knives are excellent tools to remove animals from crevices in rocks, to peel bark from decaying logs thus exposing animals, and to slip under animals to lift and transfer them to sample containers.

2. Mason jars in 1/2 to 1 pint sizes serve as the most economical sample containers and provide visibility of the preserved specimens.

3. Common garden rakes are valuable to retrieve rocks, brush, logs and aquatic vegetation for inspection.

4. Fine-meshed dip nets are good devices for sweeping animals from vegetation or out from under overhanging rock ledges.
5. Buckets are handy to quickly receive rocks and debris, thus preventing escape of the swift running animals.

6. Sheet polyethylene, 6 x 6 feet, can be spread on the stream bank and substrate materials placed upon it. As the materials begin to dry, the animals will abandon their hiding places and can be seen readily as they migrate across the sheet seeking water.

7. U.S. Standard Series No. 30 soil sieves can be used to scoop up fine sediments and sieve out its inhabitants. The entire qualitative

sample can also be screened to standardize the organism sizes taken at various sampling sites.

8. Any other tools, such as forceps, scalpels, shovels, and forks are legitimate devices and can prove their merit in individual situations.

Following these general observations, the investigator collects appropriate quantitative samples of the various kinds of organisms present in the aquatic area. He makes certain that: (1) The sampling area selected is representative of stream conditions, and (2) the sample is representative of and contains those forms predominant in the area and encountered during the qualitative search.

Bottom samples in lakes usually may be collected with an Ekman grab, although the physical composition of the bottom determines to a great extent the type of sampler that must be used to collect an adequate sample. The Ekman grab consists of a square box of sheet brass 6 x 6 inches in cross section. The lower opening of this box is closed by a pair of strong jaws so made and installed that they oppose each other. When open, the jaws are pulled apart so that the whole bottom of the box is open; the jaws are held open by chains attached to trip pins. To close the dredge, the trip pins are released by a brass messenger sent down the attachment rope and the jaws snap shut by two strong external springs. The sampler is especially adapted for use in soft, finely divided mud and muck; it does not function properly on sand bottoms or hard substrates. The Ekman can also be mounted on a pipe for shallow stream sampling and tripped by a thrust-through rod.

Drift nets may be suspended in flowing waters to capture invertebrates that have migrated into the water mass from the bottom substrates and are temporarily being transported by currents. Their principal uses have been to study migratory movements and to evaluate sublethal toxicants, especially insecticides, on the fauna. Before toxicants become lethal the animals are weakened and cannot maintain their benthic position and thus are swept away by the currents and carried into the nets. These nets must be standardized in an individual study. As of now no single style of net has been standardized among investigators.

After suspension in the water, these nets require constant tending. Within a fraction of an hour the nets efficiency is reduced through clogging of the net by drifting animals and detritus that soon results in significant volumes of water and organisms being diverted around the mouth of the net.

To sample riffle areas in streams, a square-foot bottom sampler, originally described by Surber (66), is widely used. It consists of two 1-foot-square brass frames hinged together at right angles; one frame supports the net which is held extended downstream by current velocities, the other encloses the sampling area. In field operation, the sampler is so placed that organisms dislodged by hand from the substratum within the sampling frame will be carried into the net by the current. In stagnant or in slowly moving water, it often is not practical to employ this square-foot sampler.

In practice, it may be found convenient to remove the larger rocks from inside the sampling frame, placing them in a bucket or tub partially filled with water. Here, the organisms can be washed or scraped from the rocks, and concentrated by a sieve as described earlier, before being combined with those from the Surber sampler in a sample jar with preservative.

Artificial substrates are placed in the water for 3- to 6-weeks and then carefully removed to prevent losing the organisms that have made them a temporary home. As nearly as possible the substrates should be placed at similar depths and in similar physical relationship to the stream at all stations. Usually, then are placed suspended in the water column or placed directly on the natural substrate.

Plankton Sampling--

The waters of streams and rivers are generally well mixed, and subsurface plankton sampling is sufficient. Sample in the main channel and avoid backwater areas. In lakes where plankton composition and density may vary with depth, take samples from several depths. The depth at the station and the depth of the thermocline (or sometimes the euphotic zone) generally determines sampling depths. In shallow areas (2 to 3 meters, 5 to 10 feet), subsurface sampling is usually sufficient. In deeper areas, take samples at regular intervals with depth. If only phytoplankton are to be examined, samples may be taken at three depths, evenly spaced from the surface to the thermocline. When collecting zooplankton, however, sample at 1-meter intervals from the surface to the lake bottom.

The type of sampling equipment used is highly dependent upon where and how the sample is being taken (i.e., from a small lake, large deep lake, small stream, large stream, from the shore, from a bridge, from a small boat, or from a large boat) and how it is to be used.

The cylindrical type of sampler with stoppers that leave the ends open to allow free passage of water through the cylinder while it's being lowered is recommended. A messenger is released at the desired depth to close the stoppers in the ends. The Kemmerer, Juday, and Van Dorn samplers have such a design and can be obtained in a variety of sizes and materials. Use only nonmetallic samplers when metal analysis, algal assays, or primary productivity measurements are being performed.

Fish Sampling--

Fish samples may be collected by nets, seines, poisons, and electrofishing. Electrofishing is conducted by means of an alternating or direct electrical current applied to water that has a resistance different from the fish. This difference in resistance to pulsating direct current stimulates the swimming muscles for short periods of time, causing the fish to orient and be attracted to the positive electrode. An electrical field of sufficient potential to demobilize the fish is present near the positive electrode, but decreases in intensity with distance. After the fish are identified, weighed, and measured, they commonly can be returned to the water uninjured.

The electrofishing unit may consist of a 110-volt, 60-cycle, heavy duty generator, an electrical control section, which is a modified commercially sold variable voltage pulsator, and electrodes. The electrical control section provides selection of voltages from 50 to 700 volts a.c. and 25 to 350 volts d.c. The a.c. current acts as a standby for the d.c. current and is used in cases of extremely low water resistance. The variable voltage allows control of field size in various types of water.

Sample Analyses

For a detailed discussion of the laboratory examination of biological samples, Standard Methods for the Examination of Water and Wastewater (14) should be consulted.

Benthos Samples--

Samples collected with grabs, tubular devices, and artificial substrates contain varying amounts of finely divided materials such as completely decomposed organic material, silts, clays, and fine sand. To reduce sample volume and expedite sample processing in the laboratory, these fines should be removed by passing the sample through a U.S. Standard No. 30 sieve. Sieves may range from commercially constructed models to homemade sieves framed with wood or metal. Floating sieves with wooden frames reduce the danger of accidental loss of both sieve and sample when working over the side of a boat in deeper waters. A good sieve contains no cracks or crevices in which small organisms can become lodged.

If at all possible, sieving should be done in the field immediately after sample collection and while the captured organisms are alive. Once preserved, many organisms become quite fragile and if subjected to sieving will be broken up and lost or rendered unidentifiable.

Sieving may be accomplished by one of several techniques depending upon the reference of the individual biologist. In one technique, the sample is placed directly into a sieve and the sieve is then partially submerged in water and agitated until all fine materials have passed through. The sieve is agitated preferably in a tub of water.

The artificial substrate samplers are placed in a bucket or tub of screened water and are dismantled. Each individual piece of substrate material is shaken and then cleaned gently under water with a soft brush (a soft grade of toothbrush is excellent), examined visually, and laid aside. The water in the bucket or tub is then poured through a U.S. Standard No. 30 sieve to remove the fines.

When samples are collected of animals associated with the lake or stream bed the organisms and debris are usually preserved with 10 percent formalin or 70 percent ethanol. The formalized sample is washed in the laboratory to remove the strong formalin solution. From this point it is necessary to remove and segregate the animals on which an interpretation will be made from the debris within the sample jar. A number of flotation methods have been proposed by various authors to reduce the time expended in this operation. When an investigation includes stream reaches that are heavily polluted with organic sludges or that produce prolific growths of slimes and other attached organisms, flotation methods do not work well. Thus, as a routine measure the somewhat laborious effort of separating organisms from debris though hand sorting must be employed.

A white enamel pan with a depth of approximately 1-1/2" is often used in the hand picking operation. It is convenient to half fill the pan with water and then place 2 or 3 tablespoons of material from the sample jar in the center of the pan. By teasing the sample to all sides with the aid of forceps, small animals can be removed without difficulty. It is helpful for later identification to keep the removed organisms separated into the taxonomic groups that are discernible with the unaided eye. When it is noted that organisms within the collected sample are limited to a few (2 to 4) kinds and are extremely abundant as they often are when sludgeworms reproduce in great numbers in organic sludge, samples may be split to reduce time and labor in removing organisms. This is accomplished by placing the sample in the white pan without water, leveling the sample surface, and randomly selecting 1/2, 1/4, 1/16, or 1/32, of the sample for organism removal. When this is done, the entire sample should be examined for those larger organisms that may not be numerous. In reports written principally for those outside of the biological discipline, bottom faunal abundance is expressed usually as the number of a particular kind of organism per square foot. Organisms from a 6" x 6" Ekman dredge sample, for example, would be multiplied by 4 to arrive at the number per square foot. When the sample is split and only an aliquot examined, the appropriate conversion multiplication must also be used. Further identification through the use of a stereoscopic microscope and counts to ascertain numbers within a particular group are made to facilitate interpretation of water quality.

As organisms are picked from the debris, they should be sorted into major categories (i.e., insect orders, mollusks, worms, etc.) and placed into vials containing 70 percent ethanol. All vials from a sample should be labeled internally with the picker's name and the lot number and kept as a unit in a suitable container until the organisms are identified and enumerated, and the data are recorded on the bench sheets.

Plankton Samples--

Some waters contain sufficient plankton (phyto- and/or zooplankton) so that samples must be diluted to obtain adequate numerical information; however, with a sparse plankton sample, concentration should be used. The phytoplankton in samples from most natural waters require neither dilution nor concentration and should be enumerated directly. Correspondingly, zooplankton often are not sufficiently abundant to be counted without concentration. Selection of methods and materials used in plankton enumeration depends on objectives of the study, density of plankters in the waters being investigated, equipment available, and experience of the investigator.

The Sedgwick-Rafter cell has been and continues to be the most commonly employed device for plankton enumeration. It is easily manipulated and provides reasonably reproducible information when used with a calibrated microscope equipped with an eyepiece measuring device, usually a Whipple ocular micrometer. It can be used to enumerate undiluted, concentrated, or diluted plankton samples. The biggest disadvantage associated with the cell is magnification. The cell cannot be used for enumerating very small plankton unless the microscope is equipped with special lenses that provide sufficient magnification (400X or greater) and clearance between objective lenses and the cell.

The Sedgwick-Rafter cell is 50-mm log by 20-mm wide by 1-mm deep (a total volume of one milliliter). A "strip" the length of the cell thus constitutes a volume 50-mm long, 1-mm deep, and the width of the Whipple field. Two or four strips usually are counted, depending on the density of plankters. Counting more than four strips is not expedient when there are many samples to be enumerated; concentrating procedures then should be employed, and counts made of plankters in the concentrate.

$$\text{No. per ml} = \text{Actual Count} \times \frac{1{,}000}{\text{Volume of "strip" } (mm^3)}$$

If the sample has been concentrated, the concentration factor is divided into the actual count to derive the number of organisms per ml. For separate field counts (usually 10 or more fields):

$$\text{No. per ml} = \text{avg. count per field} \times \frac{1{,}000}{\text{Volume of field} \times \text{No. of fields}}$$

When special lenses are not used and there is a need to enumerate small plankton which are usually abundant, other procedures may be employed in connection with and related to counts obtained from the Sedgwick-Rafter cell.

Identification

The taxonomic level to which animals are identified depends on the needs, experience, and available resources. However, the taxonomic level to which identifications are carried in each major group should be constant throughout a given study. The accuracy of identification will depend greatly on the availability of taxonomic literature. A laboratory library of basic taxonomic references is essential.

For comparative purposes and quality control checks, store identified specimens in a reference collection. Most identifications to order and family can be made under a stereoscopic microscope (up to 50X magnification). Identification to genus and species often requires a compound microscope, preferably equipped with phase contrast (10, 45, and 100X objectives).

To make species identifications, it is often necessary to mount the entire organism or parts thereof on glass sides for examination at high magnification. Small whole insects or parts thereof may be slide-mounted directly from water or 70 percent ethanol preservative if CMC mounting media is used. Label the slides immediately with the sample log number and the name of the structure mounted. Euparol mounting medium may be preferable to CMC for mounts to be kept in a reference collection. Place specimens to be mounted in Euparol in 95 percent ethanol before mounting.

BIOASSAY PROCEDURES

The ultimate purpose of bioassays is to predict the response of native populations of aquatic organisms to specific changes within the natural environment. Whenever possible, therefore, tests should be carried out with species that are native (indigenous) to the receiving water. Water obtained from the receiving water in question should also be used as the diluent for the bioassay. Bioassays are important because in most cases the success of a water pollution control program must be judged in terms of the effects of water quality on the condition of the indigenous communities of aquatic organisms. Also, in many cases, bioassays are more sensitive than chemical analyses. Finally, bioassays can reveal effects of complex wastes on organisms. This is especially important for highway runoff evaluations. The constituents of this runoff are numerous and can exist in a variety of forms. Bioassays on individual constituents in pure dissolved form can be very misleading.

Two general kinds of bioassays are recognized:

1. Laboratory tests conducted to determine the effects of a substance on a species; more or less arbitrary conditions are employed,

2. *In situ* tests conducted to determine the effects of a specific natural or impacted environment; the test organisms are held in "containers" through which the water circulates freely (See Volume II for description of method).

Laboratory Bioassays

The general principles and methods of conducting laboratory bioassays presented in Standard Methods for the Examination of Water and Waste Water (14) apply to most bioassays, and the described methods can be used with many types of aquatic organisms with only slight modification.

Bioassays can be conducted over almost any interval of time, but the test duration must be appropriate to the life stage or life cycle of the test organisms and the objectives of the investigation. The purpose of short-term tests, such as acute mortality tests, is to determine toxicant concentrations lethal to a given fraction (usually 50 percent) of the organisms during a short period of their life cycle. Acute mortality tests with fish generally last about 4 to 7 days. Most toxicants, however, cause adverse effects at levels below those that cause mortality. To meet this need, long term (chronic) tests are designed to expose test organisms to the toxicant over their entire life cycle and measure the effects of the toxicant on survival, growth, and reproduction. Sometimes only a portion of the life cycle is tested, such as studies involving growth or emergence of aquatic insects. With fish, such test usually last for 30, 60, or 90 days and are often termed subacute.

Laboratory bioassays may be conducted on a "static" or "continuous flow" basis. The specific needs of the investigator and available test facilities determine which technique should be used. Generally, the continuous-flow technique should be used where possible. Apparatus advantageous for conducting flow-through tests includes diluters, valve controlling systems and chemical metering pumps.

Algal Assay--

The Algal Assay Procedure (or Bottle Test) was published by the National

Eutrophication Research Program (67) after 2 years of intensive evaluation, during which excellent agreement of the data was obtained among the 8 participating laboratories. This test is the only algal bioassay that has undergone sufficient evaluation and refinement to be considered reliable. The following material represents a brief outline of the test.

An algal assay is based on the principle that growth is limited by the nutrient that is present in shortest supply with respect to the needs of the organism. The test can be used to identify algal growth-limiting nutrients, to determine biologically the availability of algal growth-limiting nutrients, to quantify the biological response (algal growth response) to changes in concentrations of algal growth-limiting nutrients, and to determine whether or not various compounds or water samples are toxic or inhibitory to algae.

The specific experimental design of each algal assay is dictated by the particular problem to be solved. All pertinent ecological factors must be considered in planning a given assay to ensure that valid results and conclusions are obtained.

Two parameters are used to describe the growth of a test alga: maximum specific growth rate and maximum standing crop. The maximum specific growth rate (μ max) for an individual flask is the largest specific growth rate (μ) occurring at any time during incubation. The maximum specific growth rate for a set of replicates is determined by averaging the values of max of the individual flasks. The specific growth rate, , is defined by:

$$= \frac{\ln (X_2/X_1)}{t_2 - t_1}$$

where:

ln = log to the base "e",

X_2 = biomass concentration at the end of the selected time interval,

X_1 = biomass concentration at the beginning of the selected time interval,

$t_2 - t_1$ = elapsed time (days) between selected determinations of biomass.

Because the maximum specific growth rate occurs during the logarithmic phase of growth (usually between day 3 and day 5), the biomass must be measured at least daily during the first 5 days of incubation.

The maximum standing crop in any flask is defined as the maximum algal biomass achieved during incubation. For practical purposes, the maximum standing crop is assumed to have been achieved when the rate of increase in biomass has declined to less than 5 percent per day.

Present the results of spiking assays together with the results from two types of reference samples: the assay reference medium and unspiked samples of the water under consideration. Preferably, the entire growth curves should be presented for each of the two types of reference samples. Present the results of individual assays in the form of the maximum specific growth rate (with time of occurrence) and maximum standing crop (with time at which it was reached), both with the confidence interval indicated.

Growth rate limiting nutrients can be determined by spiking a number of replicate flasks with single nutrients, determining the maximum specific growth rate for each flask, and comparing the averages by a Student's t-test or other appropriate statistical tests.

Data analysis for multiple nutrient spiking can be performed by analysis of variance calculations. In multiple nutrient spiking, accounting for the possible interaction between different nutrients is important and can readily be done by factorial analysis. The same methods described above can be used to determine the nutrient limiting growth of the maximum standing crop.

Macroinvertebrates--

In general, most of the considerations covered by Standard Methods (14), apply equally well to macroinvertebrate tests in fresh and marine waters. Recent refinements in acute and chronic methodology for aquatic insects, amphipods, mussels, and *Daphnia* have been described by Gaufin (68), Bell and Nebeker (69), Arthur and Leonard (70), Dimick and Breese (71), Woelke (72), and Biesinger and Christensen (73), respectively. In most cases, however, Standard Methods procedures should be used. Refinements such as these will eventually be incorporated into Standard Procedures after this validity has been rigorously demonstrated.

Fish--

The general principles and methods for acute and chronic laboratory fish toxicity tests are presented in Standard Methods (14) and in the report of the National Technical Advisory Committee (74). Sprague (75, 76) has recently reviewed many of the problems and the terminology associated with fish toxicity tests.

Chronic test are becoming increasingly important as sublethal adverse effects of more and more toxic agents are found to be significant. At present, a chronic fish bioassay test is a relatively sophisticated research procedure and entails large allocations of manpower, time, and expense. Important contributions in this area include those by Mount and Stephan (77), Brunds (78), Eaton (79), and McKim *et al*. (80).

SECTION 4
SITE SELECTION

INTRODUCTION

Selection of suitable sites for conducting field investigations of highway runoff impacts on receiving waters systems is an involved and difficult task. Characteristics of the highway systems and receiving water system have to be carefully matched to meet the objectives of the study. Highway and receiving water features can have a tremendous effect on the hydrological, water quality and/or biological impacts identified through a field study. Other factors which are important considerations in the selection process include logistical problems, safety considerations and extraneous factors such as planned construction or maintenance activities. Logistics of conducting a detailed field study can adversely affect the suitability, accuracy and reliability of any data collected. Construction or maintenance activities might have impacts so pronounced that more subtle impacts of pollutants from normal highway operation are masked.

All of these considerations must be defined relative to the objectives of the field study as site selection criteria. Objectives need to be developed prior to initiating the site selection process and the objectives can then be utilized to define proper limits (criteria) for all factors affecting "potential" impacts. This section will include (a listing of three hypothetical study objectives,) detailed description of important site characteristics which must be considered in determining site selection criteria, and a discussion of how to obtain information on potential sites and their suitability. Furthermore, after defining the required site characteristics, locating a suitable site can be very difficult.

SITE SELECTION CRITERIA

Highway Characteristics

Detailed reviews of highway system characteristics which influence the water quality of highway runoff, runoff rates, and runoff volumes are contained in several reports (1, 2, 9, 81, 82, 83). In this monitoring guide, highway characteristics which have the most direct effect on the determination of receiving water impacts will be addressed. These include:

1. Traffic volume
2. Highway drainage design
3. Type of pavement
4. Highway maintenance practice.

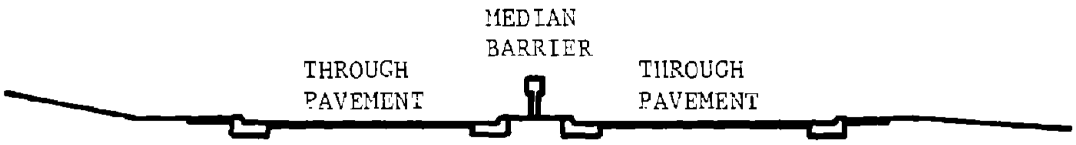
Traffic Volume--

Traffic volume is one of the most important characteristics affecting pollutant accumulation on a highway system since it is a direct measure of one primary source of pollutants - vehicles. In previous studies, traffic volume or annual average daily traffic (AADT) has been divided into three categories: AADT less than 30,000 is low traffic volume, 30,000 to 100,000 is medium and an excess of 100,000 is high (84). These categories also reflect pollutant characteristics of the highways since pollutant accumulation increases greatly from the low to high traffic volume categories (1, 84). However, medium and high levels of AADT are generally found in heavily urbanized areas. Receiving waters in these areas have large portions of their watersheds which can contribute similar pollutants as the highway system (85). This can effectively mask most influences of the highway system on a receiving water. In other terms, highways with medium and high traffic volumes and receiving waters unimpacted by other non-point or point sources are often mutually exclusive. Traffic volume drops off quite rapidly outside of urban areas such that even major interstate highways between urban areas seldom have an AADT greater than 50,000. If the objective of the study is to determine the greatest receiving water impacts possible from highway runoff, the trade-off between traffic volume and receiving water quality must be carefully weighed. If the objective of the study is to evaluate impacts of a proposed highway system, the selected study site should have traffic characteristics similar to that projected for the new highway.

Based on a initial study of highway runoff from six sites throughout the country, a statistical relationship was developed between AADT and pollutant accumulation (as estimated from end-of-the-pipe runoff quality data) (84). Results from an investigation entitled "Source and Migration of Highway Runoff Pollutants" (2) indicate that traffic volume is an excellent indicator of pollutant accumulation. However, other site characteristics, drainage design and climatological factors, may determine how the pollutants are transported within and from the highway right-of-way. A research study to draw all the relevant work together entitled "Design Procedure To Estimate Pollutant Loading from Highway Stormwater Runoff" is now underway under FHWA sponsorship.

Drainage Design--

Figure 27 illustrates two typical highway drainage designs. A curb and gutter system is typical of many urbanized areas where the size of the highway right-of-way is limited. There are drains located along the gutters and runoff is transported by a sewer system to a receiving stream, ditch along the highway right-of-way or to an adjacent storm sewer system. The presence of the curb serves as a barrier to particles (and associated pollutants) which are being deposited and transported laterally along the highway surface by wind and the air movements from traffic. As solids and miscellaneous debris accumulate next to the curb, they tend to entrap additional solids. Figure 28 shows a picture of solids accumulation along a highway curb. These solids can be readily transported by runoff, since the gutter formed by the curb is the initial collection and transport path for runoff from the highway surface. Depending on the quantity and intensity of rainfall, a large portion of the



WITH CURBS

WITH FLUSH SHOULDERS

Figure 27. Typical roadway sections.

Figure 28. Accumulation of sediment size material and debris next to a curb along I-94 in Milwaukee, WI.

accumulated solids will be suspended in the runoff and carried into the secondary transport system.

A flush-shoulder type of design is more typical of suburban or rural highways where more space is allowable for a highway right-of-way. In this case, wind and the air movements from vehicular traffic move the solids and associated pollutants into the emergency lane and grassed area next to the pavement. Research results indicate that a large portion of the particles and associated pollutants become incorporated into the soil and vegetation within a short distance (20-30m) of the highway (2). Runoff resulting from rainfall also flows laterally across the highway and through the grassed area prior to collection in a ditch or possibly an under-drain system in the highway median. This runoff and accumulated pollutants are not concentrated at the same location in the right-of-way. Therefore, runoff is less efficient in suspending particles. Also, the grassed area tends to slow the velocity of the runoff, further limiting the ability to suspend particles and allowing for additional particles to settle out from the runoff.

The two drainage designs described are quite common but there are numerous variations. A report entitled, "Constituents of Highway Runoff: Vol. I, State-of-the-Art Report" (81) has a detailed review of many types of highway drainage. The various designs will all have different pollutant accumulation and runoff characteristics. However, drainage systems which tend to concentrate pollutants and convey runoff for discharge at one location will generally deliver the most pollutants to receiving waters.

Secondary drainage devices such as storm sewers, paved ditches or grassed ditches also have an effect on pollutants transported to receiving waters. These drainage devices are typically designed with a single purpose; to transport runoff effectively away from the highway. Storm sewers and paved ditches are high velocity conveyance systems. They transport runoff and particulate materials very efficiently to additional conveyance systems or receiving waters. Particulates may accumulate at various low velocity points such as channel or sewer junctions, etc. following one or several low volume/low intensity precipitation events. However, this material will be scoured from the conveyance system following a medium to high volume/intensity event.

In contrast, a grassed ditch is not a high velocity runoff conveyance system and must therefore be much wider and deeper than the paved ditch or storm sewer to accommodate runoff. These systems are typically in suburban and rural areas where the highway right-of-ways can be wider. Low velocities are necessary in these system to prevent erosion, but this also allows for particulate material being carried in the runoff to settle. The critical velocity for settling of a particle of a given size is roughly equivalent to the scouring velocity to resuspend it (96). Therefore, settled particulates in grassed ditches are not likely to be resuspended and transported to a receiving water unless erosion of the ditch is occurring. The particulate material accumulating in these grassed ditches has been shown to be incorporated with the soil/grass matrix (2). Grass and other vegetation growing in highway runoff conveyance ditches have been shown to have high levels of several metals in the plant tissue (2).

Grassed ditches can also function to significantly reduce the runoff volume. This is primarily due to the increased pervious surface area of highway right-of-ways with grassed ditches, and runoff from impervious areas must be transported through these pervious areas. Studies of two highway systems in Milwaukee, Wisconsin have shown that grassed drainage systems (draining primarily grassed right-of-way not pavement) exhibited surface flow of runoff only during 9 high volume/intensity precipitation events or during frozen ground events such as spring snow-melt (1). In contrast, a storm sewer conveying runoff from a curb and gutter completely paved highway drainage area carried runoff for nearly all precipitation events greater than 0.05 inches of rainfall (2). A highway system in rural Wisconsin with flush shoulder drainage design, and a combination of paved, riprap and grassed drainage ditches, generally had measurable runoff following precipitation events of 0.25 inches (0.64 cm) or more (See Volume II).

Type of Pavement--

Data on the effect of pavement on highway runoff pollutants is not definitive. An early study (1974) by URS on water pollution aspects of street surface contaminants examined street litter from eight cities across the United States (85). Rates of pollutant accumulation on streets were developed for five pollutant groups - total solids, BOD_5, COD, total nutrients, and total heavy metals. Asphalt streets were found to have 80 percent higher accumulation rates than concrete streets. This is probably attributable to the better durability of concrete pavement in comparison with asphalt pavement. The URS study also showed that pollutant accumulation rates were approximately 2.5 times higher on streets in poor to fair conditions in comparison with streets in good to excellent condition.

Differences in the constituents present in runoff from highways due to pavement type are not easily discerned. Sites which have been studied in the past have different traffic volumes, drainage designs, climates, etc. in addition to having either asphalt or concrete pavement.

Despite the limited information on pavement type influences on runoff quality, this factor should be considered relative to study objectives in selecting a site. If the objective of the study is to determine the impact of a planned project, the selected study site should have the same pavement type as the planned projects. This factor can then be eliminated as a basis for invalidating study results.

Maintenance Practices--

There are a number of normal highway maintenance practices which can influence the quality of highway runoff and hence the impacts on the receiving waters. These practices include:

1. Roadway deicing,
2. Street sweeping (urban highways),
3. Repair activity,
4. Right-of-way mowing, and
5. Herbicide applications.

The impacts of the activities on the quality of highway runoff are discussed in several literature reviews and research reports (1, 8, 81). The potential receiving water impacts of these activities are also discussed using available literature in Volume III of this report entitled, "Resource Document for Environmental Assessments". An on-going FHWA study entitled "Highway Maintenance Impacts to Water Quality" (due 11/84) should provide the best insight into this area.

In many cases, the impacts of these activities are transient and have little impact on either runoff or receiving water quality. For example, salt application to highway and subsequent transport to a receiving stream during spring snow-melt often do not cause water quality violations due to the high stream flows and dilution in the spring. However, salting activity in some streams has resulted in chloride levels higher than criteria for drinking water supplies (See Volume III).

Maintenance activities in urban areas with highways having curb and gutter drainage design may include street sweeping. Sweeping of highways would generally not be conducted in rural or suburban areas with flush shoulder design highways. Studies conducted as part of the National Urban Runoff Program (NURP) have generally indicated that street sweeping is not an effective means for improving the quality of urban runoff (87). In Winson-Salem, North Carolina, this was due to inefficiency of mechanical street sweeping in picking up the smaller particle sizes along curbs and the multitude of other areas for pollutants to accumulate in urban areas other than along street curbs (87). For an urban freeway in Milwaukee, Wisconsin street sweeping (ie., using vacuum sweepers) was shown to be more effective in removing accumulated particulates (2). This is particularly true during the early spring in northern climates where a substantial quantity of material has accumulated over the winter. In Milwaukee, street sweeping was found to remove approximately 73 percent of the accumulated particulate material available to be removed by highway runoff in the spring. In the summer, this removal was 90 percent (2), but the accumulated load on the highway was much lower.

Maintenance activities differ on a regional, state and even county basis. The use of anticaking agents for deicing agents may differ from county to county. Herbicide applications, repair activity and sweeping may all vary widely. Other than impacts from deicing agents, receiving water impacts from these activities are not well documented. The potential impact of these activities should be evaluated on the basis of study objectives in selecting suitable study sites. Maintenance activities may even be the primary reason for conducting a study. The North Carolina Division of Highways (N.C. Department of Transportation) and Division of Environmental Management (N.C. Department of Natural Resources and Community Development) recently conducted a joint study on the biological impact of bridge sandblasting and painting (7). No impacts were identified in this study.

Receiving Water Characteristics

There are several categories of characteristics of receiving waters which can influence the water quality, biological and/or hydrological impacts of highway runoff:

1. Type of receiving water
2. Watershed characterization

a. area

b. length of highway

c. land use - nonpoint sources

d. point sources

3. Water Quality/Aquatic Biota

4. Intended and Supported Uses.

Each of these categories and the way they influence identified impacts are discussed below in terms of selection criteria.

Type of Receiving Water--

Receiving waters for runoff from highway systems can be almost any form of water body. Highways which are built along a ridge line may drain to headwater streams. If the highway crosses a major valley between ridges, highway drainage may go to increasingly larger streams and rivers. Likewise, highway areas may contribute runoff to ponds, lakes, freshwater wetlands, saltwater marshes, etc. depending on the geographic location of the highway. All of these systems have different hydrological, water quality and biological characteristics such that they will respond differently to pollutant inputs from runoff. Volume III of this report, "Resource Document for Environmental Assessments", provides a detailed review of impacts of highway runoff and how these impacts vary for different water bodies. Volume IV of this report "Procedural Guidelines For Environmental Assessments" provides a detailed discussion of receiving water types, regulatory framework for their protection, associated impacts which might be expected and means to assess the potential for these impacts. The following paragraphs include highlights of receiving water types and potential impacts important in the site selection process. Obviously, the site selected should match study objectives.

In terms of lotic or flowing water bodies, headwater streams are probably most likely to exhibit impacts from highway runoff. The increase in impervious surface area resulting from a highway in the small watershed to these streams can alter peak flows resulting from a precipitation event. This could result in a change in the stream channel and the bottom substrate. Water quality conditions of a small stream can change dramatically as a result of runoff. Deicing salt application to the highway may alter the chloride, calcium, and sodium content of the stream and possibly impact sensitive aquatic biota. Accumulated toxics in the sediments of these streams may also impact biota. Sedimentation of particulate materials may reduce available habitat in the stream bottom for aquatic organisms. These impacts have not been identified as part of this research investigation but are possible based on the results of others (88).

Larger streams (formed from several headwater streams) and rivers (generally considered to have low flows greater than 5 cfs) are less likely to be influenced by highway runoff due to the larger watershed area and dilution. The types of impacts which could be experienced by these streams and rivers are the same as for the small stream. However, these impacts should be more intermittent and localized. For example, peak runoff from the portion of the watershed with the highway may influence flow and water quality briefly until runoff from the upstream watershed contributes. Figure 29 shows a hydrograph following a precipitation event for Sugar Creek in Southeastern Wisconsin. Sugar Creek has a watershed of approximately 25 mi^2 (62 km^2) at this point and receives runoff from approximately a 3 mile (5 km) length of highway all within about 2.0 stream miles (3.3 km) of the stream flow gage. A detailed description of this site can be found in Volume II of this report (3). The first flow peak is a result of runoff from the highway and the directly adjacent watershed. The second, higher and longer flow peak results from the upstream watershed. This illustrates the transient hydrological and potential water quality effects highway runoff can have on a larger stream. Any sediment and biological impacts should also be localized near the entry-points of highway runoff.

Small lakes and ponds with long hydraulic retention times may exhibit impacts due to the accumulation of pollutants from runoff. Nutrient loadings

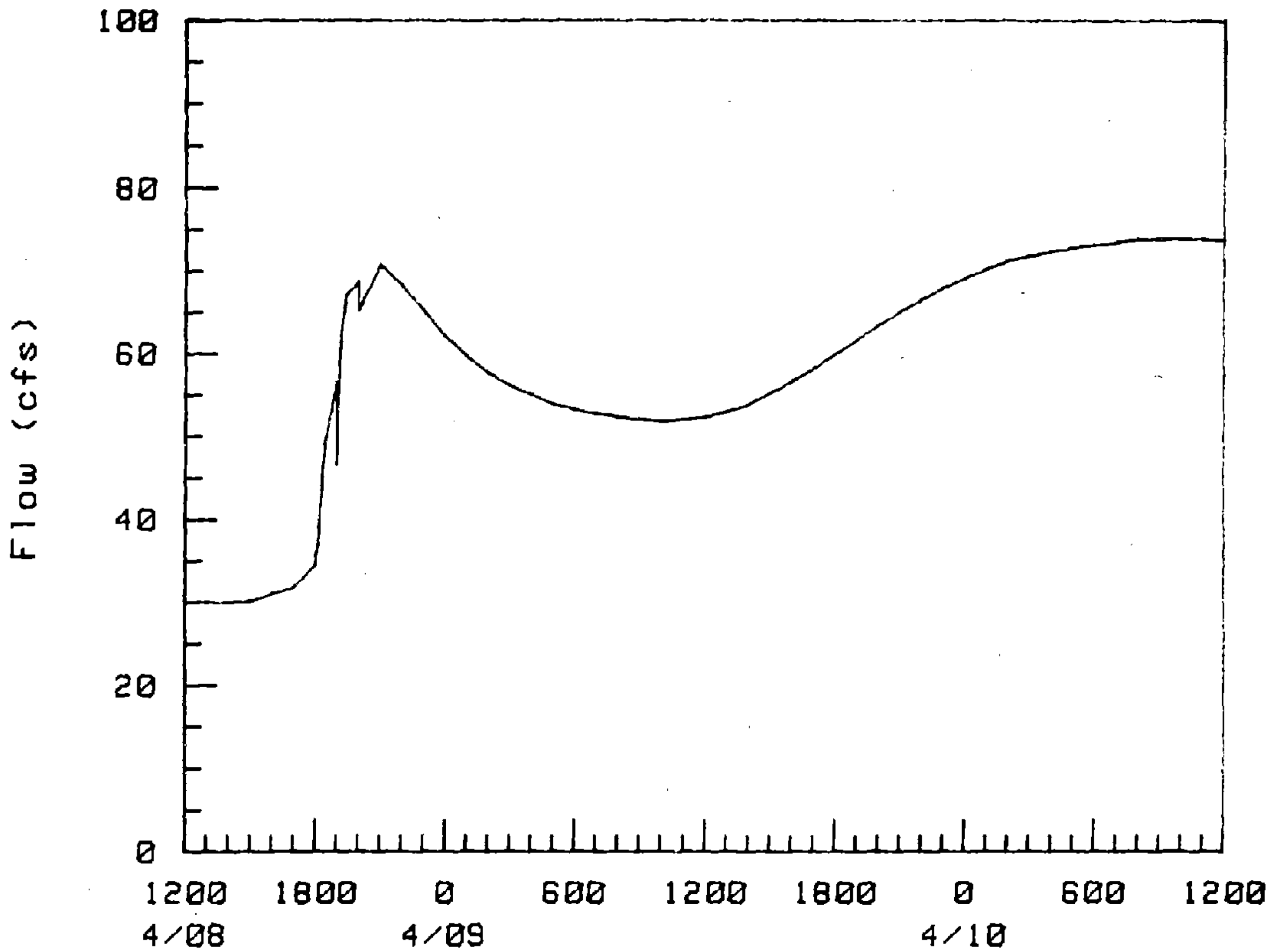


Figure 29. Hydrograph of Sugar Creek in Southeastern Wisconsin.

from highway land use is greater than most undeveloped landuse (e.g. forestry, pasture) and may contribute to eutrophication. Large inputs of deicing salts may cause more dramatic density gradients than exist due to temperature stratification. This has prevented the mixing of surface and bottom water in some lakes even during seasons when the temperatures of the two water masses are similar (89, 90, 91, 92). Highway runoff can also impact the sediments of lakes, however it is likely to be localized near the point of runoff entry depending on the settling characteristics of the particulates. The particulate material accumulating in lake sediments will not likely alter the available habitat as in a stream system, but can increase metals and oil and grease content of the sediments. The long term water quality or biological impacts of accumulated toxics in lake sediments is not well-understood (93) and probably varies by sediment type as well as regional soil characteristics.

Large lakes and reservoirs may exhibit localized sediment/biological impacts similar to small lakes but are not likely to suffer from the long-term accumulation of runoff pollutants. Dispersion at the point of entry of runoff will determine whether water quality criteria are exceeded due to runoff (94).

Wetlands may be affected by highway runoff by excessive flushing from peak runoff. Sediments and vegetation in wetlands may also accumulate highway runoff pollutants. Wetland systems have been considered to have potential to mitigate the impacts of highway runoff on other water bodies. A detailed review of wetlands and highway runoff is contained in a two volume series entitled, "Effects of Highway Runoff on Wetlands - Volume A: Research Report: Volume B: Management Guidelines" (95).

Watershed Characteristics--

The area of the receiving stream watershed is, of course, related to the type and size of the water body. Larger streams and rivers have much larger watersheds than small streams. However, there is little relationship between lake size and watershed area. Many lakes and reservoirs have large watershed areas but can range from small (several hundred acres) to quite large (tens of thousands of acres). Two of the largest lakes in the world, Lakes Michigan and Superior have approximately the same area of land draining to them as the lake surface area. Wetland areas can also have various watershed sizes.

The appropriate watershed size for a study of highway runoff impacts depends on the objectives of the study. In general, the larger the ratio of contributing highway area to watershed area, the more likely it becomes that an impact can be identified. It may be that the portion of the watershed with the highway dominates a certain portion of a stream or lakes watershed.

The three study sites used for the research portion of this project (See Volume II) can be utilized as examples of various relationships between the highway drainage area and the receiving watershed. Figures 30, 31 and 32 are maps indicating the receiving watershed and highways for the WI State Hwy 15/Sugar Creek site (in southeastern Wisconsin), the I-94/Lower Nemahbin Lake site (also in southeastern Wisconsin) and the I-85/Sevenmile Creek site (in the lower piedmont region of North Carolina).

The I-85/Sevenmile Creek site is an example of a highway which has been built along the ridge line. There are several headwater tributary streams which have drainage areas which range from 300 to 2,000 acres (120 to 800 ha) that receive runoff from the highway. These streams eventually combine with other tributaries to form Sevenmile Creek. Sevenmile Creek receives highway runoff throughout its length and the I-85 right-of-way makes up approximately 2.5 percent of the stream's 9,340 acre (3,780 ha) watershed. Of this 2.5 percent, 45 acres (18 ha) are pavement and 180 acres (72 ha) are grassed right-of-way. This site provided an opportunity to study small streams dominated by the highway as well as a larger stream with a substantial portion of the watershed area as highway.

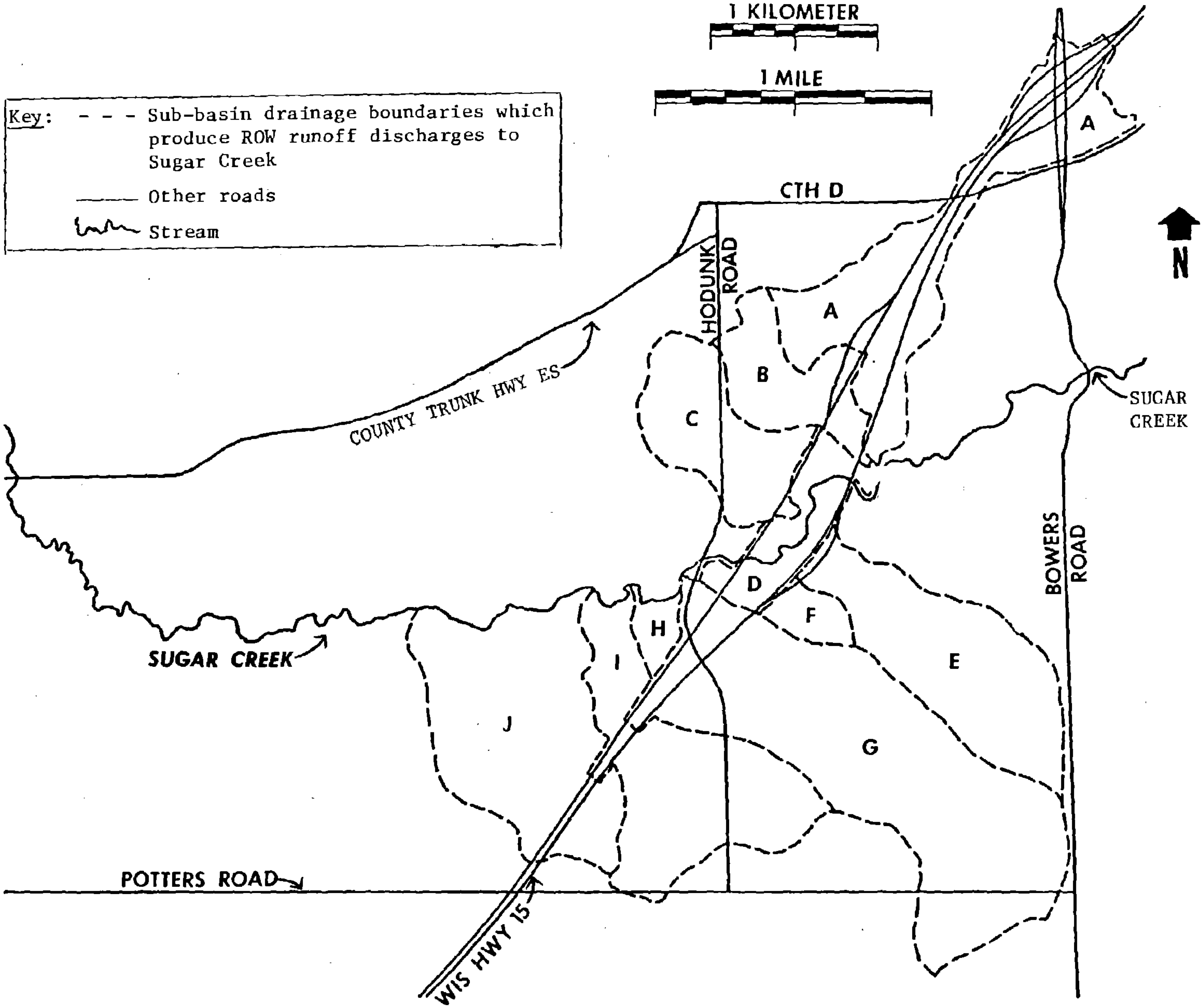


Figure 30. Map of the WI state Hwy 15/Sugar Creek site in Southeastern Wisconsin.

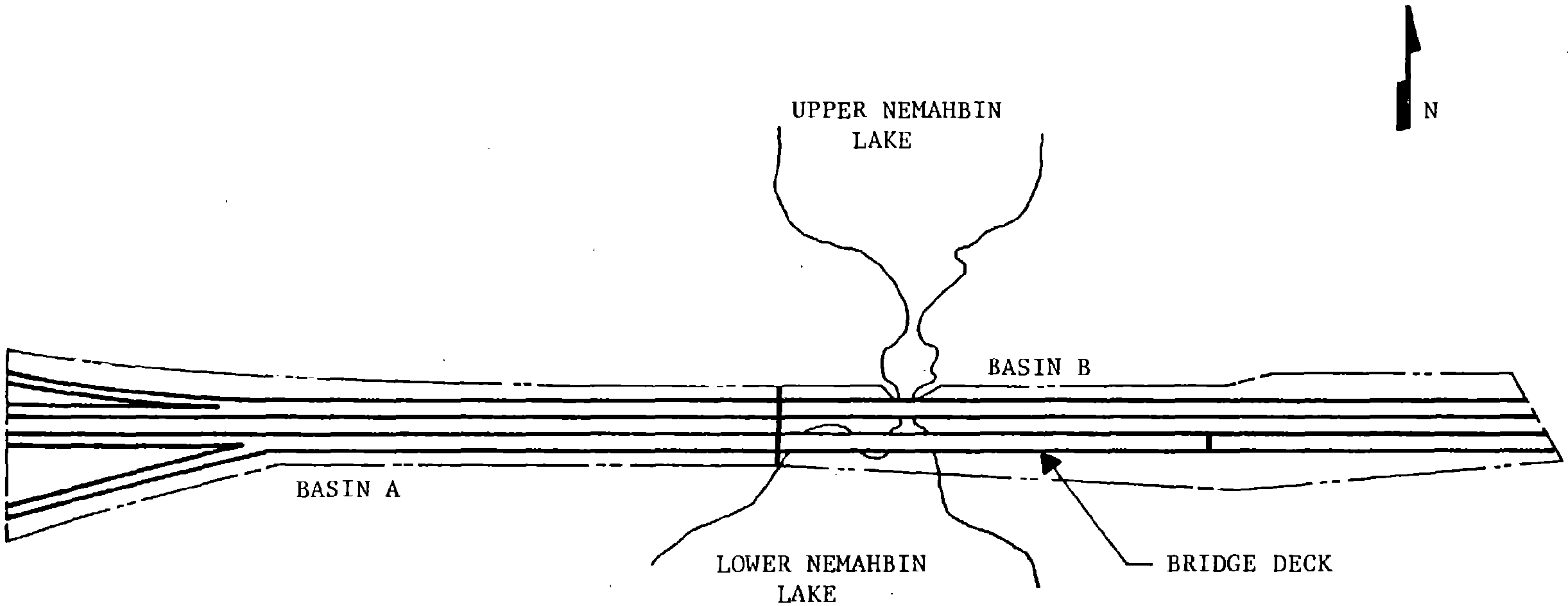


Figure 31. Portion of I-94 Right-of-way tributary to Lower Nemahbin Lake.

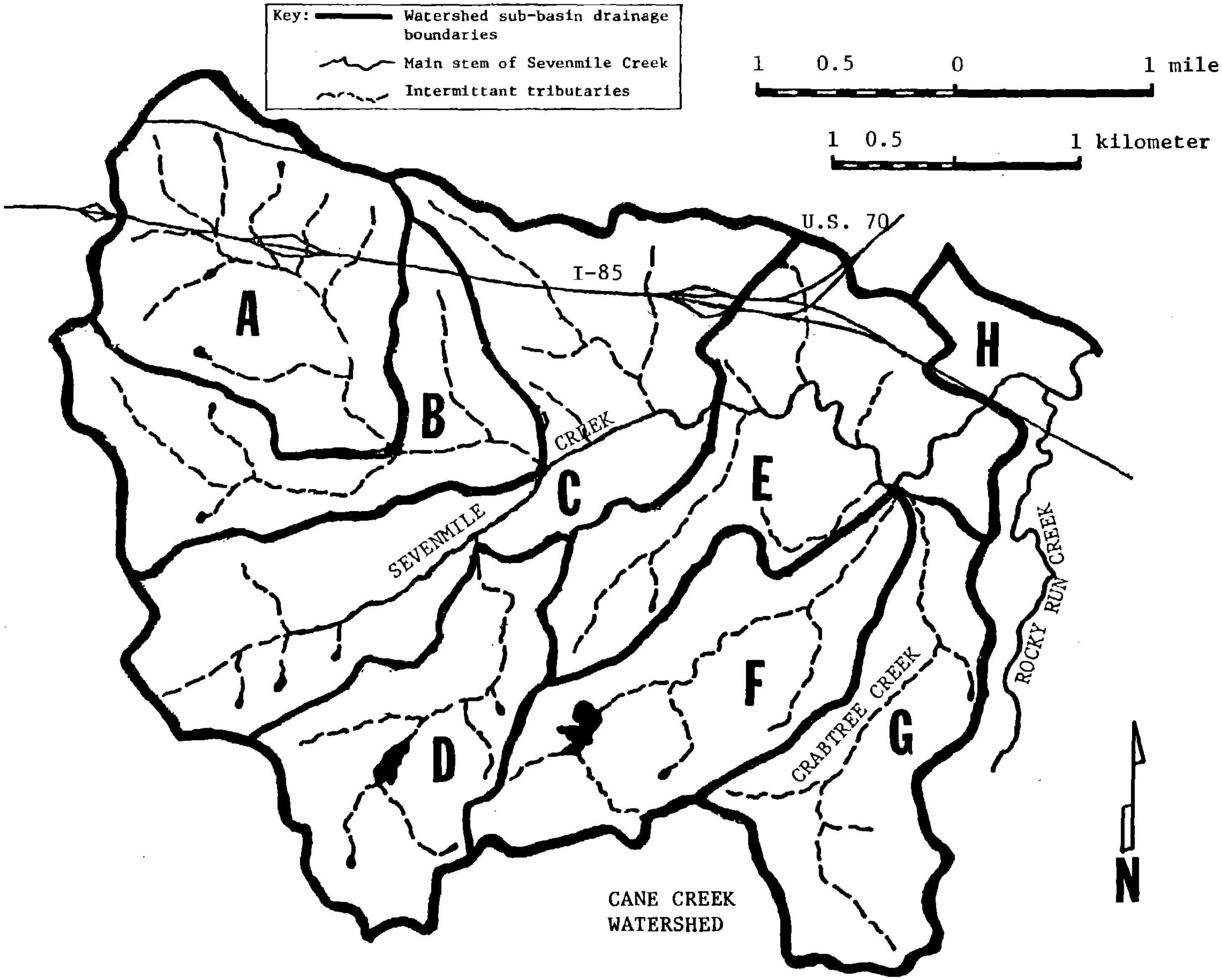


Figure 32. Map of the I-85/Sevenmile Creek site in Central North Carolina.

The Hwy 15/Sugar Creek site also has a large highway right-of-way which contributes to a 2.0 mile (3.3 km) length of the stream. The highway right-of-way has an area of 430 acres (172 ha) and the portions of the watershed containing the highway right-of-way have an area of 2109 acres (844 ha). The highway dominates this portion of the basin, but upstream of the highway influenced area, there is a watershed of approximately 26,500 acres (10,700 ha). This site provided an example of a receiving watershed where a central portion had a high percentage of highway but as an entire watershed basin, the percent highway land use was relatively small.

The I-94/Lower Nemahbin Lake site is an example of a receiving lake with a relatively small direct tributary watershed, 595 acres (238 ha), but substantial upstream watershed. Lower Nemahbin Lake is part of the Bark River watershed which has a drainage area of 30,000 acres (12,000 ha) upstream of I-94 and the lake. Despite this upstream watershed, the 19 acre (7.6 ha) I-94 drainage area contributes directly to the northern portion of the lake. This could result in a localized highway effect greater than the entire upstream watershed. This is largely because the Bark River must pass through a chain of lakes upstream of Lower Nemahbin Lake, providing considerable dampening of other nonpoint impacts.

Another important characteristic of the watershed for site selection is land use. Use and disturbance of land introduces sediment and other pollutants into waterways. Since these pollutants also enter via precipitation and subsequent runoff, these other runoff pollutants can mask any influences from highway runoff. Nonpoint source pollution occurs to some degree in almost every watershed, but it is important to minimize this pollution to the extent necessary to meet the study objectives. If the objective of a study is to determine the highway runoff impact in a watershed with some agricultural activity, a site should be selected with the appropriate proportion and type of agricultural land use. Likewise, the impact of a proposed highway through a relatively undisturbed mountain watershed should be evaluated using a watershed with similar land use. Urban land use within a watershed should be minimized as much as possible since urban runoff pollutants are quite similar to pollutants in highway runoff (1). Other highways can cause a problem if they carry a similar traffic volume as the highway of interest and the objective of the study is to evaluate the impact of one highway.

Point source inputs to a stream may not be desirable if they significantly impact water quality or aquatic biota. Point source inputs of pollutants can eliminate sensitive aquatic biota which could be affected by highway runoff. They may also introduce similar pollutants such as metals and oil and grease. Point sources are an indicator of population. Therefore, potential study sites with point sources may also be receiving urban runoff. Properly treated inputs of domestic wastewater such as at highway rest areas or some rural residential developments generally will not have a marked effect on impacts from highway runoff.

Water Quality/Aquatic Biota--

An evaluation of watershed land use characteristics and point sources of pollution will provide an indication of receiving water quality and the likelihood of a balanced population of aquatic biota. However, any available water quality and biological data should be reviewed to determine whether there are sources of pollution which are not apparent based on land use/point sources. If data are not available, a field survey to collect limited water quality data and evaluate the aquatic community is warranted. Preliminary field surveys will be discussed in a later portion of this section.

An important water quality consideration is the presence of a portion of the receiving watershed (for a stream or river) or receiving water (for a lake or wetland) which is not affected by highway runoff. This area of the receiving watershed should also be representative of the land use and point sources in the entire watershed so that it can serve as a "control" upon which any impacts of highway runoff can be based. An examination of Figures 30, 31, and 32 indicates different approaches to a control watershed concept. At the Hwy 15/Sugar Creek site, the control watershed was located on Sugar Creek just upstream of the highway contribution. This site allowed for a thorough evaluation of water quality of the stream due to nonpoint sources since all the upstream land use was represented. At the I-85/Sevenmile Creek site, the control site was located on a tributary with a watershed representative of the Sevenmile Creek watershed (excluding the major highway). At the I-94/Lower Nemahbin Lake site (Figure 31) the control location is in the southern lake away from the direct influence the Bark River watershed and the highway. This portion of the lake is influenced only by the small land area contributing to this portion of the lakes.

A control site is also required for any study of aquatic organisms and ideally, this should be the same location as the water quality control. At a lake site, the water quality control area will be well-suited for studies of planktonic or benthic organisms. For stream and rivers, bottom substrate is a critical factor. Riffle zones with rock bottoms are required for many organisms. Streams with sand or silt bottoms may be difficult to evaluate for the subtle changes which may result due to highway runoff. The streams may have excellent water quality, but sensitive organisms may not be present due to the unstable conditions of the bottom substrate.

In addition to water quality and biological control stations, a potential site must have suitable locations for monitoring highway runoff and receiving water quality in highway influenced areas. Runoff monitoring stations need not be located measure the contribution from all of the highway area draining to the receiving water. One or two suitable locations draining representative portions of the highway right-of-way are generally sufficient. Receiving water stations can be located to evaluate varying influence from the highway. Biological stations for evaluating highway influence in streams and rivers also require riffle zones with appropriate substrate. A detailed discussion of the requirements for monitoring stations is included in Section 2, Planning a Monitoring Program.

Intended and Supported Uses--

The intended and supported uses of a potential receiving water site are generally not critical to actual conducting of a field study. However, it can be very important relative to study objectives. Nearly all States classify waters for best intended uses such as swimming (primary recreation), fishing and boating (secondary recreation), raw water supply, shellfishing areas (for estuarine areas), cold-water fishery (trout waters), warm-winter fishery, etc. If an objective of a study is to evaluate the effect of highways on trout streams, only streams classified for trout and supporting a trout fishery should be considered. Likewise, a study of the contribution of toxics to drinking water supplies from highways should include sites where downstream waters are being utilized or are intended for use as water supplies. Matching the intended uses and support of uses (water quality relative to standards) of receiving waters with study objectives will increase the value of any study of highway runoff impacts.

Miscellaneous Selection Criteria

In addition to characteristics of the highway or receiving water system, there are several other factors which need to be considered in selecting a study site. These can include climate, safety, logistical considerations, and planned construction activities.

Climatological considerations have been a major factor in the selection of sites nationwide for previous studies of highway runoff and receiving water impacts (1, 2). Precipitation quantities, seasonal patterns, the occurrence of snow, temperature, etc. can all affect the suitability and monitoring requirements for a particular site. For example, the extremely dry season in Sacramento, California required a detailed dustfall monitoring program. Air movements from wind and traffic were the major transport mechanisms for pollutants removal from the highway pavement during dry periods (2).

For most studies of highway runoff, climate will not be a major selection factor since state agencies or consultants will generally be restricted to a climalogical zone. In many States, particularly those with mountain and coastal zones, there are distinct climalogical zones and these should be considered in selecting suitable sites.

Safety considerations for site selection are primarily common sense. Monitoring locations should be readily accessible from roads and there needs to be an adequate emergency lane so vehicles used by field personnel due not increase the likelihood of traffic accidents. It should also be noted that both daylight and night time access to monitoring locations should be considered depending on the monitoring strategy.

Logistical considerations include the distance and travel time for field personnel to a site, number of monitoring stations versus number of available personnel, length of study period, availability of power for monitoring equipment, etc. These factors can influence the scope of a monitoring program, the ability to effectively maintenance monitoring locations, and the budget for a study.

Planned construction activities for a highway or similar activities in the receiving watershed can affect the suitability of a potential site. Erosion from construction activity can introduce large quantities of sediment into runoff. This can over-ride any impact from highway runoff.

INFORMATION SOURCES AND PRELIMINARY SITE ANALYSIS

The ultimate decision in the selection of a site must be based upon an analysis of available information for the highway and receiving water as well as field visits (pilot surveys) of potential sites. This is necessary to establish site characteristics for the site selection criteria.

Information on the highway system such as traffic and drainage information can be obtained through the appropriate state transportation agency. Many States publish a booklet which lists the current estimates of traffic volume on major highways. This can be useful for screening potential sites. Drainage design plans or As-Built Plans are extremely useful in determining where the highway enters the receiving water and which portions of the highway right-of-way are in the receiving watershed. Data on the receiving water quality and biology after be obtained through state pollution control agencies, U.S. Geological Survey, fish and game agencies area-wide planning agencies, and universities. Biological data is often the easiest means of evaluating the water quality condition of a potential receiving water site. Data on land use for a receiving watershed can possibly be obtained from the U.S. Soil Conservation Service, State or County agricultural or forestry agencies, and regional or county planning agencies. If land use is not available, aerial photographs for determining land use may be available from these same agencies or the state transportation agency.

Generally, only limited information is necessary to begin screening potential sites. Depending on site selection criteria, information on traffic volume, drainage design, and either a quantitative or qualitative assessment of water quality is sufficient to obtain a list of potential sites. Discussion with regional highway engineers, water quality personnel, and biologists can be an excellent starting point for the selection process. When several potential sites which seem to meet the criteria are identified; highway drainage plans, land use information, additional water quality or biological information and maps can be obtained. This information will allow for a further determination of whether a site meets the critical selection criteria.

Care must be taken not to spend too much of the available study resources on gathering and analyzing background data on numerous potential study sites. Although valuable information can be obtained through a desk-top analysis of information on potential sites, a field visit or pilot survey can often provide a rapid assessment of a sites' suitability. Characteristics of the highway site such as drainage pattern, runoff channels, potential monitoring stations, accessibility, etc. can be examined first hand. Examination of the receiving water system should include location of known sources of pollution, identifying flow, water quality, and biological stations (especially a "control" station), and identification of major watershed features. An extremely important aspect of a pilot survey is the collection and screening of benthic macro-invertebrate samples for the presence of pollution "sensitive" or "tolerant" biota and collection of water quality samples if necessary.

All of the information gathered from various sources and the pilot survey can be used to select the site or sites which most closely match the selection criteria. Short-cuts can always be taken in selecting a study site. However, only a diligent delineation of selection criteria and evaluation of a sites match with these criteria will ensure that the study objectives are met by the field study.

SECTION 5

INSTALLATION AND MAINTENANCE OF EQUIPMENT

Once the planning process is complete and the appropriate equipment selected and procured, the actual field work can commence. Among the first tasks will be site preparation and equipment installation, with routine equipment maintenance procedures followed throughout the study duration. Specific field monitoring tasks such as baseline and wet weather surveys, hydrological characterizations, and sediment and biological sampling methods were addressed in SECTION 3 - FIELD MONITORING STRATEGIES.

SITE PREPARATION

In general, major site modifications should be avoided whenever possible to allow determination of potential receiving water impacts under natural conditions. This is not always possible, especially with regard to runoff channels, where accurate quantitative pollutant loading determinations must be made. Dendritical drainage ditches might have to be rechannelized, bulkheads might be required to contain high flow surges and vegetation, rocks or other debris might have to be removed if they interfere either with flow measurement or sampling. Such measures are not usually required, however. Often, only very localized modifications are required for specific equipment installation such as weirs, flumes or stilling wells.

Other site preparatory work which might be required includes bringing power to the site (or several stations within the site) and preparing a foundation for monitoring sheds or other equipment shelters. These preparations are more extensively discussed in Gupta, et al., (8).

EQUIPMENT INSTALLATION

Not all equipment types described in SECTION 2 require permanent or semipermanent field installation. Many are portable and used as such. In general, equipment should be installed according to manufacturers' instructions, where applicable. Several types of installations require special descriptions either because of nonspecific instruction manuals or because they must be fabricated by the user. These are as follows:

1. Equipment shelters,
2. Highway runoff monitoring stations, and
3. Stilling wells.

Equipment Shelters

Monitoring equipment which is to be left in the field for extended periods of time should be housed in a locked enclosure to protect the instruments and reduce the possibility of vandalism. Full-sized walkin sheds of sheet metal or plywood (insulated if heated and used in a cold climate) as described in Gupta, et al., (8) can be used. If the acquisition and installation costs for such shelters are prohibitive, smaller shelters can be used. Figure 33 shows a heavy gage aluminum shelter mounted on a stream stilling well on Sevenmile Creek in Efland, North Carolina (See Volume II).

Highway Runoff Monitoring Stations

Once the general locations of runoff monitoring stations have been determined, proper placement of the flow control device (weir or flume) in the runoff channel is critical. There are several good references available for design and installation of weirs and flumes (17, 18, 19, 96). It is advisable that the user obtain these references and adhere, as much as practical to the guidelines contained therein. Other installation recommendations are:

1. Utilize a straight flat section of channel for runoff monitoring. If such a section does not exist, site modification, if affordable, might be advisable. If significant site modification is to be undertaken, (eg., digging with back-hoe, land grading, etc.) it is advisable to employ standard erosion and sediment control measures during the construction phase.

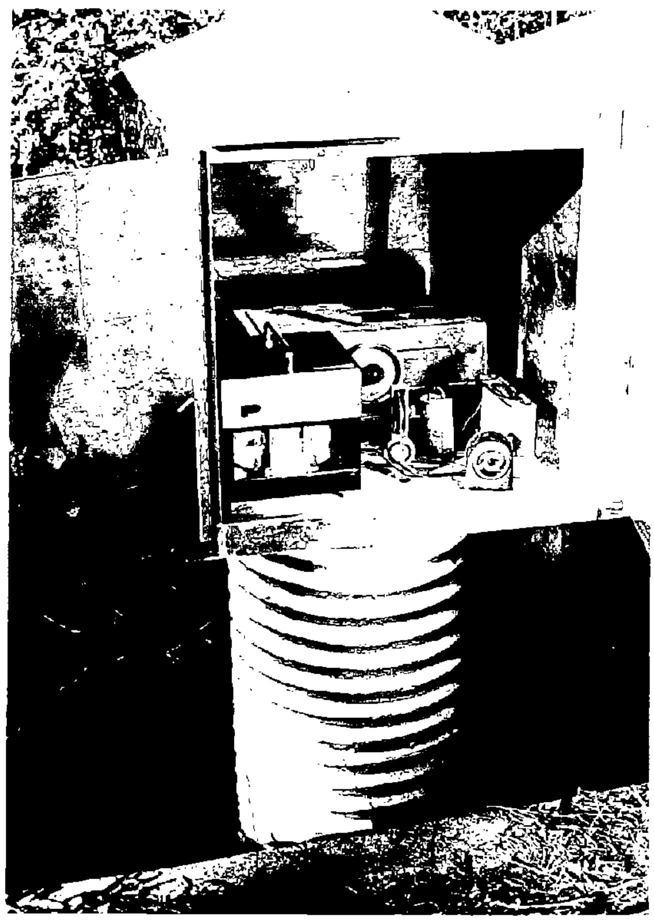


Figure 33. Aluminum shelter for protection of stilling well equipment at I-85/Sevenmile Creek site.

2. Locate the runoff station far enough upstream of the receiving water to avoid backwater influences during flood conditions.

3. It is generally advisable that the distance from the crest of a weir to the bottom of the approach channel be twice the maximum head available above the crest. However, this is often not possible in actual practice due to limited upstream available head. If project funds are not adequate to use a flume, weirs can still be used, but their field calibration becomes even more critical.

4. A deep concrete footing should be used immediately upstream of the flow control structure (weir box or flume). This footing should be at least a foot deep and tightly sealed to the leading edge of the flow control structure. This will prevent short circuiting of water beneath the flow control structure.

Once installed, the elevations of the weir crest, approach channel (weir box), and flume surface should be determined with a surveyor's transit. These elevations should be periodically checked to ensure that the structure has not settled or heaved (especially in winter). It is also critical to calibrate the control device over a wide range of flow conditions. Textbook rating curves should be verified since significant deviation can occur. Calibration procedures are discussed in SECTION 3.

It is preferable to locate secondary control device bubbler tubes or floats in stilling wells to dampen out turbulent fluctuations and minimize tampering by vandals or animals.

Stilling Wells

Stilling wells for stream or lake level recording are usually installed in the bank of the receiving water. It is often more convenient to place the well in the receiving water and attach it to a bridge abutment or pier.

According to Buchanon and Somers (19, 21) the bottom of the stilling well should be at least a foot below the lowest stage elevation. If the stilling well is installed in the bank, the bottom should be sealed to prevent groundwater intrusion and stream water leakage. The height of the stilling well depends upon the application. For typical USGS long term gaging stations, the well should be higher than 50-year flood stage (21). For short term monitoring, this might not be necessary. As a minimum, the stilling well should be several feet above the main bank of the receiving water to prevent equipment flooding.

The type and size of the water intake depends on the location and size of the stilling wells. If the well is placed in the receiving water, two or four-inch diameter holes drilled in the stilling well and facing normal to the direction of flow should be adequate. These holes should be vertically spaced at about one foot intervals, with the lowest hole being at least six inches below the lowest expected stage and above the bottom of the well to prevent sediment blockage.

Stilling wells located in the bank require the use of intake pipes of galvanized steel or PVC. The diameter of these intakes should be designed to minimize the lag time in well water level change compared to the receiving water level yet still dampen turbulent fluctuations. Table 11 summarizes recommended inlet hole and pipe diameters as a function of stilling well size (19). In cold climates, the lowest intake pipe should be located below the frostline. Intake pipes should extend into the receiving water at an angle normal to the direction of flow or aligned slightly downstream. Static tubes can also be used to eliminate stilling well water pickup or drawdown caused by velocity past the inlet pipe (21).

Both the stilling well and associated staff gages should have their relative elevations determined and periodically checked with a surveyor's transit. This is especially critical if the staff gage is mounted to a post driven into the receiving water bottom rather than fixed to a concrete or metal bridge pier or abutment.

Table 11. Recommended inlet hole and pipe diameters as a function of stilling well size (19).

Size of stilling well (feet)	Diameter of inlet hole (inches)	Diameter of inlet pipe 20 to 30 feet long (inches)
1.00 diameter	0.50	0.50
1.33 diameter	0.50	0.75
1.67 diameter	0.63	0.75
2.00 diameter	0.75	1.00
2.50 diameter	1.00	1.50
3.00 diameter	1.25	2.00
3 x 3 square	1.25	2.00
3 x 4 rectangular	1.50	3.00
3 x 5 rectangular	2.00	4.00

If comprehensive monitoring over winter months in cold climates is to be attempted, additional installation tasks must be accomplished. Water and gas lines must be buried below the frostline or enclosed in electrical heat tape wrapped conduits. Sheds or shelters must be heated to protect mechanical instruments from freezing. If electrical power is not available, then propane-fired heaters will be required. Heat type can also be wrapped around rainfall collectors to melt snow and ice and allow measurement of total precipitation volume.

EQUIPMENT MAINTENANCE

Maintenance requirements are obviously specific to the type and quantity of equipment being utilized. Manufacturers' recommendations on lubrication, parts and desiccant replacement, cleaning and calibration should be strictly followed. Maintenance of fabricated equipment is also crucial. For example, weirs and flumes should be frequently cleaned of debris and settled materials, stilling wells and intakes should be cleaned out periodically, and biological samplers should be checked for damage or debris.

Table 12 provides a list of maintenance responsibilities for typical equipment used in the field monitoring portion of this contract (See Volume II). Note that winter monitoring can necessitate more intensive maintenance requirements. For example, batteries must be changed more frequently, methanol must be replenished frequently in wet/dry and bulk precipitation collectors, antifreeze must be added to rainfall buckets, and dissolved oxygen meters must be more frequently calibrated. Instruments must also be more frequently checked for timing and accuracy since very low temperatures can affect performance or even completely disable the instrument.

A maintenance logbook should be kept for each equipment shed or shelter and all maintenance activities duly noted along with date, time and name of individual performing the activity. It is preferable to use carbon copy logs so that a duplicate copy can be filed in the office in the event that a field log is lost or stolen.

Table 12. Summary of field monitoring requirements and responsibilities at I-85/Sevenmile Creek site near Efland, North Carolina.

Monitoring task	Equipment or sampling item	Maintenance requirement
Background monitoring & routine maintenance	Precipitation gages	Weekly changing of charts & winding clock for Belfort gages, biweekly or monthly maintenance for Fischer and Porter Co. gage
	Wet/dry collector	Monthly (biweekly during winter) check of batter; add copper sulfate (and methanol in winter) to collector buckets
	Meteorological station	Monthly changing of chart and batteries
Highway runoff monitoring installation	-Flow control structure	Clean debris biweekly
	-ISCO Flowmeter	Change charts and check batteries biweekly, change desiccant weekly
	-ISCO Water sampler	Check operation batteries and bottles prior to survey use, change desiccant weekly
Stream monitoring installations	-Flow control structure	Clean debris monthly
	-Leupold and Stevens Type A-71 level recorder	Wind up clock weight monthly, change charts every three months, check weekly
	-Fischer and Porter Co. level recorders	Collect magnetic tape monthly, check and/or change batteries monthly
	-ISCO Water sampler	Check operation, batteries and bottles prior to survey use, change desiccant weekly

Monitoring task	Equipment or sampling time	Maintenance requirement
	Grab sampling points	Check staff gage for debris monthly (during baseline survey)
Baseline water quality monitoring	YSI DO meter	Check & charge battery, change membrane and solution, winkler calibrate before and after survey
	YSI Cond./temp. meter	Check battery and calibrate before and after survey
Wet weather water quality monitoring	Automated survey	Check automatic water sampler operation prior to storm event; set level actuator height; change sample bottles during survey depending on survey duration
	Intensive survey	Check automatic water sampler operation prior to storm event; set level actuator height; change sample bottles during survey depending on survey duration, prepare YSI meters as in baseline survey

SECTION 6
DATA EVALUATION

Caution should be exerted not to underestimate the amount of work involved in data reduction and analysis. For extensive field monitoring programs (especially those which provided continuous measurements), it will be necessary to utilize computer storage and handling systems. Statistical analyses and predictive models are also likely components of the data evaluation process.

AUTOMATED DATA HANDLING

Today, the handling of environmental monitoring data is greatly facilitated by Electronic Data Processing (EDP) equipment and automated instrumentation. This section of the monitoring guide describes the many different types of equipment available, their use and relationship to each other. Associated with the automation of data handling are data base development, data analysis, data presentation and communications.

Automated data handling systems consist of three primary components:

1. Data base,
2. Hardware, and
3. Software.

Before determining the hardware and software to handle data, an analyst needs to understand the kind of data base which needs to be developed. Associated with this development is the determination of how the data acquired are to be used and where they may have to be transferred.

Data Base Design

Environmental monitoring data bases are a complex mix of information with many different forms. The types of data can be divided into three major categories:

1. Text,
2. Discrete, and
3. Continuous.

The first, Text, includes all information of a qualitative nature:

1. Proposal,
2. Log books,
3. Observations called in from the field,
4. Notes of Meetings,
5. Telephone Call Logs,
6. Equipment Inventories,
7. Descriptions of:
   a. Animal Life,
   b. Plant Life,
   c. Soil Types,
   d. Sediments,
   e. Site Characteristics,
8. Reports.

All of this information is stored in sequential character string files. This data contains the keys to understanding all of the quantitative data. It includes pointers indicating where data may be suspect because of unusual events. The Text portion of the data base is by far the largest and most comprehensive (affecting all phases of the project).

The second category of information contained within the monitoring data base is Discrete. Discrete data is either data monitored on an individual event (snapshot) basis or long term accumulations (including summaries, regressions). Included in this category can be:

1. Wet Weather surveys,
2. Baseline surveys,
3. Vegetation surveys,
4. Zoological surveys,
5. Soil surveys,
6. Sediment studies,
7. Rest area runoff,
8. Agricultural runoff,
9. Bulk precipitation,
10. Statistical summaries of surveys,
11. Summaries of continuously recorded data (by event, month, year), and
12. Tables of regression results.

The third category is Continuous data, information recorded on a regular basis (interval driven as opposed to event driven). Information falling in this category includes:

1. Precipitation,
2. Air temperature,
3. Wind speed & direction,
4. Highway runoff flow or quality (conductivity, temperature, etc.),
5. Streamflow, and
6. Receiving water quality (conductivity, temperature, etc.).

A large amount of storage is usually required because the data may be recorded at intervals of five minutes during the entire study period (1 year - 100,000 values). The data base must be able to handle a wide variety of problems:

1. Correction of machine errors,
2. Correction of human errors,
3. Laboratory reruns,
4. Recalibrations as more data becomes available,

5. Missing values,
6. Not sampled,
7. Not analyzed,
8. Vandalized,
9. Not detected,
10. Data collected in a form different from that planned, and
11. Incompatible dimensions.

Because of the many problems encountered when dealing with real data, editing, converting and estimating techniques must be used.

File Name Coding--

As part of the data base design an analyst must develop a consistent means of coding file names to allow users to quickly identify the contents of a file. The first step is to determine the maximum number of characters allowed in naming files on each system utilized (may require special encoding e.g., date). Each file can be identified as shown below:

File Names	File Codes
Site (overall study area)	1 - Sugar Creek, WI
	2 - Sevenmile Creek, NC
	3 - Lower Nemahbin Lake, WI
Type of survey (discrete only)	B - Baseline
	W - Wet Weather
Type of data	P - Precipitation
	L - Laboratory Quality
	S - Synoptic
	V - Vegetation
Location (within study area)	1 - Most Upstream Monitoring
	2 - Next Upstream Monitoring
	N - Most Downstream Monitoring

Time (date, event number, period)	810112 date
	810113 condensed date[a]
	#1 event
	01 month within study

[a] Condensed Date Coding

If required an analyst may have to encode the date of event files with three rather than six characters. To do this the month, day and year are each coded with a single character.

e.g. 17B (July - 12th, 1981)

Year: 1 - 1981
2 - 1982
etc.

Day: 1 - 1st
2 - 2nd
:
B - 12th
etc.

Month: 1 - Jan. A - Nov.
2 - Feb. B - Dec.

Utilizing an event number to describe which survey in a series the file is associated with can lead to problems if the criteria for qualifying as a particular kind of event cannot be determined initially. Later confusion may arise as the events need to be renumbered throughout text and discrete files. Precipitation "events" are illustrative of this problem. Criteria on time duration between storms, volume and intensity all need to be established in order to define "events".

Media Storage and Labeling--

The location of each file must be documented (system, type of media, format). The analyst should make frequent backups of active portions of the data base in case recovery of the latest form is required. Location of backups offsite is highly recommended.

Standard Parameter Coding--

With the great variety of parameters being quantified, it is critical that all occurrences of a parameter be labeled in a consistent manner; e.g., Date, Pb (lead), Fe (iron).

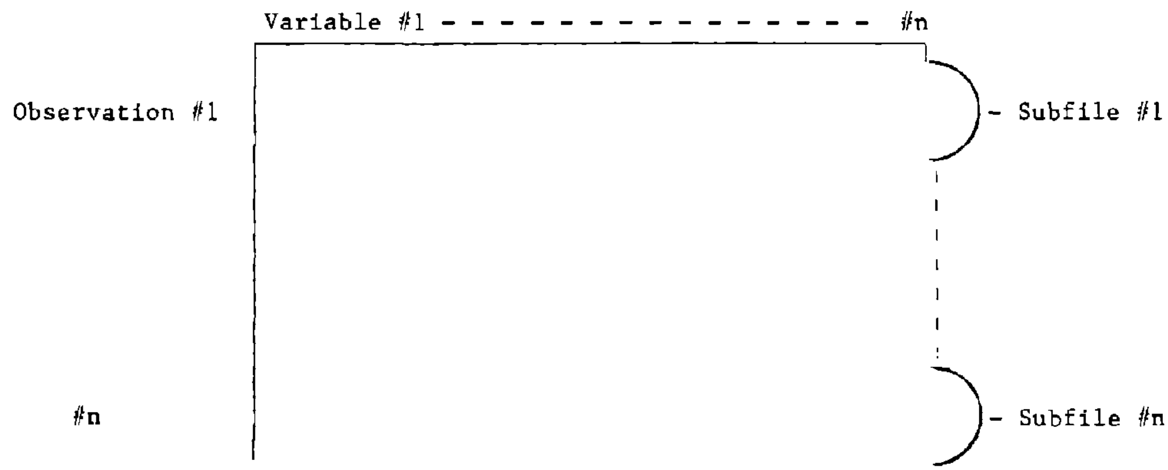
In conjunction with standard parameter codes, each time data appear, the order in which they are listed should remain the same. Standard units of measure should be maintained for a parameter (and all parameters) wherever possible. This usually requires conversion of data at point of entry into the data base because of the wide variety of sources for results.

Discrete Data File Structure--

Many data base management programs can be purchased to handle discrete data files. A standard format utilized by many statistical packages is ideal because the data frequently must be summarized, subjected to regression analysis or plotted. Other important features are the ability to extract sections of data easily and direct compatibility with graphics programs. The standard files are named as described previously in File Name Coding. The files are structured as follows:

1. A key record containing:
    a. Title (description of contents),
    b. Number of variables,
    c. Number of observations,
    d. Variable names,
    e. Number of subfiles,
    f. Subfile names, and
    g. Subfile locations.

2. Additional records containing a two-dimensional array holding data in the following form



<u>Continuous Data File Structure--</u>

There are three basic ways of storing continuously recorded data:

1. Discrete Data File Structure
2. NAWDEX (National Water Data Exchange - USGS)
3. Custom Compact Form

All three forms have advantages and disadvantages and must be looked at for a particular study.

The first form, Discrete, has the advantage of being directly compatible with all discrete data files and routines written for them including statistics, summary, extraction and graphics. An additional advantage is recording values at nonstandard increments as required (e.g. one day at the same value could be represented by a single entry or fine detail only during events). The primary disadvantage is the huge amount of storage space consumed; as much as fifty (50) times that of the other methods.

The NAWDEX form of storing continuously recorded values is very restrictive. Normally data is recorded at equal intervals during the entire monitoring period. This means the same detail is stored for event as well as nonevent periods, not allowing for greater detail during events. This method requires an intermediate amount of storage. The NAWDEX format represents a nationwide standard utilized by many governmental and private agencies. This yields advantages when trying to send data to/or receive data from other organizations. Other advantages are the library to analyze NAWDEX format data and its compatibility with using automatic data acquisition equipment.

The third way is to develop a custom method for the particular application. By storing data in character form (only the required number of significant digits) with fields separated by control characters a large amount of data can be stored minimizing required storage space. Only changes in a parameter need to be stored, with time intervals widely varying. It represents an excellent means of storing rapidly changing conditions during events. This method handles all possible data collection schemes, particularly manually transposed field recordings. Disadvantages include nonstandard format, complex structure and the need to manipulate control characters.

Hardware

At the heart of today's automated data handling systems are computers with strong processing, communications, mass storage, input and output capabilities. Relatively inexpensive microcomputer systems ($10,000) now offer features that a few years ago were only found on large expensive computer systems. The cost of the required capabilities is continually decreasing. The most important feature is that they all can talk to each other. This means that if your system is unable to perform a required function, it simply calls another system that is capable and transfers the required data. Figures 34 and 35 illustrate the components that make up a typical computer system.

AUTOMATED DATA HANDLING HARDWARE

PROCESSING
- Mainframe Computers
- Minicomputers
- Microcomputers
- Calculators

COMMUNICATIONS
- RS232
  - Serial
    - Asynchronous
    - Bisynchronous
      - IBM 2780/3780/HASP
      - IBM 3270
  - Parallel
- IEEE-488 (GP-IB)
- BCD
- IEEE-802 (Ethernet)

Figure 34. List of typical automated data handling hardware.

AUTOMATED DATA HANDLING HARDWARE (CONT.)

- MASS STORAGE
  - Magnetic Tape
    - Cassette
    - Cartridge
    - Reel to Reel
  - Disc Devices
    - Flexible
    - Winchester
    - Hard
  - Punched Cards
  - Punched Paper Tape
  - Bubble Memory

- INPUT
  - Keyboard
  - Digitizer

- OUTPUT
  - Display
  - Printer
  - Plotter

Figure 34. List of typical automated data handling hardware (continued).

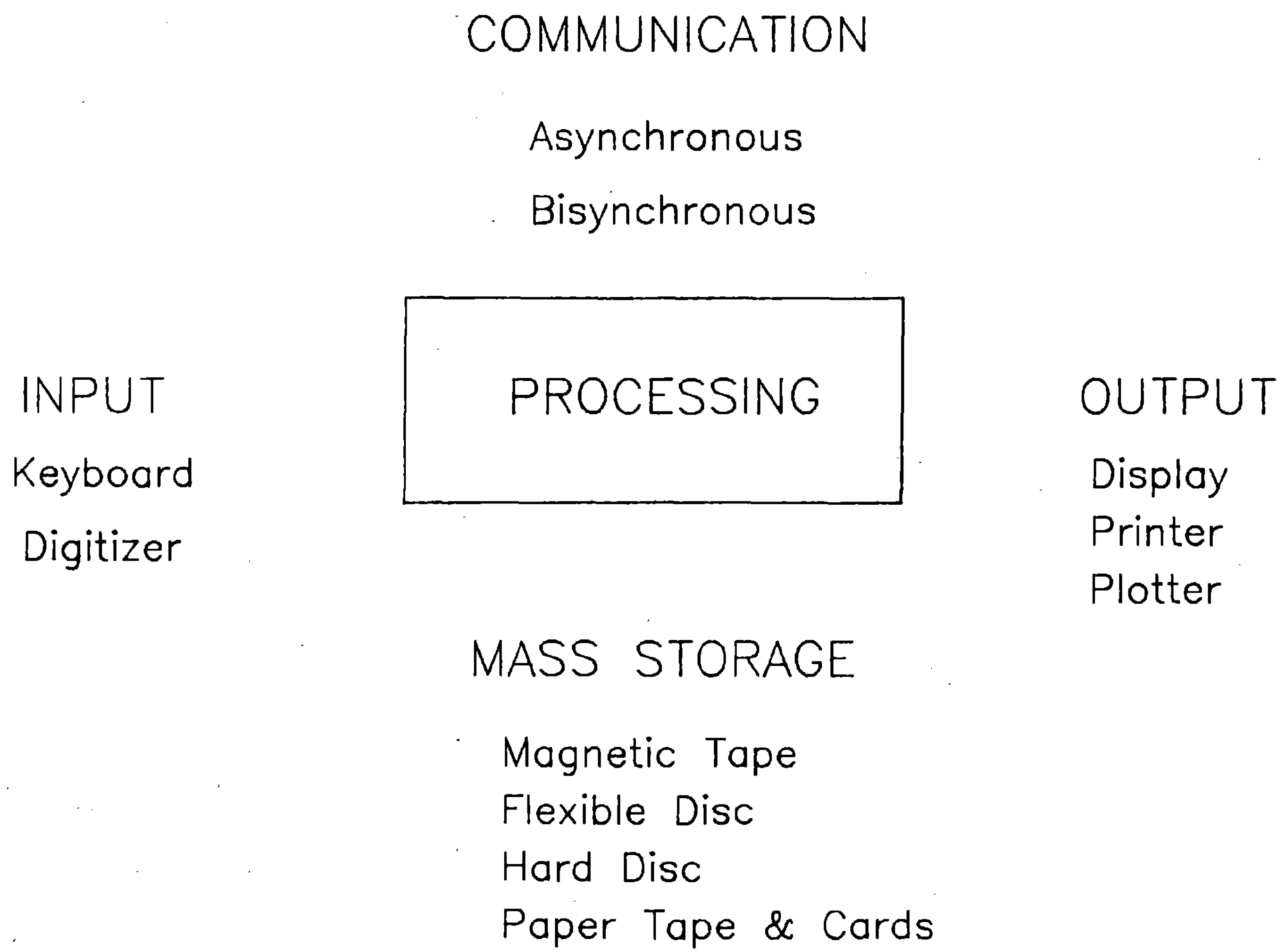


Figure 35. Typical automated data handling hardware diagram.

Processing--

A wide variety of systems is available today to process environmental monitoring data. The systems range from small handheld calculators to large multitasking main frame computers. The processing done by these systems includes calculating, input/output control and data manipulation.

In many cases several systems are used during a study. Processors can be categorized as:

1. Calculators,
2. Microcomputers,
3. Minicomputers, and
4. Mainframes.

Calculators today are small hand-held devices. The smallest, least expensive perform only the four basic arithmetic functions. Many allow programs to be created and stored for future use. A few today go much further. They allow a user remote communications, instrumentation interfacing and external printing and plotting.

Microcomputers are full function computers of very compact size. They range from 4K to 5M bytes of memory. Some are multitasking and multiuser. All tend to be very easy to utilize. They usually provide integrated alphanumeric and graphics on the same display. Many microcomputers are compact and portable (5 - 20 pounds). The continual improvement in computer technology has brought the cost of the least expensive to under fifty dollars ($50).

Minicomputers are multiuser systems with large memories. They are well equipped with special hardware to enhance number crunching. They are frequently found in laboratories that acquire information directly from analytical equipment.

Large mainframe computers handle hundreds of users. They provide a wide range of communication options. They are very expensive and are often utilized only on a time-sharing basis.

Communications--

Computers need to interface with their peripherals, instrumentation, and other computers. There are four primary means of interfacing:

1. RS232
2. IEEE-488 (GP-IB)
3. BCD
4. IEEE 802 Ethernet

RS232 communications is the most common means of interfacing equipment. It is used in both serial (sending one bit of information at a time) and parallel (eight bits/one character at a time) applications. Its most important use is in telephone communications.

Telephone communications and simple networking of computers via RS232 is done in two primary ways. The first is asynchronously (one way at a time) which is a universal standard. Literally all computers can talk this way. The second way is bisynchronously (two way simultaneously). This method allows talking to the other computer while it is transmitting to yours, allowing feedback on correctness of data transferred. Two IBM protocols are frequently used; 2780/3780/HASP and SNA/SDLC.

These methods generally require the use of modems which encode the digital output of the computer to an analog signal that will travel along a telephone line and decode incoming signals.

The GP-IB (General Purpose - Instrumentation Bus) is a parallel form of interfacing. It is designed to have up to sixteen different devices (instruments, computers and peripherals) sharing the same line. BCD (Binary Coded Decimal) is a high speed parallel interfacing technique (normally for numbers) used with many instruments.

Ethernet communications is referred to as a Local Area Network (LAN). It provides very high speed (10-100 times faster than RS232) transfers of data along simple twisted pair cables. It is a developing standard which should become firm by 1985.

Mass Storage--

The storage of large quantities of information is one of the primary purposes of today's computer systems. The means of storing data over a period of time can be broken down into three main categories (1) tape (2) disk and (3) miscellaneous type devices. Tape devices have the advantages of not deteriorating over long periods of time and their media are generally less expensive than disk media. The primary disadvantage is the inability to rapidly access any piece of data on a tape. Instead they require passing through a lot of tape to reach a particular piece of data. Disk devices spin their media continuously moving the read/write head radially allowing for nearly instantaneously random access of information anywhere on the media.

The least expensive tape device is an ordinary audio cassette recorder. It is frequently utilized with inexpensive micro-computers. More expensive, but more reliable and faster, are certified tape cartridge or streaming drives. The more traditional reel-to-reel tape drives provide very low cost backups of data stored on-line with disc devices.

Disc devices include low cost flexible disk drives (3.5, 5.25 and 8.0 inch). They have inexpensive removable media and are a good way to get started in random access applications. Winchester drives are fixed media, moderately expensive with large capacity. They are gaining wide acceptance, especially in conjunction with streaming tape drives for backup. Hard disc drives contain removable packs. They provide very high capacities but at higher costs.

Three secondary means of storing information are on punched cards, punched paper tape or bubble memory. Punched cards were the traditional means of storing information. Punched tape is usually used as intermediate storage between field recorders and computer systems. Bubble memories remember their contents even after power is removed unlike regular computer memory. It is frequently used to remember configuration values.

Input--

Data is entered into a computer system via mass storage devices, keyboard or digitizing devices. Mass storage devices were covered in the previous section. Keyboards are found on calculators, microcomputers and terminals. They allow typewriter-like input into computer systems.

There are three basic types of digitizers available:

1. Mechanical,
2. Ultrasonic, and
3. Electromagnetic.

Mechanical digitizing devices are plotters; either flatbed (paper fixed, with arm movable in X and Y direction) or roll (paper slides under arm in X, arm movable in Y). The user moves a scope over the point to be entered utilizing keys on the plotter control panel or at the computer keyboard, then presses a key to enter the point. With an ultrasonic or electromagnetic digitizing system a user moves a cursor or stylus along the graph to be digitized, pressing a button on the device for each desired point. These devices also have a stream mode which continuously sends points to the computer. If the button is depressed they are kept. Alternately some systems record a point if a certain distance or time increment has occurred. The scale for the graph is entered by digitizing two coordinate pairs with different X and Y values. Ultrasonic digitizers have the advantage of being able to read metallic backing chart paper.

Output--

Output from computer systems is generally in five forms:

1. Remote communication,
2. Mass storage media,
3. Printing,
4. Plotting, and
5. Displays.

The first two have already been discussed.

Printing's primary purpose is to generate text material. Some printers are thermal which require special chemically treated paper adding to operating costs. They have the advantage of being quiet enough not to disrupt normal office functions.

Impact printers are much noisier and should be housed inside an acoustic hood. They are built to handle large volumes of reports which can be printed on relatively inexpensive paper. Daisy wheel printers are somewhat slower but generate letter quality documents. They allow for easy changing of character forms by changing daisy wheels.

Newer developments include ink jet and laser printing systems. Ink jet systems are slightly more expensive and less proven than those described above. Laser systems require large volumes of documents to justify the cost. Plotting devices include flat bed pen plotters where an arm moves a pen across a stationary sheet of paper or film. Roll and drum plotters slide the paper in one axis while an arm moves in the other. The second kind of plotter offers advantages when generating a series of plots. Electrostatic plotters generate an image of a screen on specially treated paper.

Displays--

In the category of displays are included video monitors (CRT-Cathode Ray Tube) and video image output to other devices (e.g. slide camera or wall projector). Standard CRT's contain 24 lines with 80 characters (TV's can only support 24 lines with 55 characters making wordprocessing and other functions more abstract). CRT's with 27 lines of 132 characters can be found. Video image output to projectors and slide cameras can greatly enhance presentations.

Software

Once the data base to be acquired has been determined and available hardware that can be utilized, the analyst must determine what kinds of standard software are required for each system to manage, analyze, present and transfer the data. In many cases use of an outside computer resource for statistical, graphical or simulation software is required. Any system should be flexible enough to include communications software to reach other resources. Figure 36 illustrates the components of automated data handling software.

Figure 36.

AUTOMATED DATA HANDLING SOFTWARE

DATA ACQUISITION

COMMUNICATIONS

DATA BASE MANAGEMENT

DATA ANALYSIS
Statistics
Report Generation
Numerical Analysis
Simulations
Finite Element Analysis

DATA PRESENTATION
Word Processing
Text Processing
Graphics Presentation
CAD/CAM

UTILITIES

Data Acquisition/Communications--

Software required by field instrumentation is usually available from the manufacturer. Therefore only minor modifications are normally required for a particular installation.

Communications software (minimally an asynchronous terminal emulator) should be considered a must for every system utilized. Although there may be no need according to initial planning, this insures that any changes can be handled.

Data Base Management--Many comprehensive data base management packages are available. The choice of package is directly affected by available hardware. The package should provide for:

1. Creating file with appropriate field definitions,
2. Adding records,
3. Editing records,
4. Converting fields (critical for calibration), and
5. Extracting records based on query.

Data Analysis--After the data has been collected, a great many analyses must be performed. They include determination of stage/discharge curves, receiving water basin volumes, relationships between various quality parameters, etc. To perform these analyses the following types of software may be required:

1. Statistical package:
    a. Summary statistics (mean, median, range, standard deviation),
    b. Regression analysis (linear, polynomial, multilinear, stepwise, nonlinear),
    c. Analysis of variance,
    d. Paired t-test,
    e. Duncan's multiple range test,

2. Custom report generation,
3. Summary tables (generally unique to data collected),
4. Numerical analysis (e.g., integration routines),
5. Simulations (general purpose and custom designed after data collection), and
6. Finite element analysis system (e.g., thermal stratification studies).

Data Presentation--The generation of progress reports and the final report are greatly facilitated through the use of a word processor or an advanced text editor. Storing the progress reports electronically allows tables and sections of importance to be directly integrated into the final report. To handle graphic information a general purpose graphics presentation program is very useful. Computer Aided Drafting (CAD) systems can be effectively utilized to produce site maps, installation layouts, and equipment illustrations.

Utilities--Programs may be needed to read in tapes containing information from external sources or to write tapes for shipment to sponsoring agencies. Subroutines for sorting numeric and text information are frequently required. Format conversion routines to change external data into the form required for entry into the data base are needed.

Implementation

After the scope and nature of the data base has been determined, hardware installed and software implemented the following can proceed:

1. Data entry,
2. Data analysis, and
3. Data presentation.

There are many different ways to accomplish the above tasks. At each point the analyst must determine what equipment is available and to what extent it is practical to automate the data handling process. Figure 37 is a flow diagram illustrating automated data handling implementation.

Data Entry--

Environmental monitoring data is acquired in many forms:

1. Field recorders:
   a. Punched paper tape,
   b. Charts, and
   c. Telemetry,
2. Sampling:
   a. Automatic,
   b. Manual,
3. Field measurements, and
4. Logged observations.

Field Recorders--Field recording equipment is generally utilized to acquire data continuously or at equal time intervals. The recorded information is subject to small gaps due to routine maintenance (one or two missing time intervals). Larger gaps occur during periods of malfunctioning (particularly during winter periods). When the field recorders have been fitted with paper tape punches, equipping the computer with a paper tape reader allows the recorded data to be read directly into the continuous data base.

Chart recordings can be entered into the data base in two different ways. First the charts can be read manually, with the values entered via keyboard into the data base. Alternately, the charts can be entered by digitizing them.

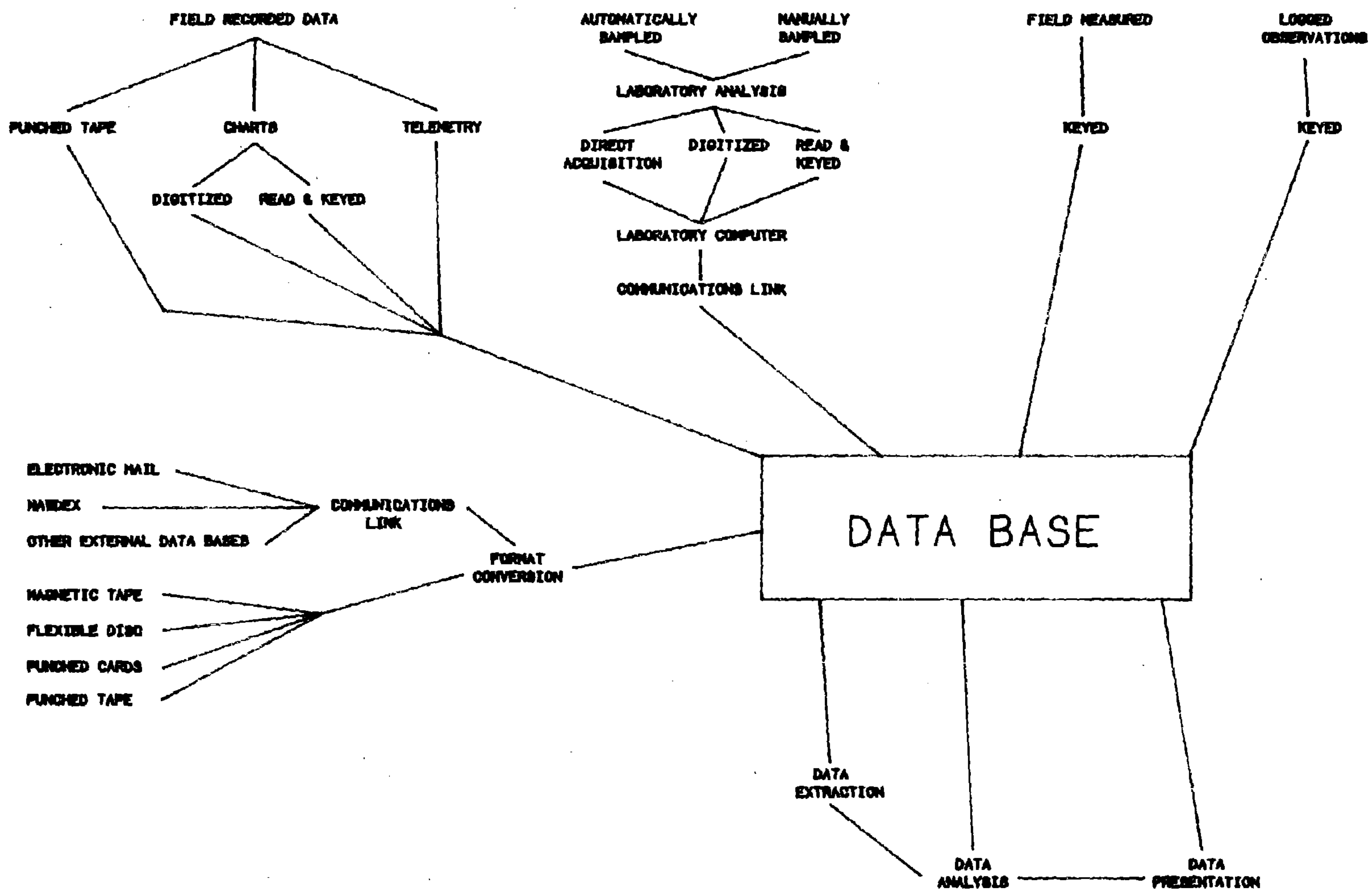


Figure 37. Flow diagram for automated data handling implementation.

Telemetry is the latest development. By placing communications capability at the recorder, a small local (1 to 10 mile max.) field computer can automatically read values at any time. At periodic intervals a base computer at the home office transfers collected data to the main data base. By utilizing this technique malfunctions can be detected or the monitoring sequence can be altered from the home office.

Sampling--The gathering of water samples is facilitated by automatic samplers taking samples at specified time or volume intervals. This method can become imperative for very hard to access installations. Alternately samples must be taken manually. The samples are then taken to one or more laboratories for analysis. A the laboratory level data is passed either directly from instrumentation to their computer, via manually reading and keying in information or digitizing charts produced by instrumentation or meters and digital readouts manually entered. From the laboratory computer the data is communicated to the data base or printed reports are sent, which must be manually keyed in.

Field Measurements and Logged Observations-- Field measurements are written into log books as they are made. The values are keyed into the data base. Logged observations including field measurements are typed as text into the data base. Additional observations are called in and keyed on the computer.

Communications--

Communications with external sources of data can be critical to a monitoring program. Many times data is collected by other agencies, especially when sites are located in other States. A direct telephone link, magnetic tape or punched cards are all viable alternatives for transporting the data values.

The importance of dial up telephone based communications systems is magnified by the ability to send and receive electronic mail when dealing with the sponsoring or cooperating agencies. A large amount of time spent trading phone calls and mailing information can be eliminated. Another important function of communications is to extract prior site data from external data bases such as NAWDEX.

Data Analysis--

Analysis of environmental monitoring data is diverse, crossing into many disciplines and requiring many manipulations. Data must be extracted from the data base that meets certain criteria (e.g. all bulk precipitation values). The data may need to be converted into the units required for final form. Missing values can be estimated by using a weighted average ratio or by running a linear regression forcing the regression line through zero (Note: this cannot be done using the ordinary least squares method linear regression - a special procedure is required). Both techniques yield a means of estimating data that is independent of the units of measure of the data used to develop the ratio. Once the proper data has been made ready, it should be stored in final form in the data base in case subsequent analyses need to be modified or the same data rerun.

Data Presentation--

The real benefits of automated data handling occur when the data is to be presented. Data entry should have been done gradually over the life of the project. With the data already in proper format all efforts can be turned toward presentation of the data.

Through the utilization of word and/or text processing, all of the information from past progress reports can rapidly be synthesized with the new text. The numbering of pages and generation of table of contents can be handled automatically. Summary tables are quickly formatted.

The graphics that can be generated with many computer systems are extensive:

1. Maps showing site location in relationship to surrounding environment,
2. Maps showing the location of monitoring equipment within the site,
3. Illustrations of monitoring equipment to show operational features,
4. Step bar charts for precipitation (hyetograph),
5. Line graphs showing:
   a. flow rates (hydrograph),
   b. depth profiles, and
   c. graphical representations of simulations,
6. Line graphs combined with symbols to show quality levels (pollutographs),
7. Range bar charts with means (or medians), and
8. Scattergrams with regression lines.

HYDROLOGICAL BUDGETS

Streams and Rivers

The use of the stage/discharge relationship for stream and river gaging was extensively described in Section 3. THe hydrologic budget for streams and rivers generally consists only of the calculation of average discharge rates and monthly and annual water yield. Computer analyses for these calculations are most efficient. The discrete stage levels (measured continuously over the study period) are input and stored. These values are then converted to instantaneous discharge values (water volume per unit time) using the statistically valid stage/discharge equation. These real-time discharge data are then integrated as a function of time; daily, weekly, monthly or annually, depending on the needs of the program. This integration provides water yield, i.e., total water volume. To obtain mean discharges, the water yield is simply divided by the respective time intervals and normalized to a unit value, usually (m^3/s) cfs.

Attempting to compartmentalize water volumes into surface water runoff, direct precipitation, evapotranspiration and groundwater inflow or outflow can be accomplished, but greatly complicates both the field monitoring effort and subsequent data analyses. Transpiration and groundwater flows are most difficult to quantify and often are not vital to the receiving water impact analysis for lotic series.

Separation of the runoff hydrograph into stormflow and baseflow (i.e., that contributed by groundwater) components can be more important, especially for the calculation of basin or subbasin runoff to rainfall volume (often called Q/R) ratios. Such ratios provide information on the hydrologic response of a given basin to various rainfall and antecedent conditions. Unfortunately, precise, deterministic approaches to baseflow separation are not readily available. Huff and Begovich (97) made a comparative evaluation of two hydrograph separation techniques. Both methods are somewhat arbitrary and there were significant differences in the results obtained for an actual watershed. The recommendation of a preferred method was subjectively based on user needs, i.e., ease of application, processing cost, and usefulness of information. A much more complicated method (by successive approximations) was developed by Bultot and Dupriez (98, 99), which involves manipulation of a complex model incorporating all elements in the water budget.

By far, the most common approach is described in Hjelmfelt and Cassidy (100), though it still only provides a crude estimate. Figure 38 illustrates several possible groundwater or baseflow configurations for a given hydrograph (segment ACE) for several antecedent or basin conditions. The complexity in hydrograph separation is quite apparent. Baseflow segment BGF would have occurred had there been no additional rainfall. Segment BID is a typical response when the stream or river stage rises faster than the groundwater table, whereas line BJD reflects the opposite condition. Usually a line is arbitrarily drawn from point G (located on the prestorm baseflow recession curve BGF right at the hydrograph peak) to D and the area under the curve BGD represents the baseflow while the difference in area between BGD and BCD is the surface runoff volume. Hjelmfelt and Cassidy (100) maintain that the surface runoff volume will be approximately the same no matter which baseflow curve is assumed, but that the runoff time distribution will be quite different.

The hydrograph separation task becomes even more difficult when complex hydrographs resulting from multiple storm events occur. Figure 38 illustrates this situation. In this case, baseflow is often separated by comparing hydrographs obtained from similar single event storms and by making estimates of runoff duration. The dashed lines on Figure 38 represent the assumed baseflow curves for this hydrograph. Again, note the subjectiveness of the method. Unless complex hydrologic models are used, this is the only method available.

Lakes and Wetlands

Constructing water budgets for lakes and wetlands is somewhat simpler, although estimation of groundwater flow and direction is still difficult. In fact this component of the budget is usually determined by difference, knowing all other components of the budget such as precipitation, surface inflows and outflows, evapotranspiration, and change in storage volume. The change in storage volume is calculated by continuous monitoring of lake level and combining these data with detailed geometric knowledge of lake morphology. Since detailed hydrographic surveys are expensive, and because state and local agency hydrographic maps seldom have the required precision, a simplified approach is often employed. This simply consists of multiplying the change in stage (depth) data by the mean lake surface area and adding this to the mean lake volume.

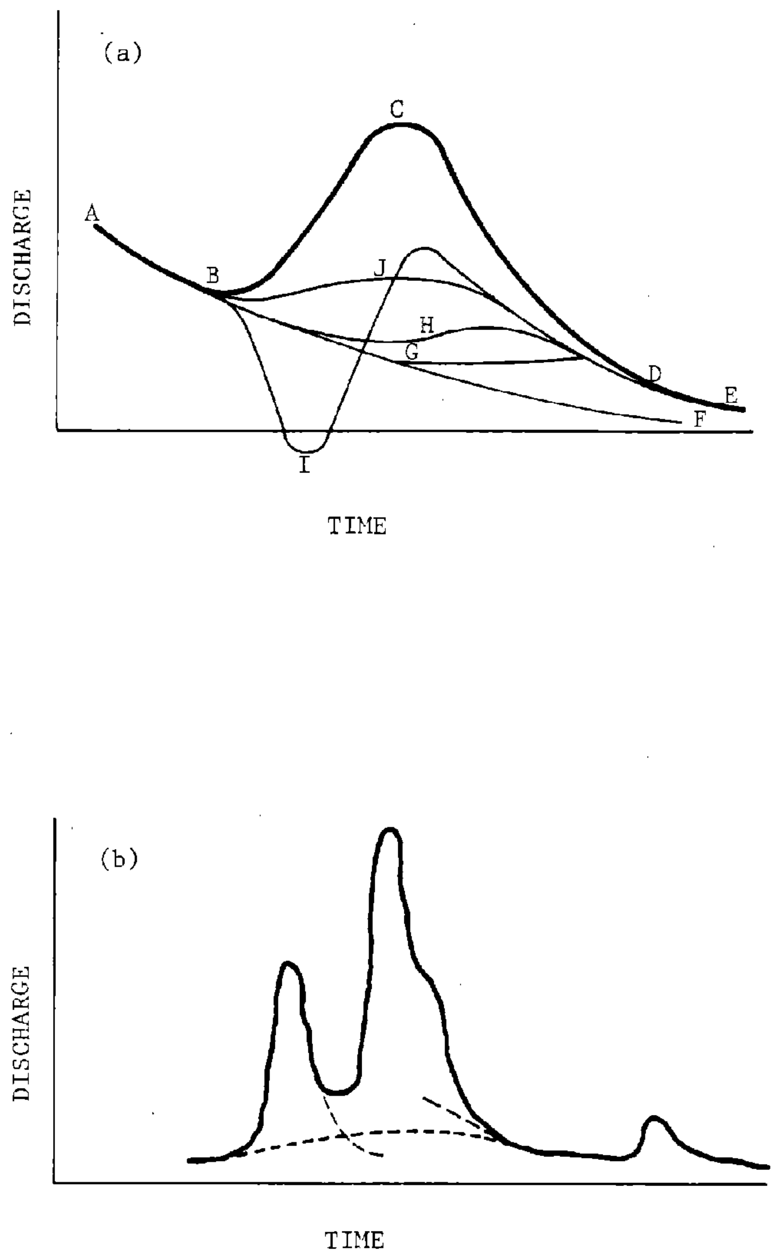


Figure 38. Relationship of baseflow to total discharge hydrographs for a hypothetical watershed [after Hjelmfelt and Cassidy (100)].

STATISTICAL ANALYSES

Whenever adequate project funds are available, sufficient data should be collected to provide statistically meaningful results. During the planning stages of the field monitoring program, such an analysis should be undertaken to estimate the number of samples taken to ensure reliable statistical results. This program may have to be modified during the course of the study to reflect differences in data dispersion from what was initially assumed. It is the purpose of this section to briefly describe selected statistical procedures commonly used in water quality studies. Detailed descriptions, including equations and sample calculations are given in two FHWA manuals (8, 28), by the U.S. Geological Survey (44), and most statistics textbooks.

Methods of Determining Central Tendency and Dispersion

Determination of central tendency (arithmetic and geometric means, median, mode and skewness) and dispersion (range, variance and standard deviation) has become quite commonplace for most engineers and scientists. Detailed explanation is not required here. One note of interest is in order, however. In dealing with analytical results from a laboratory, one is often confronted with the problem of handling data values which are below the analytical detection limits. Often, these values are handled in data arrays as if the value were equal to the detection limit. For some chemical parameters, such as total solids, where most values are relatively high and the analytical detection limit is low, such handling of the data will not seriously distort the analysis. For other parameters (such as trace metals), where the measured values are often near or below the detection limit, serious distortions can arise. In these situations, the median or mode are more accurate indicators of the central tendency of the data.

Regression Analyses

Regression analyses are used to provide insights into the relationship between sets of data. These data sets can represent either random variables or a more functional relationship between independent and dependant variables. Typical regression analyses involve only two variables, but multiple regressions involving one dependant and several independent variables are also common. Note that the existence of a positive statistical correlation does not necessarily verify a causal relationship. Therefore, caution should be exercised in the application of regression techniques. It is preferable to attempt to correlate only those variables which have some intuitively obvious physical relationship.

In highway runoff pollution studies, the technique has been most commonly employed in predictive modeling of stormwater pollutant loads (2, 84, 10[illegible]); and especially to establish relationships between a carrier pollutant (such as total suspended solids or total solids less than 250 m) and other highway runoff constituents such as metals.

Correlation techniques are also quite common in hydrological analyses (44). Kerri, et al., (28) describe an example of developing a model to predict flow in a ungaged tributary stream based on continuous data from a downstream gaging station on the main branch. Regression analyses were also used at Sugar Creek (See Volume II) to fill in gaps in streamflow data due to recorder failure. Three gaging stations were established on Sugar Creek as shown in Figure 39. Knowing the travel time between stations as derived from dye studies, it was possible to develop regression equations which, when corrected for time of travel, reasonably predicted flows at a given station based on flows at other stations (usually upstream). Application of this predictive equation is illustrated in Figures 40 and 41 for both dry and wet weather conditions at stations SD1 and SD2. The dashed portions of the discharge curve are the regression predictions.

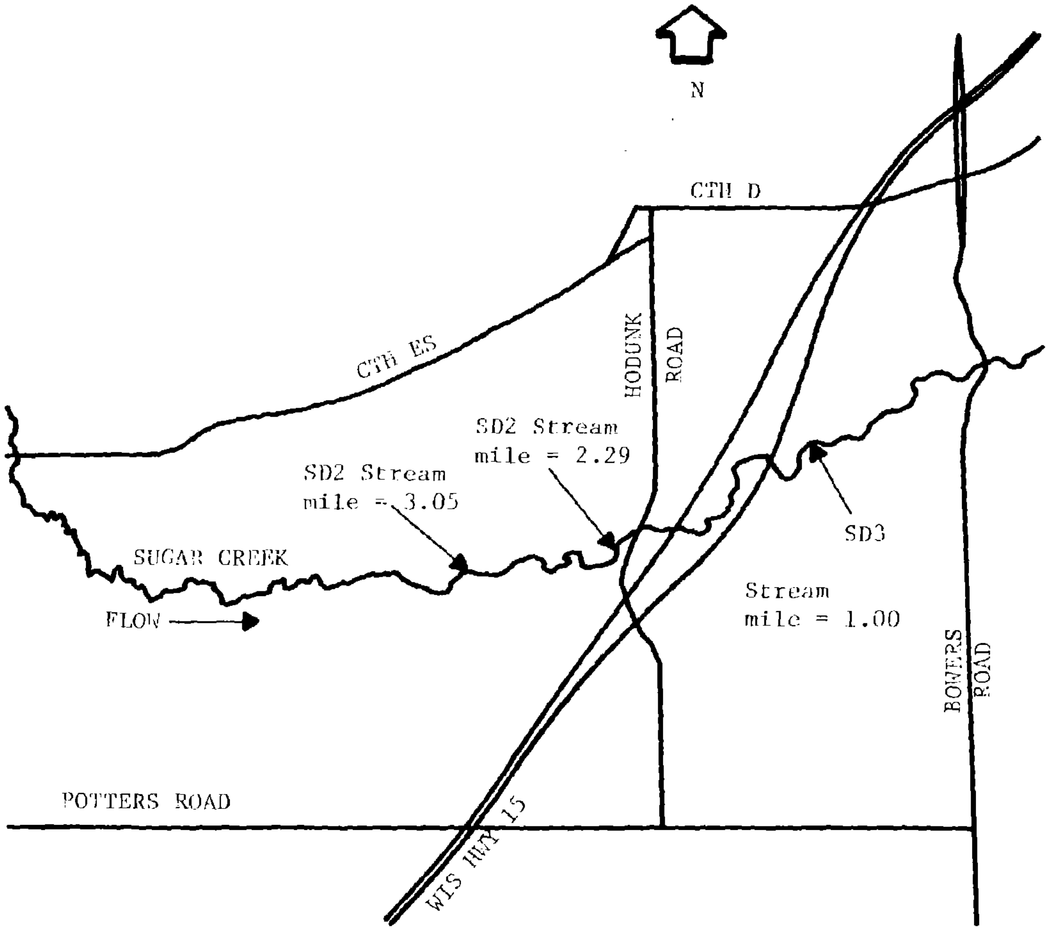


Figure 39. Location of stream discharge monitoring stations for WI 15/Sugar Creek site.

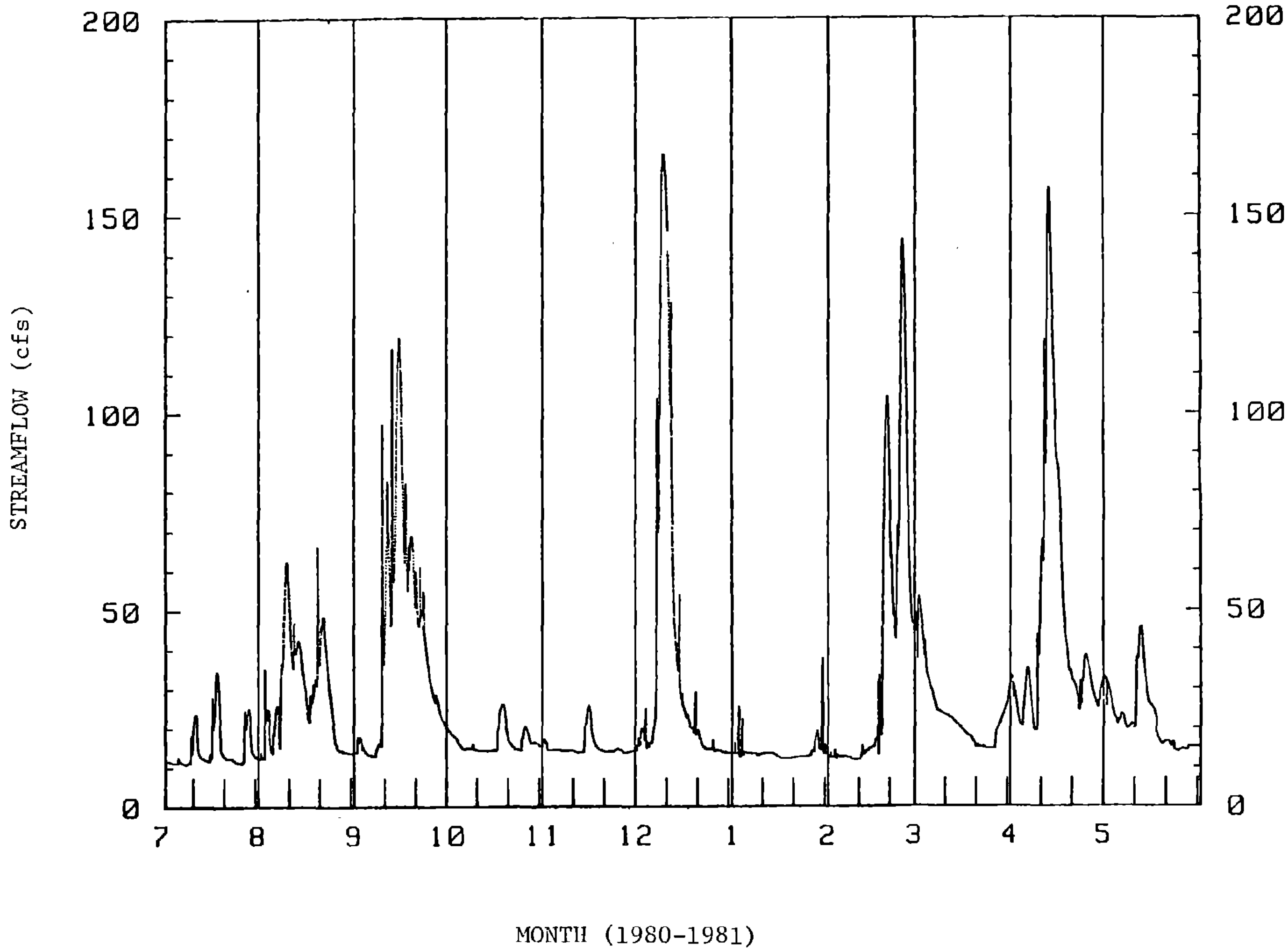


Figure 40. Stream discharge for station SD2 at Wisconsin Highway 15/Sugar Creek site. Dashed portions are travel-time corrected regression estimates.

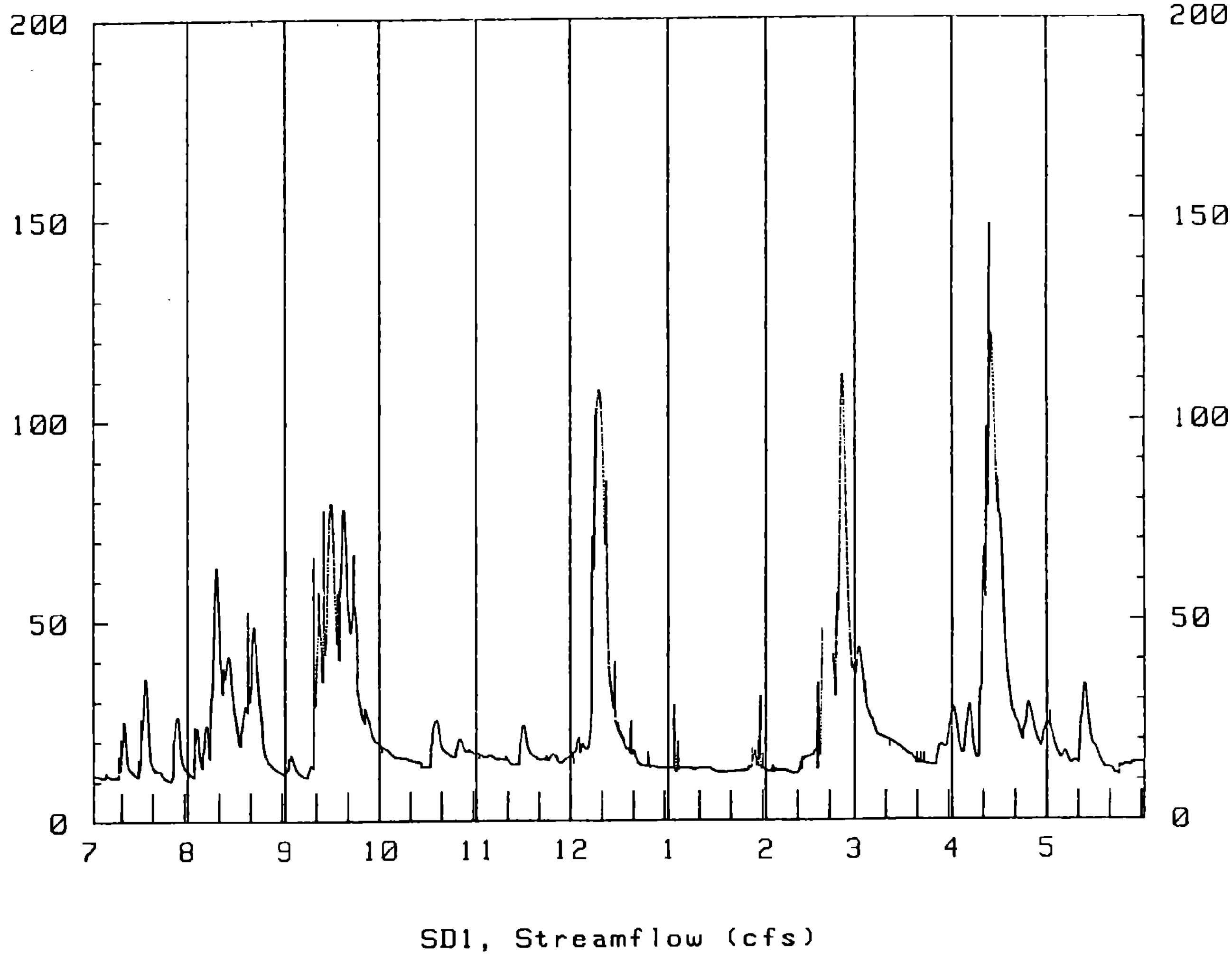


Figure 41. Stream discharge for station SD1 at Wisconsin Highway 15/Sugar Creek site.
Dashed portions are travel-time corrected regression estimates.

Comparison of Data From Different Stations

Determination of statistically significant differences between control and highway runoff influenced data or between a measured value of a given water quality parameter and a standard is normally achieved by several techniques. These methods determine whether the mean or variance of two or more sample populations are significantly different on the basis of measured dispersion of the populations.

A one-way analysis of variance classification using the F-test is most common for determining whether significant differences exist between two stations; e.g., control versus highway influenced stations. The students' t-test is most common for comparing measured water quality at a given station or site with existing or proposed water quality standards. The test generally is designed to determine whether the means of two populations are equal (28).

If multiple stations are utilized, it will be desirable to show whether significant differences exist between all stations. In theory, it is possible to utilize the t-test and compare each station to one other, progressively going from pair to pair. This would not only be tedious, but it would be impossible to assign an overall level of significance to the procedure since the tests are not independent (102).

A much more useful analysis of variance procedure is a multiple - comparison test such as Duncan multiple - range test (102). The assumptions underlying this test are essentially the same as the one-way classification where sample sizes are equal. The test compares the range of any set of means with an appropriate least significant range. The test was used effectively by Lorenz (103) in a study of heavy metals impacts on stream water sediments and biota due to urban runoff. Table 13 is illustrative of the standard display format for results of this test. The table presents the comparison of mean lead concentrations for all stream components and stations at a level of

Table 13. Example of use of Duncan's multiple range test for comparing lead concentrations in stream components (after Lorenz (103)).

Stream component	Stream Station and corresponding mean lead concentration*					
Dissolved lead, µg/l	5	6	4	2	1	3
	14.0	9.5	8.6	5.4	4.6	4.4
Total lead, µg/l	5	6	4	2	1	3
	14.0	12.0	10.2	8.0	7.0	6.6
Sediment, µg/g	4	6	5	3	1	2
	21.6	16.1	15.6	12.0	8.2	8.2
Detritus, µg/g	4	5	2	3	6	1
	36.1	31.0	23.6	21.9	21.1	16.2
Caddisflies, µg/g	4	6	2	1		
	24.2	14.6	14.0	9.2		
Snails, µg/g	2	6				
	7.4	7.0				
Crayfish, µg/g	3	2	1	5	4	6
	12.9	11.4	11.4	10.3	10.1	6.1

*Means connected by the same bracket are not significantly different from each other at the 0.95 level.

statistical significance of 0.95. Note that station means for each stream component are arranged in descending order. Means connected by the same bracket are not significantly different. Several conclusions which can be drawn from this analysis are:

1. Lead concentrations at Station 4 (immediately below major stormwater input) were significantly greater than the upstream control station (Station 1) for sediment, detritus and caddisflies.

2. Total lead concentrations in the water were significantly higher at runoff influenced Stations 5 and 6 than the upstream control (Station 1).

USE OF PREDICTIVE OR ASSESSMENT MODELS

The use of predictive models to supplement field monitoring programs can be an effective means of providing comprehensive impact assessment information without extravagant cost. Model complexity can range from simple regression equations or desk top calculations to complex, multidimensional dynamic models requiring extensive computations facilities. In most cases, the user of this manual will be seeking simpler procedures which will not require extensive modeling expertise or computational facilities. This section will therefore concentrate on this area. For a more detailed review of complex receiving water models, the user is referred to Zison, et al. (104), Grimsrud, et al. (105) and Hamilton and Fucik (106).

Models which can be of benefit include highway runoff models, models for predicting runoff characteristics from adjacent land uses, hydrological and receiving water quality models and models for biological or ecological assessments. A more detailed discussion of modeling for impact assessment is provided in Volume IV.

Highway Runoff Models

A predictive procedure for determining pollutant characteristics in highway runoff was developed as part of FHWA's program on constituents of highway runoff (84). This model predicts runoff quantities and quality from highway systems based on data gathered from six sites: Milwaukee, WI; Harrisburg, PA; Nashville, TN; and Denver, CO. Equations for three highway site types are utilized to predict runoff volume and pollutant concentrations and loadings for 17 water quality parameters including TS, SS, VSS, TVS, TKN, BOD, TOC, COD, NO_2+NO_3, TPO_4, Cl, Pb, Zn, Fe, Cu, Cr, and Cd. The three highway site types include:

1. Type I sites: Urban, elevated bridgedeck, 100 percent paved with impact barriers containing each set of lanes.

2. Type II sites: Mountable curbs and inlets on paved area with paved and nonpaved drainage area.

3. Type III sites: Rural sites with flush shoulders, paved and nonpaved runoff through ditches.

Model inputs include a rainfall record (total rain, rainfall duration and dry days) and site characteristics (size of total drainage area, average daily traffic, type of site and site length). Rainfall record may be a historical record (typical year, extreme year, etc.) or a design storm (10 yr, 15 yr, etc., recurrence interval storm). Both desk top and computerized versions of this model are available (84).

A highway runoff pollutant loading model has been developed for the State of Washington (101). Rainfall of long duration and low intensity is characteristic of this state. This model should provide reasonable estimates of runoff quantity and quality for areas with long duration, low intensity rainfall patterns. Predicted water quality parameters include TSS, VSS, COD, TOC, Pb, Zn, Cu, TKN, NO_2+NO_3 and TP. Currently, research is being conducted to extend the model to more effectively reflect sanding operations.

The California Department of Transportation (Caltrans) is currently developing a predictive procedure for estimating potential pollutant loads from road surfaces. The model, California Pavement Runoff Model (CALPROM-1), is being developed from data collected at monitoring sites in Los Angeles, Walnut Creek, Sacramento and Placerville, CA (82). Water quality parameters include TS, SS, Pb, Fe, NH_4, TP, ortho-P, TKN, NO_3, O&G, Cu, Cr, Cd, Ni, Zn, COD, Cl, Hg, SO_4 and Mg.

Field data which characterizes highway runoff has been collected for the states of California (1, 107), Colorado (1), Florida (108, 109), Minnesota (110), North Carolina (2, See also Volume II), Ohio (112), Pennsylvania (1, 2), Tennessee (2), Washington (112, 9, 113, 114, 115, 83, 116), and Wisconsin (1, 2, 3, See also Volume II). A study to draw together the data from this work and refine the methodology developed by Gupta, et al. (84) is being sponsored by FHWA.

Models to Estimate Runoff from Other Land Uses

Frequently, stormwater discharged from a highway system will not only contain runoff from the right-of-way but also from adjacent land uses tributary to the same runoff conveyances (ditches or sewers). In addition, most receiving waters are subject to runoff from other land uses through separate runoff paths, often upstream of highway contributions. The need for estimating the relative pollutant loadings to a water body is apparent.

If the surrounding land use is urban an appropriate model to estimate quantity and quality may be the U.S. Army Corps of Engineers Storage, Treatment, Overflow, Runoff Model (STORM). This model (117) computes runoff quantity and quality, contributions from land surface erosion and treatment, storage and overflow. The treatment, storage and overflow computation block would be useful if treatment plant effluents are being discharged to the receiving water. Twenty land uses including agricultural can be specified using STORM. STORM is designed for period of record analysis using continuous hourly precipitation data. In this respect, STORM is a continuous simulation model although it can be used for single events or design storm analysis. Loads and concentrations of six basic water quality parameters are computed; suspended and settleable solids, biochemical oxygen demand, total nitrogen, orthophosphate and total coliform.

Another model which may be appropriate for estimating the quantity and quality of runoff from other land uses is the Air Force Runoff Model (AFRUM). AFRUM (118) is a stormwater runoff simulation model designed to predict stormwater flow and quality resulting from real or design storms for small watersheds generally limited to 2,000 acres or less. The principal model inputs are watershed area, land use characteristics, percent forested, percent impervious, and percent denuded.

If the land use surrounding the receiving water is predominantly agricultural an appropriate model may be the Agricultural Runoff Management (ARM) Model. The ARM Model (119) simulates runoff quantity, sediment, pesticides and nutrient contributions to receiving waters from both surface and subsurface sources on small agricultural watersheds.

A series of planning models for nonpoint runoff assessment, in terms of pollutant loadings, are available from EPA (120, 121, 122, 123). These planning models are generalized tools designed for initial gross assessments with refinement capabilities to provide ball park numbers for decision making.

If modeling is not feasible, Horner and Mar (124) have compiled literature data which will provide order of magnitude values for pollutant loadings from both general land use categories (Table 14) and specific land use categories (Table 15).

Table 14. Storm runoff pollutant loadings for general land use categories (124).

Land use	Loading (lb/acre/yr)							
	TSS	COD	Pb	Zn	Cu	NO_3+NO_2-N	TKN	TP
General urban	400	18-240	0.13-0.45	0.3-0.5	0.04-0.12	0.3-4.0	7.1	1.8
General residential	375	27-270	0.05	0.02	0.03	0.3-3.4	5.4	1.6
General agricultural	17,900-44,000	N/A	0.002-0.07	0.004-0.3	0.002-0.08	0.3-7.1	0.3-30	0.1-8.0
Forested or open	6-76	1.8	0.01-0.03	0.01-0.03	0.02-0.03	0.3-0.5	1.5-2.7	0.06-0.08

Notes: (1) Means given where available; otherwise ranges are reported.

(2) N/A = Not available.

Table 15. Storm runoff pollutant loadings for specific land use categories (124).

Land use	Loading (lb/acre/yr)							
	TSS	COD	Pb	Zn	Cu	NO_3+NO_2-N	TKN	TP
Central business district	964	955	6.3	2.7	1.9	4.0	13	2.5
Other commercial	750	906	2.7	2.9	N/A	0.6	13	2.4
Industrial	50	56	1.8-6.3	3.1-11	0.3-1.0	0.4	2-13	0.8-3.6
Single-family residential	15	25	0.1	0.2	0.03	0.3	1-5	0.2-1.3
Multiple-family residential	390	297	0.6	0.3	0.3	3.4	3-4	1.2-1.4
Cropland	402	N/A	0.004-0.005	0.03-0.07	0.01-0.05	7.0	1.5	0.3
Pasture	306	N/A	0.003-0.013	0.02-0.15	0.02-0.04	0.3	0.6	0.06
Forested	76	N/A	0.01-0.03	0.01-0.03	0.02-0.03	0.5	2.6	0.08
Open	6	1.8	N/A	N/A	N/A	0.3	1.5	0.06

Notes: (1) Means given where available; otherwise ranges are reported.

(2) N/A = Not available.

Hydrological and Receiving Water Quality Models

Planning Models--

There is no substitute for actual field monitoring of precipitation volumes. Historical data simply cannot be used to predict rainfall for a given monitoring period. Another component in the hydrologic budget, evaporation, can be more effectively modeled as a function of several meteorological parameters such as wind velocity, water surface temperature, vapor pressures of air near water surface (actual and saturation) and the average air temperature (100). These empirical models are quite simple and easily applied if enough detailed meteorological data are available.

Streamflow and associated water quality modeling techniques can be more complicated. Fairly simple desk top models are available for streamflow and quality analysis, but these invariably require assumptions of steady-state flow, plug flow (i.e., negligible dispersion) vertically and laterally mixed systems, and first order decay of nonconservative pollutants. It is obvious that virtually all of these assumptions are violated for the dynamic responses associated with storm events. This all but mandates continuous field monitoring of streamflow quantity and quality unless the more complex dynamic models can be utilized.

Simple lakes or impoundments can be more readily modeled using appropriate mass balance, complete mix and sedimentation rate assumptions (104). Both stratified and unstratified lakes can be quite effectively modeled using steady-state, one-dimensional models which require at most, desk top calculators and a minimal amount of data input (104, 120). Dynamic, two and three dimensional models are available for more complex situations, but again these require more expertise and hardware for application.

Predictions from Dye Studies

Dye studies provide much useful information for stream and river water quality studies. The most important of which is time of travel for given reaches between stations as described in Section 3. These travel times are used not only to plan synoptic water quality studies, but also in several other ways. One is for the development of time-of-travel adjusted correlations of flow between stations to fill in gaps in recorded streamflow data. Another use is in the calculation and application of dispersion characteristics of the stream.

Dispersion is the process by which a conservative pollutant (e.g., road salt) concentration will be attenuated as it moves downstream. This is due largely to lateral velocity variation. Knowledge of the dispersion characteristics of a stream or river will greatly facilitate modeling evaluations (if appropriate) and of particular interest in this regard is the dispersion coefficient, which is a vital input parameter to many water quality/hydrodynamic models. Knowledge of relative dispersion characteristics in several reaches will also allow estimation of relative impacts of pollutant loadings for planning purposes. The differential equation which describes one-dimensional dispersion is as follows (125):

$$\frac{\partial \bar{c}}{\partial t} + u \frac{\partial \bar{c}}{} = D \frac{\partial^2 \bar{c}}{\partial x^2}$$, where

$\bar{c}$, $\bar{u}$ = cross-sectional mean values of concentration and velocity,

x = distance in direction of main flow,

t = time, and

D = longitudinal dispersion coefficient.

For steady, uniform flow, this simplifies to the following:

$$\bar{c}\ (x,t) = \frac{M}{A\sqrt{4\pi Dt}} \exp\left[-\frac{(x-\bar{u}t)^2}{4\ Dt}\right]$$, where:

A = area of flow cross section

M = mass of conservative substance at t = 0 and x = 0.

Several methods are available for calculation of the dispersion coefficient from tracer data. The recommended method is the method of variance change (also referred to as the method of moments) described by Fischer (126, 127) and supported by Bajraktarevic-Dobran (125). The following equation (127) is used to calculate the dispersion coefficient from dye concentration curves like those shown in Figure 16:

$$D = \frac{\Delta x^2}{2 \Delta t}, \text{ where:}$$

D = dispersion coefficient, ft^2/sec.

$\Delta\sigma x^2$ = change in variance of dye-distance curve between stations, ft^2

Δt = travel time between stations, sec.

To more easily utilize data from a concentration/time curve convert the variance as follows:

$$\sigma x^2 = V^2 \sigma_t^2, \text{ where:}$$

V = mean stream velocity between stations, ft/sec

σt^2 = variance in dye-time curve, sec^2

The term σ_t^2 is equal to the second moment about the centroid of the dye curve divided by the area under the dye concentration curve. The following example is illustrative of the actual calculation procedure for the dispersion coefficient. The stream is Sugar Creek in Southeastern Wisconsin, which was a site for the field study portion of this contract (See Volume II). Dye tracer curves for two stations (SD2 and SD3) are shown in Figures 42 and 43. Station SD2 is 2.24 miles (9665 m) upstream of SD3. Ledger sheets for calculation of the various terms are provided in Tables 16 and 17 for Stations SD2 and SD3, respectively. Note that the procedure calculates the variance with respect to time about the start time axis and then shifts this to the centroid of the curve. Using the results shown in Tables 16 and 17 the dispersion coefficient for the stream reach from SD2 to SD3 is as shown below:

Travel Time, Δt (centroid) = 4.76 hour

Mean velocities, V_2(SD2-SD3) = 0.38 fps (0.116 m/s)

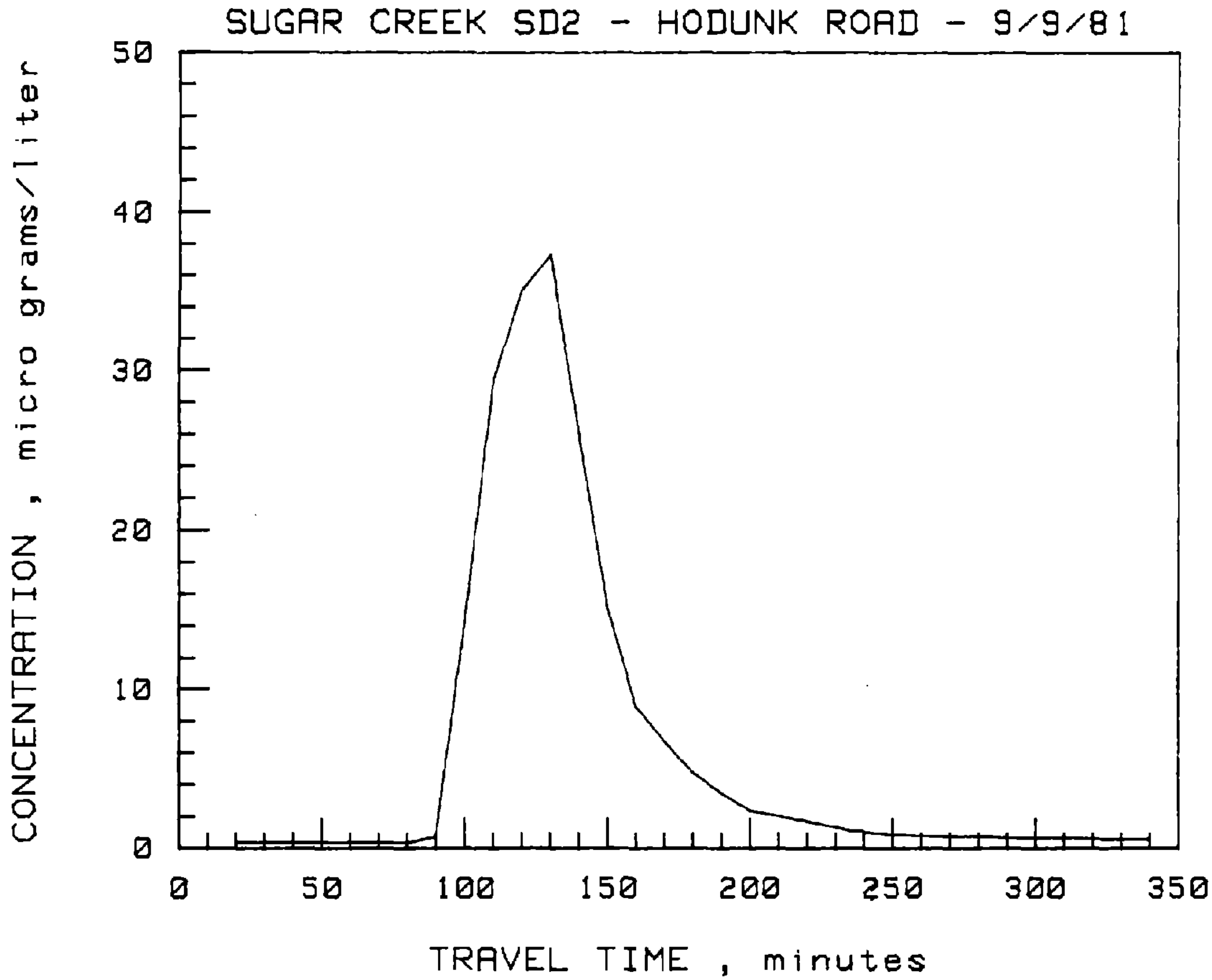


Figure 42. Dye concentration versus time for Sugar Creek station SD2.

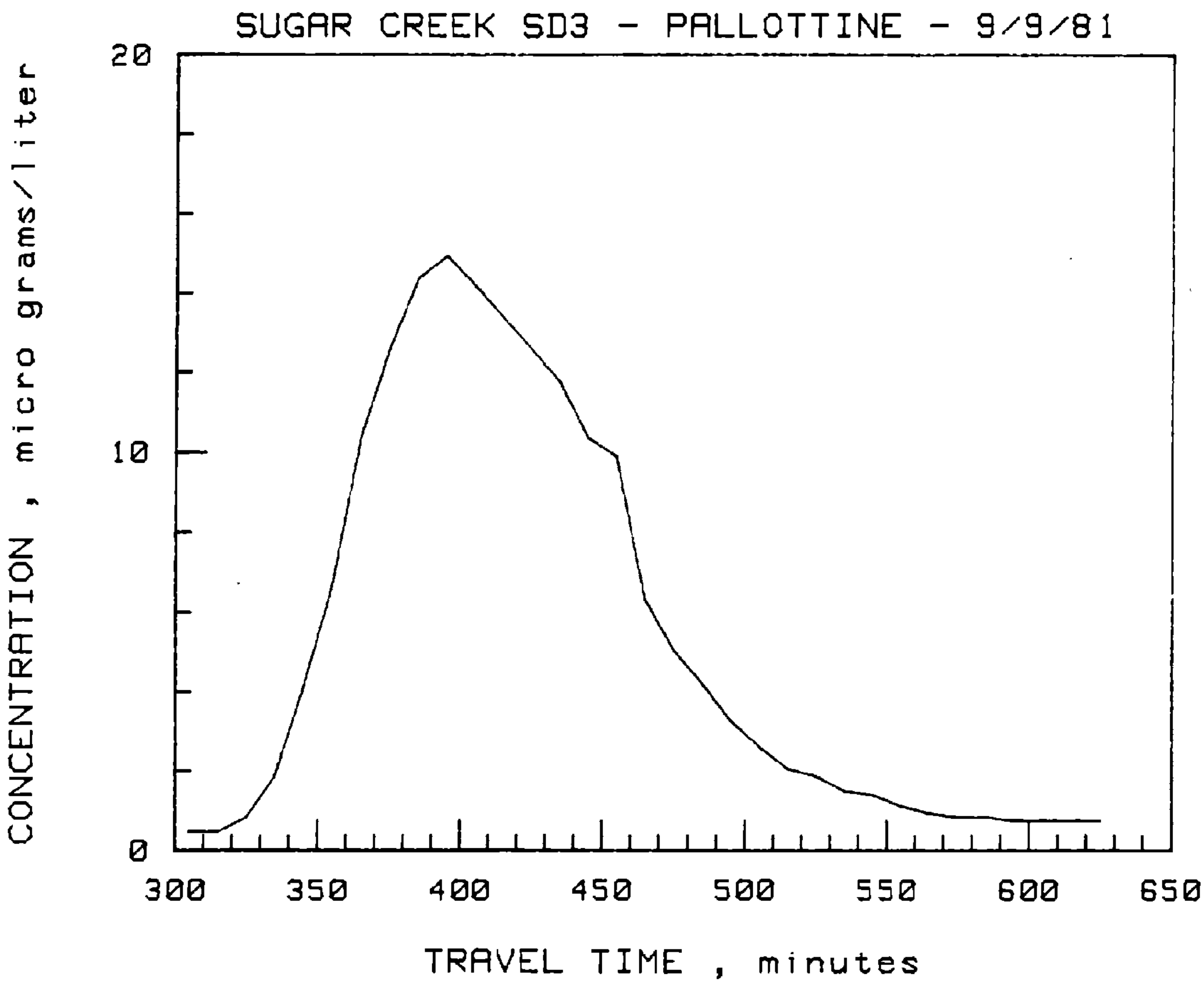


Figure 43. Dye concentration versus time for Sugar Creek station SD3.

Table 16. Ledger sheet for dispersion coefficient calculation [Location: Hodunk Road (SD2)].

(1) Interval number	(2) Time interval	(3) $\overline{C}$ µg/1	(4) t min	(5) t hr	(6) $\bar{c}\Delta t$ µg/1-hr	(7) $\bar{c}t\Delta t$ µg/1-hr^2	(8) $\bar{c}t^2\Delta t$ µg/1-hr^3
1	835- 855	0	10	.17	0.1	0.0	0.0
2	855- 905	0	25	.42	0.1	0.0	0.0
3	905- 915	0	35	.58	0.1	0.0	0.0
4	915- 925	0	45	.75	0.1	0.0	0.0
5	925- 935	0	55	.92	0.1	0.1	0.1
6	935- 945	0	65	1.08	0.1	0.1	0.1
7	945- 955	0	75	1.25	0.1	0.1	0.1
8	955-1005	1	85	1.42	0.1	0.2	0.2
9	1005-1015	14	95	1.58	2.4	3.7	5.9
10	1015-1025	29	105	1.75	4.9	8.6	15.0
11	1025-1035	35	115	1.92	5.8	11.2	21.5
12	1035-1045	37	125	2.08	6.2	12.9	26.9
13	1045-1055	26	135	2.25	4.4	9.8	22.0
14	1055-1105	15	145	2.42	2.5	6.1	14.8
15	1105-1115	9	155	2.58	1.5	3.9	10.0
16	1115-1125	7	165	2.75	1.1	3.1	8.5
17	1125-1135	5	175	2.92	0.8	2.3	6.8
18	1135-1145	3	185	3.08	0.6	1.8	5.5
19	1145-1155	2	195	3.25	0.4	1.3	4.1
20	1155-1215	2	210	3.50	0.6	2.0	6.9
21	1215-1230	1	228	3.79	0.3	1.1	4.0
22	1230-1245	1	243	4.04	0.2	0.8	3.4
23	1245-1300	1	258	4.29	0.2	0.8	3.4
24	1300-1315	1	273	4.54	0.2	0.8	3.9
25	1315-1330	1	288	4.79	0.2	0.8	3.8
26	1330-1345	1	303	5.04	0.2	0.8	4.2
27	1345-1400	1	318	5.29	0.1	0.7	3.9
28	1400-1415	1	333	5.54	0.1	0.8	4.3
Sums:		194			33.2	73.8	179.3

Area under the curve = 33.23 µg/l-hr = ΣColumn (6)

Location of centroid = 2.22 hr = $\dfrac{\Sigma\text{Column (7)}}{\Sigma\text{Column (6)}}$

Variance about start time axis = 5.39 hr^2 = $\dfrac{\Sigma\text{Column (8)}}{\Sigma\text{Column (6)}}$

Variance about centroid = 0.46 hr^2 = $\dfrac{\Sigma\text{Column (8)}}{\Sigma\text{Column (6)}} - \left(\dfrac{\Sigma\text{Column (7)}}{\Sigma\text{Column (6)}}\right)^2$

Table 17. Ledger sheet for dispersion coefficient calculation [Location: Pallottine Fathers (SD3)].

Interval number	Time interval	$\overline{C}$ µg/l	t min	t hr	$\overline{c}\Delta t$ µg/l-hr	$\overline{c}t\Delta t$ µg/l-hr^2	$\overline{c}t^2\Delta t$ µg/l-hr^3
1	1330-1340	0	300	5.00	0.1	0.4	1.9
2	1340-1350	0	310	5.17	0.1	0.4	2.1
3	1350-1400	1	320	5.33	0.1	0.7	4.0
4	1400-1410	2	330	5.50	0.3	1.7	9.4
5	1410-1420	4	340	5.67	0.7	3.9	22.0
6	1420-1430	7	350	5.83	1.1	6.4	37.6
7	1430-1440	10	360	6.00	1.7	10.4	62.2
8	1440-1450	13	370	6.17	2.1	13.0	79.9
9	1450-1500	14	380	6.33	2.4	15.2	96.1
10	1500-1510	12	390	6.50	2.5	16.2	105.2
11	1510-1520	10	400	6.67	2.4	15.8	105.1
12	1520-1550	10	420	7.00	5.9	41.2	288.2
13	1550-1600	6	440	7.33	1.7	12.7	92.9
14	1600-1610	5	450	7.50	1.6	12.4	92.8
15	1610-1620	4	460	7.67	1.1	8.1	62.2
16	1620-1630	3	470	7.83	0.8	6.6	51.6
17	1630-1640	3	480	8.00	0.7	5.6	44.8
18	1640-1650	2	490	8.17	0.5	4.4	36.3
19	1650-1700	2	500	8.33	0.4	3.6	30.3
20	1700-1710	1	510	8.50	0.3	2.9	24.7
21	1710-1720	1	520	8.67	0.3	2.7	23.4
22	1720-1730	1	530	8.83	0.2	2.2	19.4
23	1730-1740	1	540	9.00	0.2	2.1	18.9
24	1740-1750	1	550	9.17	0.2	1.7	15.7
25	1750-1800	1	560	9.33	0.2	1.5	13.6
26	1800-1810	1	570	9.50	0.1	1.3	12.6
27	1810-1820	1	580	9.67	0.1	1.4	13.1
28	1820-1830	1	590	9.83	0.1	1.2	12.0
29	1830-1840	1	600	10.00	0.1	1.2	12.4
30	1840-1850	1	610	10.17	0.1	1.3	12.9
31	1850-1900	1	620	10.33	0.1	1.3	13.3
Sums:		148			28.6	199.4	1416.7

Area under the curve = 28.57 µg/l-hr

Location of centroid = 6.98 hr

Variance about start time axis = 49.58 hr^2

Variance about centroid = 0.88 hr^2

$$\text{Dispersion coefficient, } D = \frac{1}{2}\left(\frac{V_1^2 \sigma_{t_1}^2}{\Delta t} - \frac{V_2^2 \sigma_{t_2}^2}{\Delta t}\right)$$

$$= \frac{1}{2} \; \frac{((0.51 \text{ fps})^2 (0.88 \text{ hr.}^2) - (0.38^2)(0.46 \text{ hr.}^2))\; 3600 \text{ sec/hr}}{4.76 \text{ hr}}$$

$$= 5.0 \text{ ft}^2/\text{sec } (0.46 \text{ m}^2/\text{sec}).$$

A simpler, graphical approach to predicting downstream attenuation of a given concentration of conservative substance due to longitudinal dispersion was described by Hubbard, et al. (45). Again, the results of dye studies are critical to the evaluation and the method assumes steady flow. First a log-log plot of travel time versus flow for each station is prepared. Then, also based on the results of the dye studies, a log-log plot of unit dye concentration x flow per mass of dye injected versus travel time of peak dye concentration for each station is prepared. Knowing the mass of conservative pollutant discharged and the flow rate at or near a given station, peak concentrations at downstream stations can be readily estimated.

BIOLOGICAL DATA EVALUATION

Qualitative Data

As previously defined, qualitative data result from samples collected in such manner that no estimate of numerical abundance or biomass can be calculated. The output consists of a list of taxa collected in the various habitats of the environment being studied. The numerous schemes advanced for the analysis of qualitative data may be grouped in two categories:

1. Indicator-organism scheme--For this technique, individual taxa are classified on the basis of their tolerance or intolerance to various levels of pollution. Taxa are classified according to their presence or absence in different environments as determined by field studies.

Beck (128) reduced data based on the presence or absence of indicator organisms to a simple numerical form for ease in presentation.

2. Reference station methods--Comparative or control station methods compare the qualitative characteristics of the fauna in clean water habitats with those of fauna in habitats subject to stress. Stations may be compared on the basis of richness of species or indicator organisms may be used.

If adequate background data are available to an experienced investigator, both of these techniques can prove quite useful--particularly for the purpose of demonstrating the effects of gross to moderate organic contamination on the macroinvertebrate community. To detect more subtle changes in the macroinvertebrate community, collect quantitative data on numbers or biomass of organisms. Data on the presence of tolerant and intolerant taxa and richness of species may be effectively summarized for evaluation and presentation by means of line graphs, bar graphs, pie diagrams, histograms, or pictoral diagrams.

The classification of representative macroinvertebrates according to their tolerance of organic wastes is presented by various authors. The pollutional classifications are arbitrarily placed in three categories--tolerant, facultative, and intolerant--defined as follows:

1. Tolerant: Organisms frequently associated with gross organic contamination and are generally capable of thriving under anaerobic conditions.

2. Facultative: Organisms having a wide range of tolerance and frequently are associated with moderate levels of organic contamination.

3. Intolerant: Organisms that are not found associated with even moderate levels of organic contaminants are generally intolerant of even moderate reductions in dissolved oxygen.

When evaluating qualitative data, the investigator should keep in mind the following pitfalls:

1. Since tolerant species may be found in both clean and degraded habitats, a simple record of their presence or absence is of no significance. Therefore, the indicator-organism technique can provide positive evidence of only one condition--clean water--and this only if taxa classified as intolerant are collected. An exception to this rule would occur where sensitive species may be totally absent because of the discharge of toxic substances or waste heat.

2. Because evaluations are based on the mere presence or absence of organisms, a single specimen has as much weight as a large population. Therefore, data for the original classification and from field studies may be biased by the drift of organisms into the study area.

3. The presence or absence of a particular taxa may depend more on characteristics of the environment, such as velocity and substrate, than on the level of degradation by organic wastes. This affects both the original placement of the taxa in the classificatory scheme and its presence in study samples.

4. The technique is totally subjective and quite dependent upon the skill and experience of the individual who makes the field collections. Therefore, results of one investigator are difficult to compare with those of another.

Quantitative Data

Reporting units--

Data from quantitative samples may be used to obtain:

1. Total standing crop of individuals, or biomass, or both per unit area or unit volume, and

2. Numbers or biomass, or both of individual taxa per unit area or unit volume or sample unit.

Data from quantitative samples may also be evaluated in the same manner as discussed for qualitative samples.

Standing crop and numbers of taxa in a community are highly sensitive to environmental perturbations resulting from the introduction of contaminants. These parameters, particularly standing crop, may vary considerably in unpolluted habitats, where they may range from the typically high standing crop of littoral zones of glacial lakes to the sparse fauna of torrential soft-water streams. Thus, it is important that comparisons are made only between truly comparable environments. Typical responses of standing crop or taxa to various types of stress are shown in Table 18 below.

Table 18. Organism response to various pollutional stresses.

Stress	Standing crop (numbers or biomass)	Number of Taxa
Toxic substance	Reduce	Reduce
Severe temperature alterations	Variable	Reduce
Silt	Reduce	Reduce
Inorganic nutrients	Increase	Variable--often no detectable change
Organic nutrients (high O_2 demand)	Increase	Reduce
Sludge deposits (non-toxic)	Increase	Reduce

Organic nutrients and sludge deposits are frequently associated. The responses shown are by no means simple or fixed and may vary depending on a number of factors including:

1. A combination of stresses acting together or in opposition,

2. Indirect effects, such as for example the destruction of highly productive vegetative substrate by temperature alterations, sludge deposits, turbidity, chemical weed control,

3. The physical characteristics of the stressed environment, particularly in relation to substrate and current velocity.

Data on standing crop and numbers of taxa may be presented in simple tabular form or pictorially with bar and line graphs, pie diagrams, and histograms. Whatever the method of presentation, the number of replicates and the sampling variability must be shown in the tables or graphs. Sampling variability may be shown as a range of values or as a calculated standard deviation, as discussed in the Statistical Analyses portion of this section.

Data on standing crop and number of taxa are amenable to simple but powerful statistical techniques of evaluation. Under grossly stressed situations, such analyses may be unnecessary; however, in some cases, the effects of environmental perturbations may be so subtle in comparison with sampling variation that statistical comparisons are a helpful and necessary tool for the evaluation process. For this purpose, biologists engaged in studies of macroinvertebrates should familiarize themselves with the simple statistical tools.

Diversity indices are an additional tool for measuring the quality of the environment and the effect of induced stress on the structure of a community of macroinvertebrates. Their use is based on the generally observed phenomenon that relatively undisturbed environments support communities having large numbers of species with no individual species present in overwhelming abundance. If the species in such a community are ranked on the basis of their numerical abundance, there will be relatively few species with large numbers of individuals and large numbers of species represented by only a few individuals. Many forms of stress tend to reduce diversity by making the environment unsuitable for some species or by giving other species a competitive advantage.

The investigator must be aware that there are naturally occurring extreme environments in which the diversity of macroinvertebrate communities may be low, as for example the profundal fauna of a deep lake or the black fly-dominated communities of the high gradient, bed rock section of a torrential stream. Furthermore, because colonization is by chance, diversity may be highly variable in a successional community; for this reason, diversity indices calculated from the fauna of artificial substrate samplers must be evaluated with caution. These confounding factors can be reduced by comparing diversity in similar habitats and by exposing artificial substrate samplers long enough for a relatively stable, climax community to develop.

For purposes of uniformity, the Shannon-Weaver function is recommended for calculating mean diversity d. The machine formula presented Lloyd, Zar and Karr (129) is:

$$d = C\ (N \log_{10} N - n_i \log_{10} n_i)$$

where C = 3.321928 (converts base 10 log to base 2 bits]); N = total number of individuals; and n_i = total number of individuals in the ith species.

SUMMARY OF DATA EVALUATION PROCEDURES

Section 6 of this manual was intended to provide the user with information on how to handle, interpret and utilize the data which were collected during the field monitoring program. Data analysis procedures which were described include:

1. Automated data handling systems,
2. Water budget determinations,
3. Common methods of statistical analysis,
4. Use of predictive models to supplement the field data, and
5. Methods of evaluation for biological data.

If the field monitoring program was extensive, including the collection of continuous data such as streamflow, air or water temperature, conductivity, etc., it will be necessary to use automated data handling systems. Major components of automated systems include the design of the data base, computer hardware and appropriate software. If a more simplified field monitoring program was utilized, such as intermittent sampling surveys with no continuous data collection, then obviously a more simplified data handling system will suffice. Detailed water budget calculations will not be a part of such simplified programs, but the results will still require some rudimentary statistical analysis (e.g., mean, range, regression, etc.). The use of predictive models to supplement the field data will probably be more important for simplified field programs. The limited event data can be used to calibrate or verify the predictive model, which would subsequently be used to extrapolate the findings from limited sampling programs for a more comprehensive analysis of potential impact.

INTEGRATION OF THE FIELD MONITORING DATA INTO THE ENVIRONMENTAL DOCUMENTS

As described in the INTRODUCTION, the field monitoring program was probably undertaken to provide either general or specific observations on water quality impact for the environmental documents (Environment Assessment or EIS). If a detailed and comprehensive field monitoring program, analogous to those described in Volume II of this report, was conducted to provide generalized information on impacts, it will not be appropriate to include the entire scope of results into the environmental documents. As stated in CEQ's

NEPA regulations (130) and subsequent FHWA NEPA guidance material (131), the intent of NEPA is "better decisions and not more documentation". The EIS should be no more than 150 pages (EA's considerably shorter, of course). Therefore, the results of comprehensive field monitoring programs should be condensed into a short executive summary format for integration into the EIS or EA. A full report should be prepared, but only referenced in the main EIS volume. The results of more simplified field monitoring programs can be more easily incorporated directly into the EIS or EA.

In order for the field study results to be used in the environmental document, the data must be considered in a manner consistent with the regulatory framework of the project area. The definition of "impact" is contingent upon the type and size of the receiving water, its designated use (e.g., drinking water, fish and wildlife propogation, shellfish water, irrigation, etc.), State standards for water quality, and mitigation practice effectiveness. Volume IV of this report provides the HA with a description of this regulatory framework and procedures for making the assessment of impact from runoff from operating highways. The field study when performed, provides one of the major components of the assessment procedure.

SECTION 7
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SECTION 8
GLOSSARY OF TERMS

Acute - Lethal, short term effect.

Algae - Any number of simple plants of the Monera and Protista possessing chlorophyll.

Backwater* - Water backed up or retarded in its course as or compared with its normal or natural condition of flow.

Bedload* - Sediment moving by sliding, rolling or skipping on or very near the streambed.

Benthic macroinvertebrate - Bottom dwelling organism large enough to be retained by U.S. No. 30 sieve.

Bioassay* - A method of determining toxic effects of wastes by using viable organisms or live fish as test organisms.

Bulk precipitation - The combination of dry and wet (precipitation related) atmospheric deposition on land surfaces over a given duration of collector bucket exposure.

Caddisflies - Common name of an insect in the group Trichoptera.

Canopy - Overhanging tree foliage which shades streams and rivers.

Carrier pollutant - That pollutant exhibiting the highest degree of association with all other pollutants; usually total or suspended solids.

Chronic - Long term, sublethal effect.

Composite sample - A sample which represents a flow-weighted average; either obtained with a flow-proportional automatic sampler or mixed by hand from discrete samples.

Deterministic model - A mathematical model based on theoretically-derived conceptually accurate equations.

Diptera - An order of insects including flies and midges.

Drift organisms - Those organisms which have entered the water column of a stream.

Dustfall - Combined accumulation of both dry and wet weather atmospheric deposition of particulate matter.

Dynamic model - A model (usually deterministic) which does not incorporate assumptions of steady-state conditions.

Epilimnion - The upper layer in thermally stratified lakes or reservoirs which is subject to wind induced mixing.

Estuary - A coastal riverine system characterized by both tidal and salinity interactions.

Euphotic zone - The lake zone in which photosynthesis exceeds respiration.

Evapotranspiration* - Water withdrawn from a land area by evaporation from water surfaces and moist soil and plant transpiration.

Fauna* - The collective term for all types of animals within a given area or period.

Flume - A primary flow measurement device; most commonly used are Palmer-Bowlus and Parshall flumes.

Gage height* - Water-surface elevation referred to some arbitrary gage datum.

Grab sample - A sample taken at a discrete time and location; usually obtained by hand.

Hydrograph* - A graph showing stage, flow, velocity or other property of water with respect to time.

Hydrographic map - A map of a lake, wetland, reservoir, bay, sound or ocean which shows lines of equal bottom depth.

Hyetograph - A plot of rainfall intensity (in/hr) versus time.

Hypolimnion - The lower layer in a thermally stratified lake or reservoir which is relatively stagnant and isolated from the surface layer.

Lentic* - Refers to standing water sives; for example lakes, ponds, swamps.

Littoral - Of, or pertaining to, a shore. Usually the nearshore region of a lake or sea where light penetrates the water to the bottom and rooted plants occur.

Longitudinal dispersion - Downstream attenuation of conservative pollutant concentration due to lateral velocity irregularities, especially for sinuous streams and rivers.

Lotic* - Refers to running water sives; for example streams and rivers.

Macrobenthos - Another term for benthic macroinvertebrates.

Mayflies - Common name of an insect in the group Ephem eroptera.

Metalimnion - The layer in a thermally stratified lake between the epilimnion and hypolimnion, where temperature decreases rapidly with depth; also called the thermocline.

GLOSSARY OF TERMS (continued)

Midges - Common name of an insect in the group Chironomidae.

Morphology - Structural features of organisms, watershed, receiving water, etc.

Nonpoint source pollution - Pollution which cannot be traced to a single discrete source; stormwater runoff from both agricultural and urban land areas are the most prevalent forms.

Periphyton* - The assemblage of a wide variety of organisms that grown on underwater substrates such as rocks, plant stems and includes but is not limited to, bacteria, yeasts, molds, algae and protozoa.

Plankton* - Organisms suspended in a body of water and because of their physical character or size are incapable of sustained mobility in directions counter to water currents. Plankton consist of plants (phytoplankton) and animals (zooplankton).

Point source pollution - Pollution which can be traced to a single, discrete source such as effluent pipie from municipal wastewater treatment plant or industry.

Pool zone - Deeper, slower moving sections of streams and rivers.

Profundal - The deepest portion of a lake.

Raw precipitation - Rain water, sample collected and analyzed immediately after the event.

Respirometer - A chamber, or vial, of known volume in which oxygen consumption (uptake) is measured either volumetrically or by direct chemical or polarographic measurement.

Riffle zone - Shallow, fast moving sections of streams or rivers where stones, rocks or gravel provide effective habitat for benthic invertebrates, especially insects.

Runoff* - That part of precipitation which appears in surface streams.

Sediment oxygen demand (SOD) - Oxygen uptake by bottom sediments as measured by insitu or laboratory respirometers.

Seiche - Periodic upwelling and downwelling of lakes due to wind, tide or Coriolis (earth's rotation) forces.

Site - For the purposes of this report, a site is defined as the totality of the affected receiving water, direct tributary drainage area, and highway right-of-way contributing runoff to the receiving water.

Sludge-worm - An aquatic earthworm in the group Tubificidae.

Stage* - The height of a water surface above an established datum plane.

Station - A specific sampling location within a site.

Stilling well - An enclosure used to dampen random wave action and provide a stable measurement environment for stream or lake stage recording.

Stochastic model - A mathematical model based entirely on statistically drived relationships rather than theoretical accuracy.

Stonefly - Common name of an insect in the group Plecopter.

Substrate* - The base or material upon which an organism lives.

Suspended sediment* - The very fine soil particles that remain in suspension in water for a considerable period of time without contact with the solid-fluid boundary at or near the bottom. They are maintained in suspension by upward components of turbulent currents or may be fine enough to form a colloidal suspension.

Synoptic survey - A water sampling method for streams or rivers which attempts to sample the same "slug" or mass of water as it moves downstream; requires prior knowledge of travel times between sampling stations.

Thermocline - See Metalimnion.

Total atmospheric deposition - Same as dustfall.

Transect line - A sampling line across lake stream, or river designed to characterize the spatial or plume nature of pollutant dispersion in a receiving water.

Travel-time* - The time required for water flowing in a stream to travel from a given point to some other downstream point.

Vascular plants - Higher plants characterized by a continuous system of vessels for conveyance of fluids (sap).

Watershed* - The area contained within a divide above a specified point on a stream.

Weir - A primary flow measurement device; common types are V-notch, rectangular, broad-crested, etc.

Wet/Dry Collector - A device which automatically segregates wet and dry atmospheric deposition of particulates; a sensor detects rainfall and transfers a cover from the wet to dry bucket.

GLOSSARY OF TERMS (continued)

Yield - Total water volume discharged at a given point of a stream or river over a specified time period; e.g. - annual yield.

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*These definitions are from Kerri, K.D., et al., "Water Quality Manual, Volume IV: Glossary of Terms for Water Quality Studies", U.S. Dept. of Transportation (FHWA) Implementation Package 77-1, October, 1976.

All other definitions were provided by the authors.