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Technical Manual for the Measurement and Modeling of Non-point Sources at an Industrial Site on a River

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Technical Manual for the Measurement and Modeling of Non-point Sources at an Industrial Site on a River

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1.0 OBJECTIVE

This Technical Manual presents a guide to planning a measurement and modeling program for non-point sources of water pollution from an industrial site. The emphasis of the manual is on stormwater runoff and the impact of the runoff on stream water quality.

The manual describes the criteria for designing a measurement program, including factors to be considered in sampling site selection and options for sampling methodology. The planning to be done includes: 1) the choice of pollutant parameters for analysis, 2) the determination of sampling frequency, 3) analysis of alternative techniques of sample collection, and 4) the selection of flow measurement methodology. In addition, sample analysis and data analysis procedures must be considered.

The resulting measurement program is designed to be compatible for use with a mathematical model. A model, with a minimum amount of measured field data as input, can be used to predict the quantity and quality of runoff and its impact on a river for a wide variety of storm, site, and river conditions. This manual includes a guide to the application of one model especially adapted for stormwater runoff.

Data is also presented to assist in the development of estimates for manpower and time requirements, field equipment costs, and for computer time.

An example of the possible application of a plan for the measurement and modeling of stormwater runoff from a coal-fired utility plant is presented in Section 6.

2.0 INTRODUCTION

A precise definition of non-point source water pollution does not exist; however, for the purpose of this manual the following definition applies:

> Non-point source water pollution is the accumulated pollutants in a receiving body of water from runoff due to snow melt and rain, seepage and percolation, and chemical spills and leaks, contributing to the degradation of the quality of surface waters and groundwaters.

Non-point source water pollution can have a major influence on water quality. Thus, identifying non-point source pollution and its impact on natural water bodies is of significant concern to those developing water management plans to maintain and improve water quality.

To date, non-point source water pollution has been studied in some detail for urban and agricultural environments. However, little attention has been paid to industrial stormwater runoff.

As Section 208 Areawide Waste Treatment Management Plans are enacted by regional agencies on a nationwide scale, more emphasis can be expected on non-point source controls in both the municipal and industrial sectors. Also, with increasing enactment of Best Practicable Treatment (BPT) for point sources, more stress will be placed on BPT for non-point sources in those areas where water quality still falls short of attainment goals.

In addition, more regulations may be forthcoming on the quality of stormwater outfall discharges and subsequent controls may be required.

For these reasons, more concern is being directed toward runoff from industrial non-point sources. Sources with the highest potential for contaminating runoff are generally material storage piles and fallout from fugitive and point source air emissions which accumulate on impervious surfaces.

This manual will assist the facilities engineer and agency water quality planner to develop the framework of a program to assess the impact of stormwater runoff on stream water quality. This manual discusses the approach to the measurement and modeling of stormwater runoff from most industrial sites. The discussion of measurement and modeling of the impact on receiving waters, however, is limited to rivers, the most likely industrial receiving body.

This manual is the second volume in a set concerning the evaluation of non-point pollution sources from industry. The first volume[1] is a technical report of sampling and modeling of non-point sources at coal-fired utilities. The measurement and modeling guidelines described in this manual were developed in conjunction with the program described in the first volume.

3.0 DEVELOPMENT OF A FIELD SURVEY PROGRAM

The field survey procedures chosen for a runoff sampling program are specific both to the industry and to the site. The following considerations are important for the development of a plan for such a runoff survey.

1. Purpose of Sampling Program. What is the reason for the sampling program? What is the intended use of the results?

2. Resource Availability. What resources in terms of manpower, equipment and money are available to perform the sampling program? Are they adequate to fulfill the objectives of the program?

3. Site Location. What are the flow and mixing characteristics of the river likely to be? Is flow in the river regulated by a dam? Is there the likelihood of a suitable amount of rainfall during the sampling period? Can plant discharges and runoff be isolated from other discharges, tributaries, etc.?

4. Runoff Sources and Characteristics. What are the likely sources of runoff (i.e., material piles, from fugitive dust on parking lots and roads, from material-loading/unloading areas, etc.)? What types and quantities of materials are likely to run off? What are the physical properties of the material subject to run-off? How are the runoff sources located with respect to drainage patterns, storm sewers, etc.? How large an area is drained? Is there evidence of runoff patterns? How is runoff disposed of? How can it be quantified? Are local topography and drainage systems amenable to interception?

5. Parameters to be Analyzed. Is there a river flow recording station nearby? What is the river water quality? What chemical compounds are specific to the runoff material? What pollutants are important to the program objective?

Each of these elements must be addressed in the development of specific test plans for the sampling program. A site visit and discussions with plant personnel are usually adequate to answer many of these questions and to develop the test plan. Some preliminary samples may be necessary to fill gaps in available information.

3.1 Selection of Sampling Sites

One of the principal objectives of the initial on-site visit is to gather enough information to select the runoff and river sampling locations.

3.1.1 Runoff Sampling Sites

From a visual survey of the industrial site and site maps, the possible significant sources of runoff are determined. These may include piles of raw materials such as coal and wood, waste material disposal piles such as bark, and areas of significant accumulated dirt and dustfall.

The path of surface water flow from these sources to a stream is defined by the drainage basins of the site. The drainage basins can be determined in a variety of ways. Contours from existing topographic maps of the site can be used to define the drainage area. If these maps are not available or if there is uncertainty as to the size and shape of a basin, visual observations of drainage patterns should be made during one or more storm events and during dry conditions. Many plants have storm sewer systems which can be located through the use of sewer system drawings. These sewer systems can also be used to divide the plant into basins. A more accurate but more costly method of determining drainage basins is to perform a topographic survey of the site.

Figure 3-1 shows a plant site which has been divided into drainage basins through visual observation and storm sewer network maps. The four drainage basins are numbered 1 through 4. Basin 1 discharges to the river via overland flow at discharge point No. 1. Basins 2, 3 and 4 discharge to the river via a storm sewer system at discharge point No. 2.

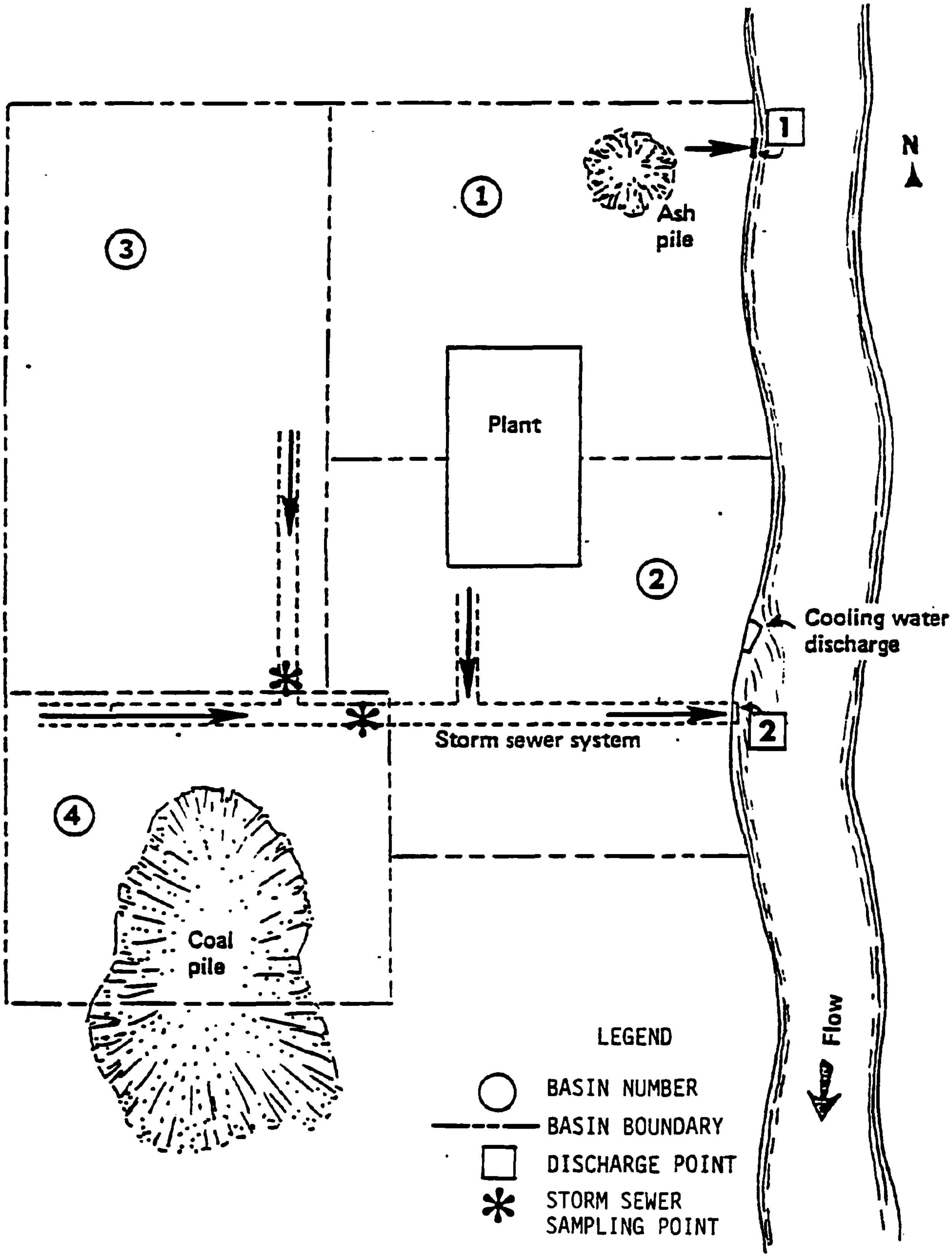

Figure 3-1: Site divided into drainage basins.

To isolate the runoff from these drainage basins, stormwater runoff should be intercepted as close to the source as possible. For example, in Figure 3-1, sampling should occur in the storm sewer as close as possible to the location where Basin 3 drains into Basin 4 and the combined drainage from Basins 3 and 4 discharge into Basin 2. These locations are marked with asterisks in Figure 3-1. Sampling must also be performed at all major discharges to the river to get a total quantity of runoff to the receiving water. In Figure 3-1, points Nos. 1 and 2 indicate the discharge locations of Basin 1 and Basins 2-4, respectively.

The access to the sampling sites of both manpower and equipment must also be considered. Related considerations for storm sewers include: 1) Location of the manholes; 2) for accurate flow measurement, the change of slope of the sewer lines influent to and exiting from the manhole; 3) possible drop manholes; 4) possible bends in the manhole channels; and 5) effect changes in river depth and flow rate after heavy rains will have on storm sewer outfall access.

3.1.2 River Sampling Sites

Once the drainage basins and the runoff sampling points have been defined, river sampling stations can be selected upstream and downstream of the basin discharges from the plant. Several factors must be considered to assure that these sites produce representative river samples. For example, river mixing patterns relative to the discharge points and runoff areas must be adequately defined. All stations must be positioned at locations which are well-mixed; i.e., having uniform chemical and physical properties.

The upstream sampling station should be located above any influence from the discharges of the plant site in a well-mixed reach to obtain samples truly representative of background pollutant levels in the stream.

The downstream station should be placed at a location where the runoff plume (portion of river influenced by runoff) has fully dispersed across the river to ensure that the samples collected are representative of time average pollutant loadings. To determine discharge plume dispersion, various tests can supplement visual observation. These include tracking floating tags and fluorometry which measures optically the concentration of fluorescent dyes in waterways.

For both upstream and downstream sampling sites, consideration must also be given to the effect of heavy rain on the runoff plume flow rate and consequently on the plume dispersion behavior. Also the sampling equipment must be sited well above the expected high water level caused by heavy rainfall.

One sampling location upstream and one downstream will usually provide sufficient data, although increasing the number of sampling stations to two or three per location will insure more representative sampling in situations where less than ideal conditions exist such as rivers with poor mixing or wide, deep rivers which have a low velocity. Any point discharges (such as the cooling water discharge shown in Figure 3-1), tributaries, etc., between the upstream and downstream sites must also be sampled to account for their effects on the river.

During dry conditions the upstream and downstream data should be approximately the same, excluding any point source discharges. (If there are major point source effluents, these should be reflected in the downstream data.) If unaccountable major differences in data exist, the downstream and possibly the upstream station(s) should be moved until agreement is attained.

3.2 Sampling Methodology

3.2.1 Selection of Parameters to be Measured

Table 3-1 shows a list of typical parameters associated with non-point sources. The objectives of the field survey may allow deletion of some constituents or require the addition of others. The water quality of the receiving body, the likelihood of detecting the various contaminants in the river, and the type of source being analyzed will affect the choice of parameters. For example, coal pile runoff dictates different parameters than agricultural runoff. Contaminants previously present in high concentrations in the receiving body may mask similar contaminants discharged in the runoff.

Sample preservation and analysis requirements may also affect the choice of parameters to be studied. Table 3-2 shows the minimum sample volume, method of sample preservation, and recommended maximum storage time requirements for commonly-sampled pollutants. Review of these recommended storage times indicates that parameters such as BOD, phosphate, kjeldahl nitrogen, ammonia, phenol, cyanide, and TOC, which require rapid analyses, should be determined in a field laboratory or immediately shipped to a nearby home laboratory. On the other hand, metals samples can be acidified and stored for analysis at the end of the sampling program. In addition,

TABLE 3-1

PARAMETERS COMMONLY MONITORED IN WATER NON-POINT SOURCE PROGRAMS

1. Solids

   Total Suspended
   Total Dissolved
   Turbidity

2. Organic Materials

   Oil & Grease
   Total Organic Carbon (TOC)
   Biochemical Oxygen Demand (BOD)
   Chemical Oxygen Demand (COD)
   Dissolved Oxygen (DO)

3. Metals

   Iron
   Cadmium
   Copper
   Manganese
   Lead

4. Nutrients

   Phosphate (Ortho, total)
   Total Kjeldahl Nitrogen (TKN)
   Ammonia Nitrogen
   Nitrate-Nitrite

5. Others

   Sulfate
   Cyanide
   pH
   Phenol

TABLE 3-2[2]

MINIMUM VOLUME, PRESERVATION AND MAXIMUM STORAGE TIME OF SAMPLES FOR COMMON POLLUTANTS

Pollutant	Minimum Volume (mℓ)	Sample Preservation	Maximum Storage Period
Total Suspended Solids	100	Cool, 4°C	7 Days
Total Dissolved Solids	100	Cool, 4°C	7 Days
Turbidity	100	Cool, 4°C	7 Days
Oil & Grease	1000	Cool, 4°C H_2SO_4 to pH<2	24 Hrs in glass container only
Total Organic Carbon	25	Cool, 4°C H_2SO_4 to pH<2	24 Hrs
Biochemical Oxygen Demand	1000	Cool, 4°C	6 Hrs
Chemical Oxygen Demand	50	H_2SO_4 to pH<2	7 Days
Metals	100	HNO_3 to pH<2	6 Mos
Phosphate	50	Cool, 4°C	24 Hrs
Kjeldahl Nitrogen	500	Cool, 4°C H_2SO_4 to pH<2	24 Hrs
Ammonia	400	Cool, 4°C H_2SO_4 to pH<2	24 Hrs
Sulfate	50	Cool, 4°C	7 Days
Cyanide	500	Cool, 4°C NaOH to pH 12	24 Hrs
pH	25	Cool, 4°C	6 Hrs
Dissolved Oxygen (Winkler)	300	-	No Holding, glass only
Dissolved Oxygen (Probe)	300	-	No Holding, glass only
Phenol	500	Cool, 4°C H_3PO_4 to pH<4 1.0g$CuSO_4$/ℓ	24 Hrs, glass only

as a screening process, some laboratories only analyze for oil and grease on samples with a visible oil sheen or floating grease matter. This procedure thus reduces the number of samples to be transported for analysis. Reference should be made to Methods for Chemical Analysis of Water and Wastes (EPA-625-/6-74-003) and to Standard Methods for the Analysis of Water and Wastewater, 14th ed., 1975, APHA-AWWA-WPCF, for specific details concerning preservation and storage times.

Some parameters such as pH, turbidity, and dissolved oxygen can be measured using continuously recording monitors. Measuring these parameters continuously can reduce the load on the analytical laboratory and provide a real time indication of changes in water quality. For example, during dry weather, these parameters (pH, etc.) should be very similar upstream and downstream in the river when point source dry weather flows are subtracted from the downstream data. If they are not similar, it is highly probable that the sites are located in non-representative sections of the river and should be moved, if possible, and re-sampled.

It should also be noted that frequent (weekly during sampling) calibration of dissolved oxygen and pH probes is advisable for accurate readings. In addition, dissolved oxygen values determined using a DO probe can be compared to dissolved oxygen values determined by the Winkler Method (Section 218, Standard Methods) from random samples fixed on-site.

3.2.2 Number and Frequency of Samples

Timing of sample collection is one of the problems associated with sampling runoff. Because runoff is diffuse and it is usually not feasible to collect all of it, total quantification must be estimated from a limited number of samples. Even if it were possible to collect all runoff from a particular basin as it discharges to the river, the data generated from summing all the basins in a test area could still have significant errors. These errors could be caused by some of the basin runoff draining to or from an adjoining basin outside the test area. The measured data would not, therefore, quantify and qualify the runoff generated by the test area. Instead, many factors are used in the timing of sampling periods and the number and frequency of samples within those periods and fewer samples need to be collected and analyzed in dry weather than in wet weather. River conditions are more stable in dry weather than they are during and after a rainfall event when short-term and dynamic changes in pollutant values occur in the river. It is important to initiate sampling at the first instance of rainfall and then take samples often because a large quantity of materials may wash off the surface almost immediately, especially in paved areas. This effect is called "first flush." For longer-duration storms, the sampling rate can be reduced.

The number of samples deemed adequate is also dependent upon the program objective and the available resources. A data base constructed from many samples can allow greater confidence in deriving conclusions from the program and in calibrating the model. Cost savings can be obtained by analyzing fewer than the total number of collected samples (e.g., analyze every third or fourth sample initially). If the reduced number of analyses show a trend, then additional analyses can be performed on selected samples to fill in the missing data. If no trend is indicated, additional analyses are not cost-effective.

A determination of sampling frequency can be made by the relationship between variation in runoff character and the acceptable error in the average result. It can be assumed that the greater the variability, the greater the number of samples that must be integrated to yield a composite sample with a reasonable value.

For example, the SSWMM-RECEIV-II model divides a storm into rainfall intervals, with the intensity of the rainfall and the length of the interval as input data. How many discrete samples must be integrated in that interval period to obtain an average sample that will vary no more than 5 lb/day suspended solids from the true average based on 95% confidence limits? From previous sampling and analysis, 10 samples taken over the interval show a standard deviation of 10 lb/day suspended solids.

The Student 't' distribution can be utilized to estimate n, the number of samples. This relationship is defined as:

$$n = \frac{t^2 s^2}{d^2} \qquad (3\text{-}1)$$

where:

s is the sample standard distribution,

d is allowable margin of error,

t is the percentile of the 't' distribution at ν degrees of freedom and $(1-\alpha)$ confidence limits.

In this case,

$s = 10$ lb/day

$d = 5$ lb/day

$t = t_{1-\alpha/.2} = t_{.975} = 2.262$

$\nu = (10-1)$ degrees of freedom $= 9$

$$n = \frac{(2.262)^2\ (10)^2}{(5)^2} = 20.46$$

Approximately 21 discrete samples should be integrated over the designated rainfall interval so that the value of suspended solids in the composite will vary no more than ±5 lb/day with 95% confidence limits.

However, it should be noted that this methodology can be used only for estimation purposes, as the value of the sample standard deviation, determined by preliminary sampling, is based on factors not necessarily reproducible in each storm. For example, the number of dry days between storms will affect the dust and dirt accumulation and the subsequent variability of the runoff samples. Wide variations in storm intensity and duration can also affect sample variability.

Sampling frequency methods must be taken into account so that project objectives are not compromised by too few samples or analyses.

3.2.3 Sample Collection Methods

3.2.3.1 Overland Runoff

Where runoff from an industrial site follows a storm sewer or natural or earth channel, open channel methods of sample collection can be utilized. However, where runoff is likely to follow a poorly-defined path overland, plug collectors can be placed in the ground to trap water flowing over them. These plugs (see Figure 3-2) should have a screen cover to prevent "pushalong" solids from collecting in them. Plug collectors can be used with a system of dikes and berms to channel flow in an impervious area to a discharge point where the flow can then be sampled.

3.2.3.2 Open Channel Flow

Runoff and river samples in sewers and channels are collected with manual and automatic samplers. The sampling equipment is selected based on the parameters chosen, the number and frequency of samples to be taken, and location of the sampling stations.

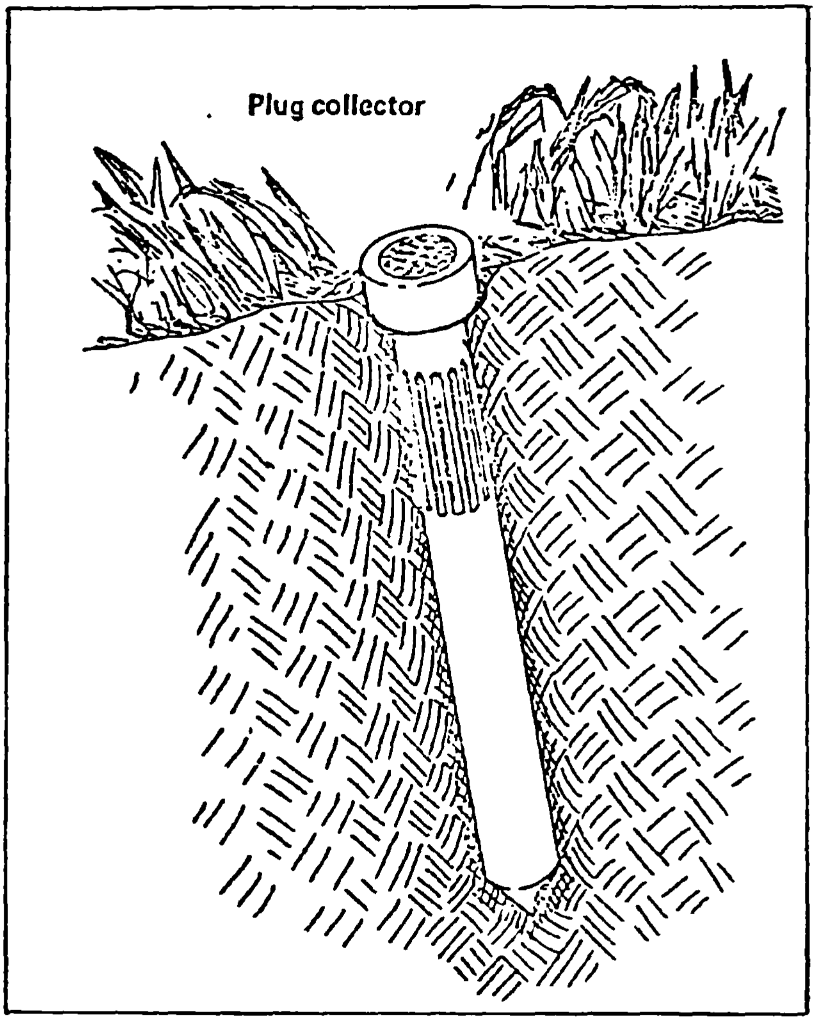

Figure 3-2: Plug Collector

3.2.3.2.1 Manual Samplers

Manual sampling of runoff and rivers is best suited to those areas where a small drainage area must be surveyed or where significant manpower resources are readily available during storm activity. Manual sampling should not be considered if the manpower available is less than one person/sampling site. A "honey dipper" or bucket-type container with a rod or rope is one of the oldest types of manual samplers. It is used to obtain grab samples from shallow runoff channels or storm sewers.

In addition, samplers have been developed to take dissolved oxygen (DO) and BOD samples without significant sample aeration. A BOD bottle(s) is placed in a bucket-type device and lowered into the stream flow. Water enters the inlet and flows through a tube to the bottom of the BOD bottle. When the chamber and bottle are full, the device is raised and the bottle is removed for BOD and/or DO analysis.[3] These samplers are not suited to shallow areas.

Similarly, Van Dorn bottles are manual samplers for deep channel areas. These samplers consist of an open-ended cylinder which is lowered into the stream. When there is a representative sample within the cylinder, a triggering mechanism is activated to seal the chamber.

3.2.3.2.2 Automatic Samplers

Automatic samplers have advanced in reliability and sophistication in recent years. These samplers, which are manufactured by a number of firms, are either the scoop type or the pumping type. A majority of present-day samplers are pumping systems.

Scoop samplers utilize a ladle-type dipper activated by a time clock or electrical impulse. Periodically, at a prescribed interval, the scoop is lowered into the runoff stream and a sample is extracted and emptied into a composite receiver.

Scoop type samples operate best in sewers and shallow manholes and are not suited for river sampling.

Automatic samplers utilizing pumps are suited to both runoff and river sampling, as the sampling hose can be extended to sites in channels, manholes, sewers and mid-stream, while the main unit with the pump and sample bottles remains in an accessible location.

Automatic samplers have several advantages in runoff sampling:

1. Automatic samplers can assure that the beginning of the storm is not missed. Rising water level in the channel can activate a mercury switch on the sampler and the sample pump automatically starts. In this manner the "first flush" of the storm where the highest pollutant loads can occur is accurately measured.

2. Sequential samplers containing many small bottles can take integrated samples (composite of individual samples with time) at predetermined intervals within each bottle and still offer the discrete-sample advantage of separate bottles. In this manner, individual samples can be taken of the "first flush" of the storm while composite samples can be generated for the latter portions of the storm event as runoff and loadings decrease.

3. Most automatic samplers can be coupled with compatible flow measurement equipment to generate flow proportional samples.

4. Refrigerator containers in the samplers are available to maintain sample integrity for many parameters,[4] although they may not be necessary for short storm events.

Table 3-3 presents a comparison of manual and automatic sampling techniques

TABLE 3-3

COMPARISON OF MANUAL AND AUTOMATIC SAMPLING

Manual	Automatic
1. Manpower requirement is quite large; therefore, manual sampling is an advantage only when sampling small drainage areas.	1. Manpower requirement is minimal; only maintenance and removal of samples require manpower.
2. Sample collection equipment expenditures are not excessive. Simple submersible pumps and/ or weighted water samplers will suffice.	2. Sample collection equipment becomes a capital expenditure because it is automated and must be sheltered from weather and vandalism and often must be specially designed.
3. Field measurements can be made by individual or combined meters.	3. Field measurements can be made by meters used in conjunction with the automatic collection system, or they may be designed into the system.
4. The beginning of the storm event can be missed if mobilization of manpower is not immediate.	4. Since automatic collectors can be activated by precipitation or an increase in flow or water level, the initial influence of the storm will not be missed.
5. Samples will be non-representative if untrained collectors are used.	5. Samples will be lost or non-representative only if equipment malfunctions or power source is interrupted or depleted.
6. If samples need to be collected at close time intervals, extensive manpower may be required at each station or the intervals may be missed altogether.	6. Automatic samplers make collection easier at close time intervals.

3.2.4 Type of Sample

In a runoff sampling program both discrete and composite samples can be generated. Individual discrete samples require more resources and time for analysis but better reflect rapid changes in water quality and "slugs" of pollutants. Composite samples are suited for river sampling upstream of the runoff sampling site and downstream of the site when waste characteristics do not vary significantly over the sample interval.

Samples for parameters such as bacteria counts, dissolved oxygen, chlorine, and sulfide need to be analyzed quickly and are, therefore, best taken as grab samples. Sampling programs with an emphasis on oil and grease should utilize a sampling technique which requires no transfer of the sample to another container, i.e., requires discrete samples.

Most runoff sampling programs will require a combination of discrete and composite samples. Discrete samples will be generated by automatic samplers with some of the discrete samples integrated to reflect steady state conditions in the runoff and river during that interval. For example, samples of runoff remaining after the main storm event can easily be combined into a composite sample. Discrete or "grab" samples are then taken for parameters such as fecal and total coliform, dissolved oxygen, temperature, and pH.

Acceptable storage containers for the pollutants being sampled should be used. Specific parameters such as phenols, oil and grease, and dissolved oxygen must be collected in glass bottles. Reference should be made to Methods for Chemical Analysis of Water and Wastes and Standard Methods for Examination of Water and Wastewater.

3.2.5 Measurement of Runoff and River Flow

A weir or flume installed across the discharge or storm drain intake is an excellent means of measuring the runoff flow rate. Flumes, which are specially shaped open channel flow sections providing a restriction in area, are compatible with runoff flow measurement since they are self-cleaning. The high velocity through the flume can eliminate the deposition of solids and sediments. In addition, the accuracy of the flume is less affected by varying approach velocities than is the weir.[5]

Figure 3-3 illustrates the application of a weir to measure runoff through a storm drain in an industrial site. Weirs, which are obstructions to the flow, can cause deposition of materials behind the weir which affect the accuracy of the flow measurement. In addition, time delays behind the weir can effect problems in highly variable flow conditions. In these cases, water quality samples taken at the weir cannot be correlated with simultaneous flow measurements taken behind the weir, causing difficulty in data interpretation. Therefore, weirs should be designed with consideration to the expected flow rates and should be maintained between storms to prevent interference from solids deposition.

In areas where neither a storm drain nor a defined drainage pattern (to use plugs) exist, ditches can be dug to collect and channel the runoff flow for sampling and flow measurement. Ditches must be constructed carefully because alteration of the soil porosity will affect runoff quantity and quality. Ideally, ditches should be lined with impervious material, such as polyethylene sheeting, to reduce the risk of pollutants reacting with or leaching into freshly exposed soil.

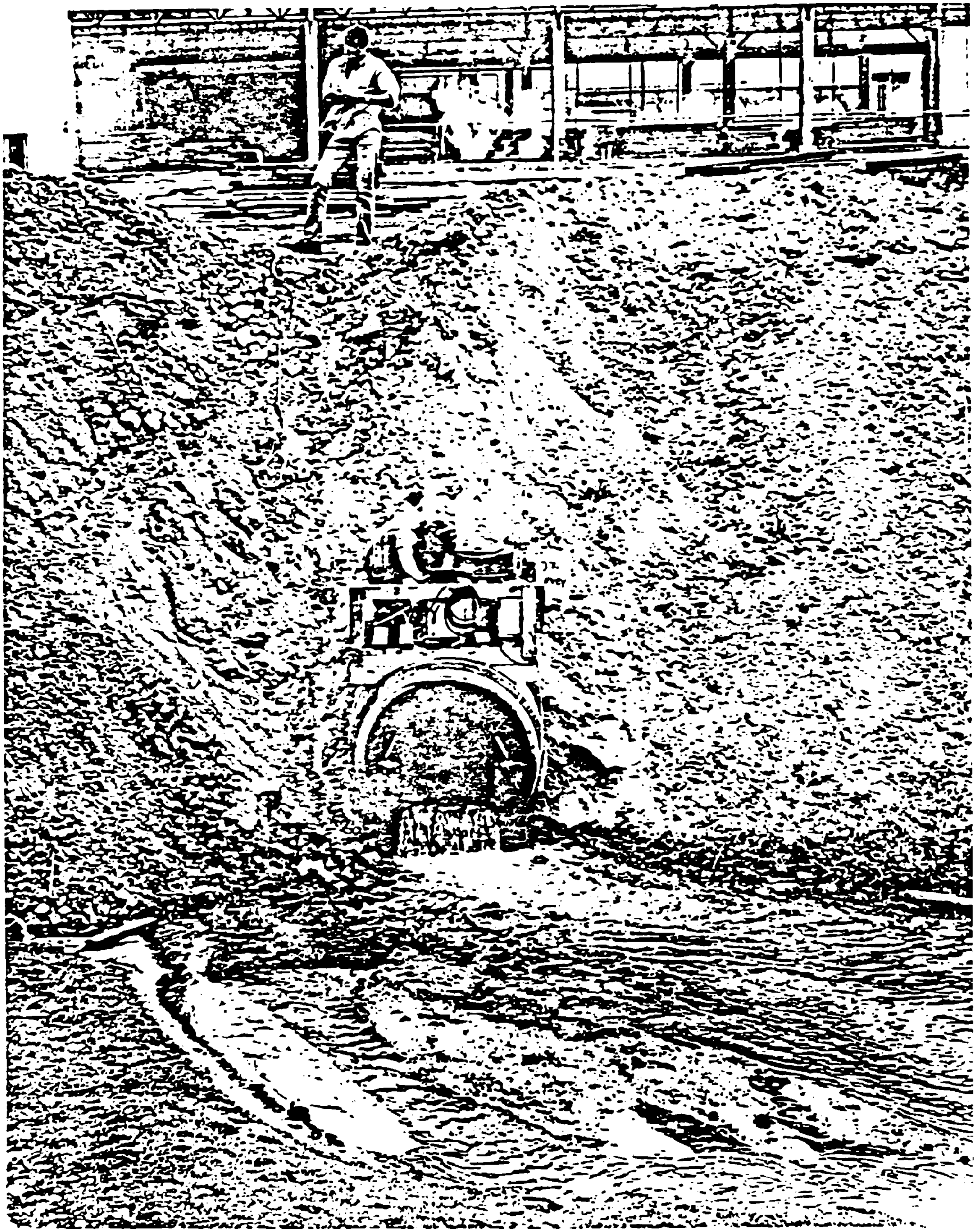

Figure 3-3: WEIR INSTALLATION IN STORM DRAIN

River flow can be determined in several ways. If there are U.S. Geological Survey (USGS) continuous recording gaging stations nearby upstream and downstream of the site, their flow data will usually be satisfactory. If gaging stations do not exist, local flow rates can be estimated as the product of the cross-sectional area of the river and measured velocity.

In addition, if the river is dammed, a measurement of the water level behind the spillway can be used to provide a suitable estimate of flow, when taken at a distance behind the dam equal to at least four times the water level.

3.3 Sample Analysis

Analytical procedures for pollutants of interest can be found in the previously mentioned Methods of Chemical Analysis of Water and Wastes and Standard Methods for the Analysis of Water & Wastewater. It is important to use these accepted methods to ensure the data's comparability with other studies and acceptability to regulatory agencies. Analysis time and cost can be reduced by analyzing only a portion of the samples (e.g., analyze every third or fourth sample) and investigating further only if important trends appear.

The laboratory should follow accepted quality assurance procedures to ensure the validity of the data. These procedures should include an inventory file of all instrumentation, standards, chemicals and samples, a file for instrument calibration, and a semi-annual State or EPA analytical audit. Additionally, it is recommended that the laboratory repeat analyses of a specified portion of the samples (e.g., 10 percent) and include an audit sample (split sample or known standard) as a further check on the results.

3.4 Data Reduction and Analysis

The data used to evaluate the runoff and its impact on the river should be compiled to present time-dependent changes in:

- river flow
- rainfall
- runoff rates
- pollutant concentrations in runoff, river, and rain

Hyetographs (plots of rainfall versus time), hydrographs (river flow versus time) and plots of pollutant concentrations versus time can together provide a graphic indication of the relationship between runoff and the receivi body water quality.

In addition, flow and concentration data can be related by plotting the mass loadings of pollutants versus time for both runoff and receiving water bodies.

There are a number of ways to present and analyze runoff and receiving water data to ascertain any trends. Table 3-4 shows the range of pollutant concentrations measured at runoff sources and upstream and downstream river locations in a coal-fired utility non-point source program.[1] Alternatively, only the mean values of each range could have been given. However, data can be presented to show its variability. Giving the standard deviation and the coefficient of variation of data values is one method of expressing the variability of sampling measurement. The sample standard deviation, S, is the square root of the sample variance, S^2, which is defined as

$$S^2 = \frac{\Sigma(X-\bar{X})}{n-1} \qquad (3\text{-}2)$$

and the coefficient of variation, $CV = \frac{S}{\bar{X}}$ (3-3)

where: X = value in sample

$\bar{X}$ = mean value of sample

n = number of values in samples.

TABLE 3-4

RANGE OF POLLUTANT CONCENTRATION AT THE SAMPLING LOCATIONS

OF COAL-FIRED UTILITY

Pollutant	RANGE OF POLLUTANT CONCENTRATIONS, mg/l					
	Upstream		Downstream		Coal Pile Discharge Pipe	
	Dry	Wet	Dry	Wet	Dry	Wet
Total Suspended Solids	1 - 21	2 - 5	1 - 11	2 - 12	12 - 19000	1700 - 13000
Total Dissolved Solids	100 - 170	60 - 130	80 - 180	-	2300 - 21700	2300 - 115000
Iron	.14 - .40	.09 - .17	.06 - .34	.09 - 1.03	160 - 23500	700 - 1400
Aluminum	N.D.[1]	N.D.[1]	N.D.[1]	N.D.[1] - 26.6	20 - 1800	70 - 100
Manganese	.013 - .090	.025 - .040	N.D.[2] - .040	.030 - .060	2 - 100	9 - 15
Sulfate	11 - 20	12 - 17	11 - 22	12 - 24	90 - 57000	1600 - 2700
Total Alkalinity @ $CaCO_3$	38 - 48	38 - 42	36 - 45	40 - 41	-	-
Total Acidity @ $CaCO_3$	-	-	-	-	200 - 38000	1900 - 2900
pH	6.77 - 7.80	6.60 - 6.76	6.77 - 7.60	6.36 - 6.87	1.48 - 3.37	2.35 - 3.36

[1]None detected, < 0.2 mg/l

[2]None detected, < 0.012 mg/l

Another method is to state the level of confidence that a measured value will fall within a certain interval. Table 3-5 illustrates the 95% confidence limits of pollutant concentrations for upstream and downstreams sites of an example sampling program.[1] In this case, the observed values of the confidence interval will bracket the mean value 95 out of 100 times.

If the data is plotted and the magnitude of the parameter versus the frequency of occurrence demonstrates a normal distribution, then the confidence limits can be defined by use of Student's 't' distribution. The confidence limits are:

$$L = \bar{X} \pm t_{1-\alpha/2} \sqrt{\frac{S^2}{n}} \qquad (3\text{-}4)$$

where: L = the limits of the confidence interval

$\bar{X}$ = arithmetic mean of data set with 'n' elements

t = percentile of the 't' distribution at ν degrees of freedom and $(1-\alpha)$ confidence limits

S^2 = best estimate of sample variance of 'n' elements in data set

In the analysis of runoff data, it is sometimes desirable to determine if there are statistically different pollutant values in the receiving stream upstream and downstream of the runoff discharges. While the 't' test can be utilized to determine if mean values of parameters differ upstream and downstream within certain confidence limits, the 'F' test is used in a similar manner to derive a confidence interval for the variances of the sample. The 'F' ratio is a ratio of variances of the upstream and downstream samples. The critical 'F', like the 't' test, is the percentile of the 'F' distribution at ν upstream and ν downstream degrees of freedom and $(1-\alpha)$ confidence limits.[6]

TABLE 3-5

MEAN POLLUTANT CONCENTRATIONS WITH 95% CONFIDENCE LIMITS ON RIVER AT COAL-FIRED UTILITY

Pollutant	POLLUTANT CONCENTRATION, mg/l			
	Upstream		Downstream	
	Dry	Wet	Dry	Wet
TSS	8.11 ± 2.26	7.25 ± 3.18	4.13 ± 2.04	5.50 ± 2.71
SO_4	13.89 ± 0.84	15.09 ± 0.94	13.83 ± 1.45	16.65 ± 2.25
Fe	0.23 ± 0.02	0.12 ± 0.03	0.21 ± 0.09	0.39 ± 0.27
Mn	0.028 ± 0.005	0.032 ± 0.003	0.023 ± 0.005	0.043 ± 0.012
Alk	41.65 ± 0.85	40.33 ± 0.94	39.33 ± 0.89	40.30 ± 0.34

95% confidence limits = $\bar{x} \pm t_{\nu,.025}\sqrt{\frac{s^2}{n}}$

Table 3-6 illustrates how the 't' test and 'F' test were used to determine if the pollutant values varied to a statistically significant degree upstream and downstream of runoff sites at a coal-fired utility.[1]

If the pollutant values prove to be statistically different upstream and downstream during a rain event, then further investigation and data evaluation of the runoff would be made. The presence of point discharges, tributaries, etc. between the upstream and downstream sites will complicate the statistical calculations. These data must be subtracted from the downstream data before a statistical analysis can be performed comparing upstream and downstream conditions.

In general, increasing the number of samples will increase the confidence with which conclusions can be drawn. However, it may take several rainfall events over several months to get a set of data to properly define whether a problem exists and, if it exists, to gather enough data to design a cost-effective control system. This procedure is impractical from cost and time standpoints. Therefore, in an attempt to define non-point sources from industry more cost effectively, the use of a mathematical model as a replacement for most of the sampling is recommended. Applicable models are discussed in Section 4.

TABLE 3-6

COMPARISONS OF MEAN VALUES & VARIANCES WITHIN 95% CONFIDENCE LIMITS
AT UPSTREAM & DOWNSTREAM SITES DURING DRY & WET SAMPLING PERIODS
AT COAL-FIRED UTILITY

Pollutant	Degrees of Freedom	t Test	Difference Between Means	Is Difference Between Means Significant?	Critical 'F' for 95% Confidence	'F' Ratio	Is Difference Between Variances Significant?	
			UPSTREAM DRY - DOWNSTREAM DRY					
TSS	50	7.47	3.98	No	2.69	3.38	Yes	Upstream > Downstream
SO_4	44	3.06	0.06	No	2.53	0.55	No	
Fe	52	0.138	0.02	No	2.416	0.12	Yes	Upstream < Downstream
Mn	51	0.015	0.005	No	2.422	2.00	No	
Alk	65	2.59	2.32	No	2.173	1.72	No	
			UPSTREAM WET - DOWNSTREAM WET					
TSS	16	8.45	1.75	No	4.82	1.88	No	
SO_4	19	4.57	1.56	No	3.96	0.196	Yes	Upstream < Downstream
Fe	17	0.495	0.27	No	4.36	0.011	Yes	Upstream < Downstream
Mn	18	0.019	0.011	No	4.72	0.10	Yes	Upstream < Downstream
Alk	17	1.86	0.03	No	4.10	6.52	Yes	Upstream > Downstream
			UPSTREAM WET - UPSTREAM DRY					
TSS	45	9.26	0.86	No	2.50	0.43	No	
SO_4	37	2.91	1.20	No	2.57	0.41	No	
Fe	43	0.086	0.11	Yes	2.52	0.33	No	
Mn	44	0.017	0.004	No	2.42	0.10	Yes	Wet < Dry
Alk	50	3.81	1.32	No	2.44	0.20	Yes	Wet < Dry
			DOWNSTREAM WET - DOWNSTREAM DRY					
TSS	21	6.71	1.37	No	3.38	0.77	No	
SO_4	26	4.96	2.82	No	2.98	1.16	No	
Fe	26	0.42	0.18	No	3.01	3.62	Yes	Wet > Dry
Mn	25	0.0202	0.0200	Marginal	3.10	2.00	No	
Alk	32	2.80	0.97	No	2.73	0.05	Yes	Wet < Dry

4.0 MATHEMATICAL MODELING

4.1 Model Selection Criteria

Mathematical models properly applied provide a cost-effective means of quantifying impacts on water quality resulting from stormwater runoff and of evaluating alternatives for the control of polluted runoff. In recent years many mathematical models have been developed to simulate the quantity and quality of stormwater runoff and the impact of such runoff on the quality of water bodies. These models were developed to satisfy different needs, ranging from the design of municipal storm sewer systems to the assessment of land use as it influences flooding and water quality. Although none of the models were developed specifically for industrial runoff, some models can be adapted to such use. There are many criteria that can be used when selecting a model, but in general the simplest model which satisfies project needs should be selected for use since such a model is normally the most economical choice.

Once a model has been selected, it must be adapted to the specific site or area being studied. A model is adapted through the process of calibration and verification. Calibration is achieved by adjusting the model to reflect site specific field data. After the model has been calibrated, it should be tested against a second set of field data. If the second set of field data and the modeled results compare favorably, the model is considered to be verified and ready for application.

To be adaptable to industrial applications a model must predict the quantity and quality of stormwater runoff, the transport of such runoff to a receiving body of water, and the impact of such runoff on the quantity and quality of the receiving water. In addition, since storm events are dynamic, a model must also be capable of simulating functions in a dynamic (time-dependent) fashion.

To predict the quantity and quality of stormwater runoff, a model must be able to simulate the effects of such items as the intensity and the duration of the storm event, infiltration and drainage characteristics, the accumulation of pollutants between storms, and the washoff of such pollutants during storms. For continuous simulation of multiple storms, a model must be able to simulate dry weather flows as well as storm flows.

To predict the transport of stormwater runoff for industrial land use, a model must be able to simulate overland flow and routing in man-made systems (channels, sewers, etc.). To describe the impact of the stormwater runoff on a receiving body of water, a model must be capable of simulating the quantity and quality responses of the receiving water to the runoff. For increased flexibility, a model should simulate various types of receiving waters including rivers, lakes, and estuaries.

4.2 Possible Industrial Non-Point Source Models

Table 4-1 lists ten (10) mathematical models for runoff and/or receiving waters with possible adaptability to an industrial site.

The EPA Stormwater Management Model (SWMM), Water Resource Engineers Stormwater Management Model, Short Stormwater Management Model - RECEIV II (SSWMM-RECEIV II), Hydrocomp Simulation Program (HSP), and Dorsch Consult Hydrograph Volume Method are capable of dynamically simulating the quantity and quality of stormwater runoff and its impact on the quantity and quality of receiving waters. These models can best be described as runoff and receiving water models. The quality simulation portion of each of these models must be modified for industrial application. The quality relationships are based on land utilization with all types of industry lumped into one land use category -

TABLE 4-1

POSSIBLE MODELS FOR INDUSTRIAL RUNOFF APPLICATIONS

EPA Stormwater Management Model - Release II (SWMM)

Water Resource Engineers Stormwater Management Model

Short Stormwater Management Model - RECEIV II (SSWMM - RECEIV II)

Hydrocomp Simulation Program (HSP)

Dorsch Consult Hydrograph Volume Method

Corps of Engineers Storage, Treatment, Overflow, and Runoff Model (STORM)

Battelle Wastewater Management Model (BWMM)

Metcalf and Eddy Simplified Stormwater Management Model

EPA - Hydrocomp Agricultural Runoff Management Model (ARM)

Pyritic Systems: A Mathematical Model

industrial. No attempt is made to specify the particular type of industry. If industry-specific data is available on pollutant accumulation, washoff characteristics, and pollutant characteristics of dirt and dustfall, then these models can be utilized.

The Corps of Engineers Storage, Treatment, Overflow, and Runoff Model (STORM), Battelle Wastewater Management Model (BWMM), and Metcalf and Eddy Simplified Stormwater Management Model are capable of dynamically simulating the quantity and quality of stormwater runoff, but not its impact on receiving waters. Consequently, these models are designated as runoff models. As with the preceding model group (runoff and receiving water models), the quality portion of the runoff models is not adequate to meet the program objectives. Again, the quality relationships for runoff are based on general land utilization categories that do not specify the type of industry; hence, quality relationships addressing pollutant accumulation and washoff must be supplied for the industry. In addition to this limitation, the runoff models were not designed to simulate the impact of stormwater runoff on receiving waters. To simulate this impact, it is necessary to interface the runoff models with a receiving water model. RECEIV - II,[7] developed by Raytheon Company for EPA, is a Water Quantity and Quality receiving water model that can be used in conjunction with such runoff models.

The EPA - Hydrocomp Agricultural Runoff Management Model (ARM) and Pyritic Systems: A Mathematical Model are designed to quantify and qualify stormwater runoff for the agricultural and mining industries, respectively. These models are described as specific industry models. As with the runoff models, the specific industry models cannot simulate the impact of stormwater flows on receiving waters. They must be interfaced with a receiving water model to simulate such impact. Since ARM was developed specifically for the agricultural industry, it is not necessary to modify the program quality relationships but only to calibrate and verify existing quality relationships with field data. On the other hand, Pyritic Systems: A Mathematical Model is designed for a drift (subsurface) mine. Extension of this model to surface mining (strip mining) requires both quantity and quality program modifications.

One combined runoff and receiving water model found very suitable for industrial application is the Short Stormwater Management Model (SSWMM) - RECEIV II. SSWMM, developed by the University City Science Center, Philadelphia, Pennsylvania in 1976, is a simplified version of the runoff and transport portions of the EPA-SWMM model; RECEIV II, developed by the Raytheon Company and the EPA in 1974, is a modified version of the receiving water portion of the EPA-SWMM model.[8]

A brief description of SSWMM-RECEIV II, as linked for industrial applications,[1] will follow as an example on (1) how such models are utilized, (2) the necessary input data, and (3) what model results are presented.

4.3 Example Industrial Runoff and Receiving Water Model - SSWMM-RECEIV II

4.3.1 General Description

SSWMM-RECEIV II is capable of dynamically simulating both the quantity and the quality of industrial stormwater runoff and the impact of such runoff on the quantity and the quality of receiving waters including rivers, lakes, and estuaries. The user can define, with certain restrictions, the quality parameters which he chooses to simulate. Pollutant transport can be modeled by both overland flow and sewer routing. Dry weather flows can also be simulated. The model is primarily designed to simulate individual storm events but can be used to model multiple storm periods.

The linked SSWMM-RECEIV II model[1] consists of the following four programs:

SSWMM (Short Stormwater Management Model Program)
LNKPRG (Link Program)
SETUP/QUANTITY (RECEIV II Quantity Program)
QUALITY (RECEIV II Quality Program)

4.3.2 Computer Requirements

SSWMM-RECEIV II is written in Fortran IV and was developed for installation on a Univac 90/30 digital computer with a basic compiler (equivalent to an IBM 370 Level G compiler). The program requires 100K bytes of core storage.

4.3.3 Model Utilization

Without performing a detailed field measurement program, SSWMM-RECEIV II can be used to simulate industrial non-point source pollution associated with stormwater runoff from material storage piles and from areas of dust and dirt accumulation. It also simulates the subsequent impact on receiving waters (rivers, lakes, or estuaries). Pollutants that can be modeled are user-selected and include items such as solids, nutrients, and metals.

Typical model applications for new or existing plants might include:

- Defining industrial stormwater runoff flow and pollutant concentrations. The quantity and quality of stormwater runoff at user selected storm intensities can be affected.

- Identifying if an impact results from stormwater runoff and if so, defining its significance and frequency of occurrence.

- Defining design criteria for stormwater treatment. The volume flow rate and total volume of stormwater runoff and the pollutant mass loads caused by the stormwater runoff for user selected design storms can be predicted.

- Evaluating stormwater treatment alternatives. The impact of various wastewater treatment efficiencies on water quality in the receiving waters can be described. The relative merits (cost vs. improved water quality) of different treatment alternatives can be weighed.

As with any mathematical model, SSWMM-RECEIV II must be applied correctly. The user must understand model limitations and use the model within these limitations. At this time SSWMM-RECEIV II:

- Cannot simulate stormwater percolation through or the erosion of material storage piles, but can only simulate stormwater runoff from material storage piles.

- Has not been tested to simulate dynamic background source flows and loadings in the receiving water.

- Must be used within temporal and spatial limits defined in the model.

More detailed descriptions of SSWMM-RECEIV II user restrictions can be found in the technical report prepared for this program on the sampling and modeling of non-point sources at a coal-fired utility.[1]

4.3.4 Model Input Information Requirements

Table 4-2 summarizes the model input information requirements for SSWMM-RECEIV II, as categorized by the individual programs. SSWMM input includes information such as physical descriptions of user selected discretization

TABLE 4-2

SSWMM - RECEIV II MODEL INPUT REQUIREMENTS

INPUT DATA	PROBABLE DATA SOURCE
SSWMM Program	
1) drainage basins 2) land use characteristics 3) spatial framework of storm sewers, sub-catchments, drainage ditches on site	plant site maps and engineering drawings
4) rainfall intensity 5) storm duration and dry days between storm	National Weather Service or installation of on-site rain gage
6) dust and dirt accumulation rate 7) pollutant characteristics of dust and dirt	field measurement and laboratory analysis
LNKPRG Program	
1) background receiving flows and pollutant mass loads 2) industrial flows and pollutant mass loads	USGS, NOAA, and state pollution control agencies
Setup/Quantity Program	
1) spatial segmentation of receiving water into nodes and channels of uniform hydraulic and water quality properties	USGS, 7.5' topographic maps, US Army Corps of Engineers flood studies, National Ocean Survey bathymetric maps
2) rates of rainfall and evaporation (optional)	National Weather Service
Quality Program	
1) initial pollutant concentrations in receiving water	plant data, USGS data, or state pollution control agencies
2) reaction rates	literature values or results of field measurement program
3) water temperatures and temperature compensation coefficients	USGS or state pollution control field data with literature values for coefficients

elements, storm activity, and pollutant generation and washoff data. LNKPRG input includes the information output files from SSWMM and an input deck. The card input consists of user-determined program interface instructions to link SSWMM and RECEIV II and instructions for non-storm input to or withdrawals from the receiving waters. Input requirements for the Setup/Quantity portion of RECEIV II include the information output file from LNKPRG and input card decks, including geographical, hydraulic, and meteorological data describing the receiving waters. The QUALITY program requires input data describing the initial pollutant concentrations in the receiving water and pollutant reaction kinetics.

4.3.5 Model Results

Model results are printed for each of the programs (SSWMM, LNKPRG, SETUP/QUANTITY, QUALITY) in the SSWMM-RECEIV II model. SSWMM-RECEIV II model utilizes a mixed system of English/metric units.

Results from SSWMM include:

- Initial pollutant loads (mg) on each subcatchment prior to the storm.
- Stormwater flow (cfs) and associated pollutant mass loads (lbs/min) for each timestep.
- Total amount of rainfall (cu. ft.), total infiltration (cu. ft.), total runoff (cu. ft.), total surface storage (cu. ft.), and the percentage error computed for unaccounted water.
- Total pollutant mass (lbs) washed from the land surface during the storm.

LNKPRG results include the stormwater flows and pollutant mass loads from SSWMM converted to a format acceptable to RECEIV II (SETUP/QUANTITY, QUALITY).

Results from SETUP/QUANTITY include:

- Hydraulic head (m) or water level in the receiving water at each node for each timestep.
- Water flow (m^3/sec) and velocity (m/sec) in the receiving water in each channel for each timestep.

Results from QUALITY include:

- Pollutant concentrations (mg/l) in the receiving water at each node for each timestep.
- Daily maximum, minimum, and average pollutant concentrations (mg/l) in the receiving water at each node.

The complete set of results, then, quantifies and qualifies stormwater runoff and its impact on the quantity and quality of the receiving water.

5.0 PROGRAM COSTS AND TIME CONSIDERATIONS

The cost and time requirements of a runoff study will vary with the number of sampling sites, parameters to be measured, number of samples to be taken, as well as other complicating factors. These factors may include the interference of other sources or tributaries in the test area and the variability of river flows. This section outlines the considerations necessary for planning the resources to conduct an industrial runoff measurement and modeling study.

5.1 Manpower for Measurement Survey

In order to outline manpower requirements, a typical runoff study, including modeling, was developed. This runoff study was based on several assumptions:

(1) site was 300 miles from contractor's base
(2) most runoff collected by storm sewers
(3) regulated flow stream at 60 m^3/s
(4) 2 receiving body and 4 runoff sampling sites
(5) 4 week sampling program (16 weeks without modeling)
(6) 960 samples collected (3840 samples without modeling)
(7) 6 parameters analyzed
(8) 500 samples analyzed (2000 samples without modeling)

Table 5-1 shows an estimate of the manpower requirements for the assumed 4-week sampling program using modeling (and the assumed 16-week program without modeling). The Senior Engineer/Scientist would serve as project coordinator and review the conclusions of the field program. The Engineer/Scientist would develop the test plan, supervise the field work and analyze the data. Preparation and field support and analyses would be handled by the Junior Engineer/Technician.

TABLE 5-1

ESTIMATED MANPOWER REQUIREMENTS FOR RUNOFF STUDY

	Task	Senior Eng./Scientist (Hours)	Eng./ Scientist (Hours)	Junior Eng./Tech (Hours)
1.	Pretest Survey & Site Selection	20	40	-
2.	Test Plan	8	120 (100)	40
3.	Preparation For Field	-	40 (80)	180 (360)
4.	Field Study	-	320 (1280)	320 (1280)
5.	Sample Analysis	-	240 (480)	240 (1400)
6.	Data Evaluation	8	40 (240)	40 (100)
	Total Hours	36	800 (2220)	820 (3180)

( ) without modeling

Using this sampling program as a guideline, the manpower costs for individualized programs can be estimated.

5.2 Other Direct Costs For Measurement Survey

Table 5-2 presents estimated costs for equipment purchases and other major expenditures excluding travel and subsistence for a program including modeling. The vehicle rentals and on-site communication are estimated to be $2200 and $850 respectively for a program which does not include modeling. The estimate for equipment assumes a laboratory is available for use in the program without additional equipment expense. The equipment costs can be mitigated by taking advantage of rental or lease arrangements offered by many vendors. These costs will vary proportionally with the complexity of the source rather than the duration of the study.

In addition, Table 5-3 outlines the cost per sample of some parameters for analysis in an industrial runoff study. These costs are from one commercial laboratory which was found to be in the median range for such analysis and are quoted for 6 or more samples. Some laboratories offer a volume rate for large numbers of samples and these costs can be adjusted accordingly.

5.3 Elapsed Time Requirements

Figure 5-1 shows an estimate of the elapsed time requirements for conducting a field survey program. The entire survey using modeling can be completed in 3-6 months. Equipment preparation and acquisition take the longest amount of time to complete. If a model is not used, the program will take from 9 to 12 months to complete.

TABLE 5-2

ESTIMATED COST OF EQUIPMENT-
ESTIMATE OF OTHER DIRECT COSTS FOR EXAMPLE RUNOFF STUDY

1.	Equipment	
	Sequential Samplers (6)	$ 9,050
	Flow Measuring Device & Recorder (4)	8,500
	Rainfall Measuring Device & Recorder (2)	2,130
	pH Monitor (2)	2,200-3,200
	DO Monitor (2)	4,900
	Dual Pen Recorder (2)	1,100-3,200
	Boat with Outboard Motor	1,100
	Misc.	1,100
2.	Shipping	850
3.	Vehicle Rentals	650
4.	On-Site Communication	220
	TOTAL (12/77) DOLLARS	$31,800-34,900

TABLE 5-3

ESTIMATED COST/PARAMETER ANALYZED/SAMPLE

Parameter	Cost/Sample (based on 6 or more samples, 1978 dollars)
acidity	$ 2.00
alkalinity	2.00
BOD_5	7.25
COD	6.25
color	2.00
cyanide	5.00
dissolved oxygen*	2.00
hardness	3.25
ammonia nitrogen	3.50
total Kjeldahl nitrogen	5.50
organic nitrogen	5.50
nitrite nitrogen	2.00
nitrate nitrogen	3.50
oil and grease	
soxhlet extraction	7.25
infra-red	15.75
TOC	7.50
pH*	2.00
phenol	5.00
total phosphate	7.50
total solids	3.25
sulfate	6.50
turbidity	2.00
common metals (each)	5.00

*can be determined in the field with continuous monitors

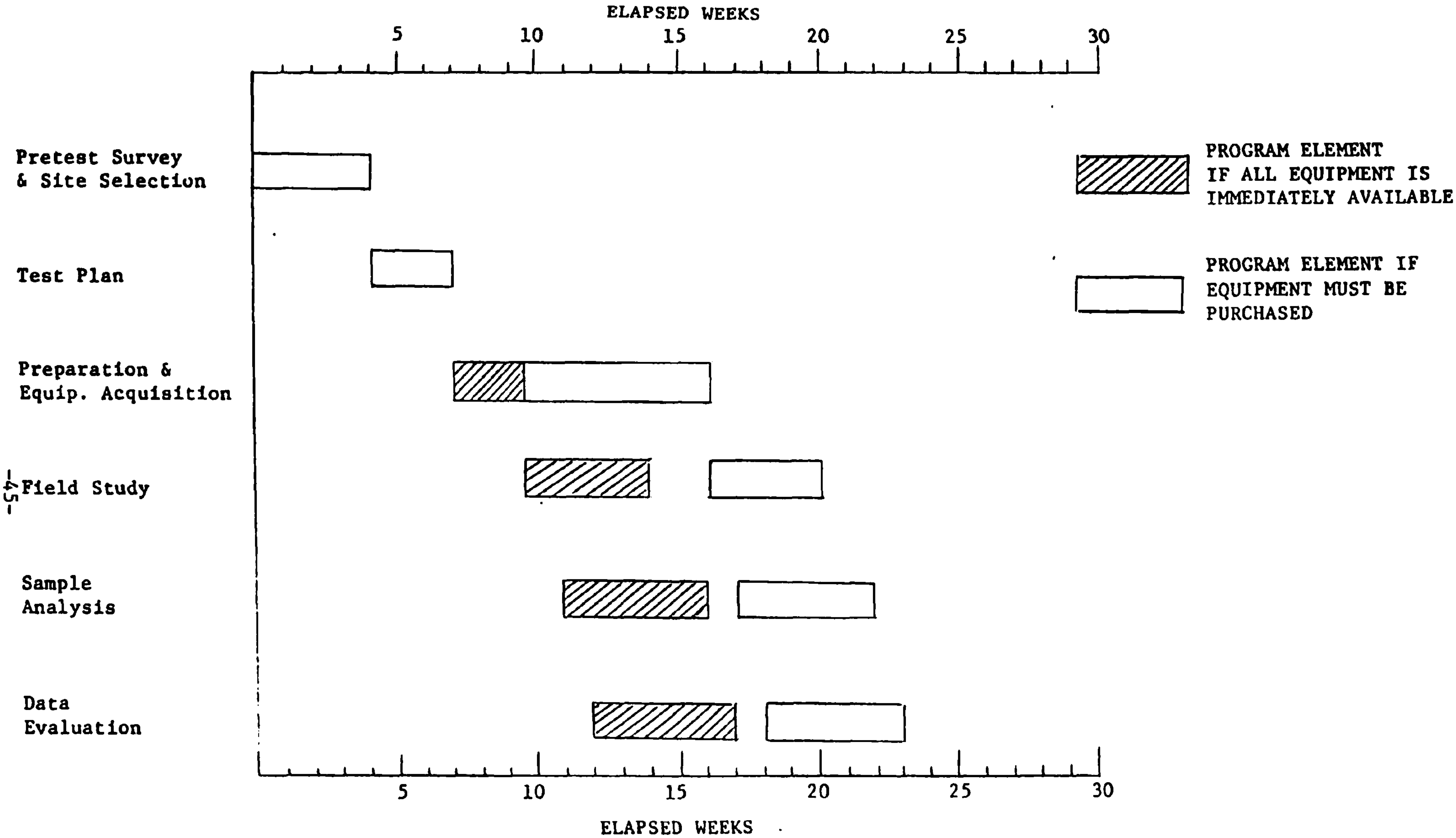

Figure 5-1: Elapsed time estimates for runoff study which is to be used in conjunction with a mathematical model

5.4 Labor and Computer Time to Implement SSWMM-RECEIV II for Case Run

The labor and computer time necessary to utilize SSWMM-RECEIV II are directly related to the complexity of the plant site to be modeled and are site specific. To provide comparative information to the potential user, a program run was designed and executed for a coal-fired utility plant on a river system and the labor and computer time requirements for this exercise are listed. Labor includes the time to define the problem, gather, reduce, code, and keypunch the input information, run the model, and analyze the results. Estimates are based on using a Univac 90/30 computer. Operational costs may differ for other computers.

The labor and computer time for the sample program is listed in Table 5-4. To define the problems, gather, reduce, code and keypunch the input information, run the model, and analyze the results require 12 hours of a Senior Engineer/Scientist, 48 hours of an Engineer/Scientist, and 88 hours of a Junior Engineer/Scientist. Computer time requirements based on a Univac 90/30 rate of speed were 14 minutes and 14 seconds.

TABLE 5-4

LABOR AND COMPUTER TIME BASED ON EXAMPLE CASE

Task	Labor (Man-Hours)* Sr Engr/Sci	Engr/Sci	Junior Engr/Sci	Computer Time**
1. Problem Definition	8	8		SSWMM - 44 sec.
2. Input Data Acquisition		8	16	LNKPRG - 17 sec
3. Input Data Reduction		20	40	SETUP/QUANTITY- 9 min., 34 sec
4. Input Coding/ Keypunching			16	QUALITY - 3 min., 39 sec.
5. Run Model (including debugging)		4	8	
6. Analyze Results	4	8	8	
TOTAL	12	48	88	14 min., 14 sec.

* Based on using a Univac 90/30 computer.

** Based on Univac 90/30 rate of speed.

6.0 SUMMARY: HYPOTHETICAL CASE

Application of the Measurement and Modeling Techniques to Stormwater Runoff from a Coal-Fired Utility on a River.

6.1 Introduction

This section provides an example of the application of the measurement and modeling techniques to a coal-fired electric utility plant.

The example is an uncomplicated case applied to an average-sized plant on a small river.

6.2 Background Information

The objective of the sampling program was to provide data to evaluate the effects of runoff on the river. The following information was obtained from an initial site visit and interviews with plant personnel.

Figure 6-1 shows a plant layout of a coal-fired electric utility station. With a typical 100-day supply of coal on hand, the 200,000 tons of coal cover 11 1/2 acres. The ash-handling area covers 23 acres on the opposite side of the plant. The coal pile runoff drains into a branched storm sewer, while the ash pile runoff is discharged from a collection pipe into the river.

The site is located on a fast-moving, very clean river. Other than the cooling water intake and discharge, there are no other normal discharges into the river. Runoff patterns and drainage areas are visible in the texture and type of soil, rock, and vegetation. These drainage areas are practically flat, making runoff flow measurements difficult.

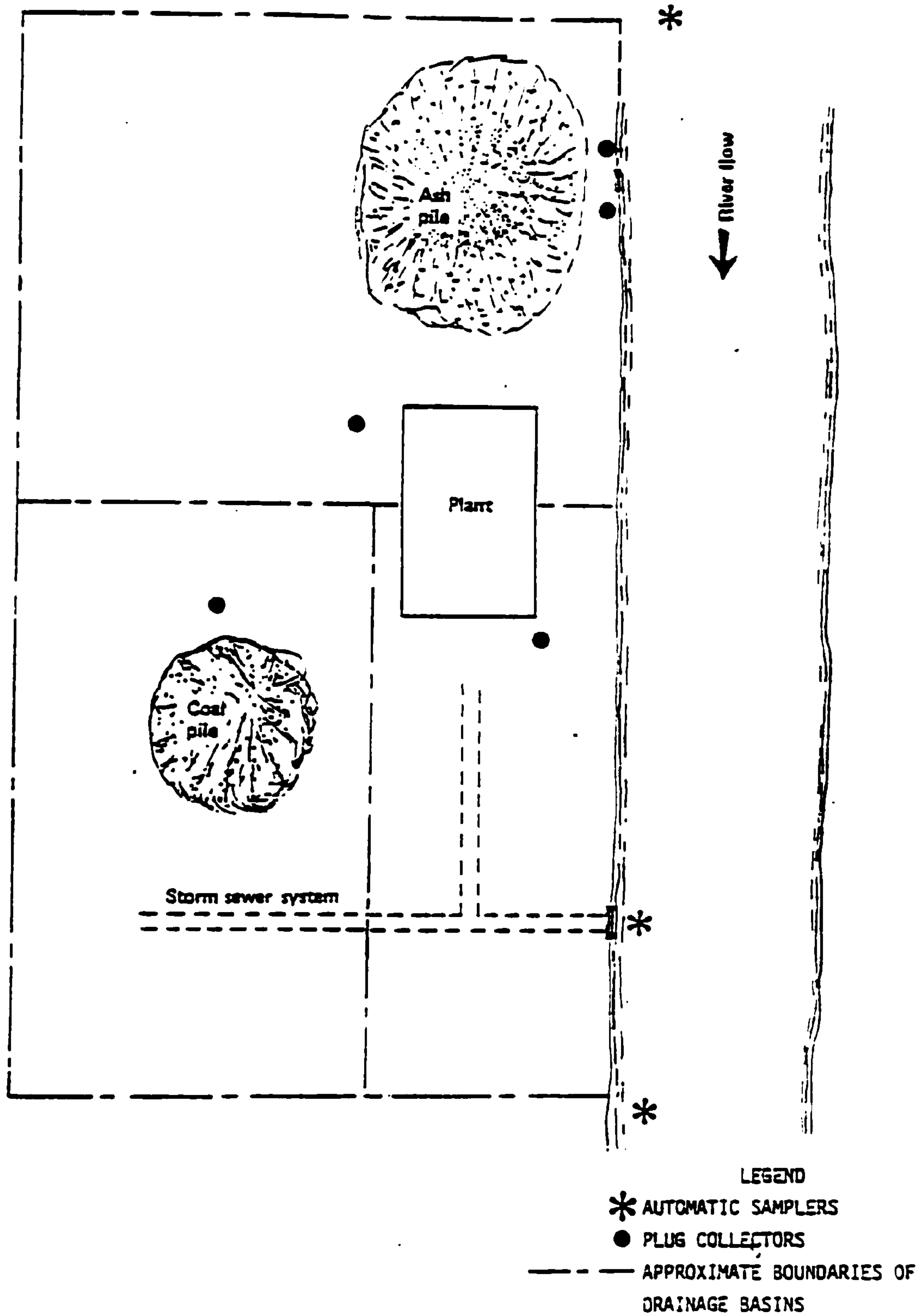

Figure 6-1: Site layout, coal-fired utility station example case.

6.3 Selection of Sampling Sites

Figure 6-1 also shows the delineation of drainage basins and the locations of sampling sites. As runoff from the coal pile, fly ash pile and roof of the plant were of major interest, sampling stations were placed in these areas. The river background sampling site was located upstream of the ash pile runoff's entry into the river. It was placed approximately one third of the distance across the river and the sampler intake was adjusted to 1/3 the river depth. The downstream site was placed approximately 150 meters (500 feet) downstream of the storm sewer entry into the river, where the discharge plume was dispersed.

6.4 Sampling Methodology

6.4.1 Parameters for Analysis

For evaluation of coal and ash pile runoff, the following constituents were of interest in both the river and runoff:

Total suspended solids
Total dissolved solids
Iron
Aluminum
Sulfate
pH
Manganese
Alkalinity

Of the above parameters, only sulfate and alkalinity requires cooling of the samples and analysis within a short period. Analysis of samples for these parameters was performed in a field laboratory to guard against sample degradation. The samples of metals were acidified and shipped to the home laboratory with solids samples for analysis. Values of pH for the river stations were determined in the field with pH probes.

6.4.2 Sampling Frequency

In order to sample the first flush of runoff at the initiation of the rainfall, automatic samplers were used which were activated with the rising water level. In order to collect representative samples at this stage of the storm, the automatic samplers drew samples every 2 minutes and these were integrated to represent 10 minute intervals. The sample plugs were also emptied every 10 minutes. If the storm duration was greater than 90 minutes, pollutant concentrations leveled out and the sampling frequency was consequently reduced to half-hourly integrated samples. This rate was continued after the storm until noticeable effects had diminished.

River samplers were set to integrate hourly composites of 15-minutes discrete samples during dry weather for background flow data.

6.4.3 Method of Sample Collection

As shown by Figure 6-1, automatic samplers were utilized in the storm drains and at the river stations. Samples of runoff around coal and ash piles were collected in sampling plugs.

The automatic samplers were pump-type sequential samplers. The river samplers were set in inflatable rafts since the sample line could not reach far enough into the river and still maintain proper purge and backflush cycles. These rafts also supported the pH probe while the monitors were sheltered on land.

6.4.4 Flow Measurement

For the storm sewer, flow data were obtained by a combination rectangular and V-notch weir located at the discharge end of the pipe. The V-notch is used to measure the lesser dry weather flows and the rectangular weir measures the wet weather flows. The water level sensor must be calibrated to a combination weir. Flow data from the ash pile area were obtained by applying standard hydraulic formulas to the depth, slope, and diameter of the collection pipe. Dry weather flow from this pipe and the cooling water discharge flow and quality were also measured.

River flow data were obtained from USGS gaging stations located approximately 0.5 miles upstream and 1.5 miles downstream. The upstream gaging station was located downstream of the nearest tributary and there were no major point source discharges between the gaging station and the sampling site. Rainfall data were obtained from a rain gage installed at the plant.

6.4.5 Sample and Data Analysis

Samples taken at the coal-fired utility site were analyzed in accordance with procedures described in Standard Methods for the Examination of Water and Wastewater. After trends in the analysis results were established, every fourth sample was analyzed.

As shown in Tables 3-4, 3-5, and 3-6, analytical results were arranged in dry and wet weather categories, by pollutant, to facilitate the comparative data analysis. Sample variance, standard deviations, etc. were calculated and analys of the variance and means were performed to establish the comparability of the site data.

The upstream and downstream dry weather data should vary in a similar fashion and their means should be essentially the same. Conclusions concerning wet weather data were more subjective. If the runoff affects the river, then the downstream values should be greater than the upstream on a statistically significant basis.

Comparison of the hydrographs and graphs of pollutant concentration versus time and interpretation of statistical analyses provided the basis for conclusions on the runoff's effect on the river.

6.5 Model Application to Example Case

The SSWMM-RECEIV II model was selected for the case of the coal-fired utility station on a river. This model, as previously discussed, simulates the conveyance of the runoff to the river and the impact of the runoff on the downstream water quality.

In addition to the water sampling described in Section 6.4, dust and dirt accumulation at the plant site was measured and analyzed to determine its constituents. The stormwater runoff from the coal and ash piles as well as the runoff from the dust and dirt constituted the sources of non-point source pollution input to the model. The pollutants modeled included total suspended solids, dissolved solids, sulfates, total iron, manganese, and aluminum.

Land and river areas were divided into discrete elements for modeling purposes, as depicted in Figure 6-2. Input data required for the river elements are, for the nodes: (1) water surface elevation, (2) surface area, (3) depth of bottom, and (4) Manning coefficient, and for the channels: (1) channel length, (2) width, (3) depth, (4) Manning coefficient, and (5) initial velocity. Input data for the land elements include the physical dimensions of the runoff collection system as outlined in Table 6-1.

Timesteps were chosen for the model, with 60 seconds for the hydraulic river model, 720 seconds for the RECEIV II Quality model, and 900 seconds for the SSWMM stormwater model. In addition, storm activity was recorded and rainfall intensity was input to SSWMM, as well as background river and non-storm-related source flows.

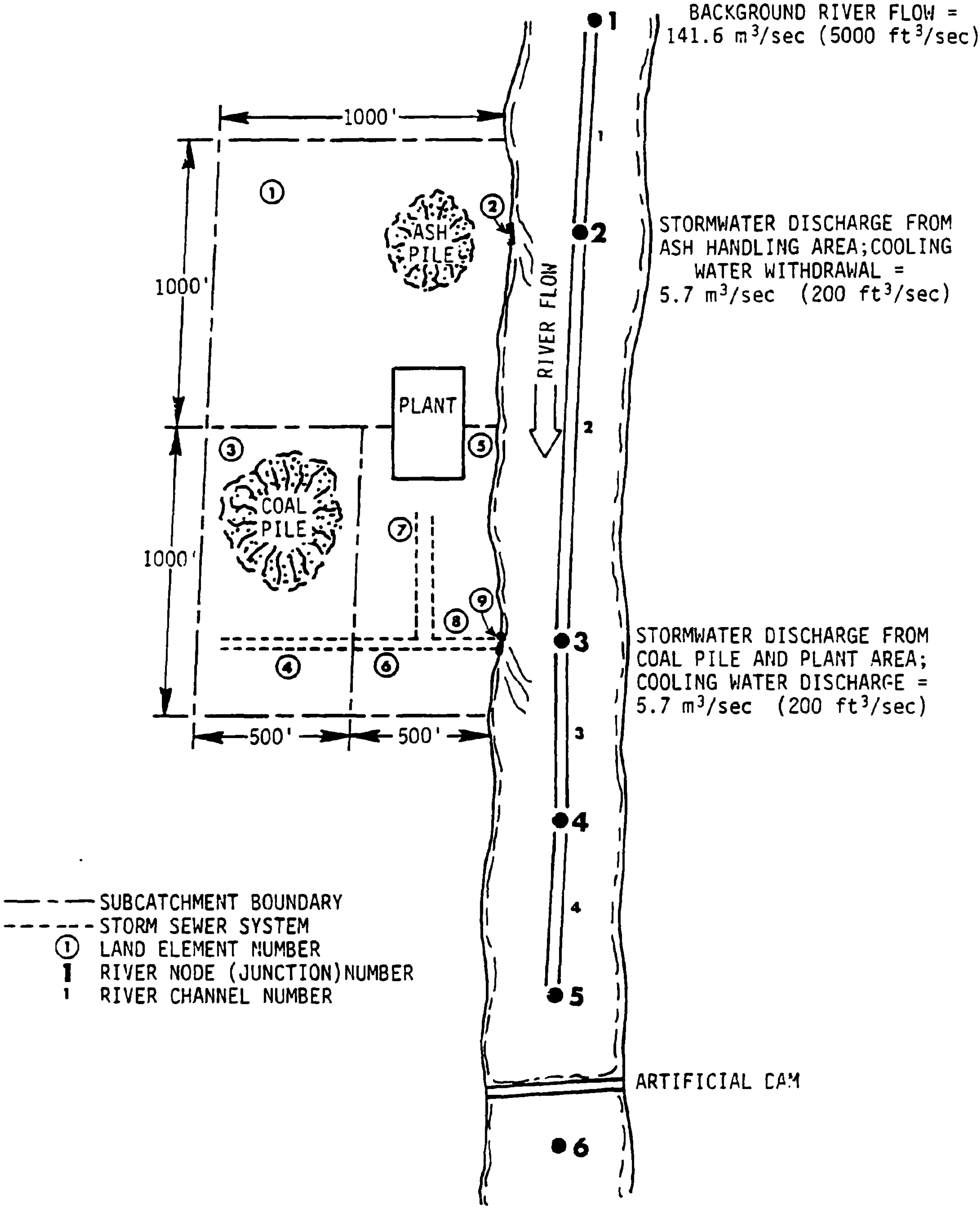

Figure 6-2: Land and river model element schematic, coal-fired utility station example case

TABLE 6-1

PHYSICAL DIMENSIONS OF LAND ELEMENTS

COAL-FIRED UTILITY STATION EXAMPLE CASE

Element Number	Description	Type*	Area (Acres) or Pipe Diam. (ft)	Slope (ft/ft)	Width Overland Flow (ft) or Pipe Length (ft)	% Imperviousness
1	Ash Handling Area (Dust & Dirt Accumulation)	1	23.0	.01	1000.	50.
2	Inlet to River for Ash Handling Area	2	----	---	-----	----
3	Coal Pile Area (Pile & Dust & Dirt Accumulation)	1	11.5	.01	500.	100.
4	Storm Sewer Draining Coal Pile Area	2	1.5	.01	335.	----
5	Plant Area (Dust & Dirt Accumulation)	1	11.5	.01	2000.	100.
6	Storm Sewer Draining Coal Pile Area	2	1.5	.01	250.	----
7	Storm Sewer Draining Plant Area	2	1.5	.01	667.	----
8	Storm Sewer Draining Coal Pile & Plant Areas	2	3.0	.01	250.	----
9	Inlet to River for Coal Pile & Plant Areas	2	----	---	-----	----

* 1 = Subcatchment
  2 = Gutter (Pipe or Inlet)

NOTE: For a subcatchment, use area, slope, width of overland flow, and percent imperviousness. For a gutter (pipe), use pipe diameter, slope, and pipe length. For a gutter (inlet), just identify type.

Selected results from the case run are presented for each program in SSWMM-RECEIV II (SSWMM, LNKPRG, SETUP/QUANTITY, and QUALITY) in Tables A-1, A-2, A-3, and A-4 in the Appendix. Selected SSWMM results (Table A-1) include the pollutant mass loads on each subcatchment prior to the storm, flow and pollutant mass loading information for each inlet to the river at time 50,400 seconds of Day 2, total rainfall, total infiltration, total runoff, total surface storage, percentage error for unaccounted water during the storm period, and the total storm-induced pollutant loads for each inlet to the river. Selected LNKPRG results (Table A-2) include background river and power plant cooling water loadings. Other selected LNKPRG results include flows and stormwater pollutant concentrations from SSWMM. The selected results from SETUP/QUANTITY (Table A-3) include the head or water level at each node and the river flow and velocity in each channel. Selected QUALITY results (Table A-4) include the pollutant concentrations at each node (junction) in the river and the maximum, minimum, and average pollutant concentrations for each node in the river for Day 2.

6.6 Conclusion

This hypothetical case of an industrial runoff study demonstrates how such a study is planned and enacted. The costs incurred in the project can be developed from the cost data presented in Section 5.

The case of the coal-fired utility plant is based on TRC's collective efforts in this field. It has been outlined to show in an uncomplicated manner a diverse number of runoff sources and the measurement and modeling that can be used to address the impact of industrial runoff.

REFERENCES

[1]EPA-600/2-77-199 Sampling and Modeling of Non-Point Sources at a Coal-Fired Utility by TRC - THE RESEARCH CORPORATION of New England for the Industrial Environmental Research Laboratory, Research Laboratory, Research Triangle Park, N.C.

[2]EPA-625-16-74-003 Methods for Chemical Analysis of Water and Wastes, U.S. Environmental Protection Agency, Washington, D.C. (1974).

[3]Technical Bulletin No. 183, National Council of the Paper Industry for Air and Stream Improvement, June 1965.

[4]EPA-600/4-77-031 Sampling of Water and Wastewater, Shelley, P., Office of Research and Development, U.S. EPA.

[5]Stevens Water Resources Data Book, Leupold & Stevens, Inc., June 1975.

[6]Experimental Statistics, Handbook 91, U.S. Dept. of Commerce, 1966.

[7]New England River Basins Modeling Project Final Report, Volume III-Documentation Report, Part I-RECEIV II Water Quantity and Quality Model, Raytheon Company (Washington, D.C.: U.S. Environmental Protection Agency), EPA Contract No. 68-01-1890, December 1974.

[8]Stormwater Management Model, Metcalf & Eddy, University of Florida and Water Resources Engineers, Inc., 4 Volumes, U.S. EPA Report Nos. 11024 DOC 7/71, 8/71, 9/71, and 10/71.

APPENDIX

SELECTED RESULTS - SSWMM-RECEIV II MODEL

CASE RUN FOR EXAMPLE
INDUSTRIAL NON-POINT SOURCE RUNOFF STUDY

TABLE A-1

TRC SSWMM SELECTED MODEL RESULTS
COAL-FIRED UTILITY STATION EXAMPLE CASE

```
 POLLUTANT CONCENTRATIONS AND INITIAL MASS LOADS AREPRINTED OUT FOR 6 CONSTITUENTS.
THESE CONSTITUENTS, IN ORDER, ARE.....
                2-----TOTAL SUSPENDED SOLIDS
                3-----SULFATES
                4-----TOTAL IRON
                5-----MANGANESE
                6-----ALUMINUM
                7-----TOTAL DISSOLVED SOLIDS

ON WATERSHED  1 THERE ARE 1.1340E 07 GRAMS OF DUST AND DIRT.

            THE MG CONTENT OF EACH CONSTITUENT ONTHIS WATERSHED IS
            0.0000E-01  1.1227E 10  1.1340E 07  2.2680E 08  5.6700E 06  5.6700E 07  1.1340E 08  0.0000E-01

            THE MG CONTENT OF EACH CONSTITUENT IN THE CATCHBASINS FOR THIS WATERSHED IS
            0.0000E-01  0.0000E-01  0.0000E-01  0.0000E-01  0.0000E-01  0.0000E-01  0.0000E-01  0.0000E-01

ON WATERSHED  3 THERE ARE 5.6700E 06 GRAMS OF DUST AND DIRT.

            THE MG CONTENT OF EACH CONSTITUENT ONTHIS WATERSHED IS
            0.0000E-01  5.6133E 09  5.6700E 06  1.1340E 08  2.8350E 06  2.8350E 07  5.6700E 07  0.0000E-01

            THE MG CONTENT OF EACH CONSTITUENT IN THE CATCHBASINS FOR THIS WATERSHED IS
            0.0000E-01  0.0000E-01  0.0000E-01  0.0000E-01  0.0000E-01  0.0000E-01  0.0000E-01  0.0000E-01

ON WATERSHED  5 THERE ARE 5.6700E 06 GRAMS OF DUST AND DIRT.

            THE MG CONTENT OF EACH CONSTITUENT ONTHIS WATERSHED IS
            0.0000E-01  5.6133E 09  5.6700E 06  1.1340E 08  2.8350E 06  2.8350E 07  5.6700E 07  0.0000E-01

            THE MG CONTENT OF EACH CONSTITUENT IN THE CATCHBASINS FOR THIS WATERSHED IS
            0.0000E-01  0.0000E-01  0.0000E-01  0.0000E-01  0.0000E-01  0.0000E-01  0.0000E-01  0.0000E-01
```

TABLE A-1
(Cont'd)

COAL FIRED UTILITY STATION EXAMPLE CASE

SUMMARY OF QUANTITY AND QUALITY RESULTS FOR TIME 50400.
QUANTITY - FLOW IN CU FT/SEC
QUALITY - POLLUTANT LOADINGS IN LB/MIN; COLIFORMS (IF MODELED) IN MPN/MIN

ELEMENT	FLOW		TSS	SULFATES	TOTAL FE	MANGANESE	ALUMINUM	TDS
2	2.83	0.000	36.313	0.1641	3.282	0.082	0.821	1.641
9	5.50	0.000	46.401	0.1223	2.446	0.061	0.612	1.223

TABLE A-2

TRC LNKPRG SELECTED MODEL RESULTS
COAL-FIRED UTILITY STATION EXAMPLE CASE

BACKGROUND INFORMATION AT TIME = D. IS AS FOLLOWS
FLOW IN CU M/SEC
POLLUTANT LOADINGS IN MG/SEC; COLIFORMS (IF MODELED) IN MPNE+06/SEC.

PTSRC	FLOW	SO4	TOTFE	MN				AL			TDS	TSS
3	141.6000	0.1E 07	42480.0	4250.0	0.0	0.0	0.0	141600.0	0.0	0.0	0.7E 07	0.1E 07
4	-5.7000	57000.0	1710.0	170.0	0.0	0.0	0.0	5700.0	0.0	0.0	285000.0	57000.0
5	5.7000	57000.0	1710.0	170.0	0.0	0.0	0.0	5700.0	0.0	0.0	285000.0	57000.0

TABLE A-2
(Cont'd)

INPUT INTO RECEIV II AT TIME 50400. SEC ARE AS FOLLOWS
FLOW IN CU M/SEC
POLLUTANT LOADINGS IN MG/SEC; COLIFORMS (IF MODELED) IN MPNE+06/SEC.

INLET	FLOW	SO4	TOTFE	MN				AL			TDS	TSS
1	0.0802	1240.6	24812.1	620.3	0.0	0.0	0.0	6203.0	0.0	0.0	12406.0	289644.4
2	0.1559	924.6	18491.7	462.3	0.0	0.0	0.0	4622.9	0.0	0.0	9245.8	350788.1

TABLE A-3

TRC RECEIV II SETUP/QUANTITY SELECTED MODEL RESULTS
COAL-FIRED UTILITY STATION EXAMPLE CASE

EXAMPLE RUN 1
ALL LOADINGS TREATED AS FINITE SOURCES

BASIN CONTAINS 3 SUBCATCHMENTS,4 PIPES,AND 2 INLETS   TOTAL AREA=46 ACRES

DAY IS 2

*********************** T I M E H I S T O R Y O F S T A G E ***********************

HOUR	JUNCTION 1 HEAD(M)	JUNCTION 2 HEAD(M)	JUNCTION 3 HEAD(M)	JUNCTION 4 HEAD(M)	JUNCTION 5 HEAD(M)	JUNCTION 6 HEAD(M)
0.00	2.52	2.29	2.05	1.76	0.90	255.55
0.20	2.52	2.29	2.05	1.76	0.90	257.59
0.40	2.52	2.29	2.05	1.76	0.90	259.62
0.60	2.52	2.29	2.05	1.76	0.90	261.66
0.80	2.52	2.29	2.05	1.76	0.90	263.70
1.00	2.52	2.29	2.05	1.76	0.90	265.73
1.20	2.52	2.29	2.05	1.76	0.90	267.77
1.40	2.52	2.29	2.05	1.76	0.90	269.80
1.60	2.52	2.29	2.05	1.76	0.90	271.84
1.80	2.52	2.29	2.05	1.76	0.90	273.88
2.00	2.52	2.29	2.05	1.76	0.90	275.91
2.20	2.52	2.29	2.05	1.76	0.90	277.95
2.40	2.52	2.29	2.05	1.76	0.90	279.98
2.60	2.52	2.29	2.05	1.76	0.90	282.02
2.80	2.52	2.29	2.05	1.76	0.90	284.06
3.00	2.52	2.29	2.05	1.76	0.90	286.09
3.20	2.52	2.29	2.05	1.76	0.90	288.13
3.40	2.52	2.29	2.05	1.76	0.90	290.16
3.60	2.52	2.29	2.05	1.76	0.90	292.20
3.80	2.52	2.29	2.05	1.76	0.90	294.24
4.00	2.52	2.29	2.05	1.76	0.90	296.27
4.20	2.52	2.29	2.05	1.76	0.90	298.31
4.40	2.52	2.29	2.05	1.76	0.90	300.35
4.60	2.52	2.29	2.05	1.76	0.90	302.38
4.80	2.52	2.29	2.05	1.76	0.90	304.42
5.00	2.52	2.29	2.05	1.76	0.90	306.45
5.20	2.52	2.29	2.05	1.76	0.90	308.49
5.40	2.52	2.29	2.05	1.76	0.90	310.53
5.60	2.52	2.29	2.05	1.76	0.90	312.56
5.80	2.52	2.29	2.05	1.76	0.90	314.60
6.00	2.52	2.29	2.05	1.76	0.90	316.63
6.20	2.52	2.29	2.05	1.76	0.90	318.67
6.40	2.52	2.29	2.05	1.76	0.90	320.71
6.60	2.52	2.29	2.05	1.76	0.90	322.74
6.80	2.52	2.29	2.05	1.76	0.90	324.78
7.00	2.52	2.29	2.05	1.76	0.90	326.82
7.20	2.52	2.29	2.05	1.76	0.90	328.85
7.40	2.52	2.29	2.05	1.76	0.90	330.89
7.60	2.52	2.29	2.05	1.76	0.90	332.92

TABLE A-3
(Cont'd)

7.80	2.52	2.29	2.05	1.76	0.90	334.96
8.00	2.52	2.29	2.05	1.76	0.90	337.00
8.20	2.52	2.29	2.05	1.76	0.90	339.03
8.40	2.52	2.29	2.05	1.76	0.90	341.07
8.60	2.52	2.29	2.05	1.76	0.90	343.10
8.80	2.52	2.29	2.05	1.76	0.90	345.14
9.00	2.52	2.29	2.05	1.76	0.90	347.18
9.20	2.52	2.29	2.05	1.76	0.90	349.21
9.40	2.52	2.29	2.05	1.76	0.90	351.25
9.60	2.52	2.29	2.05	1.76	0.90	353.28
9.80	2.52	2.29	2.05	1.76	0.90	355.32
10.00	2.52	2.29	2.05	1.76	0.90	357.36
10.20	2.52	2.29	2.05	1.76	0.90	359.39
10.40	2.52	2.29	2.05	1.76	0.90	361.43
10.60	2.52	2.29	2.05	1.76	0.90	363.47
10.80	2.52	2.29	2.05	1.76	0.90	365.50
11.00	2.52	2.29	2.05	1.76	0.90	367.54
11.20	2.52	2.29	2.05	1.76	0.90	369.57
11.40	2.52	2.29	2.05	1.76	0.90	371.61
11.60	2.52	2.29	2.05	1.76	0.90	373.65
11.80	2.52	2.29	2.05	1.76	0.90	375.68
12.00	2.52	2.29	2.05	1.76	0.90	377.72
12.20	2.52	2.29	2.05	1.76	0.90	379.75
12.40	2.52	2.29	2.05	1.76	0.90	381.79
12.60	2.52	2.29	2.05	1.76	0.90	383.83
12.80	2.52	2.29	2.05	1.76	0.90	385.86
13.00	2.52	2.29	2.05	1.76	0.90	387.90
13.20	2.52	2.29	2.05	1.76	0.90	389.94
13.40	2.52	2.29	2.05	1.76	0.90	391.98
13.60	2.52	2.29	2.05	1.76	0.90	394.02
13.80	2.52	2.29	2.05	1.76	0.90	396.06
14.00	2.52	2.29	2.05	1.76	0.90	398.10
14.20	2.53	2.29	2.05	1.76	0.90	400.14
14.40	2.53	2.29	2.05	1.76	0.90	402.18
14.60	2.53	2.29	2.05	1.76	0.90	404.22
14.80	2.52	2.29	2.05	1.76	0.90	406.26
15.00	2.52	2.29	2.05	1.76	0.90	408.30
15.20	2.52	2.29	2.05	1.76	0.90	410.34
15.40	2.52	2.29	2.05	1.76	0.90	412.37
15.60	2.52	2.29	2.05	1.76	0.90	414.41
15.80	2.52	2.29	2.05	1.76	0.90	416.45
16.00	2.52	2.29	2.05	1.76	0.90	418.49
16.20	2.52	2.29	2.05	1.76	0.90	420.53
16.40	2.52	2.29	2.05	1.76	0.90	422.57
16.60	2.52	2.29	2.05	1.76	0.90	424.61
16.80	2.52	2.29	2.05	1.76	0.90	426.65
17.00	2.52	2.29	2.05	1.76	0.90	428.69
17.20	2.52	2.29	2.05	1.76	0.90	430.73
17.40	2.52	2.29	2.05	1.76	0.90	432.77
17.60	2.52	2.29	2.05	1.76	0.90	434.80
17.80	2.52	2.29	2.05	1.76	0.90	436.84
18.00	2.52	2.29	2.05	1.76	0.90	438.88
18.20	2.52	2.29	2.05	1.76	0.90	440.92
18.40	2.52	2.29	2.05	1.76	0.90	442.95

TABLE A-3
(Cont'd)

18.60	2.52	2.29	2.05	1.76	0.90	444.99
18.80	2.52	2.29	2.05	1.76	0.90	447.03
19.00	2.52	2.29	2.05	1.76	0.90	449.06
19.20	2.52	2.29	2.05	1.76	0.90	451.10
19.40	2.52	2.29	2.05	1.76	0.90	453.14
19.60	2.52	2.29	2.05	1.76	0.90	455.17
19.80	2.52	2.29	2.05	1.76	0.90	457.21
20.00	2.52	2.29	2.05	1.76	0.90	459.24
20.20	2.52	2.29	2.05	1.76	0.90	461.28
20.40	2.52	2.29	2.05	1.76	0.90	463.32
20.60	2.52	2.29	2.05	1.76	0.90	465.35
20.80	2.52	2.29	2.05	1.76	0.90	467.39
21.00	2.52	2.29	2.05	1.76	0.90	469.42
21.20	2.52	2.29	2.05	1.76	0.90	471.46
21.40	2.52	2.29	2.05	1.76	0.90	473.50
21.60	2.52	2.29	2.05	1.76	0.90	475.53
21.80	2.52	2.29	2.05	1.76	0.90	477.57
22.00	2.52	2.29	2.05	1.76	0.90	479.61
22.20	2.52	2.29	2.05	1.76	0.90	481.64
22.40	2.52	2.29	2.05	1.76	0.90	483.68
22.60	2.52	2.29	2.05	1.76	0.90	485.71
22.60	2.52	2.29	2.05	1.76	0.90	487.75
23.00	2.52	2.29	2.05	1.76	0.90	489.79
23.20	2.52	2.29	2.05	1.76	0.90	491.82
23.40	2.52	2.29	2.05	1.76	0.90	493.86
23.60	2.52	2.29	2.05	1.76	0.90	495.89
23.80	2.52	2.29	2.05	1.76	0.90	497.93
24.00	2.52	2.29	2.05	1.76	0.90	499.97

TABLE A-3
(Cont'd)

EXAMPLE RUN 1
ALL LOADINGS TREATED AS FINITE SOURCES

BASIN CONTAINS 3 SUBCATCHMENTS,4 PIPES,AND 2 INLETS   TOTAL AREA=46 ACRES

DAY IS 2

* * * * * * * * * * * * * * * T I M E H I S T O R Y O F F L O W A N D V E L O C I T Y * * * * * * * * * * * * * * *

HOUR	CHANNEL 1 2 FLOW CU M/S	CHANNEL 1 2 VEL. M/S	CHANNEL 2 3 FLOW CU M/S	CHANNEL 2 3 VEL. M/S	CHANNEL 3 4 FLOW CU M/S	CHANNEL 3 4 VEL. M/S	CHANNEL 4 5 FLOW CU M/S	CHANNEL 4 5 VEL. M/S	CHANNEL 4 5 FLOW CU M/S	CHANNEL 4 5 VEL. M/S	CHANNEL 4 5 FLOW CU M/S	CHANNEL 4 5 VEL. M/S
0.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
0.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
0.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
0.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
0.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
1.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
1.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
1.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
1.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
1.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
2.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
2.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
2.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
2.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
2.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
3.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
3.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
3.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
3.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
3.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
4.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
4.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
4.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
4.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
4.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
5.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
5.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
5.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
5.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
5.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
6.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
6.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
6.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
6.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
6.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
7.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
7.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				
7.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258				

TABLE A-3
(Cont'd)

7.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
7.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
8.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
8.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
8.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
8.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
8.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
9.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
9.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
9.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
9.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
9.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
10.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
10.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
10.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
10.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
10.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
11.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
11.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
11.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
11.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
11.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
12.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
12.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
12.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
12.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
12.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
13.00	141.60	0.882	135.90	0.865	141.61	0.941	141.60	1.258
13.20	141.60	0.882	135.91	0.865	141.62	0.941	141.62	1.258
13.40	141.59	0.881	135.92	0.865	141.66	0.942	141.65	1.258
13.60	141.59	0.881	135.93	0.865	141.71	0.942	141.69	1.258
13.80	141.59	0.881	135.95	0.865	141.75	0.942	141.73	1.259
14.00	141.59	0.881	135.96	0.865	141.79	0.942	141.78	1.259
14.20	141.59	0.881	135.97	0.865	141.82	0.942	141.81	1.259
14.40	141.60	0.881	135.97	0.865	141.81	0.942	141.81	1.259
14.60	141.61	0.881	135.97	0.865	141.79	0.942	141.80	1.259
14.80	141.61	0.881	135.95	0.865	141.76	0.942	141.78	1.259
15.00	141.60	0.881	135.95	0.865	141.73	0.942	141.74	1.259
15.20	141.60	0.881	135.94	0.865	141.69	0.942	141.70	1.258
15.40	141.60	0.881	135.93	0.865	141.67	0.942	141.68	1.258
15.60	141.60	0.882	135.92	0.865	141.65	0.942	141.66	1.258
15.80	141.60	0.882	135.91	0.865	141.63	0.941	141.64	1.258
16.00	141.60	0.882	135.91	0.865	141.62	0.941	141.63	1.258
16.20	141.60	0.882	135.91	0.865	141.62	0.941	141.62	1.258
16.40	141.60	0.882	135.90	0.865	141.61	0.941	141.61	1.258
16.60	141.60	0.882	135.90	0.865	141.61	0.941	141.61	1.258
16.80	141.60	0.882	135.90	0.865	141.61	0.941	141.61	1.258
17.00	141.60	0.882	135.90	0.865	141.61	0.941	141.60	1.258
17.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
17.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
17.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
17.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
18.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
18.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258

TABLE A-3
(Cont'd)

18.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
18.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
18.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
19.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
19.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
19.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
19.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
19.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
20.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
20.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
20.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
20.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
20.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
21.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
21.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
21.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
21.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
21.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
22.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
22.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
22.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
22.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
22.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
23.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
23.20	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
23.40	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
23.60	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
23.80	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258
24.00	141.60	0.882	135.90	0.865	141.60	0.941	141.60	1.258

TABLE A-4

TRC RECEIV II QUALITY SELECTED MODEL RESULTS
COAL-FIRED UTILITY STATION EXAMPLE CASE

EXAMPLE RUN 1
ALL LOADINGS TREATED AS FINITE SOURCES

BASIN CONTAINS 3 SUBCATCHMENTS,4 PIPES,AND 2 INLETS   TOTAL AREA=46 ACRES

JUNCTION CONCENTRATIONS, DURING TIME CYCLE   2 ,QUALITY CYCLE 70. UNITS ARE MG/L, EXCEPT 10**6 MPN/L COLIFORMS.

JUNCTION	SULFATES	TOTAL FE	MANGANESE	ALUMINUM	TDS	TSS
1	10.000	0.300	0.030	1.000	50.000	10.000
2	10.003	0.471	0.034	1.042	50.058	11.638
3	9.999	0.566	0.037	1.365	50.060	12.819
4	9.999	0.528	0.036	1.056	50.051	12.001
5	9.998	0.485	0.035	1.045	50.035	11.393
6	9.000	0.200	0.020	0.900	45.000	9.000

TABLE A-4
(Cont'd)

```
EXAMPLE RUN 1
ALL LOADINGS TREATED AS FINITE SOURCES

        AVERAGE JUNCTION CONCENTRATIONS DURING TIDAL OR TIME CYCLE    2, CONSTITUENT NUMBER   1     SULFATES

                   1          2          3          4          5          6          7          8          9          10
  JUNCTIONS.

BASIN CONTAINS 3 SUBCATCHMENTS,4 PIPES,AND 2 INLETS          TOTAL AREA=46 ACRES
  1  TO   6 0.1000E 020.1000E 020.1000E 020.1000E 020.1000E 020.9000E 01

                                                    MAXIMUMS
  JUNCTION
  1  TO   6 0.1000E 020.1000E 020.1000E 020.1000E 020.1000E 020.9000E 01

                                                    MINIMUMS
  JUNCTION
  1  TO   6 0.1000E 020.1000E 020.9998E 010.9998E 010.9995E 010.9000E 01
```

TABLE A-4
(Cont'd)

```
EXAMPLE RUN 1
ALL LOADINGS TREATED AS FINITE SOURCES


        AVERAGE JUNCTION CONCENTRATIONS DURING TIDAL OR TIME CYCLE    2, CONSTITUENT NUMBER   2     TOTAL FE

                 1         2         3         4         5         6         7         8         9        10
  JUNCTIONS.

BASIN CONTAINS 3 SUBCATCHMENTS,4 PIPES,AND 2 INLETS          TOTAL AREA=46 ACRES
 1  TO    6 0.3000E 000.3107E 000.3178E 000.3176E 000.3178E 000.2000E 00

                                                   MAXIMUMS
 JUNCTION
 1  TO    6 0.3000E 000.4761E 000.6034E 000.6129E 000.6188E 000.2000E 00

                                                   MINIMUMS
 JUNCTION
 1  TO    6 0.3000E 000.3000E 000.3000E 000.3000E 000.2818E 000.2000E 00
```

TABLE A-4
(Cont'd)

```
EXAMPLE RUN 1
ALL LOADINGS TREATED AS FINITE SOURCES

          AVERAGE JUNCTION CONCENTRATIONS DURING TIDAL OR TIME CYCLE    2, CONSTITUENT NUMBER   6     TSS

                  1         2         3         4         5         6         7         8         9         10
   JUNCTIONS.

BASIN CONTAINS 3 SUBCATCHMENTS,4 PIPES,AND 2 INLETS         TOTAL AREA=46 ACRES
  1  TO    6 0.1000E 020.1010E 020.1023E 020.1023E 020.1023E 020.9000E 01

                                                          MAXIMUMS
  JUNCTION
  1  TO    6 0.1000E 020.1215E 020.1477E 020.1507E 020.1602E 020.9000E 01

                                                          MINIMUMS
  JUNCTION
  1  TO    6 0.1000E 020.1000E 020.1000E 020.1000E 020.9989E 010.9000E 01
```

EXAMPLE RUN 1
ALL LOADINGS TREATED AS FINITE SOURCES

AVERAGE JUNCTION CONCENTRATIONS DURING TIDAL OR TIME CYCLE 2, CONSTITUENT NUMBER 3 MANGANESE

```
                 1         2         3         4         5         6         7         8         9        10
  JUNCTIONS.

BASIN CONTAINS 3 SUBCATCHMENTS,4 PIPES,AND 2 INLETS          TOTAL AREA=46 ACRES
  1  TO   6 0.3001E-010.3028E-010.3045E-010.3045E-010.3045E-010.2000E-01

                                                          MAXIMUMS
  JUNCTION
  1  TO   6 0.3001E-010.3440E-010.3755E-010.3779E-010.3794E-010.2000E-01

                                                          MINIMUMS
  JUNCTION
  1  TO   6 0.3001E-010.3001E-010.3001E-010.3001E-010.2955E-010.2000E-01
```

TABLE A-4
(Cont'd)

```
EXAMPLE RUN 1
ALL LOADINGS TREATED AS FINITE SOURCES


          AVERAGE JUNCTION CONCENTRATIONS DURING TIDAL OR TIME CYCLE    2. CONSTITUENT NUMBER  4     ALUMINUM

                    1         2         3         4         5         6         7         8         9        10
   JUNCTIONS.

BASIN CONTAINS 3 SUBCATCHMENTS,4 PIPES,AND 2 INLETS         TOTAL AREA=46 ACRES
  1  TO    6 0.1000E 010.1003E 010.1004E 010.1004E 010.1004E 010.9000E 00

                                                         MAXIMUMS
  JUNCTION
  1  TO    6 0.1000E 010.1043E 010.1074E 010.1077E 010.1078E 010.9000E 00

                                                         MINIMUMS
  JUNCTION
  1  TO    6 0.1000E 010.1000E 010.1000E 010.1000E 010.9952E 000.9000E 00
```

TABLE A-4
(Cont'd)

```
EXAMPLE RUN 1
ALL LOADINGS TREATED AS FINITE SOURCES



        AVERAGE JUNCTION CONCENTRATIONS DURING TIDAL OR TIME CYCLE    2, CONSTITUENT NUMBER   5     TDS

                  1         2         3         4         5         6         7         8         9        10
   JUNCTIONS.

BASIN CONTAINS 3 SUBCATCHMENTS,4 PIPES,AND 2 INLETS         TOTAL AREA=46 ACRES
  1  TO   6 0.5000E 020.5000E 020.5000E 020.5000E 020.5000E 020.4500E 02

                                                          MAXIMUMS
  JUNCTION
  1  TO   6 0.5000E 020.5006E 020.5007E 020.5007E 020.5007E 020.4500E 02

                                                          MINIMUMS
  JUNCTION
  1  TO   6 0.5000E 020.5000E 020.5000E 020.5000E 020.4998E 020.4500E 02
```

TECHNICAL REPORT DATA *(Please read Instructions on the reverse before completing)*		
1. REPORT NO. EPA-600/7-79-049	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Technical Manual for the Measurement and Modeling of Non-point Sources at an Industrial Site on a River		5. REPORT DATE February 1979
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) G.T. Brookman, J.J. Binder, P.B. Katz, and W.A. Wade, III		8. PERFORMING ORGANIZATION REPORT NO.
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16. ABSTRACT The manual provides a guide for the implementation of a measurement and modeling program for non-point sources at an industrial site on a river. Criteria for developing a field survey program and model selection are provided, along with program costs and manpower requirements. A sample list of equipment and computer costs is also provided. The development of a field survey includes sample site selection, selection of parameters to be measured, number and frequency of samples, collection methods, analytical methods, and data reduction and analysis. Included in the modeling section is a description of the SSWMM-RECEIV-II model which has been adapted to a coal-fired utility site. Application of the outlined procedures to the measurement of non-point sources from a coal-fired utility is also presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Leaching	Pollution Control	13B	07D,07A
Utilities	Dust	Stationary Sources		11G
Measurement		Non-Point Sources	14B	
Mathematical Models			12A	
Runoff			08H	
Stream Pollution				

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