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POLLUTANT LOADINGS AND IMPACTS FROM HIGHWAY STORMWATER RUNOFF

Volume I: Design Procedure

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16. Abstract
This is one of four final documents of an investigation dealing with the characterization of stormwater runoff pollutant loads from highways, and the prediction of water quality impacts they cause. Study results are based on monitoring data from 993 individual storm events at 31 highway runoff sites in 11 States. Impact prediction is based on a methodology previously developed and applied to urban runoff and adapted for highway runoff applications. This document provides a step-by-step procedure for computing the estimated impacts on water quality of a stream or lake that receives highway runoff. Guidance is provided for evaluating whether or not a water quality problem will result, and the degree of pollution control required to mitigate impacts to acceptable levels.
The four publications resulting from this study are:

FHWA-RD-88-006, Volume I: Design Procedure. This document.

FHWA-RD-88-007, Volume II: Users Guide for Interactive Computer Implementation of Design Procedure. A Users Guide for an interactive computer based user-friendly version of the design procedure of document FHWA-RD-88-006 .

FHWA-RD-88-008, Volume III: Analytical Investigation and Research Report. The basic research report, which provides a description of the analysis procedures employed and a summary and discussion of study results.

FHWA-RD-88-009, Volume IV: Research Report Data Appendix.

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FOREWORD

The highway system is a potential source of a wide variety of possible pollutants to surrounding surface and subsurface waters through the mechanisms of the natural hydrologic cycle. The effects of a highway system on the environment plays an increasingly important role in the planning, design, construction, and operation of a transportation system. The Federal Highway Administration and State highway agencies, charged with the responsibility of protecting the environment from pollution from highway sources, have approached the problem in a multi-phase, multi-million dollar research effort including studies to:

Phase 1 - Identify and quantify the constituents of highway runoff.
Phase 2 - Identify the sources and migration paths of these pollutants from the highways to the receiving waters.
Phase 3 - Analyze the effects of these pollutants in the receiving waters.
Phase 4 - Develop the necessary abatement/treatment methodology for objectionable constituents.

This investigation, primarily a Phase 3 item, is a culminating analytical effort utilizing other research studies and their data coupled with applied hydraulics and related environmental and highway concerns. A largely statistical based design procedure for estimating highway stormwater pollutant loadings is presented.

This publication will be of interest to research engineers and scientists and others wishing to study the technology background for highway runoff pollutant loading impacts to receiving water.

Sufficient copies of this publication are being distributed by FHWA memorandum to provide three copies to each FHWA Region. Additional copies for the public are available from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Thomas J. Paskø, Jr., P.E.
Director, Office of Engineering and Highway Operations Research and Development

NOTICE

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

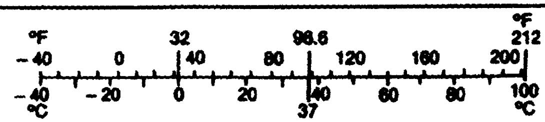
Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.093	metres squared	m²
yd²	square yards	0.836	metres squared	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	kilometres squared	km²
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.028	metres cubed	m³
yd³	cubic yards	0.765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

Symbol	When You Know	Multiply By	To Find	Symbol
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
ha	hectares	2.47	acres	ac
km²	kilometres squared	0.386	square miles	mi²
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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1.0 INTRODUCTION

The objective of this document is to describe a procedure for estimating impacts to the water quality of a stream or lake that directly receives highway stormwater runoff. A basis for deciding whether or not projected changes in water quality are likely to create problems is included in the procedure. For cases where a potential water quality problem is predicted, this document describes how to incorporate this analysis with the information provided in the Federal Highway Administration's (FHWA) performance characteristics given in the report, "Retention, Detention, and Overland Flow for Pollutant Removal From Highway Stormwater Runoff," to assess the ability of selected control measures to mitigate any anticipated problem conditions.(1)

The estimating procedure incorporates information presented in greater depth and detail in the research report (FHWA/RD-88-008) for this study. Information from the research report that is important to the procedure is provided in summary form in this document. However, the user should refer to the research report for further information on any of the condensed summaries included in this document.

This manual supplements and expands upon the widely used six-volume Envirex Report, issued in 1981, and reflects the continued FHWA effort to improve the ability to address highway stormwater runoff issues.(2) The data base utilized in this study included all of the Envirex data, but was considerably expanded by the inclusion of additional highway sites that were monitored after 1981. The additional sites help to provide national coverage. The regression analyses previously used for prediction of highway pollutants were, with the expanded data base, determined to be less suitable for broad, nationwide application than the predictive procedure developed in this study. However, the general conclusions on the quality characteristics of highway stormwater runoff remain unchanged. The main enhancement to the understanding of highway stormwater runoff provided by the methodology described in this volume is the presentation of procedures for evaluating whether or not the pollutant discharges projected to occur will cause water quality problems.

For highway discharges to lakes, the Vollenweider model is employed to predict whether phosphorus discharged by highway stormwater is likely to contribute significantly to eutrophication.(3) Phosphorus concentrations in highway runoff are on the same order of magnitude as those for the principal toxicants (heavy metals), and the concentration levels in lakes that produce adverse effects are roughly comparable. The results of the eutrophication analysis may be useful in a preliminary assessment of the potential problems associated with other pollutants such as metals.

For highway discharges to flowing streams (believed to be the most common water body receiving highway discharges), the impact analysis presented addresses the potential toxic effect on aquatic biota. The available data indicate that toxicants would be much more likely to be a problem before nutrients. Heavy metals considered (copper, lead and zinc) are indicated by available data to be the dominant toxic pollutants contributed by highway stormwater runoff. The procedure employed for this analysis is a probabilistic dilution model developed and applied in the Environmental Protection Agency's (EPA) Nationwide Urban Runoff Program (NURP), and reviewed and approved by EPA's Science Advisory Board.[4] It permits the user to compute the magnitude and frequency of occurrence of in-stream concentrations of a pollutant under the variable and intermittent discharges that are produced by stormwater runoff. The procedure compares the once-in-3-year concentration to an acutely toxic value that is specified at this frequency by EPA criteria.

An overview of the design procedure is shown schematically in figure 1. As indicated by this flow chart, each of the major elements of the procedure have been organized in a worksheet format. These elements are completed in sequence and lead the user step by step through the procedure. All necessary computations can be performed manually.

The remaining sections of this manual focus on individual worksheets and provide source material and discussion to guide the user in their use. The following is a brief outline of the organization and content of the remaining sections of this volume.

<u>Section 2.0 - Site Characteristics (Worksheet A)</u>
The data needed for the analyses are identified, and guidance for parameter estimation is provided. The parameters to be estimated include drainage areas, rainfall characteristics, pollutant concentrations in the runoff, the target concentrations to be used for comparison, and the stream flow for the watershed.

<u>Section 3.0 - Highway Runoff Characteristics (Worksheet B)</u>
The computations to estimate highway runoff volume and quality, using the data assembled in the previous step, are described in this section. Runoff flow rates and volumes, mass loading, and the ratio of runoff to stream flow are computed.

<u>Section 4.0 - Stream Impact Analysis (Worksheet C)</u>
This section describes the determination of the in-stream concentration of a pollutant and the evaluation of its problem potential using the information developed in the preceding worksheets. To facilitate the analysis, computational results, using typical values for variability of the flow rates, are summarized in a table. An appendix is included at the end of this document to provide additional detail on the stream impact methodology, and guidance on using it directly, rather than the table provided.

<u>Section 5.0 - Lake Impact Analysis (Worksheet D)</u>
This section describes the determination of the average lake concentration of a pollutant (phosphorus), and the evaluation of its problem potential.

<u>Section 6.0 - Further Analysis Iterations</u>
In cases where the results of an analysis fail to allow the user to conclude that a water quality problem is not likely, one or more iterations of the analysis are appropriate. Each iteration will incorporate either (a) modifications in input values produced by the application of control measures at the site, or (b) refinements in input values resulting from more accurate site-specific estimates of site characteristics. Discussion and guidance on modifying input parameters are provided in this section.

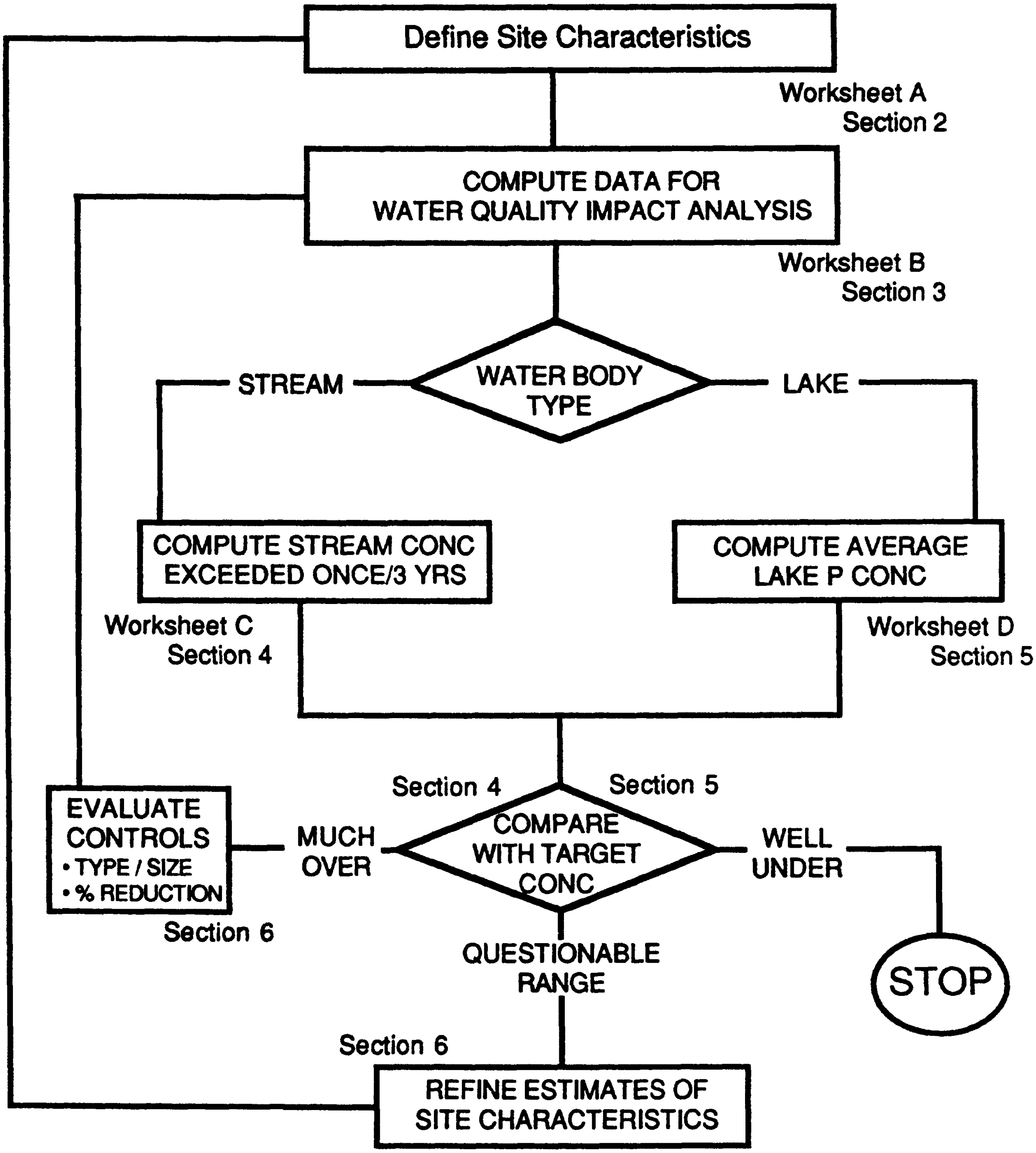


Figure 1. Outline of procedure for evaluating water quality impacts from highway stormwater runoff.

Section 7.0 - Example Use of Design Worksheets

This section provides a numerical example which illustrates the use of the design worksheets in performing a highway runoff impact analysis for a specific highway site.

Section 8.0 - References

2.0
SITE CHARACTERISTICS

This section identifies and discusses the parameters used as input for the computations. It provides data for estimating values for these parameters in a series of maps and tables. A brief discussion is provided summarizing the parameter estimation methodology, which is presented in greater depth and detail in the research report (FHWA/RD-88-008).

The site characteristics used in the evaluation procedure include information on drainage areas, area rainfall characteristics, the concentrations of pollutants in the highway runoff, the fraction of the total pollutant concentration that is in soluble form, and finally, the target receiving water concentration (against which the concentration produced by the highway runoff will be compared). This information is to be assembled in Design Worksheet A, illustrated in table 1, which is the first step in the sequence of the overall highway site evaluation procedure. Information and source material providing guidance for assigning the necessary input values are presented in the remainder of this section.

2.1 DRAINAGE AREAS

Input data required:

AROW = drainage area of total highway right of way (acres)
AHWY = area of highway pavement (acres)
ATOT = total upstream drainage area (square miles)

The design procedure requires the user to define the drainage area of the highway segment that contributes runoff to the receiving water. This includes the area of the full right-of-way (AROW), and also the area of paved surface (AHWY). These areas are reported as acres, and their ratio defines the percent impervious area (IMP). The latter is used (on the next worksheet) to estimate the runoff coefficient. The user must, in addition, define the area of the total watershed contributing flow to the stream or lake that receives the highway stormwater discharge. The watershed drainage area (ATOT) is reported in square miles.

2.2 RAINFALL CHARACTERISTICS

Input data required:

	Mean	Coef of Variation
Volume (inch)	MVP	CVVP
Intensity (in/hr)	MIP	CVIP
Duration (hours)	MDP	CVDP
Interval* (hours)	MTP	CVTP

* time interval between the midpoints of successive storm events.

Table 1. Worksheet A - Site characteristics.

1	Drainage Area of Highway Segment (Section 2.1)			
a	Total right of way	AROW	☐	acres
b	Paved surface	AHWY	☐	acres
c	Percent Impervious (= 100 * AHWY/AROW)	IMP	____	%
2	Rainfall Characteristics (Section 2.2)	MEAN		
a	Volume	MVP	☐	inch
b	Intensity	MIP	☐	inch / hour
c	Duration	MDP	☐	hour
d	Interval	MTP	☐	hour
		COEF of VARIATION		
e	Volume	CVVP	☐	dimensionless
f	Intensity	CVIP	☐	dimensionless
g	Duration	CVDP	☐	dimensionless
h	Interval	CVTP	☐	dimensionless
i	Number of storms per year (24*365/MTP)	NST	____	no. events
3	Surrounding Area Type			
a	ADT usually over 30,000 vehicles/day		URBAN ☐	
	or			
b	ADT usually under 30,000 vpd, undeveloped or suburban		RURAL ☐	
4	Select pollutant for analysis (section 2.4)		☐	name
	and			
	estimate runoff quality characteristics (use table 3)			
a	site median concentration	TCR	☐	mg/l
b	coef of variation (0.71 Urban : 0.84 Rural)	CVCR	☐	dimensionless
5	Select receiving water target concentration (section 2.6)			
	surface water Total Hardness (figure 5)	TH	☐	mg/l
	STREAM - use table 4 for target concentration			
a	EPA Acute Criterion	CTA	☐	mg/l
b	suggested Threshold Effect Level	CTT	☐	mg/l
	or			
	LAKE - use accepted level for average Phosphorus concentration			
c	target concentration is 10 micrograms/liter		10	ug/l
6	Watershed Drainage Area	ATOT	☐	square miles
	upstream of highway for a stream - total contributing area for a lake			
7	Average annual stream flow (section 2.3)			
a	unit area flow rate per square mile (figure 4)	QSM	☐	CFS/square mile
b	Coef of variation of stream flows (section 2.3)	CVQS	☐	dimensionless
c	Average stream flow (QSM * ATOT)	MQS	____	CFS

Symbols have been selected to assist in recognition of the variables they represent. For example, MVP designates Mean Volume - Precipitation; CVVP designates Coefficient of Variation of Volumes - Precipitation.

The tabulation above indicates the precipitation event statistics that are to be estimated for the site, and identifies the nomenclature used in the design procedure presented later. The required values can be computed using routine statistical procedures applied to a long-term hourly rain gauge record. The US Weather Service (Ashville NC) can provide the records for specified rain gauges. A disc that includes a microcomputer version of a computer program, SYNOP, that performs this analysis has been provided in association with study volume FHWA-RD-88-007.

Initial estimates of the necessary rainfall statistics may be made using figure 2, which summarizes typical values for different regions of the country. Note that the regions are quite broad, and that certain local areas could have quite different rainfall characteristics than those which apply for most of the region. An additional refinement in rainfall inputs will be possible in some cases by using the data summarized in table 2 for specific cities.

In situations where additional refinement for local site conditions is determined to be necessary, analysis of data from a local gauge will be required. In this case it will be necessary to secure the record for a long-term rain gauge in the area, and to analyze the record using the SYNOP program to determine the statistics of storm events. For additional detail refer to section 5.4 of the research report and the interactive user interface system provided with report volume FHWA-RD-88-007.

From the rainfall statistics indicated above, the average number of storms per year is computed as:

$$NST = \frac{365 * 24}{MTP} \tag{1}$$

where:

NST = average number of storms per year
MTP = average interval between storm midpoints (hours)

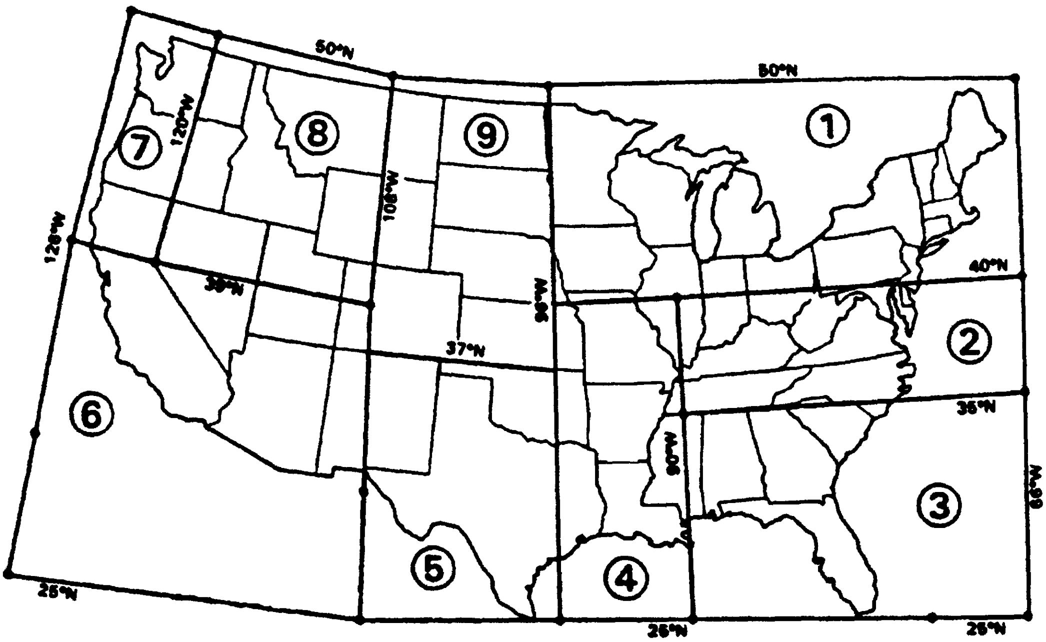
The intensity values will be used to compute runoff flow rates, which are used in the stream impact analysis. The rainfall volume values are used to compute runoff volumes and mass loads that are used in the lake impact analysis. The number of storms per year is used to determine the 3-year recurrence of a stream concentration in the stream impact analysis.

2.3 STREAM FLOW

Input data required:

MQS = annual average stream flow (CFS)
CVQS = coefficient of variation of daily flow rates

The analysis procedure requires an estimate of the annual average stream flow rate in cubic feet per second (CFS). For a stream impact analysis, the coefficient of variation of daily stream flows is also required. While stream impact analysis is concerned only with the flows in the



PRECIPITATION EVENT STATISTICS

ZONE	VOLUME (inches) mean MVP	VOLUME (inches) coef of var CVVP	INTENSITY (in/hr) mean MIP	INTENSITY (in/hr) coef of var CVIP	DURATION (hours) mean MDP	DURATION (hours) coef of var CVDP	INTERVAL (hours) mean MTP	INTERVAL (hours) coef of var CVTP
1	0.26	1.46	0.051	1.31	5.8	1.05	73	1.07
2	0.36	1.45	0.066	1.32	5.9	1.05	77	1.05
3	0.49	1.47	0.102	1.28	6.2	1.22	89	1.05
4	0.58	1.46	0.097	1.35	7.3	1.17	89	1.00
5	0.33	1.74	0.080	1.37	4.0	1.07	108	1.41
6	0.17	1.51	0.045	1.04	3.6	1.02	277	1.48
7	0.48	1.61	0.024	0.84	20.0	1.23	101	1.21
8	0.14	1.42	0.031	0.91	4.5	0.92	94	1.39
9	0.15	1.77	0.036	1.35	4.4	1.20	94	1.24

Figure 2. Rainfall input data for initial estimates.

Table 2. Rainfall event statistics for selected cities.

ZONE	CITY	STATE	VOLUME (inches) mean MVP	VOLUME (inches) coef. of var. CVVP	INTENSITY (in/hr) mean MIP	INTENSITY (in/hr) coef. of var. CVIP	DURATION (hours) mean MDP	DURATION (hours) coef. of var. CVDP	INTERVAL (hours) mean MTP	INTERVAL (hours) coef. of var. CVTP
1	Davenport	IA	0.38	1.37	0.077	1.24	6.6	1.40	98	1.01
1	Chicago	IL	0.27	1.59	0.053	1.54	5.7	1.08	72	1.00
1	Boston	MA	0.33	1.67	0.044	1.02	6.1	1.03	68	1.06
1	Caribou	ME	0.21	1.58	0.034	0.97	5.8	1.03	55	1.03
1	Detroit	MI	0.21	1.59	0.050	1.16	4.4	1.02	57	1.07
1	Lansing	MI	0.21	1.56	0.041	1.55	5.6	1.10	62	1.02
1	Minneapolis	MN	0.24	1.48	0.043	1.22	6.0	1.08	87	0.98
1	Kingston	NY	0.37	1.35	0.052	1.01	7.0	0.91	80	0.98
1	Mineola (Long Island)	NY	0.43	1.34	0.088	1.14	5.8	1.30	89	0.99
1	New York City	NY	0.37	1.37	0.053	1.04	6.7	0.93	77	0.89
1	Poughkeepsie	NY	0.35	1.31	0.052	0.95	6.9	0.87	81	0.95
1	Steubenville	OH	0.31	1.28	0.057	1.03	7.0	1.39	79	1.00
1	Toledo	OH	0.22	1.52	0.048	1.16	5.0	0.99	62	1.03
1	Providence	RI	0.39	1.57	0.050	1.26	6.7	1.03	75	0.98
2	Washington	DC	0.36	1.45	0.067	1.18	5.9	1.03	80	1.00
2	Champaign-Urbana	IL	0.35	1.47	0.063	1.37	6.1	1.02	80	1.02
2	Louisville	KY	0.38	1.45	0.064	1.42	6.7	1.08	76	1.00
2	Baltimore	MD	0.40	1.48	0.069	1.21	6.0	1.01	82	1.03
2	Asheville	NC	0.44	1.52	0.065	1.40	7.3	1.15	80	0.98
2	Charlotte	NC	0.46	1.39	0.069	1.33	7.9	1.10	94	0.97
2	Greensboro	NC	0.42	1.43	0.066	1.44	7.5	1.09	86	0.96
2	Raleigh-Durham	NC	0.44	1.30	0.070	1.35	7.5	1.07	93	0.96
2	Wilmington	NC	0.53	1.54	0.086	1.53	7.4	1.14	87	0.96
2	Zanesville	OH	0.30	1.24	0.061	1.01	6.1	0.93	77	1.03
3	Birmingham	AL	0.53	1.44	0.086	1.31	7.2	1.09	85	1.00
3	Gainesville	FL	0.64	1.35	0.139	1.14	7.6	1.66	106	1.06
3	Tampa	FL	0.40	1.63	0.110	1.21	3.6	1.11	93	1.10
3	Atlanta	GA	0.50	1.37	0.074	1.16	8.0	1.11	94	0.93
3	Columbia	SC	0.38	1.55	0.102	1.59	4.5	1.13	68	1.18

Table 2. Rainfall event statistics for selected cities (continued).

ZONE	CITY	STATE	VOLUME (inches) mean MVP	VOLUME (inches) coef of var CVVP	INTENSITY (in/hr) mean MIP	INTENSITY (in/hr) coef of var CVIP	DURATION (hours) mean MDP	DURATION (hours) coef of var CVDP	INTERVAL (hours) mean MTP	INTERVAL (hours) coef of var CVTP
4	Lake Charles	LA	0.66	1.64	0.108	1.40	7.7	1.26	109	0.99
4	New Orleans	LA	0.61	1.46	0.113	1.40	6.9	1.24	89	1.02
4	Shreveport	LA	0.54	1.39	0.080	1.27	7.8	1.09	110	0.99
4	Memphis	TN	0.52	1.36	0.086	1.31	6.9	1.07	89	1.01
5	Houston	TX	0.55	1.73	0.085	1.55	8.2	1.30	104	1.00
6	San Jose (May to Oct.)	CA	0.20	1.59	0.040	1.64	6.7	1.06	842	0.98
6	San Jose (Nov. to Dec.)	CA	0.36	1.38	0.030	1.36	12.4	1.16	127	1.39
6	Phoenix	AZ	0.17	1.38	0.055	1.26	3.2	0.97	286	1.42
6	El Paso	TX	0.15	1.54	0.047	1.12	3.3	1.07	226	1.43
6	Oakland	CA	0.19	1.62	0.033	0.74	4.3	1.03	320	1.60
7	Eugene	OR	0.63	1.88	0.026	0.88	23.1	1.35	118	1.30
7	Portland	OR	0.36	1.51	0.023	0.79	15.5	1.09	83	1.32
7	Seattle	WA	0.46	1.45	0.023	0.86	21.5	1.26	101	1.02
8	Salt Lake City	UT	0.18	1.32	0.025	1.06	7.8	0.85	133	0.97
9	Denver	CO	0.22	1.49	0.032	1.13	9.1	1.15	144	0.92
9	Rapid City	SD	0.20	1.46	0.033	1.09	8.0	1.24	127	0.95

stream receiving the highway runoff, lake impact analysis should include estimates of annual average stream flow for all streams that are tributary to the lake.

The annual average flow rate (MQS) may be established by either of the following methods:

(1) Figure 3 shows approximate regional values for average stream flow in CFS per square mile of drainage area. Multiply this by the upstream drainage area (ATOT) to determine the mean stream flow (MQS) at the point at which the highway discharge enters the stream. Note that there are gaps in this chart in the southwestern part of the country. For sites in these areas, the examination of local gauge records will be necessary.

(2) In situations where additional refinement of local site estimates is called for, examine the records from one or more local stream gauges. The desired information is provided in U.S. Geological Survey (USGS) water resources data reports for gauged stream stations. The data listed include the drainage area and the average flow for the period of record. If there is no gauge on the stream close to the discharge point, extract the desired information (average flow and drainage area) from the stream flow gauging records of nearby gauges for which this information is available. Convert to CFS per square mile, and extrapolate the information for an estimate for the site in question. The watershed drainage area associated with the highway site can be determined by a planimeter and an appropriate topographic map.

The variability of daily flow rates, required for the stream impact analysis, could be determined by statistical analysis of a stream gauge record. This analysis is, however, not routinely performed and reported. The research report (section 7.0) provides a chart which can be used to estimate the coefficient of variation of stream flow rates (CVQS). The estimate is based on the ratio of the value for the lowest 7-day flow in 10 years (7Q10), to the annual average flow rate (MQS). Both of these values are routinely reported for many stream gauges.

For initial estimates, the following typical values may be used. In humid areas, the ratio of 7Q10/MQS is commonly about 0.10 or 0.15 and a reasonable initial estimate is CVQS = 1.0. For more arid areas, an estimate of CVQS = 2.0 is suggested as a more appropriate initial estimate. In the tabulated output results for the stream impact analysis procedure, presented later in section 4.0, a coefficient of variation of stream flow of 1.5 is used as an overall approximation for the generalized case.

2.4 POLLUTANT CONCENTRATIONS IN HIGHWAY RUNOFF

Input data required:

TCR	=	Site Median Concentration of pollutant (mg/l) (the EMC for the median runoff event at a site).
CVCR	=	Coefficient of Variation of the pollutant event mean concentrations (EMCs) in runoff.

Data from 993 separate highway runoff events at 31 sites in 11 States (AR, CA, CO, FL, IA, MN, NC, PA, TN, WA, WI) were analyzed in this study, and the results provide the basis for estimating the required input values. The Data Appendix volume (FHWA-RD-88-009) provides a

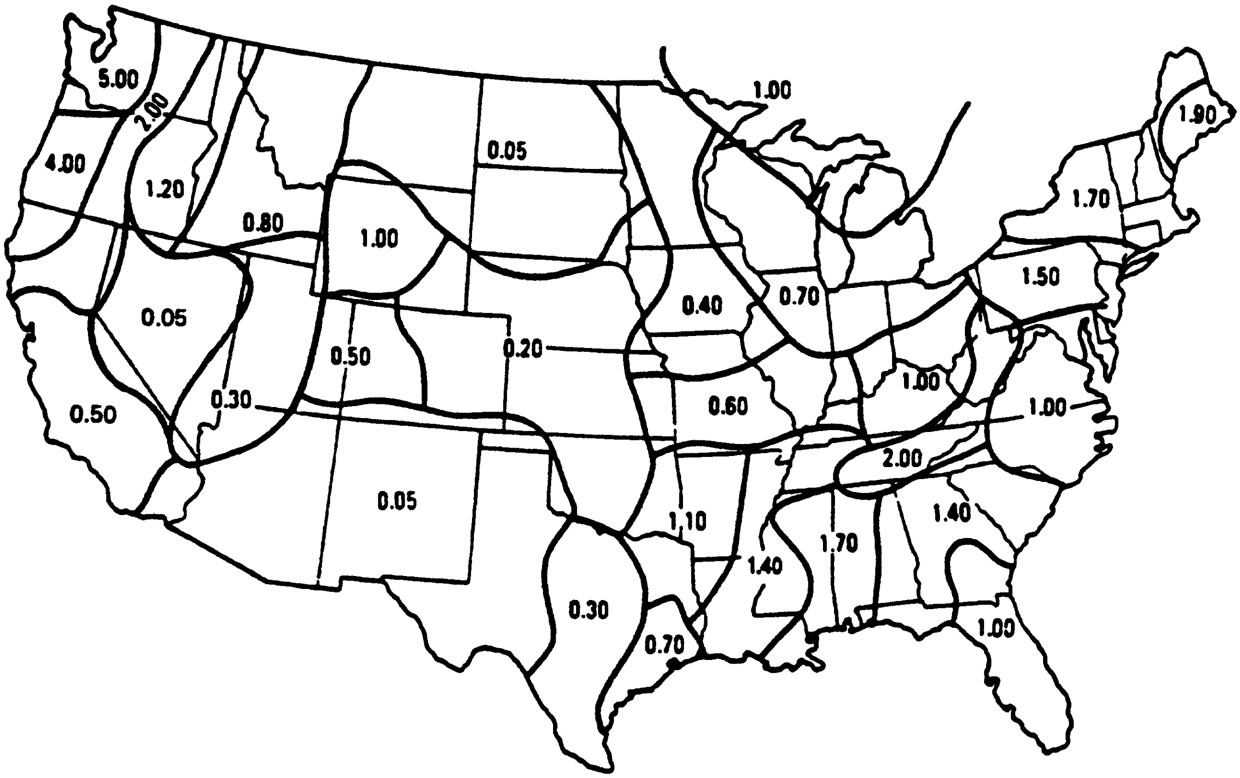


Figure 3. Regional estimates of annual average streamflow.

complete tabulation of the data, and sections 2.0, 3.0 and 4.0 of the research report (FHWA-RD-88-008) address the procedures used and the results from the analysis of these data. A summary of the results pertinent to this evaluation procedure is presented in table 3. The table provides estimates of highway runoff pollutant concentrations required by the evaluation procedure. A brief synopsis of the information provided by this table is presented below. The user should consult the research report for a more comprehensive discussion. Appendix A of this report presents further guidance for estimating pollutant concentrations.

The average concentration of a pollutant in the total runoff volume produced by an individual storm event is designated EMC (event mean concentration). EMCs for all pollutants vary from event to event. They can be treated as random variables that conform to a lognormal probability distribution. Any site's pollutant runoff characteristics can be characterized by specifying the median of the EMCs (the site median concentration), and the coefficient of variation of the individual EMCs. In the design computations the site median is designated TCR, and the coefficient of variation of EMCs is designated CVCR.

A value of CVCR = 0.75 was found to provide a good estimate for all highway sites and any pollutant. Site specific refinements can be made using a value of 0.71 for urban highways, and 0.84 for rural locations.

Site median concentrations (TCR) are different for each pollutant, and were found to fall into either of two significantly different groupings depending on whether the highway site is in an urban or a rural setting. Within each of these two classifications, the site median varies from site to site. Within each group, the observed differences between individual sites were shown to bear little relation to traffic density or any of the other site factors examined. The site median concentrations (TCR) conform to the lognormal distribution. The probability of a particular site being at different levels in the observed range has been summarized in table 3.

To estimate the site median concentration (TCR) for an urban highway, table 3(A) should be consulted, while for a highway in a rural setting, table 3(B) should be used. For example, the most probable site median value for lead concentration in runoff is 0.400 mg/l for an urban highway, and 0.080 mg/l for a rural highway. These are the values for the median (50th percentile) highway site, but other percentiles could be selected based on the user's judgement of local site factors for an alternate estimate of the most probable value. Appendix A discusses some of the considerations that a user might apply in refining local runoff concentration estimates.

The most reliable site specific estimates of the site median concentration of a pollutant will come from local monitoring data at the site itself. The research report can be used to provide guidance on how any such data can be analyzed. The user is cautioned to recognize that, because of the inherent variability in EMCs, a limited sampling effort consisting of only a few storm events may produce a poor estimate of site characteristics. Local monitoring results are best interpreted in relation to the extensive data base that was analyzed and reported in this study.

Normally, several pollutants considered to be most significant in terms of the designated use of the water body in question should be analyzed. For streams, aquatic life protection will normally emphasize heavy metals. For lakes, the effect of phosphorus discharges on trophic level is suggested to be the most important consideration. The sample analyses presented later in this report are based on lead discharges from the highway site in the stream impact analysis, and phosphorus discharges for use in the lake impact analysis.

Table 3. Range of site median concentrations in highway runoff.

(A) URBAN HIGHWAYS AVERAGE DAILY TRAFFIC USUALLY MORE THAN 30,000 VEHICLES PER DAY

SITE MEDIAN CONCENTRATION in mg/l

POLLUTANT	PERCENT OF SITES HAVING A MEDIAN EMC LESS THAN INDICATED CONCENTRATION				
	10% of Sites	20% of Sites	50% MEDIAN SITE	80% of Sites	90% of Sites
TSS	68	88	142	230	295
VSS	20	25	39	61	78
TOC	8	12	25	51	74
COD	57	72	114	179	227
NO2+3	0.39	0.49	0.76	1.18	1.48
TKN	1.06	1.27	1.83	2.62	3.17
PO4-P	0.15	0.21	0.40	0.76	1.06
COPPER	0.025	0.032	0.054	0.091	0.119
LEAD	0.102	0.163	0.400	0.980	1.562
ZINC	0.192	0.231	0.329	0.469	0.564

(B) RURAL HIGHWAYS AVERAGE DAILY TRAFFIC USUALLY LESS THAN 30,000 VEHICLES PER DAY

SITE MEDIAN CONCENTRATION in mg/l

POLLUTANT	PERCENT OF SITES HAVING A MEDIAN EMC LESS THAN INDICATED CONCENTRATION				
	10% of Sites	20% of Sites	50% MEDIAN SITE	80% of Sites	90% of Sites
TSS	12	19	41	90	135
VSS	6	7	12	19	25
TOC	4	5	8	13	17
COD	28	34	49	70	85
NO2+3	0.23	0.29	0.46	0.72	0.91
TKN	0.34	0.47	0.87	1.59	2.19
PO4-P	0.06	0.08	0.16	0.33	0.48
COPPER	0.010	0.013	0.022	0.038	0.050
LEAD	0.024	0.036	0.080	0.179	0.272
ZINC	0.035	0.046	0.080	0.139	0.185

NOTES: Median (50 %) site values are recommended for use in estimates unless the use of alternate values is warranted by site specific considerations.

This table is based on field measurements taken between 1975 and 1985. Highway practices and vehicle changes (e.g., changes in lead content of motor vehicle fuels) over decades could result in changes in the concentrations reported above.

2.5 SOLUBLE FRACTION OF RUNOFF POLLUTANTS

For a lake eutrophication analysis, the distribution of the total phosphorus in runoff between soluble and particulate fractions is not important. This is because the time scale for this type of impact, determined by the hydraulic residence time, is almost always quite long. Particulate fractions that may settle out of the water column usually have ample time to decompose and recirculate to the water column. This factor is recognized by the specification of "total P" values in the lake impact analysis model.

However, for the evaluation of stream impacts resulting from highway stormwater discharges, the intermittent exposure times are on the order of hours, and the soluble fraction of a pollutant in the runoff is the important component. The toxic water quality criteria, against which stream concentrations resulting from highway runoff will be compared, are based on soluble concentrations in the water column. The fact that the particulate fraction (rather than soluble forms) constitutes the major component of most of the pollutants of interest in the runoff from highways emphasizes the importance of this consideration.

The Student Workbook developed for the FHWA Highway Runoff Water Quality Training Course summarizes, in Section 5.0, some results from earlier studies that relate to this issue.(5) One FHWA study by Gupta concluded that most heavy metals were associated with the particulate matter in highway runoff.(6) Dissolved metal fractions were extremely small and were generally near or below detection limits. Another set of results by Morrison deals with runoff from an urban site, and shows the following soluble fractions for runoff concentrations, expressed as the approximate average for two monitored storms.(7)

Copper = 10%   Lead = 1%   Zinc = 30%

An additional basis for estimating the soluble fraction of heavy metals in highway stormwater runoff is provided by an analysis of the data reported by Yousef from a study conducted at a highway interchange in Maitland FL.(8) A total of 150 discrete sequential samples were taken during 16 storm events and were analyzed for both total and soluble heavy metal concentrations. EMCs for cadmium, nickel and chrome were all very low and frequently below the detection limit. As a result, estimates of the soluble fraction are unreliable. For the pollutants copper, lead, and zinc, the soluble fraction varied but was highest during events that produced the lower EMCs. Since the overall site median concentrations of these metals tend to fall toward the lower end of the range for all observed highway sites, the average soluble fractions are probably somewhat higher than for the average highway site. The soluble fractions for the Maitland site were 59 percent for zinc, 75 percent for copper, and 24 percent for lead.

Estimates of soluble fraction for a particular site are uncertain, but considering the foregoing source data, and results on urban runoff developed under EPA's NURP study, the following values for soluble fraction are suggested as reasonable estimates for preliminary analyses.

Copper	-	40% soluble
Lead	-	10% soluble
Zinc	-	40% soluble

2.6 TARGET WATER QUALITY CRITERIA

For short-term intermittent discharges that, on average, occur for approximately 6 hours every 3 or 4 days, it appears most appropriate to base an impact analysis on the potential for creating acute toxicity effects. Criteria values developed by EPA for protection of freshwater aquatic life are listed in table 4. It should be noted that the concentrations increase with the total hardness (mg/l as $CaCO_3$) of the receiving water. As illustrated by figure 4, surface water hardness varies considerably between different regions of the country, and thus so does the concentration that will produce toxic effects in stream biota.

The user should recognize that the formal criteria values embody significant safety factors. The safety factors are applied to the concentration that produces no adverse effect on the most sensitive (to the pollutant) of the species used in the bioassays. It is important to recognize an additional factor in the case of the intermittent, short-duration exposures produced by stormwater runoff. The bioassay results on which the criteria are based are generally the result of 96-hour test exposures for acute values, but are specified as a maximum 1-hour average with a 3-year return period.

If the average storm duration of several hours is taken as a reasonable approximation of the criterias 1-hour average for acute effects, the stream concentration distribution produced by the impact analysis discussed below (which is on an event basis) can be used for the desired comparisons. The 3-year recurrence values as computed by the easy to use tables (using the stream impact analysis as discussed later) are accordingly compared with the EPA's 3-year recurrence toxic criteria values to evaluate the significance of the highway stormwater discharge.

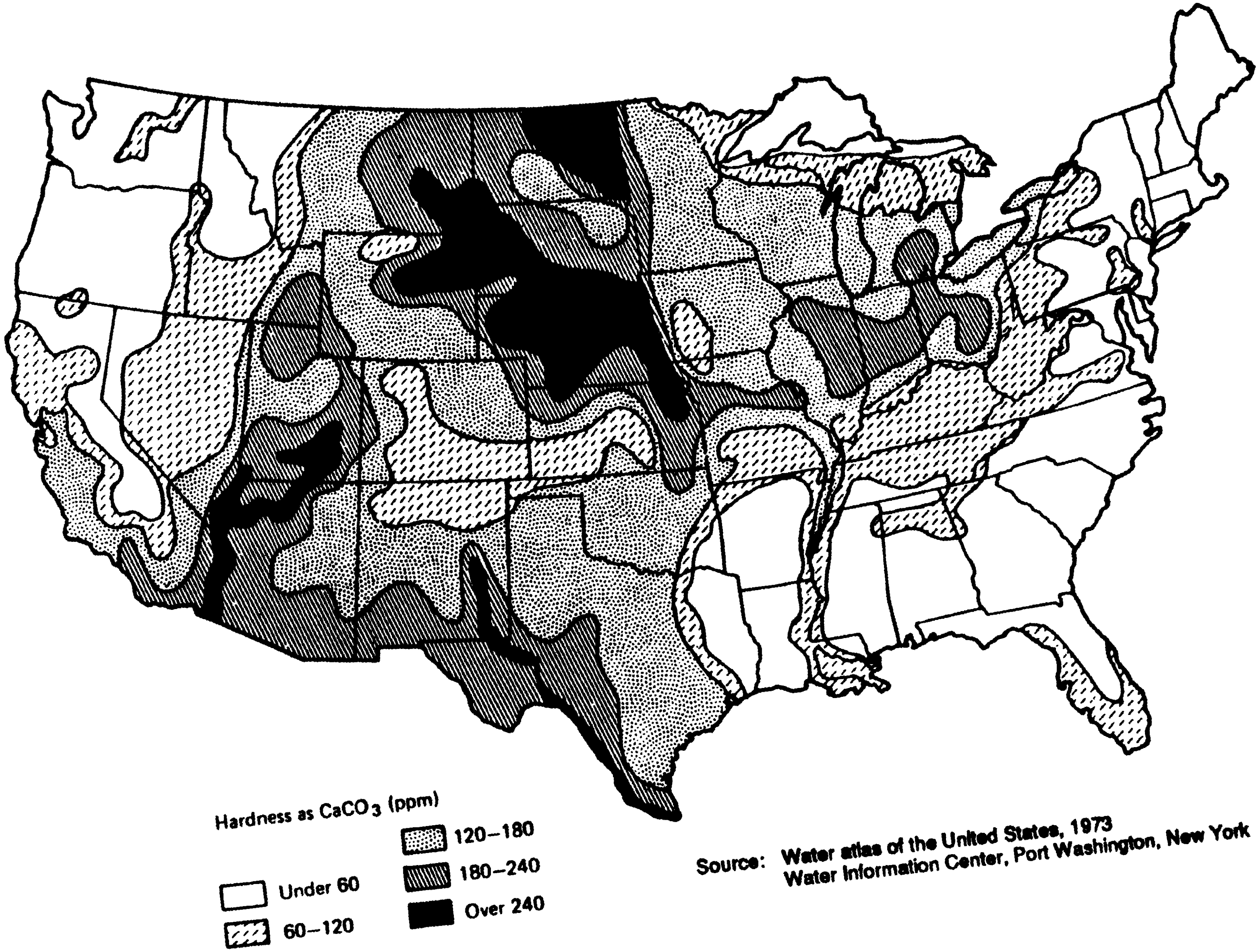
In interpreting the results of the impact computations, the user should recognize that the criteria are based on a continuous-exposure concept. There are currently no corresponding "wet-weather" criteria. Minor or infrequent exceedances of the criteria values may not result in adverse effects. In response to this issue, the EPA Nationwide Urban Runoff Program (NURP) developed estimates of approximate concentrations that would cause adverse impacts for short-duration, intermittent exposures produced by stormwater runoff. Suggested values for intermittent concentrations that would produce threshold effects, from the report for that study, are also summarized in table 4.(4)

Both sets of "target" concentrations should be utilized in an impact analysis, recognizing that (a) there are no formal criteria for wet weather discharges, (b) the formal criteria have substantial safety factors built in, and (c) the suggested "threshold effects level" values listed have no safety factor applied.

Table 4. Target concentrations for toxic effects.

SURFACE WATER TOTAL HARDNESS (PPM)	EPA ACUTE CRITERIA (mg / l)			EPA NURP SUGGESTED THRESHOLD EFFECT LEVEL (mg / l)		
	COPPER	LEAD	ZINC	COPPER	LEAD	ZINC
50	0.009	0.034	0.181	0.020	0.150	0.380
60	0.011	0.043	0.210	0.025	0.200	0.440
80	0.014	0.061	0.267	0.030	0.250	0.560
100	0.018	0.082	0.321	0.040	0.350	0.675
120	0.021	0.103	0.374	0.045	0.450	0.785
140	0.024	0.125	0.425	0.055	0.550	0.890
160	0.028	0.149	0.475	0.065	0.650	1.000
180	0.031	0.173	0.523	0.070	0.750	1.100
200	0.034	0.197	0.571	0.080	0.850	1.200
220	0.037	0.223	0.618	0.090	0.950	1.300
240	0.040	0.249	0.664	0.095	1.050	1.400
260	0.044	0.276	0.710	0.100	1.200	1.500
280	0.047	0.303	0.755	0.110	1.300	1.600
300	0.050	0.331	0.800	0.115	1.400	1.700

NOTE : THRESHOLD EFFECT -
mortality of the most sensitive individual of the most sensitive species



Source: Water atlas of the United States, 1973
Water Information Center, Port Washington, New York

Figure 4. Total hardness levels of surface waters in the continental United States.

This section describes the computations performed using the input data to define the pertinent characteristics of the stormwater runoff from a highway site. This information will be used later to compute the receiving water impacts.

Illustrated in table 5 is Worksheet B, in which the required computations are organized into a step-by-step procedure. The remainder of this section presents a brief discussion of each of these steps. The research report should be consulted for additional information as necessary.

3.1 RUNOFF RATE AND VOLUME

The runoff flow rate for the mean storm event (MQR) and the runoff volume from the mean event (MVR) are computed by the following equations.

$$MQR = Rv * MIP * AROW * \left(\frac{3630}{3600}\right) \qquad (2)$$

$$MVR = Rv * MVP * AROW * 3630 \qquad (3)$$

where:

MQR = average runoff flow rate for mean storm event (CFS)
MVR = volume of runoff for mean storm event (CF)
MVP = rainfall volume for the mean storm event (inch)
MIP = rainfall intensity for the mean storm event (inch/hour)
AROW = drainage area of the highway segment (acres)
Rv = runoff coefficient (ratio of runoff to rainfall)
3630 is a dimensional conversion factor
($43560\ ft^2/acre * 1\ ft/12\ inch$)

The runoff coefficient (the fraction of rainfall that becomes runoff) is estimated fairly well by the impervious fraction of the drainage area. A number of different formulations have been suggested, but all give comparable results. The design procedure presented here uses the relationship developed from the analysis of highway runoff data presented in the research report.

The runoff coefficient is computed as follows.

$$Rv = 0.007 * IMP + 0.10 \qquad (4)$$

where:

IMP = impervious fraction of the drainage area (as a percentage)

Table 5. Worksheet B - Highway runoff characteristics.

1 Compute runoff coefficient (Rv) (section 3.1)			
a Percent Impervious (Worksheet A- Item 1c)	IMP	[ ]	%
b Runoff Coefficient (= 0.007 * IMP + 0.1)	Rv	______	ratio
2 Compute runoff flow rates (section 3.1)			
a Flow rate from mean storm = Rv * MIP * AROW	MQR	______	CFS
b Coefficient of variation of runoff flows = CVIP (Worksheet A - Item 2f)	CVQR	[ ]	dimensionless
3 Compute runoff volumes (section 3.1)			
a Volume from the mean storm = Rv * MVP * AROW * 3630	MVR	______	cubic feet
b Coefficient of variation of runoff volumes = CVVP (Worksheet A - Item 2e)	CVVR	[ ]	dimensionless
4 Compute mass Loads (section 3.2)			
Site Median Conc (Worksheet A- Item 4a)	TCR	[ ]	mg/l
Coef of var. of site EMC's (Wksht A - 4b)	CVCR	[ ]	dimensionless
Number of storms per year (Wksht A - 2i)	NST	[ ]	number
a mean event concentration (MCR) = TCR * SQRT(1+ CVCR^2)	MCR	______	mg/l
b mean event mass load = MCR * MVR *(0.00006245)	M(MASS)	______	pounds
c annual mass load from runoff = M(MASS) * NST	ANMASS	______	pounds/year
5 Compute flow ratio (MQS/MQR) (section 3.3)			
a ratio of average stream flow (Worksheet A - 7b) to MQR	MQS/MQR	______	ratio

3.2 POLLUTANT MASS LOADS FROM RUNOFF

For the lake impact analysis, the mass load of phosphorus is required. A value for mass load is not required for the stream impact analysis, but estimates of annual loading rates might be desired for other purposes.

Mass load is provided by the product of the runoff volume and concentration, and can be computed directly from the statistical expressions developed for runoff and concentration. For uncorrelated runoff volumes and concentrations (as the analysis results presented in the research report indicate to be the case) the computation can be performed as follows. The annual mass loading from a site is estimated by the product of the mean event load and the number of events in a year. In turn, the mean mass load per event is provided by the product of the mean runoff volume and the mean EMC for the site.

The determination of the number of storms per year and the mean runoff volume were addressed in preceding sections. Concentrations, however, have been reported thus far as median, rather than mean values. The site median concentration (TCR) must first be converted to the mean EMC for the site (MCR). For lognormally distributed EMCs, this is computed as follows.

$$MCR = TCR * \sqrt{(1 + CVCR^2)} \qquad (5)$$

where:

TCR	= site median pollutant concentration (mg/l)
CVCR	= coefficient of variation of EMCs
MCR	= mean EMC for site (mg/l)

Then the mean event mass load is computed by:

$$M(MASS) = MCR * MVR * (62.45 * 10^{-6}) \qquad (6)$$

where:

M(MASS)	= mean pollutant mass loading (pounds per event)
MCR	= mean runoff concentration (mg/l)
MVR	= mean storm event runoff volume (CF)

The dimensional conversion factor ($62.45 * 10^{-6}$) is applied to provide mass loads in pounds when volume is in cubic feet and concentration is in mg/l.

The annual mass load from the highway site is the product of the mass load from the mean storm and the number of storms per year.

$$ANMASS = M(MASS) * NST \qquad (7)$$

where:

ANMASS	=	annual mass loading of pollutant (pounds/year)
M(MASS)	=	mass load for the mean event (pounds/event)
NST	=	number of storm events per year (events/year) see equation (1) - Section 2.2

3.3 FLOW RATIOS

The amount of flow in a stream has an obviously important influence on the pollutant concentrations that will be caused by runoff from a highway site. The larger the stream in terms of the flow carried, the greater the dilution provided, and therefore, the smaller the resulting concentrations produced from highway runoff.

The stream analysis presented below expresses the influence of this factor by the ratio of average stream flow (MQS) to the mean runoff flow (MQR).

$$\text{Flow Ratio} = \frac{MQS}{MQR} \qquad (8)$$

where:

MQS = average annual stream flow at discharge point (CFS)
MQR = average runoff flow rate from the mean storm event (CFS)

Local values for each of these parameters have been developed in previous steps.

4.0
STREAM IMPACT ANALYSIS

This section presents the procedure for analyzing and evaluating the impact of pollutant discharges from highway runoff on a river or stream. Worksheet C, shown in table 6, provides a step-by-step outline of the procedure. The analysis method used is the probabilistic technique described in the research report. The required inputs for the impact analysis are the mean or median and the coefficient of variation of the stream flow, the runoff flow, and the pollutant concentrations in the runoff. Values for each of these parameters will have been developed on the preceding worksheets.

Appendices at the end of this document provides a step-by-step outline of the computation (appendix B), together with a numerical example (appendix C). The calculation procedure has a number of steps, but it is straightforward. The version of the calculation procedure presented is an approximate solution that uses the method of moments. This tends to overestimate the severity of the stream impact, but has the advantage that it can be solved manually. The more accurate numerical solution is not incorporated here, because a manual calculation using it would be prohibitively tedious and complex. To provide more accurate estimates of stream impacts within the context of the computational detail adopted for this report, a correction factor is provided to adjust the results. This is presented in the appendix, and is based on comparative analyses using the accurate numerical method and the approximate result produced by the simple method of moments calculation.

To reduce the effort required of a user to conduct a stream impact analysis, table 7 has been prepared. It provides a tabulated summary of the results produced by the analysis procedure, using representative values for the coefficients of variation of the input parameters. The required mean values for the flow rates are represented by the flow ratio developed earlier (MQS/MQR). Site median concentrations vary somewhat for different sites, and substantially for different pollutants. Accordingly, table 7 has been set up based on a site median concentration of 1.0 for an unspecified pollutant. The upstream concentration of pollutants is assigned a value of zero, so that results reflect only the influence of highway runoff.

The actual variability of the input parameters (measured by their coefficients of variation) will influence the final results to some degree. In most cases, deviations from the results in table 7 will be relatively minor because the "typical" values assigned are reliable general estimates. The coefficient of variation of runoff concentrations is assigned a value of CVCR = 0.75, based on the data analysis results discussed in section 2.4. Runoff flow variability is estimated from the coefficient of variation of rainfall intensities (CVIP), for which a substantial data base exists. Based on the data summarized in section 2.2, it will be noted that the assigned value of 1.30 provides a good approximation of the coefficient of variation of rainfall intensities (and hence runoff flow rates, CVQR) in most areas. Stream flow variability is less easily approximated by a single value, but the uncertainty in estimates of CVQS is compensated for by the fact that the computation results are less sensitive to the value of this parameter for the smaller streams where the runoff effects will tend to be greater. As discussed in section 2.3, a coefficient of variation of

Table 6. Worksheet C - Stream impact analysis.

1	Define the flow ratio MQS/MQR (Worksheet B-5a)	MQS/MQR	[ ]	ratio
2	Compute the event frequency for a 3 year recurrence interval			
a	Enter the average number of storms per year (from Worksheet A - item 2i)	NST	[ ]	number
b	Compute the probability (%) of the 3 year event = 100 * (1 / (NST * 3))	PR	______	%
3	Enter value from table 7 for MQS/MQR and frequency PR	C U	______	mg/l
4	Select pollutant for analysis		[ ]	name
a	Site median concentration (table 3)	TCR	[ ]	mg/l
b	Soluble fraction (section 2.5)	FSOL	[ ]	fraction
c	Acute Criteria Value (table 4)	CTA	[ ]	mg/l
d	Threshold effects level (table 4)	CTT	[ ]	mg/l
4	Compute the once in 3 year stream pollutant concentration = CU * TCR * FSOL	C O	______	mg/l
5	Compare with target concentration, CTA = CO / CTA	CRAT	______	ratio

6 Evaluate results

a If CRAT is less than about 0.75
A toxicity problem attributable to this pollutant is unlikely — **STOP**

b If CRAT is greater than 5 reduction will definitely be required
Estimate the level of reduction possible and repeat the analysis with revised values for either concentration or flow or both — **CONTROL**

c If CRAT is still greater than 1
and greater reduction levels are not practical.....
Estimate the potential for an adverse impact (as opposed to a criteria violation) by a comparison with the threshold effects level — **EVALUATE**
= CO / CTT   CRTE ______ ratio

A further refinement in the analysis can be made using the procedure described in Appendix B. Changes will usually be nominal, based on refined local estimates of variability of flows.

Table 7. Stream impact analysis results.

SITE MEDIAN POLLUTANT CONCENTRATION IN RUNOFF = 1.000

Stream Concentration of Highway Runoff Pollutant (mg/l)
Exceeded an average of ONCE in 3 years

FLOW RATIO	Average Number of Storms per Year (NST)					
	33	80	90	100	110	120
MQS/MQR	PERCENT OF EVENTS THAT EXCEED INDICATED CONCENTRATION					
	1%	0.42%	0.37%	0.33%	0.30%	0.28%
4000	0.011	0.018	0.019	0.020	0.021	0.022
1000	0.040	0.065	0.070	0.074	0.078	0.080
800	0.048	0.079	0.085	0.090	0.095	0.098
400	0.088	0.144	0.154	0.165	0.173	0.179
200	0.158	0.257	0.277	0.295	0.309	0.319
100	0.277	0.449	0.483	0.514	0.539	0.557
80	0.330	0.533	0.573	0.610	0.639	0.660
40	0.545	0.873	0.936	0.995	1.043	1.075
20	0.836	1.315	1.406	1.492	1.560	1.607
10	1.163	1.783	1.898	2.008	2.094	2.153
8	1.268	1.923	2.044	2.159	2.250	2.312
4	1.579	2.308	2.441	2.566	2.663	2.730
2	1.910	2.680	2.818	2.946	3.046	3.114
1	2.419	3.258	3.405	3.540	3.645	3.717
0.80	2.678	3.563	3.716	3.858	3.968	4.043
0.40	4.344	5.588	5.800	5.995	6.145	6.248

NOTES :

MQS/MQR (FLOW RATIO) is the ratio of the annual average stream flow rate (cfs), to the runoff flow rate (cfs) produced by the mean storm event.

When a value of 1.0 is assigned as the site median concentration of a pollutant, the tabulated stream concentrations can be interpreted as multiples of the site median value. Multiply the stream value listed for any flow ratio and frequency combination. by the site median concentration selected for a pollutant of interest. The result is the actual concentration exceeded at the selected frequency.

Results shown are based on the following values for coefficient of variation of inputs.
Stream Flow CVQS = 1.5 Runoff Flow CVQR = 1.3 Runoff Concentrations CVCR = 0.75

1.50 for stream flows was selected as a representative value. Where questions exist as to the suitability of these assignments for a local site, the user can apply the computation procedure described in appendix B instead of using table 7.

The basic output from the computation is the mean and variance of the in-stream concentrations of a runoff pollutant, from which one can readily determine the frequency at which any selected "target concentration" will be exceeded. When the target concentration selected for comparison is based on an appropriate water quality criteria value that represents a safe level, then the comparison provides a basis for evaluating the potential for highway runoff to cause a water quality problem.

The stream concentrations listed in table 7 can be interpreted as multiples of the site median concentration in the runoff. The actual concentration is the selected table number multiplied by the median EMC estimated for the site. For each flow ratio, a series of stream concentrations is shown, corresponding to a set of selected exceedance frequencies. The frequency columns represent the percent of storm events that will produce stream concentrations equal to or greater than the listed value. The range of frequencies listed (associated with the average number of storms for an area), spans the range that provides the once-per-3-year value that is desired for comparison with criteria values.

To illustrate the use of table 7 in a stream impact analysis, consider the following example. The site conditions assumed for the illustration have been selected to provide an extreme (and presumably rare) situation. It could result if the following conditions applied: the highway drainage area was 100 percent impervious, crossed the headwaters of a stream, and occupied as much as 10 percent of the total watershed area.

- The flow ratio for the above conditions is assumed to be:

$$\frac{MQS}{MQR} = 0.40$$

- Highway is in an urban area with traffic density greater than 30,000 vehicles per day. Site median runoff concentration of lead is estimated to be 0.400 mg/l. The soluble fraction is estimated to be 10 percent.

- Rainfall statistics for the area produce an estimate of 100 storm events per year.

- Surface water total hardness is 200 mg/l.

- Water quality criteria (target concentrations) for lead (from table 4) are :

EPA Acute criterion	=	0.197 mg/l
Threshold effects level	=	0.850 mg/l

Criteria are based on a 3-year recurrence interval. In an area that averages NST=100 storms per year, this is an exceedance frequency of 1 per 300 events, or PR = 0.33 percent.

$$PR = 100 * \left(\frac{1}{NST*3}\right) = \frac{100}{300} = 0.33 \text{ percent}$$

- Enter table 7 at a flow ratio MQS/MQR = 0.40. For this flow ratio, and a frequency of occurrence of 0.33 percent, the table shows a value of 5.607.

  This is the in-stream concentration exceeded not more frequently than once in 3 years, expressed as a multiple of the site median runoff concentration.

  The actual lead concentration is:

Total lead	= 5.607 * 0.400	= 2.243 mg/l
Soluble lead	= 2.243 * 0.10	= 0.224 mg/l

- To determine whether this has a significant toxic effect, compare the soluble concentration with the target concentrations that have been selected.

  The estimated concentration (0.224) is reached or exceeded during the duration of 1 storm event (several hours) on an average of once every 3 years. It exceeds the EPA criteria value (0.197) to a nominal extent, but is less than the estimated level for threshold effects (0.850) by a factor of about 3.5.

In the absence of official "wet-weather" criteria, situations in which the once-per-3-year concentration exceeds formal criteria, yet provides a reasonable safety factor for the threshold effects level for intermittent stormwater discharges, will require decisions to be based on local policy determinations. It is suggested that wherever feasible, controls be applied to produce once-per-3-year levels that are within the formal EPA criteria. In cases where this may not be physically possible or economically practicable, the concentration levels shown for threshold or significant impacts from intermittent, short-duration stormwater loads can be used to provide an indication of the potential and magnitude of a significant problem developing.

Note that if the highway evaluated was in a rural area, with a site median lead concentration of 0.080 mg/l rather than the 0.400 mg/l estimated for an urban highway, the resulting once-per-3-year stream concentration would be only 0.045 mg/l, well under the formal criteria and clearly not a problem condition.

The step-by-step procedure for conducting a lake impact analysis is summarized by Worksheet D, illustrated here by table 8.

The lake impact analysis employs the Vollenweider model, as discussed in the research report. The model formulation is usually expressed as follows:

$$P = \frac{W'}{H/T + V_s} \tag{9}$$

where:

P = average concentration of P in lake ($gm/m^3 = mg/l$)
W' = annual unit mass loading (grams per sq meter per year)
H = average depth of lake (meters)
T = hydraulic detention (years)
V_s = net P settling velocity (meters per year)

For the design procedures addressed by this document, the basic model has been transposed to employ terms and dimensional parameters that are more convenient for highway situations, and/or which have been developed in prior steps. The settling velocity is usually estimated at 5 meters per year for small lakes. The hydraulic detention time is a function of the lake volume (surface area and depth) and the average total inflow. Accordingly, the model formulation can be transposed to the following format.

$$P = \frac{ANMASS * 112}{(MQS * 221) + (ALAK * 5)} \tag{10}$$

where:

ANMASS = annual highway mass loading (lbs per year)
ALAK = surface area of lake (acres)
MQS = average total lake inflow rate (cu ft per second, CFS)
P = average lake concentration (micrograms/liter)

An average lake total P concentration of about 10 micrograms per liter (0.010 mg/l) or less is usually considered to reflect acceptable water quality conditions. Concentrations in excess of 20 micrograms per liter (0.020 mg/l) are generally considered to be undesirable because they have a high probability of producing eutrophic conditions. In evaluating results, be aware that the 10 and 20 microgram per liter target levels are not formal criteria values. They are empirically derived values that reflect the trophic state of most, though not all, lakes. In some areas of the country higher target levels may be appropriate.(9) Conversely, lower target levels may be suitable for

Table 8. Worksheet D - Lake impact analysis.

1 Define input parameters

a	surface area of lake	ALAK	[ ]	acres
b	Annual P load from highway (Worksheet B - Item 4c)	ANMASS	[ ]	pounds
c	Average inflow rate (line A-7c) (Worksheet A - Item 7c)	MQS	[ ]	CFS

2 Compute average lake P concentration (Section 5.0)

= (ANMASS * 112) / (MQS*221 + ALAK*5) P ________ ug/l

3 Evaluate results

a If P is less than 10 micrograms per liter **[STOP]**
A eutrophication problem attributable to highway runoff is unlikely

b If P is greater than 20 some level of reduction is desireable **[CONTROL]**
Evaluate control options
Estimate the level of reduction possible
Repeat the analysis using the revised annual mass load

c If P is between 10 and 20, investigate further. **[EVALUATE]**
Refine input estimates and repeat analysis.
Check whether higher target values may be appropriate for the area.

areas that currently have very high quality. An additional important factor to consider in evaluating results is that the highway drainage area will typically represent a small fraction of the total drainage (and hence loads) to a lake.

The evaluation procedure presented in Worksheet D assumes that the highway is the main contributor of loading to the lake. It adopts the 10 and 20 microgram per liter target concentrations as the primary guides for the initial screening. If the highway area is a small portion of the contributing area, an acceptable incremental increase in phosphorus concentration should be lower than the 10 micrograms per liter target. If the highway runoff impact cannot be dismissed as insignificant (concentration much less than 10), its contribution relative to the total load from the entire drainage area should be considered. In cases where highway runoff is indicated to be a potential problem, the local situation should dictate whether the user investigates the effect of easily applied control measures or checks on the suitability of higher target concentrations.

6.0
FURTHER ANALYSIS ITERATIONS

It is expected that in many cases, the projected receiving water concentrations will be well under the target concentration. When the margin is significant, uncertainty due to possible errors in the initial input estimates will not be great enough to change the decision. As shown by the terminal decision box in the figure 1 procedure outline, it would be concluded that the runoff will not cause an adverse water quality impact. The impact analysis would be concluded at this point.

The tacit assumption here is that the decision is not sensitive to the degree of uncertainty in the initially assigned values for the site characteristics assembled in Worksheet A. When the projected concentration is well under the target, such an assumption is valid.

In cases where the projected concentration is only nominally less than the target, or where it is greater, one or more additional iterations of the analysis procedure should be made. The user has a choice of either of two routes to follow each time this decision point is reached in an analysis.

- Estimate the reduction projected for pollution control management measures that are feasible to apply at the site. Make appropriate changes in the input parameters that are affected. Repeat the analysis using the modified values.

- Refine the initial estimates of the input parameters. Develop data that are more specific to the highway site being evaluated. Repeat the analysis using the modified values.

These alternatives are discussed separately in the remainder of this section.

6.1 CONTROL OF RUNOFF

The use of management measures should be considered as the initial choice for an iteration when the physical setting and layout of the highway site permits the economical and convenient incorporation of management measures for control of the stormwater discharges. Then, if readily incorporated management measures produce a receiving water concentration well under the target, the impact analysis may be concluded. Procedures and guidelines for estimating the effectiveness of control measures that are practical to apply at highway sites are provided in a separate FHWA report.(1)

The type and size or extent of control techniques that are feasible to consider for the site in question should be determined. Then, the procedures described in the above referenced document should be used to estimate the reductions that are expected and to adjust the appropriate input parameters for the receiving water impact analyses. Then, the analysis should be repeated and the comparison of the revised results with the target levels performed in the same way as was done for the initial analysis.

Estimates of the pollutant reduction efficiency are usually in terms of a reduction in mass loading. For a lake impact analysis, the predicted reduction in mass load can be applied directly. For a stream impact analysis, the user must determine whether it is the runoff flow that is reduced (e.g., via infiltration), or the concentration in the runoff, or both. This will define which of the inputs to adjust.

Most of the management measures considered will have a modifying influence on both runoff rate and on pollutant concentration in the runoff. However, for the purposes of this evaluation procedure, it is appropriate to assign all of the predicted mass load reduction to the dominant removal mechanism. For example, a grassed swale may reduce runoff flow to some degree because of infiltration, but the dominant removal mechanism is considered to be sedimentation and filtration. These processes reduce concentrations. Accordingly, for the impact estimates developed by this procedure, all of the reported mass load reduction is assigned to a proportional reduction in the site median concentration.

The following rules are suggested for converting the performance results presented in the referenced report to the adjustment in the input parameters used in the procedures provided by this document.

- Grassed Swales - reduce the site median concentration (TCR).
- Overland Flow - reduce the site median concentration (TCR).
- Wet Pond Detention - reduce the site median concentration (TCR).
- Infiltration Devices - reduce the mean runoff flow rate (MQR).

6.2 REFINEMENT OF INPUT ESTIMATES

This alternative approach to an iteration recognizes that initial estimates for rainfall and stream flow derived from national scale summaries provide only an approximation of the actual conditions at a specific site. These estimates are expected to be close in most cases, but for some sites local values may deviate appreciably from typical values for the general region.

The user should recognize that the principal basis for refining the impact analysis derives, not from introducing some new, more elaborate analysis technique, but rather from a more accurate definition of local site characteristics. The use of the additional procedural details described in appendix B, rather than the use of the table 7 summary output results, will produce a nominal refinement in the computation in most cases. But the only basis for using this would be because the user has developed improved local estimates for the variability of the stream or runoff flow rates. In extremely rare and unusual circumstances, the complexity and environmental sensitivity of the site may argue for consideration of a more elaborate analysis procedure and the significantly enhanced local data base that this would require. Such a situation is beyond the scope of this manual.

As a general rule, however, when a refinement in the analysis is required, it will not require any change in the analysis methodology. More reliable local results will be produced by improving the local estimates of input data. The major considerations in this regard are as follows.

- Rainfall - Data listed in table 2 for individual cities provide a basis for an incremental improvement in a local estimate over the typical regional values provided by figure 2. Further refinement will require the analysis of the record of an appropriate rain gauge in the area.

- Stream Flow - Improving estimates of stream flow over those provided by the information in figure 3 will require the user to obtain summary reports (or the actual flow records) for appropriate stream flow gauges in the area.

- Runoff Concentrations - The research report provides summaries of the basic data, and a discussion of their interpretation that will provide some assistance in refining pollutant concentration estimates for a local site. Appendix A of this volume summarizes some of the important considerations. Beyond this, locally obtained site-specific data will be required for any further refinement of estimates. Reliable local monitoring studies will be relatively costly and time consuming, and would under normal circumstances be the last choice considered for refining input data.

- Stormwater Runoff Variability - Because of the inherent variability in stormwater runoff pollutant concentrations (as demonstrated in the research report), the monitoring of only a few events may provide poor estimates of site characteristics. If an adequate number of events (preferably at least 10) are monitored in a local study, the procedures described in the research report should be used to analyze the data. In cases where the local effort is restricted to only a few events, the most appropriate use of such data is in providing guidance in estimating where the local site falls within the range summarized by table 3.

- Background Stream Concentrations - The use of an upstream concentration of zero for the preliminary analyses described earlier and summarized by table 7, was based on the following reasons. The principal reason is that sufficient data on background concentrations of the pollutants of interest have not been assembled and analyzed to provide a basis for recommending representative values and ranges, as was the case for other parameters. Another reason is that a wide variation in stream concentrations is anticipated based on the type of upstream land use. Finally, for screening purposes, an analysis that indicates a trivial effect from a highway site can legitimately conclude that this source has no significant potential to contribute to a problem, regardless of whether background levels are high or low.

  The complete computation procedure described in appendix B does allows for the incorporation of background stream concentration levels (CS) in the analysis. However, there must be appropriate site specific data available that can be analyzed. In cases where this type of data is not available and the user desires to develop an understanding of the relative influences of background and highway runoff, sensitivity analyses can be performed using assumed background values that are either close to, or much lower than the target levels. In general, such analyses will show that in cases where the upstream background is close to the target, even marginal contributions from highway runoff can cause a violation of the criteria. At the same time, even extreme degrees of control of highway runoff may not be sufficient to avoid violations. Such cases will call for a comprehensive assessment of tradeoffs between controlling the various sources and cost of controls. This type of assessment is beyond the scope of this document.

7.0
EXAMPLE USE OF DESIGN WORKSHEETS

The evaluation procedure is illustrated in this section by a series of completed sample worksheets (tables 9, 10, 11, and 12) which provide a step-by-step listing of the input data the user is to provide, and show the results of the calculations to be performed. Where appropriate, section numbers, tables, and figures presented earlier that provide a basis for estimating input values are referenced. Each of the worksheets was introduced in earlier sections of this volume.

In all cases, basic inputs are indicated by fill-in boxes. These may come either from source material or by transfer from an earlier worksheet in the design sequence. Computed values (or look-up values from section 2.0 tables that summarize a range of computed values) are represented by underlined blank spaces.

The overall procedure is provided by four worksheets. Worksheets A, B, C and D are to be used in sequence, because they draw on information from preceding sheets. Worksheet A deals with the assembly of the pertinent data on site characteristics. Worksheet B organizes the computations that develop the characteristics of runoff from the highway site, based on the site input values. Then, either Worksheet C for a stream impact, or D for a lake impact would be used, depending on the type of water body receiving the highway runoff.

When further iterations in the computation of impacts are necessary, based either on the consideration of a control measure or on more refined estimates of local input data, the user should make the appropriate modification(s), and then repeat the procedure mapped out by the worksheets.

Table 9. Sample worksheet A - Site characteristics.

1	Drainage Area of Highway Segment (section 2.1)			
a	Total right of way	AROW	2	acres
b	Paved surface	AHWY	1	acres
c	Percent Impervious (= 100 * AHWY/AROW)	IMP	50	%
2	Rainfall Characteristics (from section 2.2)	MEAN		
a	Volume	MVP	0.40	inch
b	Intensity	MIP	0.07	inch / hour
c	Duration	MDP	6.0	hour
d	Interval	MTP	87.6	hour
		COEF of VARIATION		
e	Volume	CVVP	1.50	dimensionless
f	Intensity	CVIP	1.30	dimensionless
g	Duration	CVDP	1.10	dimensionless
h	Interval	CVTP	1.00	dimensionless
i	Number of storms per year (24*365/MTP)	NST	100	no. events
3	Surrounding Area Type			
a	ADT over 30,000 vehicles/day, urbanized area	URBAN	[x]	
	or			
b	ADT under 30,000 vpd, undeveloped to low density suburban	RURAL	[ ]	
4	Select pollutant for analysis (section 2.4)		lead	name
	and			
	estimate runoff quality characteristics (use table 3)			
a	site median concentration	TCR	0.400	mg/l
b	coef of variation (0.71 Urban : 0.84 Rural)	CVCR	0.71	dimensionless
5	Select receiving water target concentration (section 2.6)			
	surface water Total Hardness (figure 5)	TH	160	mg/l
	STREAM - use table 4 for target concentrations			
a	EPA Acute Criterion	CTA	0.149	mg/l
b	suggested Threshold Effect Level	CTT	0.650	mg/l
	or			
	LAKE - use accepted level for average Phosphorus concentration			
c	target concentration is 10 micrograms/liter		10	ug/l
6	Watershed Drainage Area upstream of highway for a stream - total contributing area for a lake	ATOT	4.00	square miles
7	Average annual stream flow (section 2.3)			
a	unit area flow rate per square mile (figure 4)	QSM	0.70	CFS/square mile
b	Coef of variation of stream flows(section 2.3)	CVQS	1.5	dimensionless
c	Average stream flow (QSM * ATOT)	MQS	2.80	CFS

Table 10. Sample worksheet B - Highway runoff characteristics.

1 Compute runoff coefficient (Rv) (see section 3.1)			
a Percent Impervious (Worksheet A- Item 1c)	IMP	50	%
b Runoff Coefficient (= 0.007 * IMP + 0.1)	Rv	0.45	ratio
2 Compute runoff flow rates (section 3.1)			
a flow rate from mean storm = Rv * MIP * AROW	MQR	0.063	CFS
b coefficient of variation of runoff flows = CVIP (Worksheet A - Item 2f)	CVQR	1.30	dimensionless
3 Compute runoff volumes (section 3.1)			
a Volume from the mean storm = Rv * MVP * AROW * 3630	MVR	1306.8	cubic feet
b coefficient of variation of runoff volumes = CVVP (Worksheet A - Item 2e)	CVVR	1.50	dimensionless
4 Compute mass Loads (section 3.2)			
Site Median Conc (Worksheet A - Item 4a)	TCR	0.400	mg/l
Coef of var. of site EMC's (Worksheet A - 4b)	CVCR	0.71	dimensionless
Number of storms per year (Worksheet A - 2i)	NST	100	number
a mean event concentration (EMC) = TCR * SQRT(1+ CVCR^2)	MCR	0.491	mg/l
b mean event mass load = MCR * MVR *(0.00006245)	M(MASS)	0.040	pounds
c annual mass load from runoff = M(MASS) * NST	ANMASS	4.004	pounds/year
5 Compute flow ratio (MQS/MQR) (section 3.3)			
a ratio of average stream flow (Worksheet A - 7b) to MQR	MQS/MQR	44.44	ratio

Table 11. Sample worksheet C - Stream impact analysis.

1	Define the flow ratio MQS/MQR (Worksheet B- 5a)	MQS/MQR	44.44	ratio
2	Compute the event frequency for a 3 year recurrence interval			
a	Enter the average number of storms per year (from Worksheet A - Item 2i)	NST	100	number
b	Compute the probability (%) of the 3 year event = 100 *(1 / (NST * 3))	PR	0.33	%
3	Enter value from table 7 for MQS/MQR and frequency PR	CU	0.952	mg/l
4	Select pollutant for analysis		lead	name
a	Site median concentration (table 3)	TCR	0.400	mg/l
b	Soluble fraction (section 2.5)	FSOL	0.10	fraction
c	Acute Criteria Value (table 4)	CTA	0.149	mg/l
d	Threshold effects level (table 4)	CTT	0.650	mg/l
4	Compute the once in 3 year stream pollutant concentration = CU * TCR * FSOL	CO	0.038	mg/l
5	Compare with target concentration, CTA = CO / CTA	CRAT	0.26	ratio
6	Evaluate results			
a	If CRAT is less than about 0.75 A toxicity problem attributable to this pollutant is unlikely		STOP	
b	If CRAT is greater than 5 reduction will definitely be required Estimate the level of reduction possible and repeat the analysis with revised values for either concentration or flow or both		CONTROL	
c	If CRAT is still greater than 1 and greater reduction levels are not practical. . . . . Estimate the potential for an adverse impact (as opposed to a criteria violation) by a comparison with the threshold effects level		EVALUATE	
	= CO / CTT	CRTE	0.06	ratio

A further refinement in the analysis can be made using the procedure described in appendix B. Changes will usually be nominal, based on refined local estimates of variability of flows.

Table 12. Sample worksheet D - Lake impact analysis.

1 Define input parameters				
a	surface area of lake	ALAK	1	acres
b	Annual P load from highway (line B-4c) (Worksheet B - Item 4c)	ANMASS	4.00	pounds
c	Average inflow rate (line A-7c) (Worksheet A - Item 7c)	MQS	2.8	CFS

2 Compute average lake P concentration (section 5.0)

= (ANMASS * 112) / (MQS*221 + ALAK*5) P 0.7 ug/l

3 Evaluate results

a If P is less than 10 micrograms per liter **STOP**
A eutrophication problem attributable to highway runoff is unlikely

b If P is greater than 20 some level of reduction is desireable **CONTROL**
Evaluate control options
Estimate the level of reduction possible
Repeat the analysis using the revised annual mass load

c If P is between 10 and 20, investigate further. **EVALUATE**
Refine input estimates and repeat analysis.
Check whether higher target values may be appropriate for the area.

8.0
REFERENCES

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The research report (FHWA-RD-88-008) provides a more comprehensive citation of references dealing with all aspects of the overall study. The limited selection cited above are the principal references that relate directly to the procedures described in this document.

The probability of an urban or a rural highway site having a site median concentration equal to, lesser, or greater than, a specific value is summarized in table 3. Precise predictions of site median concentrations are not possible, and the user is required to apply judgement in assigning a site median concentration for use in the impact analysis. In general, the use of the values for the median (50th percentile) site provide the best estimate (the most probable value) for the site median concentration. However, a user has the option of assigning a value other than that for the median site when his professional judgement, based on knowledge of local conditions, suggests the use of an alternate value for use in the impact analysis. This appendix presents some information that may assist a user to refine estimates of site median concentration values for a particular site.

There are a considerable number of site factors that have been or could be postulated to influence pollutant concentrations in highway runoff. Among them are the traffic density, number of traffic lanes, traffic speed, the type of roadway section (e.g., cut, fill, grade, bridge), surface type and condition, grade, proximity to intersections, the existence of curbs, the land use of the surrounding area, and catchment size itself. Other meteorological factors in addition to precipitation that might influence pollutant concentrations in runoff include temperature, wind speed and direction, and solar insolation. The 24 study sites and the large number of events in the data base provide a substantial data base, but it proves to be much too small to confirm, much less quantify, effects and possible interactions among all of these possible explanatory variables. Among all the competing influences that contribute to variability and the median EMC concentration at highway sites, the overall effect of any specific factor is lost in the "noise" resulting from all other influences.

The data suggest certain tendencies concerning whether SMCs for a particular site fall in the higher or lower end of the observed range of the experimental sets. Although there is no reliable basis for quantifying these tendencies, they are discussed below to provide a background for the procedure user. As a background for these discussions, the following summaries reproduced from section 3.0 of the research report are provided. Table 13 identifies the physical characteristics of the study sites. Table 14 lists the site median concentrations (SMCs) measured at the sites.

The "urban" and "rural" groupings in table 3 reflect the only statistically significant relationship extracted from the data base. Highways in non-urban settings are indicated to have significantly lower runoff concentrations of all pollutants than do urban highways. The division between these two groups was at an average traffic density (ADT) of approximately 30,000 vehicles per day. However, because site median concentration differences within each grouping correlated poorly with the ADT level, this suggests that the group differences are influenced to a much greater extent by the differences in general air quality between urban and rural settings, rather than by traffic level alone.

Where estimates of traffic density are available, this information may be used to refine an estimate. Although most pollutants did not show correlations significantly different than zero, based on ADT, several showed the positive trends that are intuitively expected. While the

Table 13. Physical characteristics of highway study sites.

SITE NO.	STATE CODE	SITE	AVG DAILY TRAFFIC 1000 VPD total	AVG DAILY TRAFFIC 1000 VPD monitored lanes	NUMBER of TRAFFIC LANES total	NUMBER of TRAFFIC LANES monitored	SECT TYPE (B)	SURF TYPE (C)	CURB	LAND USE (A)	AREA (ACRES)	% IMP	Annual RAIN in/YR
1	AR-1	LITTLE ROCK I-30	42	42	4	4	BF	ASP	NO	U-3	1.5	90	48.7
2	CA-1	LOS ANGELES I-405	200	200	8	8	F	CON	YES	U-2	3.2	100	12.6
3	CA-2	SACRAMENTO HWY 50	86	43	8	4	G	CON	YES	U-4	2.45	82	16.3
4	CA-3	WALNUT CREEK I-680	70	70	6	6	H	CON	YES	U-3	2.1	100	20.3
5	CO-1	DENVER I-25	149	149	10	10	G	ASP	YES	U-4	35.3	37	14.8
6	FL-1	BROWARD CO HWY 834	20	20	6	6	G	ASP	BOTH	U-2	58.3	36	62.0
8	FL-2	MIAMI I-95	140	70	6	3	B	ASP	YES	U-1	1.43	100	59.8
11	MN-1	MINNEAPOLIS I-94	80	80	10	10	C	CON	YES	U-2	21	55	24.8
12	MN-2	ST PAUL I-94	65	65	6	6	CF	CON	YES	U-2	16.3	49	24.8
13	NC-1	EFLAND I-85	26	26	4	3	G	ASP	NO	N-1	2.49	51	43.6
14	PA-1	HARRISBURG I-81 (Ph. 1)	24	24	6	6	G	CON	NO	U-4	18.5	27	37.7
15	PA-2	HARRISBURG I-81 (Ph. 2)	56	28	4	2	G	CON	NO	U-4	2.81	45	37.7
17	TN-1	NASHVILLE I-40	88	88	6	6	CG	CON	YES	U-1	55.6	37	45.0
18	WA-5	MONTSANO SR-12 (5)	7.3	7.3	2	2	G	ASP	YES	N-4	0.28	100	84.0
19	WA-6	PASCO SR-12 (6)	4.0	2.0	4	2	C	CON	YES	N-5	1.25	100	7.5
21	WA-9	PULLMAN SR-270E (9)	5.0	2.5	2	1	G	ASP	YES	N-4	0.25	100	18.0
23	WA-1	SEATTLE I-5 (1)	106	53	8	4	G	CON	YES	U-3	1.22	100	34.1
25	WA-2	SEATTLE SR-520 (2)	84	42	4	2	B	CON	YES	U-1	0.099	100	35.0
26	WA-4	SNOQ. PASS I-90 (4)	15	7.7	6	3	G	CON	YES	N-2	0.18	100	97.0
27	WA-7	SPOKANE I-90 (7)	35	17	6	3	B	CON	YES	U-1	0.22	100	17.2
28	WA-3	VANCOUVER I-205 (3)	17	8.6	6	3	G	CON	YES	U-4	0.28	100	39.0
29	WI-1	MILWAUKEE HWY 45	85	85	6	6	CG	CON	YES	U-3	106	31	27.6
30	WI-2	MILWAUKEE I-794	53	53	8	8	B	CON	YES	U-1	2.1	100	27.6
31	WI-3	MILWAUKEE I-94	116	116	8	8	H	ASP	YES	U-3	7.6	64	27.6

NOTES :

(A) land use surrounding area - U = URBAN 1= undefined, 2= commercial/residential, 3= residential, 4= suburban
N = NON-URBAN 1= undefined rural, 2= forest, 3= undeveloped, 4= agricultural, 5= desert

(B) section type - C = cut, F = fill, G = at grade, B = bridge

(C) road surface type - CON = concrete, ASP = asphalt

Table 14. Site median concentrations for monitored storm events.

SITE NO.	STATE CODE	SS (mg/l)	VSS (mg/l)	TOC (mg/l)	COD (mg/l)	NO2+3 (mg/l)	TKN (mg/l)	PO4-P (mg/l)	Cu (mg/l)	Pb (mg/l)	Zn (mg/l)
1	AR-1	112	20		94	0.71			0.019	0.108	0.167
2	CA-1	172			196		3.35	0.453		0.987	0.666
3	CA-2	90	20	22	51	0.21	1.67	0.099	0.068	0.278	0.269
4	CA-3	218			125		2.01	0.408		0.900	0.341
5	CO-1	406	77	88	291		3.51	0.821	0.104	0.705	0.644
6	FL-1	9		12	41	0.23	0.46	0.036	0.005	0.236	0.071
8	FL-2	67	70	46	169	1.02	1.25	0.140	0.043	0.623	0.303
11	MN-1	51		15			1.04	0.227	0.020	0.116	
12	MN-2	85		20			1.56	0.429	0.030	0.407	
13	NC-1	20	6	24	67	0.19	1.68	0.124	0.038	0.011	0.050
14	PA-1	25	8	11	31	0.61	1.14	0.267	0.029	0.091	0.051
15	PA-2	184	18	16	34	3.32	2.16	1.075	0.087	0.026	0.167
17	TN-1	190	49	29	113		1.86	1.687	0.056	0.411	0.259
18	WA-5	126	21	3	46	0.73	0.64	0.168	0.036	0.175	0.100
19	WA-6	101	25	10	114	0.81	3.32	0.476	0.025	0.101	0.325
21	WA-9	104	21	17	60	0.57	0.75	0.428	0.026	0.130	0.099
23	WA-1	93	26	13	106	0.83	0.90	0.217	0.037	0.451	0.382
25	WA-2	244	59	33	145	0.79	1.09	0.415	0.072	1.065	0.280
26	WA-4	43	9	2	41	0.53	0.38	0.123	0.025	0.065	0.071
27	WA-7	119	29	10	156	1.11	1.69	0.865	0.041	0.173	2.892
28	WA-3	34	9	7	32	0.45	0.60	0.098	0.017	0.046	0.040
29	WI-2	334	72	32	111	0.77	2.77	0.417	0.075	0.738	0.371
30	WI-3	140	47	27	88	1.27	1.86	0.287	0.088	1.457	0.336
31	WI-1	143	47	30	122	0.79	3.09	0.315	0.155	0.817	0.465
	MEAN	143	36	24	103	0.84	1.79	0.435	0.052	0.525	0.368
	MEDIAN	93	26	16	84	0.66	1.48	0.293	0.039	0.234	0.217
	COV	1.16	0.97	1.06	0.71	0.77	0.67	1.10	0.87	2.01	1.37
	N	24	19	21	22	18	23	23	22	24	22

correlations were too weak to justify the formulation of a reliable formal mathematical relationship, the traffic density projected for the site might, for certain pollutants, be used to weight the prediction toward the higher or lower ends of the probability distribution.

The regression equations for the correlations between site median concentrations of a pollutant and traffic density are of the form:

$$SMC = a * ADT + b \tag{11}$$

where:

SMC = site median concentration of pollutant (mg/l)
ADT = average daily traffic (in thousands of vehicles per day)

The values for coefficients "a" and "b" are shown in table 15 for those pollutants that showed a statistically significant correlation in the analyses that were presented in section 3.0 of the research report. Also shown is the percentage of the variance in the SMCs that is explained by differences in ADT. This is given by the value of "r-squared," the square of the correlation coefficient, r.

Table 15. Regression coefficients for significant correlations between ADT and various pollutant concentrations.

POLLUTANT	a	b	r-squared
VSS	0.385	11.	42 %
TKN	0.01	1.06	25 %
COD	0.874	47.	40 %
TOC	0.233	5.	42 %
ZINC	0.003	0.07	70 %

The pollutants TSS, copper, and lead showed weak positive correlations, but the r-squared values corresponded to only 5 to 12 percent. These levels are not significantly different from zero, and the use of a regression equation would not improve the estimate. For all of the other pollutants analyzed, site median concentrations showed no relationship to traffic density.

Note that the above regression relationships are based only on the data from the "urban" highway sites. Results for the "rural" highways were considered to be unsuitable for a similar analysis. The small number of sites in the data base prevents a reasonable use of regressions against ADT to provide a basis for guiding estimates. It should also be noted that two of the eight rural highway sites in the list are located in semi-arid or desert areas in the eastern part of the State of Washington, and for most pollutants, are associated with site medians in the higher end of the range. The remaining six rural sites are in humid areas, and three of these are also in the State of Washington. The geographical distribution of rural sites is not as broad as for the urban highway sites, and has a larger proportion of arid areas represented than is typical of the country as a whole.

These considerations should be recognized when the distributions are used to guide a local estimate. The user may wish to favor higher percentile values for highways in semi-arid regions, and the lower percentile values for most other areas.

Sites in relatively dry, semi-arid areas of the country appear from the data to tend toward higher concentrations of many pollutants compared with sites in more humid regions. The data base was not large enough to confirm or quantify such an influence. For example, estimates for a site with climate and surroundings similar to Denver or eastern Washington might preferably favor using values from the higher end of the distributions. Conversely, site conditions more closely related to the Florida sites might favor estimates toward the lower end of the range.

There will be situations where the surrounding area is rural in nature, but the ADT is well above the 30,000 vehicle per day division in the data base. For estimates in such cases, the user should recognize that the data show that there is an overlap between the "dirtier" rural highways and the cleaner urban highways. Figure 5 shows a frequency histogram plot of the site median concentrations for one pollutant at both urban and rural sites. There is more than a three-fold difference in the median sites for each group, but there is some overlap in the higher rural, and the lower urban highway sites. The listing in table 3 allows the user to determine that the overlap amounts to just under 20 percent of the sites in each group. For the postulated situation, a rural setting with very high ADT, it is suggested that the best estimate would be drawn either from the lower quarter of urban highway SMCs, or the upper quarter of rural highway SMCs.

There may be specific local factors, a knowledge of which can be used to refine estimates for particular pollutants. As an illustration, note the zinc SMCs listed in table 14. The Spokane site (WA-7) shows an abnormally high value compared with all other sites, which has been attributed to the presence of a nearby zinc smelter. A user may incorporate the presence of unusual local features in refining the estimates of SMCs for specific pollutants.

There is uncertainty associated with the prediction of pollutant levels in highway runoff. The procedure requires the user to apply judgement in developing local estimates but the approach helps to keep a user aware of the degree of uncertainty associated with the analysis. With alternate predictive approaches, using regressions or deterministic model outputs, it may be easier for a user to lose sight of the same uncertainties that are also a part of these techniques. The impact evaluation procedure is simple enough to apply, that sensitivity tests using alternative estimates can be made easily, to evaluate the influence of uncertainty in input estimates on the analysis results.

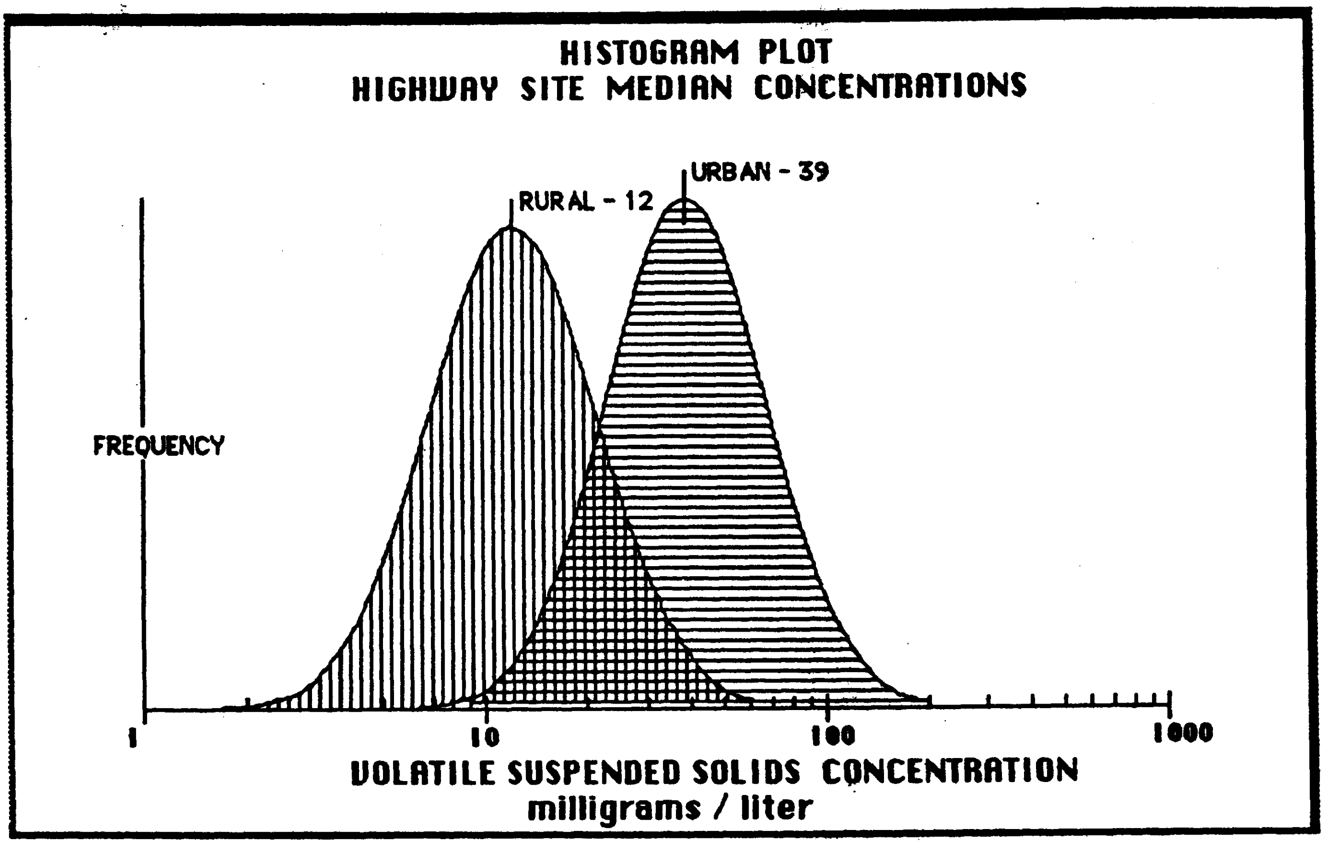


Figure 5. Illustration of overlap in observed urban and rural highway site median concentrations.

The analysis procedure used to estimate the impact of highway pollutant discharges on a stream is the probabilistic analysis method that is described in section 5.0 of the research report. It employs the statistical parameters of the stream and highway runoff, and highway runoff concentrations, in a direct computation of the probability distribution of pollutant concentrations in the stream produced by the intermittent stormwater runoff events. The procedure is illustrated schematically by figure 6.

The receiving water concentration that results from mixing the highway stormwater discharge with stream flow is influenced by the upstream flow (QS) and the upstream concentration (CS) during a runoff event. The receiving water concentration (CO) is the resulting concentration after complete mixing of the runoff and stream flows, and should be interpreted as the average concentration just downstream of the discharge. The elements that determine the average stream concentration (CO) are all variable and may have a range of values for any storm event. The elements that determine the stream concentration resulting from stormwater discharges are:

1. Average highway runoff flow (QR).
2. Average highway runoff concentration (CR).
3. Average stream flow (QS) upstream of highway input.
4. Average stream concentration (CS) upstream of highway input.

For an individual stormwater runoff event, it is possible to measure a value for each of these variables. The average stream concentration (CO), during this event, could be calculated:

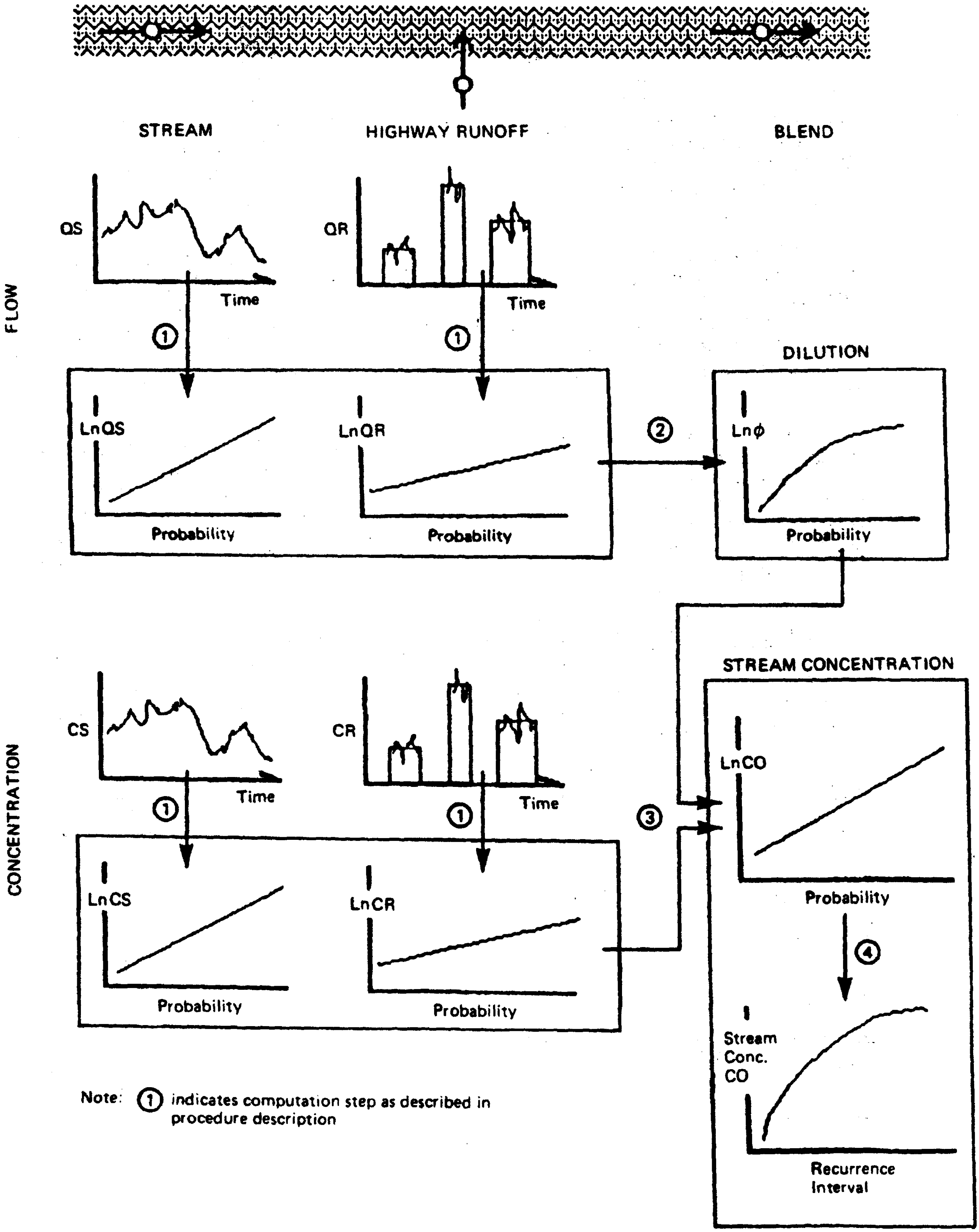
$$CO = \frac{(QR * CR) + (QS * CS)}{QR + QS} \qquad (12)$$

If a dilution factor, DF, is defined as:

$$DF = \frac{QR}{QR + QS} = \frac{1}{1 + D} \qquad (13)$$

CO may be defined in terms of DF by:

$$CO = (DF*CR) + ([1-DF]*CS) \qquad (14)$$



Note: ① indicates computation step as described in procedure description

Figure 6. Schematic outline of probabilistic analysis method.

The calculated value of CO for an individual event could be compared to some concentration limit selected as a target (CT), such as a water quality standard, or to any other stream concentration which relates water quality to protection or impairment of water use. When CO is less than CT then water quality is satisfactory and it will be assumed that the individual event would not impair the beneficial water use. By contrast, if the comparison of CO and CT indicates that during this event receiving water concentrations of the constituent in question exceed the limit, the relative concentration contributions of highway runoff and upstream sources could be ascertained.

In principle, this procedure could be repeated for a large number of runoff events. The set of variable stream concentration values that were produced could then be subjected to standard statistical analysis procedures. If this were done, the total percentage of the runoff events during which stream concentration (CO) exceeded target limits (CT) could be determined. The relative effectiveness of control alternatives could be defined in terms of the differences in the percentage of runoff events that cause the stream concentration (CO) to exceed the selected target concentration (CT).

The first step in the use of this probabilistic dilution model (PDM) is to develop the statistics of the concentrations and flows for both the stream and the highway discharges. These statistics include both the arithmetic and logarithmic forms of the mean (M), standard deviation (S), and coefficient of variation (CV). The analysis is simplified here by specifying an upstream concentration of zero (CS = 0) so that the results reflect only those effects on the receiving water due to the highway runoff, thus highlighting the comparative differences resulting from control actions. The procedure is as follows.

STEP 1 COMPUTE STATISTICAL PARAMETERS OF INPUTS

Compute the complete set of statistical parameters of the inputs, using the previously estimated values for mean (or median) and coefficient of variation of the flows and concentrations. Tabulate as shown below for convenience.

INPUT PARAMETER	ARITHMETIC VALUE	ARITHMETIC MEAN (M)	ARITHMETIC STD DEV (S)	ARITHMETIC COEF VAR (CV)	LOGARITHMIC MEAN (U)	LOGARITHMIC STD DEV (W)
UPSTREAM						
flow	QS	MQS	SQS	CVQS	UQS	WQS
concentration	CS	MCS	SCS	CVCS	UCS	WCS
HIGHWAY RUNOFF						
flow	QR	MQR	SQR	CVQR	UQR	WQR
concentration	CR	MCR	SCR	CVCR	UCR	WCR

Transformations between the different statistical parameters are made using the following equations:

$$T = \exp(U) \quad (15a) \qquad S = M * CV \quad (15b)$$

$$M = \exp(U + 0.5 * W^2) \quad (15c) \qquad W = \sqrt{\ln(1 + CV^2)} \quad (15d)$$

$$M = T * \sqrt{1 + CV^2} \quad (15e) \qquad U = \ln\left(\frac{M}{\exp(0.5 * W^2)}\right) \quad (15f)$$

$$CV = \sqrt{\exp(W^2) - 1} \quad (15g) \qquad U = \ln\left(\frac{M}{\sqrt{1 + CV^2}}\right) \quad (15h)$$

STEP 2 COMPUTE STATISTICAL PARAMETERS OF DILUTION FACTOR

Compute the statistical parameters of the dilution factor. The dilution factor was previously defined (equation 13) as:

$$DF = \frac{QR}{QR + QS} = \frac{1}{1 + QS/QR} = \frac{1}{1 + D}$$

The statistical properties of the dilution factor that are required for the analysis are calculated from the statistics of the highway runoff flow and the stream flow, specifically their log standard deviations (WQR and WQS). One additional element in the formula is the correlation coefficient between the two flows. This could be calculated from the analysis of paired data on stream flow and rainfall (converted to runoff) derived from analyzing stream gauge and rain gauge values at corresponding times.

It is, however, appropriate to assume that there is no significant correlation between runoff flows and stream flows. Assuming a correlation coefficient of zero provides a conservative estimate for the results, but a sensitivity analysis indicates the overestimate of stream concentrations to be no more than 10 to 15 percent, even in cases where flows may be rather highly correlated.

The amount of dilution at any time is a variable quantity and the flow ratio (D = QS/QR) has a lognormal distribution when both stream flow (QS) and runoff flow (QR) are treated as lognormally distributed. The log standard deviation of the flow ratio QS/QR is designated as WD. This can be calculated from the log standard deviations of runoff flow and stream flow. Thus, assuming no cross-correlation between stream and runoff flows, the log standard deviation of flow ratio D, is calculated as:

$$WD = \sqrt{WQS^2 + WQR^2} \quad (16)$$

The probability distribution of the dilution factor (DF) is not truly lognormal, even with lognormally distributed runoff and stream flows. It has an upper bound of 1 and lower bound of 0, and in the region of the plot where it approaches these values asymptotically, it deviates appreciably from the lognormal approximation. Errors introduced because of the lognormal approximation of DF used in the moments method approximation presented here can be fairly significant in some cases. The error introduced is almost always conservative; that is, it projects high concentrations to occur more frequently than they actually would be expected to.

A procedure is available for accurately calculating the probability distribution of dilution (DF) and stream concentration (CO). However, this numerical method uses quadratures and would be prohibitively tedious to perform manually. Figure 7 provides a basis for estimating a correction factor to adjust the computed concentration to the more accurate result that would be produced by the numerical method. This is based on a comparative analysis of the two procedures, using typical ranges of coefficient of variation for the inputs. The analysis procedure described here incorporates the application of this correction factor to the results computed using the approximate moments method. Table 7 presented earlier in this report also incorporates this adjustment. For the purpose of presenting the approach in a form that can be solved manually, the methodology description which follows develops a lognormal approximation for the dilution factor DF and then proceeds with the calculations for stream concentration. Then, the correction factor described above is applied to the final stream concentration result.

In the manual procedure (using the method of moments), estimates are developed of the mean and standard deviation of a lognormal approximation of the dilution factor (DF) by first calculating, and then interpolating between, the 5% and 95% probability values. The value of the dilution factor (DF) for any probability percentile (a) is defined by:

$$DF_a = \frac{TQR}{TQR + TQS * \exp(Z_a * WD)} \tag{17}$$

. . . . where the value of Z_a is taken from any standard normal probability table for the corresponding value of percentile "a". For example, when a = 95 %, Z_{95} = 1.65 ; when a = 5 %, Z_5 = -1.65. Table 16 provides a sample of the standard normal table.

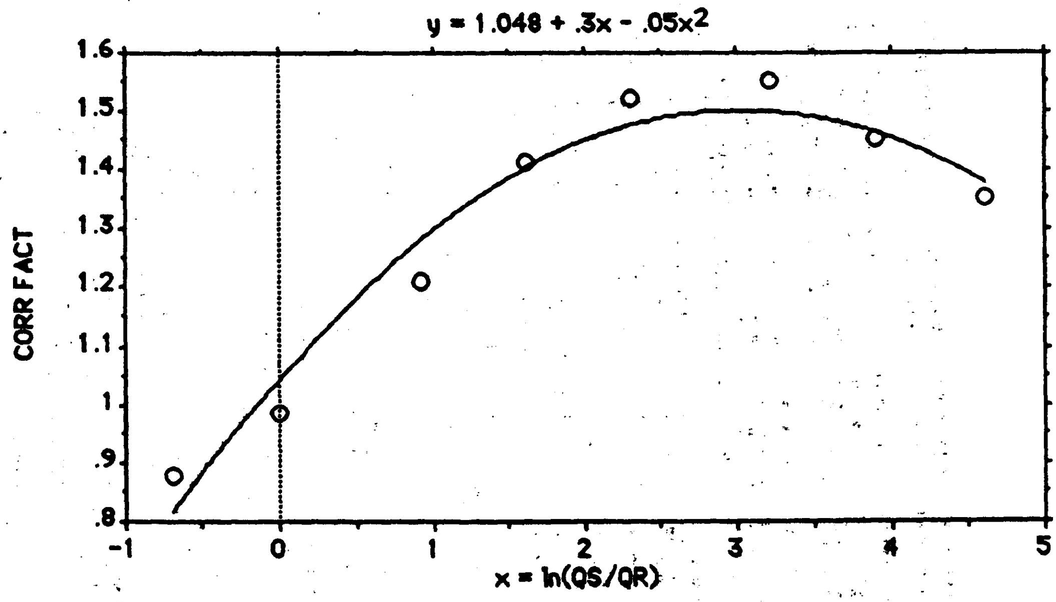
The log mean dilution factor (UDF) is estimated by interpolating between the 5% and 95% values, calculated above.

$$UDF = \frac{\ln(DF_{95}) + \ln(DF_5)}{2} \tag{18}$$

The log standard deviation (WDF) is determined by the following formula, which in effect determines the slope of the straight line on the log-probability plot, recognizing that Z_{84} (1 standard deviation) = 1.0:

$$WDF = \frac{1}{Z_{95}} * \frac{\ln(DF_5) - \ln(DF_{95})}{2} \tag{19}$$

QS/QR	CORRECTION FACTOR	ln (QS/QR)
.50	.88	-.69315
1.00	.99	0
2.50	1.21	.91629
5.00	1.41	1.60944
10.00	1.52	2.30259
25.00	1.55	3.21888
50.00	1.45	3.91202
100.00	1.35	4.60517



$$\text{CORRECTION FACTOR} = 1.05 + 0.3X - 0.05X^2$$

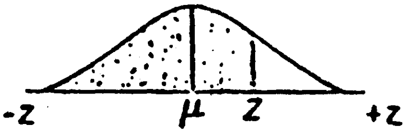
$$\text{WHERE } X = \ln(QS/QR)$$

$$\frac{\text{stream concentration computed by simple method}}{\text{correction factor}} = \text{best estimate of stream concentration}$$

Figure 7. Correction Factor for simplified stream analysis.

Table 16. Probabilities for the standard normal distribution.

Each entry in the table indicates the proportion of the total area under the normal curve to the left of a perpendicular raised at a distance of Z standard deviation units.



Example: 88.69 percent of the area under a normal curve lies to the left of a point 1.21 standard deviation units to the right of the mean.

Z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7518	0.7549
0.7	0.7580	0.7612	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9949	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9986	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998	0.9998
3.5	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
3.6	0.9998	0.9998	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
3.7	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
3.8	0.9999	0.9999	0.9999	0.9999	0.9999	0.9939	0.9999	1.0000	1.0000	1.0000
3.9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

From the log mean and log standard deviation of the dilution factor (DF), the arithmetic statistics are computed using the transform equations presented above.

STEP 3 COMPUTE STATISTICS OF STREAM CONCENTRATIONS

From the foregoing, the stream concentrations can be computed. The arithmetic mean of the receiving water contaminant concentration (MCO) downstream of the discharge, after complete mixing, is computed from the arithmetic mean values of CSO concentrations (MCR), upstream concentrations (MCS), and the dilution factor (MDF).

$$MCO = (MCR * MDF) + (MCS * [1 - MDF]) \tag{20}$$

The arithmetic standard deviation of stream concentration (SCO) is computed from the arithmetic means and standard deviations of the same factors.

$$SCO=\sqrt{SDF^2 *(MCR - MCS)^2 + SCR^2 *(SDF^2 + MDF^2) + SCS^2 *(SDF^2 + \{1 - MDF\}^2)} \tag{21}$$

The coefficient of variation (CVCO) is:

$$CVCO = \frac{SCO}{MCO} \tag{22}$$

The arithmetic statistics are now used to derive the log transforms which will be used to develop the desired information on probability. Transformation equations 15d and 15f are used, substituting the above values for mean and coefficient of variation of CO.

log standard deviation $$WCO = \sqrt{\ln(1+CVCO^2)} \tag{23}$$

log mean $$UCO = \ln\left(\frac{MCO}{\sqrt{1 + CVCO^2}}\right) \tag{24}$$

STEP 4 COMPUTE PROBABILITY OF SPECIFIC CONCENTRATIONS

The probability (or expected frequency) at which a value of CO will occur may be determined as follows. The concentration that will not be exceeded at some specific frequency (or probability) can be calculated from:

$$CO_a = EXP(UCO + Z_a * WCO) \tag{25}$$

where:

Z_a = the value of Z from a standard normal table that corresponds to the selected percentile, a (see table 16)

To determine the probability of exceedance, replace Z_a with $Z_{(1-a)}$.

One can also work in the reverse direction; that is, given some target stream concentration (CT), the probability of CO exceeding that level can be determined by:

$$Z = \frac{\ln(CT) - UCO}{WCO} \tag{26}$$

Table 16 will provide the probability for the calculated value of Z.

Because of the way table 16 is organized, the probabilities calculated using this approach represent the fraction of time the target concentration (CT) is not exceeded. The probability that the concentration will be exceeded is obtained by subtracting the value obtained from 1.0.

STEP 5 FINAL ADJUSTMENTS

When the concentration assigned to the runoff represents the total of all forms of the pollutant (soluble plus particulate forms), the stream concentration that is computed (CO_a), is also the total concentration in the water column, at the selected frequency of occurrence. It is the soluble form of a pollutant that is considered to exert toxic effects on stream biota. For an evaluation of the potential of the stormwater runoff to create toxicity related problems, the procedure estimates the stream concentration of the soluble form. The soluble concentration produced in the stream at the selected frequency is estimated by adjusting CO_a based on the soluble fraction of the pollutant (FSOL) present in the runoff.

An additional adjustment is made to account for the fact that the analysis procedure, as discussed earlier, provides an approximation of the distribution of the dilution factor. The divergence between the approximate results and more accurate projections based on a more rigorous analysis (using a numerical method that is not practical for a hand computation), varies with the ratio of the mean stream and runoff flow rates. In an analysis of the results from sensitivity runs using both the exact and the approximate methods, a correction factor (CORR FACTOR) was developed and is indicated by the relationship presented in figure 7. The correction factor, a function of the ratio between stream and runoff flow, is used to adjust the initial approximation of COa. The two adjustments described above are applied to the final stream concentration as indicated below in equation 27.

Best estimate of soluble pollutant concentration at frequency a

$$CO_a = \frac{(CO_a * FSOL)}{CORR\ FACTOR} \tag{27}$$

This appendix presents the reader with a sample computation, displaying the numerical values at each step in the procedure, as an aid in using the equations presented in appendix B. The analysis procedure provides an approximation of the expected stream concentration, and is not a precise answer. It is appropriate to round the final result to reflect this level of precision. However, in the internal computation steps, where logarithms are used, it is recommended that intermediate values be computed to as many significant digits as possible and that values not be rounded. Different computation devices (hand-held calculators, personal computers and specific software applications) often carry different numbers of significant digits. The numerical values presented in the example were developed by setting up the example computation on a microcomputer spreadsheet. There may be slight differences between the values recorded below and those generated by the user, depending on the number of significant digits carried by the device being used.

ASSEMBLE AND SUMMARIZE SITE CHARACTERISTICS

Before the computation steps begin, the data which make up the site characteristics must be gathered. Following is a description of the data collected for this numerical example.

(A) Rainfall - The rainfall for the area has the following characteristics, determined either from a SYNOP (see discussion in section 2.2) analysis of a local rain gauge, or estimated from data presented in section 2.1 (figure 2 or table 2).

STORM EVENT		MEAN			COEF of VAR		
VOLUME	(inch)	MVP	=	0.40	CVVP	=	1.50
INTENSITY	(in/hour)	MIP	=	0.07	CVIP	=	1.30
DURATION	(hours)	MDP	=	6.00	CVDP	=	1.10
INTERVAL	(hours)	MTP	=	87.6	CVTP	=	1.00

(B) Study Area Physical Properties - Assume that the study area is a 2-acre highway segment having a runoff coefficient (Rv) = 0.45. Concentrations of the specific pollutant in the highway runoff selected for analysis have been estimated to have the following characteristics.

SITE MEDIAN CONCENTRATION (TCR)	=	0.400 mg/l
COEF of VARIATION (CVCR)	=	0.71

The mean concentration in runoff is computed using transform equation 15e.

$$MCR = TCR * \sqrt{1 + CVCR^2} = 0.400 * \sqrt{1 + 0.71^2} = 0.491 \text{ mg/l}$$

(C) Stream Flow Characteristics - The highway runoff discharges into a stream that has the following characteristics.

MEAN STREAM FLOW (MQS)	=	2.80 CFS
COEF of VARIATION (CVQS)	=	1.50

Pollutant concentrations in the receiving water upstream of the discharge location are assumed to be "zero." Accordingly, the computations will reflect only the effect of the highway runoff discharge.

(D) Runoff From Mean Storm - The runoff generated by the mean storm event is computed using equation 2, and values for the runoff coefficient (0.45), the drainage area (2 acres), and the mean rainfall intensity (0.07 in/hr) as defined above for the site. The variability of the runoff flow rates is estimated to be the same as that for the rainfall intensity.

$$MQR = Rv * MIP * AROW$$
$$MQR = 0.45 * 0.07 * 2.0 = 0.063 \text{ CFS}$$

$$CVQR = CVIP = 1.30$$

CALCULATE STREAM IMPACTS

The statistical properties of the highway runoff flows and concentrations and the stream flow characteristics developed by the steps above are now used to compute the receiving water impact of the highway runoff. Specifically, the statistics of the stream concentrations downstream of the discharge are produced by the next calculation.

STEP 1 COMPUTE STATISTICAL PARAMETERS OF INPUTS

The statistical properties of each of the input parameters that were established above can be computed from the mean (M) and coefficient of variation (CV) by using the appropriate form of the transformation equation (equation 15). For each of the input parameters, the following calculations are made.

Compute LOG SIGMA $W = \sqrt{\ln(1 + CV^2)}$

Compute LOG MEAN $$U = \ln\left(\frac{M}{\sqrt{1 + CV^2}}\right)$$

Compute MEDIAN $$T = \exp(U)$$

Compute SIGMA $$S = M * CV$$

Results are summarized in the table below for the three input parameters used in the analysis. Upstream concentration (CS) has been assumed to be zero, so that results reflect only the impact of the highway stormwater discharge. The table shows both the original input values for the arithmetic mean and coefficient of variation, and the computed values for the other statistical parameters.

PARAMETER	CODE	STREAM FLOW (-QS)	HWY RUNOFF (-QR)	CONCENTRATION (-CR)
MEAN	(M--)	2.80	0.063	0.491
COEF VAR	(CV--)	1.50	1.30	0.71
LOG SIGMA	(W--)	1.08565878	0.99475685	0.63890118
LOG MEAN	(U--)	0.44029192	-3.2593911	-0.9162907
MEDIAN	(T--)	1.553	0.038	0.400
SIGMA	(S--)	4.200	0.082	0.348

STEP 2 COMPUTE STATISTICAL PARAMETERS OF DILUTION FACTOR

A dilution factor (DF) has been defined by equation 13 as the ratio of highway runoff discharge flow (QR) to total flow (QS + QR):

$$DF = \frac{QR}{QR + QS} = \frac{1}{1 + D}$$

where $D = \frac{QS}{QR}$

The LOG SIGMA of the dilution ratio (D), per equation 16, is:

$$WD = \sqrt{WQS^2 + WQR^2}$$

$$WD = \sqrt{1.08565878^2 + .99475685^2} = 1.39814213$$

The 5th and 95th percentile values of the dilution factor (DF) are computed from this value and the MEDIAN values developed in the preceding step using equation 17.

The appropriate values for Z_a are determined from table 13, as follows. Z_{95} is the Z Score corresponding to a probability of 95 percent (0.95). Find the value 0.9500 in the array of 4-digit numbers, and read the first part of the Z value (1.6) on the left of the row. The next two digits for Z are determined by the heading for the column in which the percentile falls. In this case p = 0.9500 falls about midway between columns headed by 0.04 and 0.05. You may interpolate to estimate Z for the 95th percentile to be 1.645. Predictions from the model are approximate, and for the example we have rounded to a value of Z = 1.65 for Z_{95}.

The table only lists probability values greater than 50 percent, but the relationship between probability and Z is symmetrical. Z at 50 percent (p = 0.5000) is zero, and has increasing positive values for probabilities greater than 50 percent. Probabilities less than 50 percent have corresponding negative values for Z. Therefore, Z for the 5th percentile (Z_5) is -1.65.

$$DF_{95} = \frac{TQR}{TQR + TQS * \exp(Z_{95} * WD)}$$

$$= \frac{0.038}{0.038 + 1.553 * \exp(1.65 * 1.39814213)}$$

$$= 0.00217343$$

$$DF_5 = \frac{TQR}{TQR + TQS * \exp(Z_5 * WD)}$$

$$= \frac{0.038}{0.038 + 1.553 * \exp(-1.65 * 1.39814213)}$$

$$= 0.21924155$$

The LOG MEAN and LOG SIGMA of the dilution factor are approximated by interpolating between these values, using equations 18 and 19.

$$UDF = \frac{\ln(DF_{95}) + \ln(DF_5)}{2}$$

$$= \frac{\ln(0.00217343) + \ln(0.21924155)}{2}$$

$$= -3.8245157$$

$$WDF = \frac{1}{Z_{95}} * \frac{\ln(DF_5) - \ln(DF_{95})}{2}$$

$$= \frac{1}{1.65} * \frac{\ln(.21924155) - \ln(.00217343)}{2}$$

$$= 1.39814213$$

The remaining (arithmetic) statistics are then computed using an appropriate version of of the equation 15 transformation equations.

$$MDF = \exp(UDF + 0.5 * WDF^2) = 0.058$$

$$CVDF = \sqrt{\exp(WDF^2) - 1} = 2.462$$

$$SDF = MDF * CVDF = 0.143$$

STEP 3 COMPUTE STATISTICS OF STREAM CONCENTRATION

The mean, standard deviation, and coefficient of variation of the variable stream concentrations (CO) that result from the highway runoff discharges are computed next.

MEAN stream concentration (equation 20):

$$MCO = (MCR * MDF) + (MCS * (1\text{-}MDF))$$
$$= (0.491 * 0.058) + 0$$
$$= 0.028$$

STANDARD DEVIATION of stream concentrations (equation 21):

$$SCO = \sqrt{SDF^2 * (MCR - MCS)^2 + SCR^2 * (SDF^2 + MDF^2) + SCS^2 * (SDF^2 + \{1 - MDF\}^2)}$$

$$= \sqrt{A + B + C}$$

$$A = SDF^2 * (MCR\text{-}MCS)^2 = 0.143^2 * (0.491 - 0)^2 = 0.00490995$$

$$B = SCR^2 * (SDF^2 + MDF^2) = 0.348^2 * (0.143^2 + 0.058^2) = 0.00288337$$

$$C = SCS^2 * (SDF^2 + (1\text{-}MDF)^2) = 0^2 * (0.143^2 + (1 - 0.058)^2) = 0$$

$$SCO = SQRT(0.00490995 + 0.00288337 + 0) = 0.088$$

COEFFICIENT OF VARIATION of stream concentrations (equation 22):

$$CVCO = \frac{SCO}{MCO} = \frac{0.088}{0.028} = 3.10$$

Then complete this step by computing the log transforms for the downstream concentration of the pollutant.

$$\text{LOG SIGMA} \quad W = \sqrt{LN(1 + CVCO^2)} = 1.53720$$

$$\text{LOG MEAN} \quad U = \ln\left(\frac{MCO}{\sqrt{1 + CVCO^2}}\right) = -4.74081$$

STEP 4 COMPUTE CONCENTRATION EXCEEDED AT A SELECTED FREQUENCY

The frequency with which specified criteria values, or other target concentrations, will be exceeded can be computed from the LOG MEAN and LOG SIGMA of the stream concentrations, and the appropriate values of Z from the standard normal table (table 16). The concentration at any percentile (equal to or less than) is given by equation 25:

$$CO_a = \exp(UCO + Z_a * WCO)$$

The percentile of interest in assessing the potential for a problem from the highway discharge is that which corresponds to the once-in-3-year recurrence interval on which the toxic criteria are based. This percentile (PR) is determined by the average number of storms per year (NST). See equation 1, section 2.2 of this document for the determination of NST from the rainfall statistics.

$$NST = \frac{365 * 24}{MTP} = \frac{8760}{87.6} = 100$$

The expected number of storms in three years is 3*NST, and the frequency of occurrence (probability) for the once-in-3-year event is:

$$PR = \frac{1}{3 * NST} = 0.0033 = 0.33\%$$

The standard normal table (table 13) is based on the probability less than, and the value of Z that corresponds to a probability of (1-0.0033 =) 0.9967, is

$$Z = 2.72$$

Then the stream concentration that is exceeded during one event in 3 years is

PERCENT EXCEEDING	PERCENT LESS THAN	Z	STREAM CONCENTRATION CO_a
0.33 %	99.67 %	2.72	exp(-4.74081 + 2.72*1.53720) = 0.571 mg/l

STEP 5 ADJUST AND EVALUATE THE STREAM CONCENTRATION

The once-in-3-year stream concentration computed above, using the moments approximation of the probabilistic dilution model, must be adjusted before the final comparison with the stream target concentration. There are two adjustment elements.

- Soluble Fraction of Pollutant in Runoff - Toxic effects are caused by soluble toxicants in the water column and this is the basis for the criteria values. If the runoff pollutant concentration used in the analysis was the total concentration, the final result should be factored by the estimated soluble fraction of the selected pollutant.

  For the numerical example, it is assumed that the pollutant being evaluated is lead, and its soluble fraction is 10 percent.

- Error from the Moments Approximation - The basis for compensating for this overestimate is indicated by figure 7. The error is a function of the flow ratio (MQS/MQR), and the correction factor (CF) is defined by:

$$CF = 1.05 + 0.3*X - 0.05\,X^2$$

where:

$$X = \ln\left(\frac{MQS}{MQR}\right)$$

For the assigned conditions of the numerical example, the flow ratio (44.44) yields a correction factor (CORR FACTOR) of 1.47, and for lead the soluble fraction (FSOL) is 0.10. Therefore, the soluble stream concentration to be compared with the target value is:

$$0.571 * \frac{FSOL}{CORR\ FACTOR} = 0.571 * \frac{0.10}{1.47} = 0.039\ mg/l$$