Chapter 5

A Decision Support System for Highway Runoff

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5.1 Introduction

In a study for the Federal Highway Administration (FHWA) completed several years ago, my co-workers and I assembled and analyzed pollutant runoff data for highway sites (Driscoll, Shelley, and Strecker, 1990). The data were obtained in a number of independent studies at locations throughout the USA. The studies were conducted between 1978 and 1984, and the monitoring periods were generally one or two years in duration. In addition to characterizing the quantity and quality of highway stormwater, another project objective was to develop a procedure by which a highway engineer or planner could perform a screening analysis to determine whether a receiving water quality problem was likely to be created by stormwater discharges from a particular highway site. In the event a problem condition was projected, it was desired to identify the extent of runoff control that would be required to mitigate the indicated water quality problem.

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We developed an analysis procedure and described it in a guidance document (Driscoll, Shelley, and Strecker, 1990). The procedure was structured in the form of spreadsheet-based fill-in tables to convert raw input data into values for the parameters used in the receiving water impact computation. Tables and maps were provided to assist selection of values for raw inputs. Other tables were developed which listed separately-computed impact results for a range of input values, from which a user would "look up" the answer, interpolating as necessary. General guidance was provided on how independently-determined stormwater pollutant control effects could be incorporated into the analysis.

FHWA agreed with our suggestion that, given the intended audience and use, more effective use of the impact assessment procedure would result from the availability of a user-friendly computer program which would guide a user through the procedure. This program was organized in the form of a decision support system, the structure and operation of which is described in this chapter. The Highway Runoff Decision Support System (HWY DSS) that was developed expanded on the scope of the method manual to permit a user to examine the effect of selected stormwater control measures on the mitigation of a projected adverse water quality impact. Both the types of pollutant control measures appropriate for highway stormwater, and the performance estimates that are incorporated in the DSS, are based on a separate FHWA research study (Versar & Camp, Dresser, and McKee, 1988).

5.2 Program Design

The target audience was considered to be State Department of Transportation (DOT) or other engineers or planners who would have responsibility for providing environmental input to overall planning and design of new or reconstructed highway segments. These individuals would be expected to address water quality issues as one element of a broad spectrum of concern, and were anticipated to require use of the procedure only intermittently,

perhaps a few times a year. They were presumed to be generally knowledgeable on the subject and issues, but given their range of duties and lack of sustained effort on water quality analysis, it was considered that they would benefit most from an analysis tool structured in the form of a decision support system.

The conceptual basis of the decision support system is illustrated schematically in Figure 5.1.

Figure 5.1: Schematic outline of HWY DSS.

Features that were considered important to incorporate include the following:

1. Lead the user step by step through the selection of values for the input parameters required for the analysis.
2. Provide ready access to reference information to assist the user's selection of appropriate values.
3. Avoid providing *automatic default* values so that the user is forced to choose, thereby carrying through a sense of the degree of uncertainty in the results that are generated.
4. Make it convenient to perform sensitivity analyses, to

determine the significance of alternative estimates for uncertain input values, on the final decision that would be indicated by the analysis.

5. Select a computation scheme that generates results of a type and in a form that relates to the decision to be made.
6. Select an analysis procedure that lends itself to use for screening analyses, that is, one that is sufficiently simple in execution and in data requirements to permit convenient analysis of an appreciable number of different alternatives. Sufficient accuracy for the type of decision to be made is presumed, as is the understanding that highly sensitive or complex situations may require something beyond a screening analysis.
7. Make it easy to test a variety of alternatives, keep track of and compare results for different conditions, and where appropriate (as with control evaluation), to evaluate combinations of types as well as individual measures.
8. Build in shortcuts to permit more rapid operation by users familiar with inputs required and the assignment of values for them, but maintain a base procedure that effectively serves a new or occasional user.
9. Display results in a manner that facilitates interpretation and evaluation. Favour graphical displays wherever feasible and useful.
10. Provide for the generation of hard copy or disk files for analyses that the user elects to document, but allow exploratory analysis that need not be retained to be ignored.

5.3 Impact Analysis Method

The general objective of the analysis was the assessment of the

water quality problem potential in a specific stream segment receiving the stormwater runoff discharge from a section of highway. In selecting the impact analysis method to be utilized, we narrowed the focus to the concentrations of runoff pollutants in the receiving stream. Given the normal variation of rainfall and stream flows, the impact would be expressed as the probability distribution of the concentrations. For decision purposes, the computed probability distribution would be evaluated to determine the magnitude and frequency at which an appropriate target concentration would be exceeded. Heavy metals are among the more significant pollutants present in highway stormwater runoff. At sufficiently high concentrations, they are toxic to aquatic life, the support and protection of which was presumed to be the most common beneficial use for the stream segments that will receive highway runoff. The US EPA's toxicity criteria for the protection of aquatic life are presented as concentrations which should be exceeded no more frequently than once in three years.

The decision guidance structure incorporated into the method presents a comparison which indicates the degree to which target concentration exceedence frequencies are higher or lower than the three year return period specified by the EPA toxic criteria. The methodology also permits a similar analysis for pollutants other than metals. When, as in the case of TSS, there is no comparable water quality criteria or standard for comparison, the user may apply a target concentration based on judgement or on other standards that may apply.

The receiving water impact computation method used is the Probabilistic Dilution Model (PDM), developed under EPA's NURP program, and described by DiToro (1984). Figure 5.2 presents a schematic outline of the procedure, which applies an analytical solution to compute the distribution of stream concentrations from inputs consisting of the statistics (mean and coefficient of variation) of lognormal distributions of stream and highway runoff flows, and stream and highway runoff concentrations.

The information needed to perform the analysis includes:

Figure 5.2: PDM stream impact analysis.

1. Site area and impervious fraction and rainfall characteristics representative of the area, from which runoff flow characteristics are computed. Reference information on independently-developed rain-event statistics is provided.
2. Stream flow statistics for daily average flows is required. An independently developed summary of mean flow on a unit area basis (cfs/sq mi) is provided for user reference. This is combined with the user determined upstream drainage area to determine the mean stream flow at the site. A procedure for estimating the coefficient of variation of stream flows is provided.
3. Runoff pollutant concentrations for highway sites are based on the results of the FHWA study of which the DSS development was a part. Estimates of runoff quality statistics are called up on user prompt, with provision for adjustment by the user and reference information to guide selections.

4. Upstream concentrations of the pollutant being analyzed are not considered in the analysis incorporated in the DSS. Although the analysis method provides for it's use, an independently-developed generalized summary was not available for use in providing guidance, as was the case for rainfall and streamflow. With upstream concentration tacitly assumed to be zero, the results generated represent the downstream concentration of a pollutant due *solely* to the highway discharge.

5.4 Operation of the Decision Support System

On startup, the program presents the user with several options for providing the computation component with the required input data. The *Normal Track* proceeds stepwise through the required inputs, presenting user prompts and direct access to commentary and reference material pertaining to the particular type of input being addressed. A *Fast Track* takes an experienced user directly to a series of fill-in edit fields where pertinent input parameter values may be entered. A third option, *Data File*, produces a display listing previously-stored input-data sets. Selecting the desired file-name loads that set of input data.

The user is next asked to indicate whether the receiving water to be analyzed is a stream or a lake. The discussion which follows describes program operation using the normal track routine, with a stream selected as the receiving water. Lake impacts are assessed in a parallel computation which determines phosphorus loading and lake concentrations, and compares projected levels to levels associated with different trophic states.

Assigning Input Values

Input data is required to describe the pertinent characteristics of the highway site, and for three of four parameters illustrated in the schematic presented in Figure 5.2. As noted earlier, upstream concentrations of the pollutant being analyzed are not considered,

and the analysis will reflect the impact produced exclusively by the highway stormwater.

Site Characteristics

Site characteristics are the first set of input parameters to be entered. Data entries are prompted for the watershed drainage area, and for the area of the highway paved surface and total right-of-way (and thus the percent impervious). Figure 5.3 illustrates the site data prompts presented by the program. From the percentage of impervious area, a runoff coefficient (R_v) is estimated which is used to convert rainfall to runoff flows and volumes.

Rainfall

Statistics based on a long term record are used to characterize storm event parameters that are used in the analysis. The mean and coefficient of variation of event volumes, intensities, durations and intervals are the required parameters. The program provides the necessary reference data and allows the user to call up rainfall statistics for gages in individual cities, or for preliminary estimates, typical regional values can be selected from a map. Figure 5.4 illustrates the program displays. The intention is that users will develop files for gages pertinent to their area of concern, and the program allows for the addition of rain files.

The required rainfall statistics can be developed using the statistical rainfall analysis program SYNOP, which analyzes an hourly US Weather Service rainfall record to produce the storm event statistics. Under work assignments for FHWA and EPA, we made a number of enhancements to the SYNOP program (now designated SYNOP II) and developed versions for the IBM PC and Apple Macintosh (Driscoll et al. 1990 and Driscoll et al. 1989).

DRAINAGE AREAS

WATERSHED
DRAINAGE AREA

total drainage area of watershed
contributing flow to stream
at point where highway runoff enters

enter total drainage area
of watershed - in square miles

ATOT = square
miles

HIGHWAY

CONTINUE

DRAINAGE AREAS

HIGHWAY DRAINAGE AREAS
THAT CONTRIBUTE RUNOFF DIRECTLY TO THE STREAM

RIGHT OF WAY

enter ACRES of total right-of-way
draining to stream

AROW = acres

HIGHWAY PAVEMENT

enter ACRES of paved highway area
draining to stream

AHWY = acres

CONTINUE

Figure 5.3: Prompts for site characteristics inputs.

SOURCE FOR RAIN DATA

SELECT SOURCE YOU WISH TO USE
FOR YOUR ESTIMATE
?

MAP OF RAIN ZONES

DATA FOR SELECTED CITIES

ZONE MAP

CLICK ON NUMBER
TO SELECT ZONE

Program files

- ☒ AL Birmingham
- ☐ AZ Phoenix
- ☐ CA Oakland
- ☐ CA San Francisco
- ☐ CO Denver
- ☐ DC Washington
- ☐ FL Gainesville
- ☐ FL Tampa
- ☐ GA Atlanta

Macintosh HD

Eject

Drive

Open

Cancel

SYNOPSIS RAINFALL STATISTICS

RAINFALL EVENT STATISTICS

'typical' values for ZONE 3

NOTE - you may edit listed values to record final selection

	MEAN	COEF VAR
VOLUME (Inches)	.49	1.47
INTENSITY (In/hr)	.102	1.28
DURATION (hours)	6.2	1.22
INTERVAL (hours)	89	1.05

CHECK FURTHER

OK

Figure 5.4: Rainfall data input displays.

Streamflow

The analysis method requires input values for mean and the coefficient of variation of streamflows at the point of highway runoff discharge. The program provides a map of mean runoff per square mile as well as access to a data file containing records for specific gages. Estimates of the coefficient of variation of daily stream flows are based on a separately-developed empirical relationship between the variability and the ratio of the 7Q10 to the average flow. Figure 5.5 illustrates the stream flow support material that can be accessed by the user. When users develop stream flow statistics for streams in their area of concern, results may be stored for future access in the program's reference data file.

Pollutant Concentrations

Input data required for highway runoff concentrations includes the site median concentration of the constituent being analyzed and the coefficient of variation of the storm event concentrations. The data on site median concentrations for urban and rural sites that was developed in the FHWA study is stored for reference by the program. Figure 5.6 illustrates the user prompts for selection of the pollutant type, highway type, and the site percentile to use to select from the range of observed values. For metals, the toxicity is assumed to be produced by the soluble fraction, which the user is prompted to supply, with help windows available to guide the selection. Impact assessment based on the total concentration (particulate plus dissolved fraction) can be done by assigning 100 percent as the soluble fraction.

Target Concentrations

EPA's water quality criteria are written such that effective concentrations (acute and chronic) should not be exceeded more than once every three years. For most metals, the concentrations that produce toxic effects increase with total hardness of the

Figure 5.5: Stream flow reference data displays.

Select POLLUTANT	☐ TSS	☐ TOC	☐ NO3	☒ COPPER
	☐ USS	☐ COD	☐ TKN	☐ LEAD
				☐ ZINC
				☐ PHOSPHORUS

Select HIGHWAY TYPE.	☐ URBAN	☐ RURAL
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The site median concentration (SMC) for the 50th PERCENTILE highway site is initially selected. It is the most probable value for the SMC in the absence of information to guide an alternate choice.

You may enter an alternate value for the PERCENTILE %

Use the HELP selection for discussion on percentile selection.

50 % of URBAN highway sites have
a Site Median Concentration (SMC) for COPPER
equal to or less than.
µg/l

Figure 5.6: Pollutant selection displays.

water. The EPA criteria for toxicity to aquatic life, including the hardness adjustment are incorporated in the program. Figure 5.7 indicates prompts for user selection of water hardness and the resulting target concentration that is computed and displayed. The user may modify this target value if other standards apply in the case being examined.

Input Summary

Once input data entry is complete, the program displays a summary of the values assigned for all of the input parameters, and the identifying name assigned to the input set. This display is illustrated in Figure 5.8. The user is provided the opportunity to edit any of the assigned values before proceeding further.

Display of Impact Analysis Results

When the above information has been entered, the program then calculates a predicted probability distribution of stream concentrations below the point of entry of the highway runoff, after complete mixing with streamflow. The probability computed defines the percentage of storm events that will produce stream concentrations equal or greater than a particular concentration level. When this percentile is combined with the average number of storms per year, the return period (MRI = Mean Recurrence Interval) at which the target concentration is exceeded can be calculated and displayed. Figure 5.9 shows an example of a histogram generated by the program. In the example, the predicted frequency of target exceedence (MRI = 116 days) indicates that some type of control is required to meet the assigned water quality criteria. The user can then choose to investigate the addition of a control measure or measures. In the design workbook, the user calculates the MRI and then proceeds independently to control measure evaluation (if necessary).

The display in Figure 5.9, which shows the relationship of an appropriate target level to the projected magnitude and frequency

Figure 5.7: Displays for selection of Target concentration.

SUMMARY OF INPUTS for TEST CONDITION : BASE CASE

Total Drainage Area = 10.00 sq.mi.

HWY Paved Area = 8.00 acres

TH of Surface Water = 50 mg/l

HWY Right-of-Way = 12.00 acres

RAIN EVENT

VOL(in)

INTENS(in/hr)

DURAT(hr)

INTERV(hr)

MEAN

0.49

0.102

6.20

89.00

CofV

1.47

1.28

1.22

1.05

STREAMFLOW

1.00 CFS/sq mi

MEAN =

10.00 CFS

Coef of Var = 1.50

RUNOFF FLOW

MEAN = 0.70 CFS

Coef of Var = 1.28

POLLUTANT = COPPER

Target Concentration = 9 µg/l

Site Median Concentration = 54 µg/l

Coef of Var of Site EMC's = 0.71

Soluble Fraction = 40 %

GO BACK and EDIT

OK - CONTINUE

Figure 5.8: Display for summary of input data.

Figure 5.9: Impact analysis result display.

of concentrations produced by highway stormwater, provides a concise display of the information that can guide a determination of whether or not the impact is significant, and a decision on the need for stormwater control.

The EPA toxic criteria have no legal or regulatory force; they provide guidance on water quality conditions that have been determined to be protective of a use. In many cases, the criteria are translated directly into legal water quality standards. However, a decision on a need to mitigate could, in the case of a sensitive water body for example, be based on an arbitrarily lower target level, or on a longer return period for exceedence of the selected target.

Output Processing Options

When the user elects to continue, the program displays a text summary of the result, and presents a set of options for further action. As indicated by Figure 5.10, user options at this point are:

PRINT - produces a hard copy summary of the input parameters assigned and the impact analysis results, including an optional printout of the histogram plot. A prompt allows the entry of brief comments to elaborate on the conditions that apply to this analysis set.

SAVE INPUT - creates a data file of the input values selected for this analysis. This file may be selected on startup of a future session to avoid stepwise entry of input values.

INVESTIGATE...TREATMENT - takes the user to a program element that provides for exploring the effect of the design size of several control types first on the reduction of pollutant discharges, and then on the extent to which the stream impact is modified. Program action following this selection is discussed further below.

INVESTIGATE SENSITIVITY - steps the user through a

tabulation of the parameter input values that were selected, with an opportunity to modify any of them for comparing the extent to which the output (and the decision that would be based on it) is influenced by uncertainty in any of the input values. A new output histogram display is produced with the modified input parameter values.

TERMINATE - ends the session.

For the input conditions assigned to... BASE CASE
The STREAM impact analysis indicates that the 9 $\mu\text{g/l}$ TARGET
concentration will be exceeded during 12.752 % of storm events
or ... on an average of once every 29.1 days

Once in 3 years- the concentration will exceed 37 $\mu\text{g/l}$

YOU MAY NOW DO ANY OF THE FOLLOWING
(one at a time)

- ☐ PRINT a summary of inputs and results for this case
- ☐ Save input values for this condidtion in a DATA FILE.
- ☐ Investigate the effect of runoff TREATMENT.
- ☐ Investigate SENSITIVITY to estimates of input values.
- ☐ TERMINATE this analysis.

Figure 5.10: Display of output options.

Any or all can of these options can be implemented during a session, with the program returning to this menu at the completion of each option. Program operation is terminated from this display.

Control Measure Evaluation

When the model user elects to investigate control measures, the program provides a choice of four types: grass channels, detention

basins, overland flow, and infiltration devices. These controls can be applied individually or in series (such as a grass swale leading to a detention basin). The predicted efficiencies of the grass channels and overland flow devices are based upon the draft FHWA study by Versar et al. (1988). The detention basin and infiltration devices methodology uses EPA's detention basin analysis approach developed by Driscoll (1986).

Figure 5.11 illustrates the displays presented following selection of a grass channel and a detention basin respectively. Original performance estimates for grass channels (which have been elaborated since the publication on which the DSS procedure is based) related pollutant removal to channel length. For this control, the user manually assigns a removal efficiency based on visual inspection of the displayed relationship. In the case of the detention basin shown, and the other control types, removal efficiency is computed using the site rainfall and drainage area characteristics, and device size information entered by the user. The user is permitted to examine the removal efficiency produced by various size selections before selecting the one that will be carried through for the repeat of the impact analysis.

Once the removal efficiency of the control has been projected or assigned, and is accepted as the estimate to use, the program displays the revised set of inputs and recomputes the stream concentration frequency-distribution. In the new display, illustrated by Figure 5.12, the result for the current alternative is compared with that for the base case. Continuing the program operation displays the output options window (Figure 5.9).

The user may continue to examine different control alternatives, cycling through this part of the program, and assigning a descriptive name to each alternative, ignoring inappropriate choices and documenting those worth recording.

After the first pass through the foregoing procedure, all subsequent selections of the *Investigate Treatment* option will present the display shown at the top of Figure 5.12. The removals determined may be applied to untreated stormwater to evaluate the selection as an alternate to others investigated. The new control may also be applied to the residual pollutants in the

Enter the size characteristics of the detention basin

AVERAGE DEPTH (feet) STORAGE VOLUME (cu ft)

The selected site conditions and the above design parameters produce the following design conditions for the detention basin

Surface Overflow Rate (ft/hr) = 0.13
Storage Volume Ratio (VB/VR) = 8.268

These conditions result in a long term removal efficiency for COPPER, of PERCENT

Figure 5.11: Display for control evaluation.

Figure 5.12: Comparison display for alternative assessment.

discharge from another control, which permits the examination of combinations of controls arranged in series (e.g., a swale followed by a detention basin). When this option is selected, the user is presented a list of the previous control alternatives examined, and permitted to select the one the current choice will be linked with.

5.5 Summary

The computer program provides a method for assessing the impacts of highway runoff on receiving waters, structured in a decision support system format. The technique could be applied to similar type analyses for assessing stormwater impacts from urban sources in general, with the substitution of appropriate

reference data.

The decision support system structure is one that could be applied quite effectively to a variety of analyses. In such cases, an appropriate computation element for the situation being addressed would be required, in addition to the input and decision reference data.

The reports that were cited, and floppy disks with the program (in Macintosh or IBM-PC format) are available from FHWA through the National Technical Information Service (NTIS).

5.6 References

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