Assessing the Impacts of Operating Highways on Aquatic Ecosystems

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ABSTRACT

A protocol has been developed for assessing the impacts of highway operations and maintenance and determining the need for impact mitigation measures. The general strategy applies nationally, and specific elements of the method have been developed for the state of Washington and other Pacific Northwest locations on the basis of comprehensive research that was conducted in that region on highway runoff water quality. The basic premise of the protocol is that the highway impact on the receiving water can be assessed most realistically in the context of the aggregate burden that is created by all activities in the watershed. By using an initial screening process a determination can be made as to whether or not a case is likely to have an insignificant impact. Substantial resources are expended on assessing only those cases that may have a significant impact on aquatic ecosystems. Those cases are subjected to analyses of both cumulative pollutant loadings and changes in pollutant concentrations in the receiving waters, which emphasize the most critical conditions under the circumstances. Mitigation is considered in both steps. The Washington results were employed to develop a deterministic model for the pollutant loading analysis and a probabilistic procedure for the pollutant concentration assessment. The protocol offers opportunities to forecast potential aquatic impacts of a highway at an early stage of project development and to allocate impact mitigation measures on the basis of need. This advance improves the cost-effectiveness of stormwater runoff management and aids in avoiding the expense and delay of legal challenges to highway agency actions that have potential water quality impacts.

The National Environmental Policy Act (NEPA) of 1969 requires that an environmental assessment be made of the anticipated consequences of each significant federal action. Beyond this and a few other general provisions, however, the law and regulations that are promulgated under its authority have provided little distinct guidance on impact assessment methodology. Various agencies have, however, developed guidelines for preparing environmental impact statements (EISs) for projects under their regulatory jurisdictions. In both the general situation and the highway case in particular (1), these guidelines usually concern the content of EISs and leave the selection of assessment procedures to the analyst.

A substantial amount of the applied environmental research performed since the adoption of the NEPA has had as an implicit objective the enhancement of abilities to conduct environmental impact assessments. Although many useful methods have resulted from these efforts, there have been few attempts to apply the knowledge gained to developing comprehensive assessment protocols. Even rarer has been the implementation of these research results in the practices of organizations that must prepare or evaluate EISs.

A comprehensive protocol has been developed for assessing impacts on surface waters that receive storm runoff from operating highways. The general philosophy of this protocol applies nationally, and specific elements have been developed for the state of Washington on the basis of a large amount of highway runoff water quality research conducted there. A handbook was prepared to provide step-by-step guidance for impact analysis (2). With the assistance of the researchers, the Washington State Department of Transportation is in the process of implementing the protocol in its practices (3). Following a review of the available techniques for assessing aquatic impacts of highway operations, this paper contains a discussion on the generalized protocol and its rationale as well as illustrations of its application with the specific procedures developed from the Washington results.

TECHNIQUES FOR ASSESSING AQUATIC IMPACTS OF OPERATING HIGHWAYS

Highway operations potentially affect receiving waters through peak flow increases, degradation of water quality, and modification of biotic habitats. Various hydrologic models are available to estimate highway runoff flow rates for design storm conditions and the resulting effects on stream discharges. A number of possible stormwater runoff contamination sources exist, including vehicular and atmospheric deposition, pavement wear, and various maintenance operations. Most techniques that can be applied to impact assessment reflect the overall quantities of pollutants that may be present, despite the fact that contributions from the respective sources vary spatially and temporally, both seasonally and annually.

Highway runoff also potentially affects receiving water quality over both the short and the long term. Short-term effects would be a function of high pollutant concentrations (pollutant mass per unit water volume) during individual runoff events (e.g., acute toxicity to aquatic biota). Long-term effects would be created by cumulative pollutant loadings (pollutant mass per unit time). Examples are sediment accumulation and seasonal nutrient loading to a lake. Most of the available aquatic impact assessment tools represent long-term loadings. However, most of the knowledge of aquatic ecosystem response and most water quality criteria issued as regulations are of a short-term nature.

The development of techniques that can be used to assess water quality impacts of operating highways has a very brief history. Sartor and Boyd (4) and Pitt and Amy (5) published data on pollutant accumulations on urban streets. Neither group attempted to determine their transport in storm runoff, however. The first efforts to characterize the runoff from operating highways were by Sylvester and DeWalle (6) and Soderlund and Lehtinen (7), who derived mass loadings per unit highway surface area. The Municipality of Metropolitan Seattle (8,9) introduced traffic as a variable, expressing freeway runoff pollutant loading data normalized on the basis of vehicle counts. Shaheen (10) also found traffic to be a key variable and derived linear regression equations to estimate pollutant loadings on the basis of traffic counts, vehicle deposition rates, and background pollutant levels. Envirex Inc. conducted extensive highway runoff studies at five sites east of the Rocky Mountains for FHWA. That work concluded with the development of a deposition model to predict the accumulation of pollutants in the periods preceding storms and a washoff model to forecast contaminant removal in the runoff, both on a total mass basis (11). These models were formulated for individual storm events.

Although all of these efforts yielded techniques amenable to aquatic impact assessment, none were formulated in a specific protocol for this purpose. This research effort had as a major objective the development of such a protocol and the methods necessary to apply it to problems in Washington State. The research effort was comprehensive, involving investigation of highway runoff pollutant sources, transport, fate, effects, and control. Many of the findings have been presented elsewhere (12-20), and the results of the most direct applications to impact assessment will be highlighted in this paper.

Key developments in this research were a cumulative pollutant loading model and a probabilistic approach for assessing short-term effects. The loading model consists of two components: (a) a simple algebraic equation that establishes cumulative total suspended solids (TSS) loading as a result of routine highway operation as a function of vehicles traveling during storm periods, and of runoff coefficient (ratio of runoff volume: precipitation volume), and (b) a series of multipliers for estimating loadings of other pollutants from TSS. Vehicles during storms are apparently important in controlling pollutant loading because of the spray washing that loosens contaminants deposited on vehicle undersides during dry weather. The California Department of Transportation (21) also found that introduction of this variable produced statistically significant results in its data analysis. Other pollutant loadings can be predicted from TSS because the majority of these pollutants are associated with the solids in runoff, an occurrence noted by other researchers (22,23) besides the authors. The probabilistic approach exploits the log-normal distribution of the individual storm data and permits the impact analyst to establish the frequency with which a given pollutant concentration, such as a water quality criterion, would be exceeded in a receiving water as a result of highway runoff. A similar technique was developed by the U.S. Environmental Protection Agency (24) for assessing the effects of urban runoff. It also was recommended by Loftis et al. (25) in a general review of statistical models that might be applied in water quality regulation.

GENERAL IMPACT ASSESSMENT PROTOCOL

Basic Principles

Development of the protocol for assessing the impacts of operating highways on aquatic ecosystems was based on a number of principles as follows:

1. The approach should be hierarchical, so that cases that have different potentials for aquatic ecosystem impact can be distinguished and resources for problem assessment and solution can be proportionately allocated.
2. The protocol should be adaptable for use in different locations through the application of specific analytical procedures that are appropriate to each region.
3. Assessment of the effects of routine highway operations and maintenance procedures should be separate, given the extensive spatial and temporal variability of the latter, even within the same region. Accidental occurrences also should receive separate attention.
4. The protocol should permit assessment of both short- and long-term effects.
5. The highway impact on the receiving water can be assessed most realistically in the context of the aggregate burden created by all activities in the watershed.
6. The methodology should incorporate decision criteria to assist the analyst in forecasting impacts and determining the need for the mitigation of potential impacts.

With regard to the first principle, the devised protocol has a hierarchy of three levels. The first screens out those cases that on the basis of objective criteria, almost certainly would not create significant aquatic impacts under the conditions of routine operation. Those cases that exhibit the potential to create significant impacts are analyzed in full for a typical annual cycle in the second level. In the third level, a more thorough analysis of these potential problems is emphasized and the recommendation is made to consider mitigation measures. After each level, the analyst is directed to assess the effects of maintenance and special problems in accordance with the third principle.

Both short-term occurrences (elevated stream flow and acute pollutant concentrations) and long-term conditions (cumulative pollutant loadings) may create significant aquatic impacts. Criteria for assessing the extent of these impacts are incomplete, however. Although a substantial amount of research has established the responses of aquatic organisms to concentrations of numerous pollutants under test conditions, different conditions of exposure exist in natural waters. Moreover, the biological significance of pollutant loadings is poorly understood in most cases. Given these uncertainties in the face of the need to make judgments about potential environmental impact, the most reasonable procedure appears to be evaluating highway impacts with reference to pre-existing receiving water conditions, as governed by the totality of occurrences in the watershed. In the absence of objective criteria, it can be said, for instance, that the highway can raise stream peak discharge and annual pollutant loadings by certain percentages or increase the frequency of violating a water quality criterion by a particular amount. This strategy is not perfect, because judgment still must be rendered on whether the estimated increases are excessive. Furthermore, it does not take explicit account of loading thresholds that may radically change the aquatic habitat to the detriment of the biological communities, a poorly understood phenomenon. Nevertheless, application of this principle represents an advance in organizing and quantifying impact assessment.

Conceptual Framework

Figure 1 shows a flowchart of the general impact assessment protocol. Level I is a rapid screening mechanism that is intended to identify cases that have a significant impact potential for detailed analysis. Those cases that are not expected to create significant impacts in normal operations are evaluated for the effects of nonroutine occurrences, such as maintenance, accidental spills, or other special problems. The set of screening criteria should be appropriate to the locale as well as conservative, so that only those cases that are certain to avoid significant impacts are dismissed from further analysis.

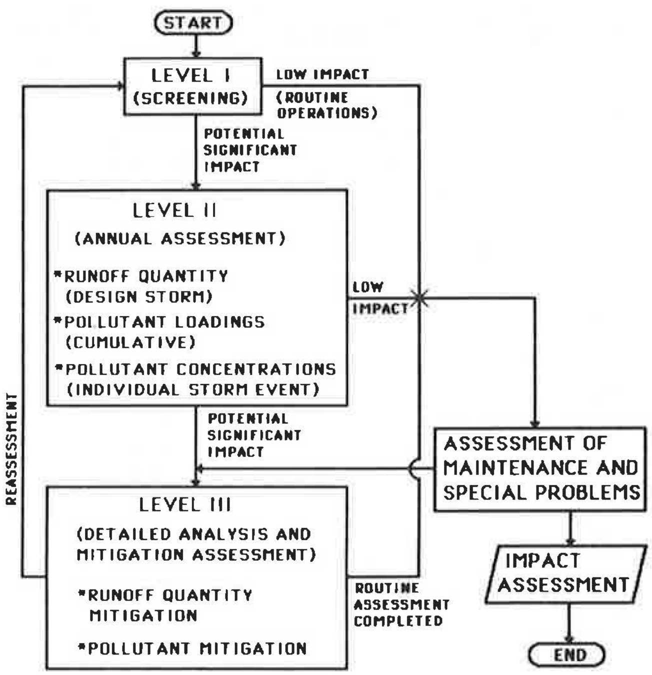

FIGURE 1 Flowchart of general impact assessment protocol.

The purposes of Level II are to guide an impact analyst through assessments of peak stream discharge and annual pollutant load increases that result from the highway's presence, and to evaluate the potential for individual storm events to cause excessive pollution of the receiving water. In each assessment, the contribution of the highway is to be evaluated in the context of pre-existing conditions. Requirements for the analyses include hydrologic, pollutant loading, and pollutant concentration models that are validated for the location of the highway. Hydrologic models of widespread applicability are abundant. However, pollutant load and concentration data are very scattered, and few models are available for any location. The effort of Envirex Inc. (11), cited earlier, has the broadest geographic basis, whereas Shaheen's work (10) was performed in Washington, D.C. Models that stem from the research in California (21) and the Pacific Northwest are available for those regions. The latter model will be discussed in the next section of this paper. Development of specific assessment tools for other areas remains a research need.

Level III is intended to provide further evaluation of the greatest potential routine operating problems revealed by previous analysis and to guide the development of impact mitigation strategies for those problems. It directs the analyst to define more exactly then in Level II, those conditions that were anticipated on the operating highway and in the watershed. In so doing, the closest possible approximation of the degree of impact may be achieved. In this level the recommendation is also made for assessing runoff quantity and quality impacts during critical periods within the annual cycle, if any. Examples are times of maximum flood potential or, conversely, periods of dry weather minimum flows, when the capacity to dilute contaminant concentrations is least.

The guidelines in Level III prompt the impact analyst to consider mitigation such as oil and grease traps, runoff retention/detention (R/D) facilities, and overland runoff discharge through vegetated drainage courses, where the assessment has shown it to be necessary. R/D facilities have the dual advantage of attenuating peak flows and removing some contaminants, especially those in solid form. Various researchers have reported on the efficiency of these facilities in treating stormwater runoff (26-30). Vegetated drainage removes pollutants through settlement, filtration, plant uptake, and various chemical processes and has been tested extensively for municipal and food processing industry wastes (31). The Washington research demonstrated highly efficient TSS and metal removal from highway runoff within 60 m of travel through vegetated ditches (17). Thus, although some data are available to predict R/D device and overland flow performance, the documentation does not extend over a wide range of conditions nor is it sufficient to support the formulation of detailed and generally applicable design criteria. Therefore, highway runoff aquatic impact mitigation represents another major research need.

After consideration of mitigation, the protocol directs the analyst to reevaluate the impact through Levels I and II with the selected mitigation measure in place. When an acceptable anticipated level of impact caused by routine operation is reached, the analyst assesses the potential effects of the maintenance operations and special problems. Included in this analysis are winter sand and deicing agent application, pesticides, accidental spills, and any other features of the highway construction or operation that may affect natural waters beyond routine occurrences. As in other areas of the process, background data and methods of analysis are not well developed in these cases. The analyst is often left with the need to use qualitative or semiquantitative judgment in order to make any assessment. Should the assessment indicate that mitigation of any of these special problems may be required, the analyst is directed back to Level III to develop a management strategy.

AN ILLUSTRATION OF THE IMPACT ASSESSMENT PROTOCOL FOR WASHINGTON STATE

Preparation for the Assessment

The preparation for a complete assessment of the aquatic ecosystem impacts of a highway requires the gathering of substantial data. Some of these data are needed for the quantitative analysis, whereas others serve as background for writing various sections of the EIS. The categories of needed information include general highway design features and operating conditions, drainage system details, physical and hydrologic characteristics of the receiving water, baseline water quality and biological data, and watershed land use characteristics. A list of the specific data needs has been prepared (2) but is not presented here because of its length.

Level I (Screening)

In the version of the protocol developed for Washington, Level I consists of three criteria on which cases can be screened to determine the need for more detailed analysis of routine operating impacts. These criteria concern traffic volume, the proportion of the watershed consumed by the highway, and the availability of mitigation. They are exercised as follows:

1. If all runoff discharges via a vegetated drainage course of at least 60 m in length, go to step 3. Otherwise, proceed to step 2.
2. If projected average daily traffic volume is less than 10,000, proceed to step 3. Otherwise, perform Level II analysis.
3. Determine the total area of the watershed located upstream from the highway runoff discharge point. If there are multiple discharge points, base the determination on the one located farthest downstream.
4. Determine the total area of impervious roadway surface that contributes runoff to the receiving water.
5. If the ratio of impervious roadway surface to total watershed area is less than 0.01, declare no impact from ordinary runoff and proceed to step 6. Otherwise, perform Level II analysis.
6. Analyze impacts associated with the particular anticipated maintenance practices or any special problem areas.

Each stated decision criterion has a basis in the research results. The minimum length of vegetated channel is the length identified (17) as reliably providing 60 to 80 percent reduction of major pollutants in highway runoff. The traffic criterion represents the volume below which no toxic effects appeared in bioassays (18). Concerning the highway-to-watershed area ratio, it is assumed that the runoff is diluted in the receiving stream in approximately the same ratio. Highway runoff can contain concentrations of toxicants comparable to LC_{50}'s (concentration lethal to 50 percent of the organisms in an acute bioassay) (18). A common means of protecting aquatic life is to limit receiving water concentrations to 0.01 x LC_{50}. In addition, investigation of the concentration-probability distributions discussed later in this paper indicates that dilution of 100:1 is generally required to ensure only a slight probability (<0.1 percent) that established water quality criteria will be exceeded. With a high dilution ratio of ordinary runoff and either low traffic volume or drainage over a vegetated drainage course, it can be stated with some assurance that impact of routine operations would be insignificant, and thus more detailed analysis can be avoided.

Level II (Annual Assessment)

The Level II runoff quantity assessment is based on procedures from general practice and the literature because no hydrologic modelling was performed under the research project. In its present form, the guide contains the recommendation to estimate the design for the 25-yr recurrence interval storm according to the Rational Method used by the Washington State Department of Transportation (32). The procedure may be modified by a user to employ a more advanced technique, such as the unit hydrograph or a more advanced hydrologic model. The highway runoff rate should be compared with the existing receiving stream peak discharge for the same design storm condition. This peak discharge may be established through analysis of the gauging record, if a sufficient one exists, by using a distribution model (33). Where there is no adequate gauging record, peak discharge can be estimated from one of a number of hydrologic models or according to a U.S. Geological Survey procedure (34). If the increased discharge caused by highway drainage exceeds a permitted amount or is judged to be excessive, the user is directed to Level III for information on designing detention facilities.

The flowchart in Figure 2 shows a guide to the Level II annual pollutant loading assessment. The flowchart requires that the analyst compare anticipated highway runoff pollutant loadings with loadings that preexisted in the receiving water. These preexisting loadings can be established either through stream water quality and flow data, where they are sufficient, or from the land use characteristics in the watershed. The procedure encompasses discharges to standing bodies of water (lakes and

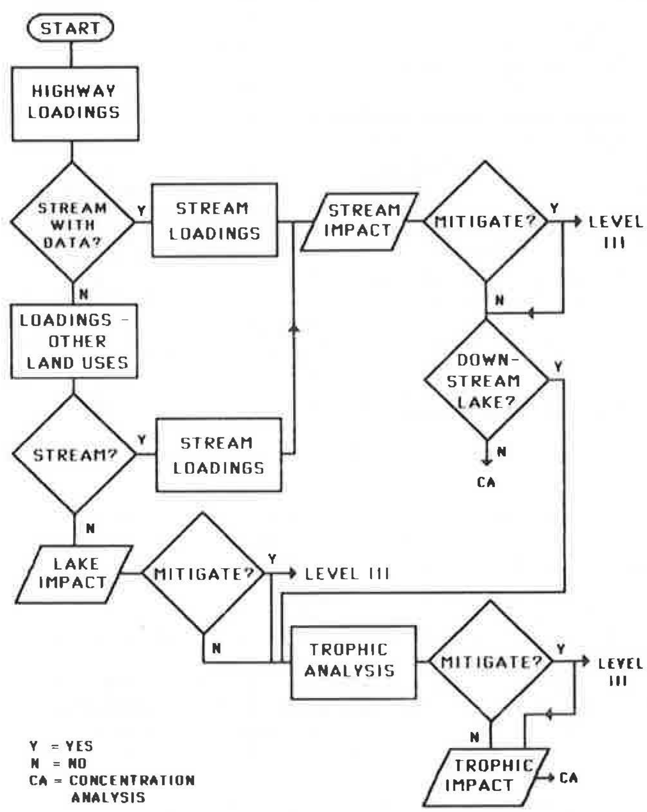

FIGURE 2 Flowchart of level II pollutant loading assessment procedure.

wetlands), along with streams. Its rather arbitrary decision criterion, which determines whether further analysis is recommended, is a loading increase of more than 10 percent of any pollutant in the receiving water as a result of the highway.

In applying this component of the procedure, TSS-loading is first estimated from the cumulative loading model developed from the research data. The basis for this model has been presented elsewhere (13,14,19,20) and represents data from more than 500 storms monitored at nine locations throughout the state. It is expressed as follows:

$$\text{TSS loading} = (K)(VDS)(RC) \quad (1)$$

where

TSS loading = annual mass flux,
K = proportionality constant,
VDS = vehicles travelling during storm periods on an annual basis, and
RC = average site runoff coefficient.

Data analysis yielded different proportionality constants for eastern and western Washington:

Eastern Washington: K (± 1 standard error) = 7.4 (±0.56) kg TSS/highway km/1,000 VDS (2)

Western Washington: K (± 1 standard error) = 1.8 (±0.24) kg TSS/highway km/1,000 VDS (3)

The elevated constant in the former case presumably resulted from deposition of the loose soils of the arid and semiarid region on roadways by relatively high and continuous winds. VDS may be determined from average daily traffic (ADT) records or projections and precipitation duration data that were assembled for a number of locations in the state. In the absence of on-site data, many hydrology texts and handbooks can provide estimates of runoff coefficients for different configurations.

The next step in the annual loading analysis is to modify TSS loading to reflect any runoff treatment provided. Table 1 presents approximate pollutant reduction capacities of various lengths of vegetated channel derived from the research results (17). Contaminant removal by R/D devices can be estimated from the references cited earlier.

TABLE 1 Highway Runoff Treatment Efficiencies of Various Lengths of Vegetated Channel

Length (m)	Approximate Fraction of Pollutant Remaining
<10	1.00
10-20	0.50
20-30	0.40
30-40	0.30
40-50	0.26
50-60	0.23
>60	0.20

Assessment of highway contaminant loadings is completed by applying appropriate multipliers to the TSS loading to estimate annual loadings of other quantities. Table 2 lists those multipliers derived from the Washington State data. They are constants throughout the state for organics and nutrients and linear functions of average daily traffic (ADT) for three heavy metals.

With the completion of the analysis of highway runoff pollutant loadings, the next step of the assessment is to compare these loadings with those that have already occurred in the receiving water. Preexisting loadings may be estimated from stream water quality and flow data, if they are adequate, or published loadings from the various land uses in the watershed for lakes and wetlands and inadequately documented stream cases. Given that consistent units are maintained, the annual pollutant loading in a stream can be estimated as the product of the average discharge and the mean contaminant concentration. For standing water or where hydrologic and water quality data are lacking, export from general land use categories may be estimated from information taken from the literature (tabulated in Table 3) and added to known point source loadings to obtain total loadings. The use of these data instead of stream records is substantially less satisfactory because of the evident dispersion created by aggregating results from many locations.

An additional eutrophication assessment procedure is given in Level II to be employed when the receiving water is a lake. This procedure is based on the phosphorus loading criteria presented by Vollenweider and Dillon (43).

The final component of Level II is an assessment of pollutant concentrations on the basis of an individual storm event. The objective of this assessment is to estimate the probability that a selected pollutant concentration, such as a water quality criterion, will be exceeded in any given storm, from which the frequency of exceedance can be forecast. A series of probability graphs was prepared from the research data to perform the assessment for Washington cases. Data from each sampling station were analyzed to determine the distributions of observed concentrations by using cumulative frequency and histogram graphics. These plots suggested that lognormal distributions would adequately describe the data for each contaminant at each site. The sites

TABLE 2 Multipliers to Estimate Loadings of Other Pollutants from TSS Loading

Pollutant	Multiplier	R^{2}[a]	Specifications
Solids	0.2	-	For all sites
Chemical oxygen demand	0.4	-	For all sites
Lead	$1.5 \times 10^{-4} + (8.7 \times 10^{-8})$ (ADT)	0.978	West Washington sites
	$5.3 \times 10^{-4} + (2.8 \times 10^{-8})$ (ADT)	0.996	East Washington sites
Zinc	$1.5 \times 10^{-4} + (3.0 \times 10^{-8})$ (ADT)	0.864	West Washington sites
	$2.0 \times 10^{-4} + (3.2 \times 10^{-7})$ (ADT)	0.932	East Washington sites
Copper	$7.9 \times 10^{-5} + (2.7 \times 10^{-9})$ (ADT)	0.739	For all sites
Total Kjeldahl nitrogen	2.7×10^{-3}	-	West Washington sites
	1.2×10^{-3}	-	East Washington sites
Nitrate + nitrite – nitrogen	2.0×10^{-3}	-	For all sites
Total phosphorus	2.1×10^{-3}	-	For all sites

[a]Coefficient of determination for linear regression equations.

TABLE 3 Storm Runoff Pollutant Loadings for General Land Use Categories

	Loading (kg/ha/yr)[a]			
Pollutant	General Urban	General Residential	General Agricultural	Forested or Open
Total suspended solids	450	420	20,100-49,400	7.0-8.5
Chemical oxygen demand	20-270	30-300	NA	2.0
Lead	0.15-0.50	0.06	0.002-0.08	0.01-0.03
Zinc	0.34-0.56	0.02	0.004-0.34	0.01-0.03
Copper	0.04-0.13	0.03	0.002-0.09	0.02-0.03
Nitrate-nitrite-nitrogen	0.34-4.50	0.34-3.8	0.34-8.0	0.34-0.56
Total Kjeldahl nitrogen	8.0	6.1	0.34-34	1.7-3.0
Total phosphorus	2.0	1.8	0.11-9.0	0.07-0.09

Note: NA = not available.

[a]Means given where available; otherwise, ranges are reported *(35-42)*.

were grouped into eastern and western Washington and high- and low-traffic categories for further analysis. Traffic groupings represented the following ADT (all unidirectional): western Washington, high-traffic: 42,000 to 53,000, low-traffic: 7,700 to 8,600; eastern Washington, high-traffic: 17,300, low-traffic: 2,000 to 2,500.

Probability distributions of each pollutant concentration in each group were graphed on log-probability paper. These plots represent the probability of exceeding any given concentration in any storm for the underlying conditions. The graphic representations were used as qualitative tests of log-normality. Log-normal data describe a straight line on such a plot. Figure 3 presents a typical graph in this series. High-traffic, low-traffic, and combined plots generally were linear; the specific traffic-level cases usually provided better fits.

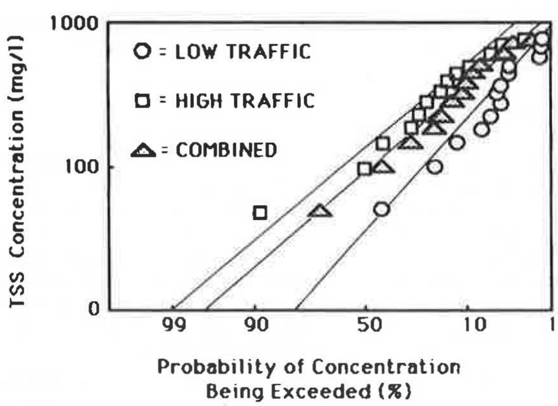

FIGURE 3 Probability distribution of TSS concentration for western Washington sites.

As the final step in the concentration-probability analysis, the distributions for each contaminant were plotted separately for eastern and western Washington high- and low-traffic cases. Parallel curves were added to these graphs to represent pollutant reductions of various amounts. These reductions could be achieved by runoff treatment, dilution by receiving waters, or a combination of the two. When available, water quality criteria were added to the graphs to serve as a basis for judgment of effect and assessment of impact.

Figure 4 provides an example of such a plot. As an illustration of its potential use in impact assessment, suppose untreated highway runoff drains to a stream that provides 25 percent pollutant reduction through dilution and that has a total hardness of 50 mg/L as $CaCO_3$. The probability of exceeding the maximum Pb concentration permitted for the protection of aquatic life (45 Code of Federal Regulations 79318-79379, November 28, 1980) would be 66 percent (i.e., a violation would be expected in two out of every three storms. Should 90 percent Pb reduction be achieved, however, the probability of exceeding the criterion would drop to 0.035 percent, a frequency of violation equivalent to about one storm in 2,900.

Level III (Detailed Analysis and Mitigation Assessment)

Level III has an arrangement parallel to Level II in that it contains guidelines on runoff quantity assessments, accumulated pollutant loadings, and individual event occurrences. The particular procedure would be applied, however, only for the specific problem or problems that are identified in the Level II analysis to have potential significance.

Level III differs from the previous level in several ways. First, the quantity assessment emphasizes design, or redesign, of detention facilities by using customary highway design procedures to prevent excessive stream peak flow increase. The loading assessment is for the monthly period that represents a critical high or low flow condition, rather than annually as in Level II. It also employs a more detailed definition of land use along with the pollutant yields presented in Table 4. Otherwise, the loading analysis is identical to the Level II procedure.

The individual event assessment is directed at water quality impact mitigation and provides a basis to design control facilities. That basis is presented in Figure 5 in the form of a probability distribution of TSS loading for western Washington (an analogous plot exists for eastern Washington). The analyst may select a design probability (e.g., the loading exceeded in only 10 percent of the storms) to use in selecting and sizing the control device. Pollutants other than TSS may be brought into the analysis by using the multipliers in Table 2.

Assessment of Impacts Associated with Maintenance Practices and Special Problem Areas

The assessment methodology described heretofore applies only to the aquatic impacts associated with ordinary runoff events on normally operating highways. Periodic and extraordinary phenomena must be analyzed separately. Included in this category are winter sanding and deicing, pesticide application, construction practices that create continuing effects on surface waters, and accidental spills. The

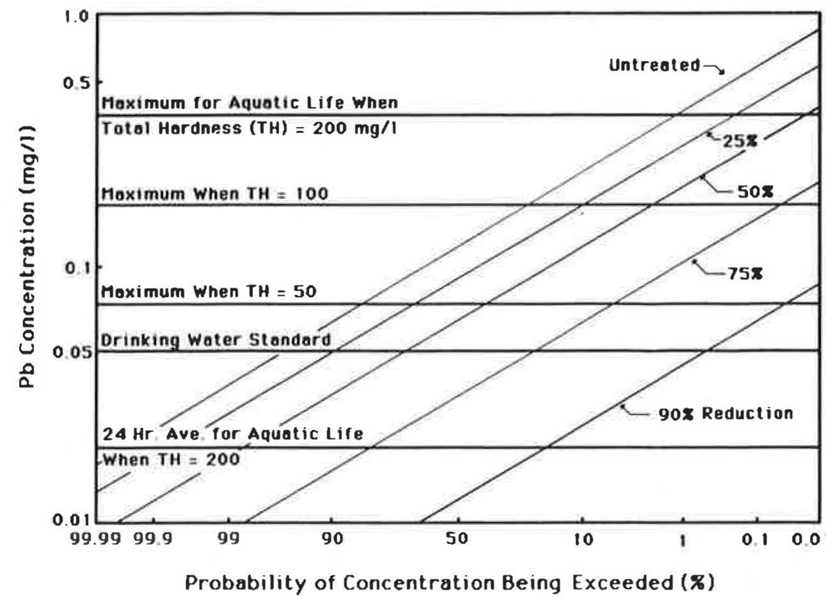

FIGURE 4 Probability distribution of lead concentration for western Washington low-traffic cases.

TABLE 4 Storm Runoff Pollutant Loadings for Specific Land Use Categories

	Loading (kg/ha/yr)[a]								
Pollutant	Central Business District	Other Commercial	Industrial	Single-Family Residential	Multiple-Family Residential	Cropland	Pasture	Forested	Open
Total suspended solids	1,080	840	56	17	440	450	340	85	6.7
Chemical oxygen demand	1,070	1,020	63	28	330	NA	NA	NA	2.0
Lead	7.1	3.0	1.0-7.1	0.11	0.67	0.005-0.006	0.003-0.015	0.01-0.03	NA
Zinc	3.0	3.3	3.5-12	0.22	0.34	0.03-0.08	0.02-0.17	0.01-0.03	NA
Copper	2.1	NA	0.34-1.1	0.03	0.34	0.01-0.06	0.02-0.05	0.02-0.03	NA
Nitrate-nitrite-nitrogen	4.5	0.67	0.45	0.34	3.8	7.9	0.34	0.56	0.34
Total Kjeldahl nitrogen	15	15	2.2-15	1.1-5.6	3.4-4.5	1.7	0.67	2.9	1.7
Total phosphorus	2.8	2.7	0.90-4.0	0.22-1.5	1.3-1.6	0.34	0.07	0.09	0.07

Note: NA = not available.

[a]Means given where available; otherwise, ranges are reported *(35-42)*.

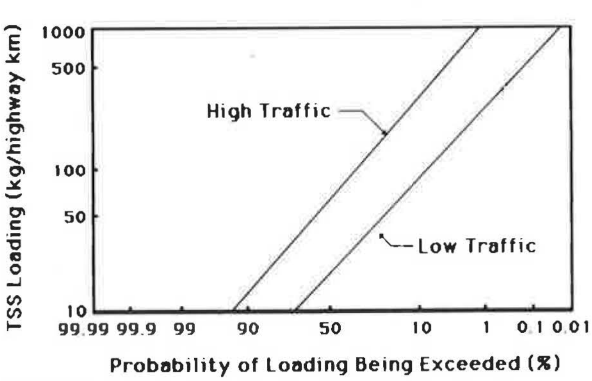

FIGURE 5 Probability distribution of TSS loading for western Washington.

assessment protocol provides guidance in these areas, although without the specificity made possible by the large data base that underlies the routine evaluation (Levels I-III).

The various pollutant loadings are augmented by the contribution from sand. Winter data demonstrated that sanding contributed a major portion of TSS seasonally, which varied with the sand application rate and other sources of solids (44). The results were insufficient to model the proportion of applied sand that entered the runoff, however; consequently, it is necessary to roughly estimate the proportion on the basis of sand characteristics, plowing, and sweeping.

The Washington research demonstrated that the ratios of other pollutants to TSS associated with sanding were equal to those reported in Table 2 at the high-traffic sites. With less traffic, pollutant deposition failed to saturate the sand particles, and the ratios were substantially lower on a cumulative basis (44). It is thus recommended that the loadings of other pollutants be established according to the procedures given for Levels II and III when ADT is projected to exceed 10,000. With less traffic, the assessment should reflect the elevated TSS loading as a result of sanding but should not augment the loadings of other pollutants in proportion to sanding TSS.

Deicing impacts were not specifically investigated in the Washington State research. The guide does provide a procedure drawn from work in Massachusetts (45) for estimating sodium and chloride loadings and concentrations from prevailing application rates.

A comprehensive study of leachates from woodwaste fill sections was undertaken during the research (15). The protocol included an aquatic impact assessment procedure for that regionally important problem. Pesticide applications and accidental spills were covered qualitatively. Insufficient risk data exist to relate, in a general fashion, the occurrence of spills with highway characteristics. In a specific case, data may be available from the same or a similar highway that would enable the analyst to make some estimates of accident probabilities, and some relevant reports were cited for the analyst's consideration (46,47). The risk of impacts to aquatic systems by accidental spills is greatest with uninterrupted transport to the water body, which allows little opportunity for removal of toxicants or time for reaction (application of spill management techniques).

SUMMARY AND CONCLUSIONS

Assessment of the impacts on aquatic ecosystems of operating highways is in its infancy. Organized paradigms to guide the assessment have been lacking, and analytical tools for quantification of anticipated impacts are few in number and are generally validated for limited areas. The same could be said of the state of impact assessment in many other fields. A general protocol has been proposed to fill the former need. The protocol contains a hierarchical arrangement to identify the most serious cases for the most complete analysis and allocation of resources for mitigation. The protocol also contains a recommendation for the evaluation of the effects of the highway in the context of other activities that influence the runoff receiving water, and for the consideration of both short- and long-range potential impacts.

A large data base was analyzed to develop the specific analytical procedures required for the application of the protocol to assess the impacts of operating highways in the state of Washington. The procedures include a simple cumulative pollutant loading model, a probabilistic method of evaluating potential acute effects of a single storm, hydrologic assessment techniques drawn from the literature, and semiquantitative or qualitative means of analyzing the potential effects of nonroutine occurrences, such as intermittent maintenance operations, accidents, and other special problems. Because of similarities in geomorphology, climate, overall land use, and aquatic ecosystems, it is the authors' opinion that these procedures are also applicable in northern California, Oregon, and portions of Idaho and British Columbia. Moreover, they offer an example of methodology that could be developed for the assessment of highway impacts in other locations or for conducting objective and quantitative environmental assessments in many other situations.

The results of the Washington highway runoff research was that limited problem areas were identified, thus providing a basis for the reduction of mitigation costs overall and the application of resources to those cases most in need of attention. Adequate research would permit the application of this principle elsewhere, thereby achieving savings and reduced legal challenges while providing environmental protection where the needs are greatest.

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