The Stochastic Empirical Loading and Dilution Model (SELDM) for analysis of flows, concentrations, and loads of highway runoff constituents


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ABSTRACT
The Stochastic Empirical Loading and Dilution Model (SELM) was developed by the U.S. Geological Survey in cooperation with the Federal Highway Administration (FHWA) to supersede use of the 1990 FHWA runoff-quality model. SELDM is designed to be a tool that can be used to transform disparate and complex scientific data into meaningful information about the risk for adverse effects of runoff on receiving waters, the potential need for mitigation measures, and the potential effectiveness of such measures for reducing these risks. SELDM is easy to use because much of the information and data needed to run SELDM are embedded in the model and are obtained by defining the location of the site of interest and five simple basin properties. Information and data from thousands of sites across the country were compiled to facilitate use of SELDM. Use of SELDM for doing the types of sensitivity analyses needed to properly assess water-quality risks are provided in a case study. For example, use of deterministic values to model upstream stormflows instead of representative variations in prestorm flow and runoff may substantially overestimate the proportion of highway runoff in downstream flows. Also, risks for total phosphorus excursions are substantially affected by the selected criteria and the modeling methods used. For example, if a single deterministic concentration rather than a stochastic population of values is used to model upstream concentrations, then the percentage of water-quality excursions in the downstream receiving waters may depend entirely on the selected upstream concentration.

INTRODUCTION
The Federal Highway Administration (FHWA) and State transportation agencies are responsible for determining and minimizing the effects of highway runoff on water quality, while planning, designing, building, operating, and maintaining the Nation's highway infrastructure (1, 2). Transportation agencies need information about the quality and quantity of runoff, potential effects on receiving waters, and the potential effectiveness of mitigation measures to address responsibilities for managing Environmental Impact Statements, National Pollutant Discharge System permits, and efforts to establish Total Maximum Daily Loads (TMDLs) (3–6). Water-resource managers are concerned about the frequencies, magnitudes, and durations of runoff concentrations and loads (the products of measured stormflow and concentration) to assess the risks of adverse effects on the quality of receiving waters (7–11). The FHWA developed a highway-runoff model that used analytical approximations to estimate the potential effects of runoff on receiving waters. Publication of the 1990 FHWA runoff-quality model was the
culmination of the FHWA runoff-quality research conducted during the 1970s and 1980s (12, 13). By the mid-1990s, however, it was recognized that the existing data and modeling methods were reaching obsolescence (14). As a result of the implementation of TMDL regulations, scientists, engineers, and decisionmakers have become increasingly aware of the importance of considering random variation in the quantity and quality of highway runoff and stormflows in upstream receiving waters for estimating the potential effects of runoff on receiving waters.

In 2013 the U.S. Geological Survey, in cooperation with the FHWA, published the Stochastic Empirical Loading and Dilution Model (SELDM) to supersede use of the 1990 FHWA runoff-quality model to indicate the risk for stormwater concentrations, flows, and loads to be above user-selected water-quality goals (15). SELDM is designed to be a tool that can be used to transform disparate and complex scientific data into meaningful information about the risk for adverse effects of runoff on receiving waters, the potential need for mitigation measures, and the potential effectiveness of such measures for reducing these risks. SELDM was designed to help inform water-management decisions for streams and lakes receiving runoff from a highway or other land-use site.

PURPOSE AND SCOPE
The purpose of this paper is to provide a brief description of SELDM and a case study demonstrating the type of risk-based information that SELDM can provide. The description of SELDM is a brief overview of the theory and implementation of the model. The hypothetical case study will demonstrate stochastic generation of stormflows, concentrations, and loads by using data and statistics available for selected sites in New England. Total phosphorus (TP) was selected as the example because nutrients are a common concern throughout the Nation (16) and data for receiving waters, highway runoff, and the performance of best management practices (BMPs) are readily available for this constituent (17–19).

SELDM
SELDM uses Monte Carlo methods to generate a stochastic population of the concentrations, flows, and loads needed to implement a mass-balance model for a receiving stream and/or lake (15). SELDM also has a stochastic BMP module to assess the potential benefits of implementing stormwater controls. Monte Carlo methods are used because the combination of different distributions of precipitation, prestorm flows, runoff coefficients, and water-quality concentrations determine the potential risk of water-quality excursions. Deterministic methods are not able to characterize the interaction of different distributions for hydrologic parameters and BMP-performance measures. Unlike deterministic hydrologic models, SELDM is not calibrated by changing values of input variables to match a historical record of values. Instead, input variables for SELDM are based on site characteristics and representative statistics for each hydrologic variable. The benefit of the Monte Carlo analysis is not to decrease uncertainty in the input statistics, but to represent the different combinations of the values of variables that
determine potential risks for water-quality excursions. Simpler methods may provide estimates of mean values, but it is commonly the extreme events that are of most interest to scientists, engineers, and decisionmakers for evaluating the potential for excursions.

A mass-balance approach (figure 1) is commonly applied to estimate the concentrations and loads of water-quality constituents in receiving waters downstream of an urban or highway-runoff outfall. In a mass-balance model, the loads from the upstream basin and runoff source area are added to calculate the discharge, concentration, and load in the receiving water downstream of the discharge point. These models commonly are based on the assumptions that the runoff and the receiving water are fully mixed and that there are no reactions that reduce the mass of the constituent at the point of mixing.

The diagram in the upper left corner of figure 1 shows a hypothetical highway site crossing a stream with inputs from the upslope areas on both sides of the stream. The mass-balance calculation also may be done for the highway on each side of the stream and the bridge as separate contributing areas (one area at a time). A highway also may be parallel to the stream, in which case the mass-balance calculations could be modeled for each discharge point or for a conceptual discharge point incorporating the entire contributing area. The mass-balance approach also may be used to model any land use discharging runoff to a stream. In each case, the mass-balance equations in the upper right corner of figure 1 would be used to calculate the downstream stormflow, concentrations, and loads on the basis of runoff values from the selected areas.

Stochastic estimates of concentrations, stormflows, and loads of constituents are needed to use the mass-balance approach for estimating the potential for excursions in runoff and receiving waters. Storm events commonly are defined as independent statistical events characterized by a volume, intensity, duration, and time between midpoints of successive storms for the purposes of planning, analysis, and sampling efforts (13, 15). Statistics describing the frequency distributions of component discharges and concentrations are needed to estimate the statistics for downstream discharges, concentrations, and loads. The lower half of figure 1 indicates how the random distributions of concentration and flow from the upstream basin and the highway site are used to calculate downstream values in SELDM. To calculate the concentrations, flows, and loads required for the mass-balance analyses (figure 1), SELDM calculates values for 17 primary environmental variables, 15 of which are modeled as stochastic variables; detailed information about these variables is available in the manual (15).

The mass-balance approach (figure 2) is based on stochastic highway and upstream stormflows (15, 20). Runoff for each storm event is calculated with stochastic storm-event characteristics, stochastic runoff coefficients for each area, and the highway and upstream drainage areas. The total upstream stormflow for each storm event also includes the stochastic prestorm streamflow.
Figure 1. Schematic diagram showing the stochastic mass-balance approach for estimating stormflow, concentration, and loads of water-quality constituents upstream of a highway-runoff outfall, from the highway, and downstream of the outfall.
Because the duration of highway runoff, BMP discharges, and upstream stormflows may be disparate, SELDM solves the mass balance equations by using concurrent stormflows (15, 21). The timing of stormflows from the highway and upstream basin are calculated by using a basin lagtime, hydrograph-recession ratio, and storm duration. The basin lagtime, defined as the time between the centroid of precipitation and the centroid of runoff, commonly is modeled as a deterministic variable that depends on basin properties. Equations for estimating basin lagtimes were calculated with data from 896 sites across the country with different basin properties. The hydrograph-recession ratio for the highway is equal to 1, but is a stochastic variable for the upstream basin. Hydrograph recession-ratio statistics were calculated with data from 41 basins from different areas of the country. If BMP modifications to the highway runoff are specified, then the timing and volume of runoff from the BMP also are calculated as stochastic variables. Dilutions in the receiving water are calculated with the upstream flow volume that coincides with highway runoff and BMP discharge.

SELDM contains the data and statistics necessary to generate stormflows from the highway site and the upstream basin for these variables (15, 20). The precipitation volume, duration, and the time between storm-event midpoints for each storm in the simulated record are calculated with data from 2,610 selected hourly-precipitation data stations in the conterminous United States. These statistics may be selected within the graphical user interface (GUI) by rain zone, by ecoregion, or by proximity to the site of interest. Prestorm streamflow statistics are calculated with data from 2,783 selected streamgages in the conterminous United States. These

Figure 2. Schematic diagram showing the upstream-flow and highway-runoff components that must be estimated for a mass-balance analysis of receiving-water quality.
statistics may be selected within the GUI by ecoregion or by proximity to the site of interest. Runoff coefficient statistics were calculated as a function of the total impervious area of the highway or the upstream basin using regression equations. These regression equations were developed with rainfall-runoff data from 58 highway sites across the country and with data from 167 sites across the country with various land uses. SELDM users may select from the predefined statistics or enter their own values.

The magnitude and variation of concentrations and flows from both the highway and the upstream basin have a substantial effect on downstream concentrations and therefore the risks for water-quality excursions (10, 15, 17, 22–24). For example, Di Toro (22) based his method on the assumption that contributing stormflows and concentrations are independent and lognormally distributed. Warn and Brew (23), however, indicated that upstream concentrations and flows are correlated. Schwartz and Naiman (24) also demonstrated the effect of correlation between concentrations and flows in receiving waters on the adequacy of planning-level estimates of concentrations and loads in runoff. Granato and others (17) developed water-quality transport curves, which are regression equations for estimating concentrations as a function of streamflow. Their results indicate that concentrations of suspended sediment and sediment-associated constituents commonly increase with increasing streamflow, whereas concentrations of dissolved constituents, such as total hardness, commonly decrease with increasing streamflow. In SELDM concentrations of upstream constituents are stochastic variables that can be calculated as purely random variables, as a function of another constituent, or as a function of upstream flow. The resulting probability distributions of downstream event-mean concentrations (EMCs) indicate the potential for water-quality excursions and therefore the potential need for more information and data that may be used to identify suitable mitigation measures. If the upstream flows are much greater than the concurrent highway runoff, the upstream concentrations may control the risk for downstream excursions.

The SELDM project developed the statistics and tools to model water quality. SELDM can be used to model any constituent for which stormwater quality statistics are available (15). A highway runoff database (HRDB) was developed as part of the SELDM development project to act as a data warehouse and preprocessor for calculating the highway runoff-quality statistics for SELDM (18). The HRDB was expanded to incorporate a large highway-runoff data set developed by the USGS in cooperation with the Massachusetts Department of Transportation (25). This version of the HRDB includes 54,384 EMCs for 194 highway-runoff constituents from 4,186 storm events monitored at 117 study sites across the United States. A set of tools were developed to obtain and interpret in-stream water-quality data from the USGS National Water Information System Web for estimating upstream constituent concentrations (17, 26). This effort led to the compilation of 1,876,000 paired values of water-quality and flow for 21 water-quality constituents from 24,581 USGS monitoring stations within the conterminous United States. Also, ecoregion-level water-quality transport curves were developed for suspended sediment, TP, and total hardness as part of this effort. Random water-quality statistics were developed for pH in each ecoregion (15).
SELDM uses a simple stochastic model of BMP performance. This model can be used to represent a single BMP or an assemblage of BMPs. This BMP-treatment module simulates volume reduction, hydrograph extension, and concentration reduction stochastically. Volume reduction is modeled to represent how BMPs can affect flows and loads from the highway site. Hydrograph extension is modeled to represent how BMPs can increase dilution in receiving waters by extending the duration of runoff from the highway site. Concentration reduction is modeled to represent changes in constituent concentrations that may result from different treatment options. Concentration reductions are limited by using a minimum irreducible concentration (MIC) variable that sets the lower limit of effluent concentrations. The three BMP-treatment variables are modeled by using the trapezoidal distribution and rank correlation with the associated highway-runoff variable. The trapezoidal distribution was selected for modeling BMP performance measures because it can be parameterized by using expert judgment or by fitting the distribution to data. Currently (2013), BMP performance statistics for these variables are being calculated with data from the International BMP Database.

Case Study
This case study is designed to demonstrate stochastic generation of stormflows, concentrations, and loads from a hypothetical highway site and an upstream basin by using data and statistics available for selected sites in New England. It also is designed to explore several stochastic modeling concepts that may help decision makers evaluate different approaches to water-quality analyses. The case study is a purely hypothetical situation, but was formulated by using actual monitoring data. The upstream basin is defined as the contributing area to USGS streamgage 01208950 Sasco Brook near Southport, CT. It has a drainage area of 7.38 square miles, a main channel length of 27,984 feet (ft), a main channel slope of 53.3 feet per mile (ft/mi), an impervious fraction of 5.5 percent and a basin development factor (BDF) of 0. The hypothetical 4-lane highway would have an area of 2.2 acres, a main channel length of 957 ft, a main channel slope of 53.3 ft/mi, an impervious fraction of 100 percent, and a BDF of 12. The BDF is an integer score between 0 and 12 with zero being a completely natural channel and 12 being a fully engineered drainage system.

Dilution Factors
SELDM uses the stochastic stormflows to calculate dilution factors for each storm. The dilution factor, as defined in the 1990 FHWA runoff model, is the ratio of highway runoff (or BMP discharge) to downstream flow. The dilution factor can vary from 0 to 1 as the highway runoff increases in proportion to the upstream flow. A dilution factor near 0 indicates that highway runoff is a negligible portion of the downstream flow. A dilution factor of 1 indicates that the downstream flow is all highway runoff. SELDM calculates dilution factors for highway runoff with and without BMP modification. BMPs will tend to decrease dilution factors if discharges are reduced or extended over a larger portion of the upstream hydrograph.
The dilution-factor output provides a quick initial assessment of the risks for water-quality excursions with and without BMP treatment. For example, examination of the dilution-factor file for each of several highway-stream crossings can be used to identify the streams with the highest potential for excursions. Similarly, if a highway with many outfalls is parallel to a stream, information about the cumulative upstream drainage and pavement areas at each outfall can be used to run SELDM. The dilution-factor file for each outfall can be used to identify the point along the stream with the highest potential for excursions. In either case, this information can be used to allocate resources for a detailed analysis at the most critical site(s).

The Sasco Brook example indicates the importance of the stochastic approach and demonstrates how BMPs can increase dilution by extending the duration of the runoff hydrograph and reducing the volume of the highway discharge. The long-term average flow in Sasco Brook is about 14 cubic feet per second (cfs), the geometric mean is 6.15 cfs and the 7-day 10-year lowflow (7Q10) is about 0.045 cfs. The average, standard deviation, and skew of the logarithms of nonzero streamflow are 0.789, 1.51, and -0.815. SELDM was used to run seven scenarios (figure 3). In the first scenario, highway runoff was modeled as if there was a full storm–sewer drainage system without a BMP. Dilution factors for this system range from 0.00013 to 0.214 with a median of 0.0049. The largest dilution factors occur for short, high-intensity precipitation events with small prestorm streamflows because the highway drains well before the peak of the upstream stormflow hydrograph. The next three scenarios are used to examine potential effects of flow extension, flow reduction, or both by use of a grassy swale. Analysis of data in the International BMP Database (27) indicates that flow extensions may range from about 0.1 to 3 hours and the ratios of outflow to inflow may range from 0.07 to 1.21. A BMP that provides only flow extension will reduce dilution factors to range from 0.00012 to 0.183 with a median of 0.0039. A BMP that provides only flow reduction will reduce dilution factors to range from 0.00001 to 0.202 with a median of 0.0026. A BMP that provides both types of hydrograph modification will reduce dilution factors to range from 0.00001 to 0.112 with a median of 0.0021. These scenarios indicate that highway runoff and BMP discharge only exceed 10 percent of downstream flows in about 0.7 and 0.5 percent of storms, respectively. If a project included many stream crossings, this information could be used to prioritize risks by comparison to dilution factors at other stream crossings.

The next three scenarios were run to evaluate potential effects of more deterministic analyses on the dilution factors and therefore the perceived risk of water-quality excursions (figure 3). In each case, the dilution factor is calculated by using a stochastic highway-runoff duration and volume for each storm. If the mean annual upstream flow rate was used, dilution factors ranged from 0.00031 to 0.26 with a median of 0.010. If mean monthly upstream flow rates were used, dilution factors ranged from 0.00017 to 0.36 with a median of 0.011. The 7Q10 was used as the deterministic streamflow for each storm in the last scenario because wastewater rules commonly are applied to stormwater discharges. If the 7Q10 was used, dilution factors ranged from 0.089 to 0.99 with a median of 0.76. On average, use of the mean annual, mean monthly, or 7Q10 value to model upstream flows result in dilution factors that are about 2.6, 3.8
or 190 times the stochastic dilution factors. These biases and their effect on downstream concentrations may result in time spent on more detailed analyses, investment in data collection efforts, and implementation of mitigation measures at sites where they are not needed.

Highway Runoff Concentrations and Loads

SELDM uses the input highway-runoff and BMP-treatment statistics to generate a stochastic population of concentrations and loads from the highway and BMP (15). In this simulation, concentrations of TP in highway runoff were modeled with the average, standard deviation and skew of the common logarithms of EMCs equal to -1.05, 0.423, and -0.679. These statistics are calculated with data from 18 storm samples collected at USGS monitoring station 423027071291301 along State Route 2 in Littleton Massachusetts (25). BMP reduction ratios for TP were calculated with data from the international BMP database (27). The minimum, lower bound of the most probable value (MPV), upper bound of the MPV, and the maximum were 0.105, 0.669, 0.827, and 3.556, respectively. Based on these trapezoidal statistics, concentrations of TP in the BMP effluent are expected to exceed influent concentrations about 66 percent of the time. The rank correlation with inflow concentrations was -0.669; the negative correlation indicates that larger ratios generally are associated with the smaller concentrations. The MIC was 0.01 mg/L.

![Figure 3. The stochastic populations of dilution factors for highway runoff or BMP discharge showing the effect of BMP treatments and upstream flow assumptions on the simulated dilution factors.](image-url)
The simulated runoff concentrations, BMP effluent concentrations, and the measured highway-runoff concentrations are shown in figure 4. In this example, simulated highway-runoff concentrations range over several orders of magnitude from 0.0008 (not shown) to 0.87 mg/L. As the graph indicates, use of the average, standard deviation, and skew of the logarithms of data reproduces the magnitude and curvature of the sample distribution. If the data were modeled as being lognormal (a log-skew of zero), concentrations would range from 0.003 to 2.33 mg/L. The simulated BMP effluent concentrations range from 0.01mg/L to 0.77 mg/L. About 0.42 percent of BMP effluent concentrations are equal to the MIC (0.01 mg/L), which is assigned when calculated effluent concentrations are below this threshold; these values appear as the horizontal line of effluent concentrations on the far right side of the graph.

Figure 4. The stochastic populations of total phosphorus concentrations in highway runoff and BMP discharge showing the risks for exceeding two hypothetical runoff-quality criteria.

To demonstrate the risk-based information provided by SELDM, these concentrations are shown in relation to the lower bound of wastewater-effluent limits (0.5 mg/L) and receiving water targets (0.1 mg/L) for TP (28). Only about 1.68 percent of highway-runoff concentrations, 0.9 percent of BMP effluent concentrations, and 3.85 percent of lognormal concentrations exceed 0.5 mg/L. About 51 percent of highway-runoff concentrations, about 59 percent of BMP effluent concentrations, and about 45 percent of lognormal concentrations exceed 0.1 mg/L. In
comparison to highway runoff, fewer BMP concentrations exceed 0.5 mg/L and more concentrations exceed 0.1 mg/L because the BMP statistics reflect the fact that it is easier to reduce high concentrations than low concentrations. If the average BMP reduction ratio (1.45) was used to model all storms then all the BMP concentrations would be substantially greater than the highway-runoff concentrations. This would result in more excursions above both criteria.

SELDM also provides annual loads from the highway and BMP based on the annual-load accounting years calculated from precipitation statistics. Annual TP loads are shown as yields (load divided by area) in figure 5. Yields are useful for comparing the highway to other sources and extrapolating the site load to all highways in an area. In this case study, the average-annual highway runoff and BMP effluent yields are about 0.99 and 0.66 pounds per acre. If annual yields are compared with the yields that would result if all storm events had a concentration of 0.1 mg/L, then the risk for exceeding this criterion would be 98 and 5.5 percent for highway runoff and BMP discharge in any given year. Although the BMP does not substantially reduce runoff concentrations, stormflow reductions do substantially reduce the loads from this site.

![Figure 5](image-url)

**Figure 5.** The stochastic populations of total annual phosphorus yields in highway runoff and BMP discharge showing the risks for exceeding a hypothetical target-yield criterion.
**Upstream Concentrations**

SELDM uses upstream-concentration statistics to generate a stochastic population of concentrations and loads in the receiving stream \((15)\). Upstream concentrations may be as important as or more important than the highway-runoff concentrations for estimating the potential number of water-quality excursions because upstream flows, and therefore loads, commonly are the largest component of downstream flows (figure 3). In this simulation, concentrations of TP in the upstream flow were modeled with a two-segment water-quality transport curve developed using 81 instantaneous values of streamflow and TP concentration measured in Sasco Brook during the 1994-1998 period. The data range from 0.01 to 0.18 mg/l with an average of 0.042; about 6 percent of these instantaneous values exceed 0.1 mg/L. The data values are not EMCs, but use of a transport curve provides an estimate of the EMC during highway-runoff or BMP discharge periods \((15, 17)\). Figure 6 shows the measured data, the transport curve, and the simulated upstream concentration. In theory, the intersection of the segments on the transport curve indicates the transition from baseflow to stormflow. Many of the simulated values fall within the baseflow range because the stormflows used are concurrent to the highway runoff, which occurs over a short period of time at the beginning of the upstream stormflow hydrograph. The simulated EMCs range from 0.0016 to 0.21 with an average of 0.36 mg/L; about 0.58 percent of EMCs exceed 0.1 mg/L. Sasco Brook is not highly developed and has no wastewater treatment plants so increases in concentration with flow indicate mobilization of TP with runoff and instream flow \((17)\).
Downstream Concentrations

Downstream concentrations are calculated as the sum of loads divided by the downstream stormflow (Figure 1). The populations of downstream concentrations indicate risks for potential effects of runoff on receiving waters and therefore the need to build and maintain BMPs at a site. Figure 7 shows the upstream concentrations and downstream concentrations with and without BMPs. Even though this is a small basin it is clear that downstream concentrations are dominated by the upstream concentrations and flows because the downstream concentrations are almost indistinguishable from the upstream concentrations. Only 10 storms, a risk of about 0.58 percent, exceed the 0.1 mg/L criterion. These results highlight the need for realistic methods for modeling upstream concentrations. If deterministic methods are used for modeling upstream concentrations, then the risk for exceeding a criterion may depend on the selected value. For example, Figure 8 shows the percentage of downstream concentrations that exceed the hypothetical criterion of 0.1 mg/L as a function of the deterministic upstream concentration. In this example, the risk of exceeding the criterion is essentially zero if the constant upstream
concentration is less than 0.05. The risk for exceeding the criterion increases exponentially to 50 percent as the constant upstream concentration approaches 0.1 mg/L and asymptotically approaches 100 percent as the upstream concentrations approach 0.105 mg/L. In comparison, the average of the instantaneous data from Sasco Brook is 0.042 mg/L and 6 percent of that data exceed 0.1 mg/L. The average upstream EMC modeled stochastically is 0.036 mg/L and 0.6 percent of these EMCs exceed 0.1 mg/L. Use of constant upstream concentrations is unrealistic and can be used to bias the results of analysis.

Figure 7. The stochastic populations of total phosphorus concentrations upstream and downstream of the highway showing potential effects of highway runoff and BMP discharges of total phosphorus on the receiving stream.
Conclusions

SELDM uses Monte Carlo methods to generate populations of flows, concentrations, and loads from a highway site and an upstream basin to provide risk-based information for decision makers to evaluate the effects of runoff on receiving waters. SELDM also uses Monte Carlo methods to model the effects of BMPs on runoff and receiving waters. SELDM is designed to facilitate sensitivity analyses to help determine the information and data needed to properly estimate values and to assess water-quality risks, which was demonstrated in a case study with data from a 7.38 square mile drainage basin near Southport, CT. For example, findings from this case study indicate that use of the 7Q10, mean annual flows, or mean monthly flows to model upstream stormflows instead of representative variations in prestorm flow and runoff may substantially overestimate the proportion of highway runoff in downstream flows. Total phosphorus (TP) was used in this case study to examine the risks for water-quality excursions in highway runoff, BMP discharge, and in upstream and downstream stormflows. This case study indicates that the risk for TP excursions are substantially affected by the selected criteria and the modeling methods.

Figure 8. The percentage of downstream total phosphorus concentrations that exceed the hypothetical criterion of 0.1 mg/L as a function of the deterministic upstream concentration.
used. For example, if a constant concentration is used to model upstream concentrations rather than a stochastically derived distribution, then the percentage of water-quality excursions in the downstream receiving waters may depend entirely on the selected upstream value.

REFERENCES


