ASSESSING ROADWAY CONTRIBUTIONS TO STORMWATER FLOWS, CONCENTRATIONS AND LOADS BY USING THE STREAMSTATS APPLICATION

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ABSTRACT
The Oregon Department of Transportation (ODOT) and other state departments of transportation need quantitative information about the percentages of different land-cover categories above any given stream crossing in the state to assess and address roadway contributions to water-quality impairments and resulting Total Maximum Daily Loads. The U.S. Geological Survey, in cooperation with ODOT and the FHWA, added roadway and land-cover information to the online StreamStats application to facilitate analysis of stormwater runoff contributions from different land covers. Analysis of 25 delineated basins with drainage areas of about 100 square miles indicates the diversity of land covers in the Willamette Valley, Oregon. On average, agricultural, developed, and undeveloped land covers comprise 15, 2.3, and 82 percent of the basins area. On average, these basins contained about 10 miles of State highways and 222 miles of non-state roads. The Stochastic Empirical Loading and Dilution Model was used with available water-quality data to simulate long-term yields of total phosphorus from highways, non-highway roadways, and agricultural-, developed-, and undeveloped-areas. These yields were applied to land cover areas obtained from StreamStats for the Willamette River above Wilsonville, Oregon. This analysis indicated that highway yields were larger than yields from other land covers because highway-runoff concentrations were higher than other land covers and the highway is fully impervious. However, the total highway area was a small fraction of the other land covers. Consequently, while highway-runoff mitigation measures can be effective for managing water quality locally, they may have limited effect on achieving basin-wide stormwater reduction goals.

Keywords: StreamStats Stochastic Empirical Loading and Dilution Model, SELDM, Total Maximum Daily Loads, TMDL, National Land Cover Dataset

INTRODUCTION

The Oregon Department of Transportation (ODOT) and other state departments of transportation (DOTs) need quantitative information about the percentages of different land-cover categories above any given stream crossing in the state. Such information is needed to assess the potential contribution of state highways and other sources to the quality of receiving streams. The ability to assess contributions from highways and other sources is needed to address responsibilities for managing Environmental Impact Statements, National Pollutant Discharge Elimination System permits, Municipal Separate Storm Sewer System (MS4) permits, and efforts to establish Total Maximum Daily Loads (TMDLs) (*1–4*). Information about highway contributions are needed to inform analyses of the quality and quantity of runoff, potential effects on receiving waters, and the potential effectiveness of mitigation measures. Knowledge of highways and surrounding and upstream land use/land cover percentages in a stream basin can inform decisions about the potential cost and effectiveness of on-site or watershed-scale best management practices (BMPs) to minimize adverse effects of runoff on receiving-water quality.

TMDLs are used as a method to calculate allowable loads of the water-quality constituents that will reduce or eliminate water-quality impairments in receiving waters. The results of TMDL analyses are used to determine load allocations for point and non-point sources of the constituents of concern. Currently (2017), the EPA reports that there are 42,527 impaired water bodies nationwide and 71,193 TMDLs have been approved since 1995 (*5*). Many of the constituents of concern for these water-quality impairments, including pathogens, nutrients, trace metals, organic carbon, and sediment, also have been identified as highway and urban runoff-quality constituents (*3*,*4*, *6–8*). Research indicates that DOTs need information, tools and techniques to address increasing concerns about their roles and responsibilities in the TMDL processes (*1*,*3*,*4*,*6*,*9*,*10*).

In 2013, the U.S. Geological Survey, in cooperation with the FHWA, published the Stochastic Empirical Loading and Dilution Model (SELDM) to provide a tool that can be used to simulate stormwater concentrations, flows, and loads from highways and other land uses (*2*,*3*, *11*). SELDM is a lumped-parameter Monte Carlo model that can be used to simulate long-term average annual runoff loads from highways and other land use areas that can be used for TMDL analyses. SELDM also has a stormwater best management practice (BMP) module to simulate potential effects of stormwater control measures on runoff flows, concentrations, and loads from the site of interest (*11*,*12*). In SELDM, each storm that is generated for an analysis is identified by sequence number and annual-load accounting year. When the time between event midpoints of a series of simulated events exceeds 365 or 366 days, those events are lumped into one annual-load accounting year. SELDM generates each storm randomly; there is no serial correlation. The order of storms does not reflect seasonal patterns. The annual-load accounting years, which are random collections of events generated with sums of inter-event times less than or equal to a year, are used to generate annual highway flows and loads for the TMDL analyses. The population of annual runoff and BMP discharge loads from the site of interest (a highway or other land-use area) indicates the potential contribution from the site of interest, the potential for reducing loads to meet any proposed load allocations, and the uncertainty of such estimates.

Purpose and Scope

The purpose of this paper is to describe and demonstrate methods for assessing roadway contributions to stormwater flows, concentrations, and loads by using the StreamStats application to obtain basin properties and by using SELDM to simulate the quality and quantity of runoff. The Oregon StreamStats application was used as an example because the USGS has implemented land cover and roadway information in cooperation with ODOT. Results of a spatial analysis with many mid-size basins was used to demonstrate the process for estimating land-cover categories and the length and area of minor roads, major roads, and State highways above any point along a stream in Oregon. Total phosphorus (TP) concentrations from the literature for different land cover types were used to demonstrate application of stormwater runoff yields with derived land-cover areas to assess contributions of different land uses in the Willamette basin above USGS streamgage 14198000 Willamette River at Wilsonville Oregon, because TP is a constituent of concern for many TMDLs nationwide (*5*). This large basin was used for the TMDL analysis because it represents an area-weighted average of the properties of its subbasins.

METHODS

The methods used for the geographic and stormwater-quality analyses used in this paper are based on previous efforts to provide hydrologic and water-quality information and stormwater simulation methods for the nation (*2,3,11,13*). In this paper, however, these methods were combined to demonstrate new practice-ready capabilities developed by the USGS that can be used by other DOTs, nationwide.

Geographic Analysis Methods

The USGS, in cooperation with the Oregon Department of Transportation added land-cover and roadway datasets to the previously existing Oregon-state StreamStats application (*14,15*). The land-cover datasets added to this application were derived from the 2011 National Land Cover Datasets (*16–18*). These datasets included the impervious percentage, natural, agricultural, and developed land covers. The natural/undeveloped land covers included the aggregated categories for water, wetlands, herbaceous, shrub land, forest, and barren land. The developed land-use categories included open space, low-intensity, medium-intensity, and high-intensity developed areas. This dataset provides the percentage imperviousness and the percentage of each land cover upstream of any point on any stream with a drainage area that is contained within Oregon. The land-cover dataset is implemented as a gridded raster dataset with a 30-meter pixel resolution. A dataset of three road classes including, non-state minor roads, non-state major roads, and state highways was developed as a vector dataset from the Oregon state-road class GIS coverage (*19*). This dataset provides the length of all roads in each road class within each delineated basin. It provides the length of each side of divided highways. These datasets were incorporated into the application by using standard USGS StreamStats processing methods.

For this paper, the area of the roadways was calculated by using the length of each type of roadway times the width. The width of the roadways was estimated by multiplying a standard lane width (12 feet) to an estimated average number of lanes for each type of road. It was assumed that the average width of non-state minor roads is 2.25 lanes, non-state major roads is 3 lanes, and state highways was 3.5 lanes (on each side of the divided highway including ramps and break-down lanes).

Two methods were used for obtaining drainage areas, land-cover percentages, and roadway lengths from StreamStats. The batch-processing method was used to obtain basin properties to analyze the distributions of land-cover percentages in stream basins within the Willamette Valley in Oregon. A geographic information system was used to analyze stream segments in the National Hydrography Dataset to locate coordinates of points along the stream network that represent drainage areas of about 100 square miles. Resulting basins were screened for specific conditions that were not representative of most stream basins in the state. Basins with atypical proportions of canals, reservoirs, lakes, or ponds were screened out so that the basins would represent free-flowing stream conditions. Basins that passed this screening test were submitted to the StreamStats batch-processing tool to obtain the basin characteristics, which included imperviousness, land cover percentages, and the lengths of minor roads, major roads, and state highways within the delineated drainage areas. The manual method, which is comprised of zooming to a point of interest, clicking on a stream cell, and requesting a basin characteristics report, was used to get the data used in the example loading analysis (*13*). StreamStats users most commonly delineate a basin and obtain basin properties and flow statistics by using the manual method.

Stormwater-Quality Analysis Methods

Long-term annual yields of TP were simulated with version 1.02 of SELDM by using methods described by Granato and Jones (*3*). Geographic information system layers of SELDM precipitation statistics created by Risley and Granato (*4*) were used to generate storm events for these analyses. Yields were calculated by using long term average event volumes, event durations, and time between event midpoints of 0.693 inches, 13.4 hours, and 136 hours, respectively. Roadway runoff coefficients were simulated by using SELDM statistics for completely impervious roadway areas (*11*). Runoff coefficients for other land-cover areas were calculated by using non-roadway runoff coefficient statistics based on the assumption that total impervious percentages for developed land covers were 33.4 percent, agricultural land covers were 0.5 percent, and undeveloped land covers (primarily forest) were 0 percent (*11*). The area of State highways was subtracted from the developed land cover area to estimate total loads for each category.

The simulated populations of annual runoff yields for the different land covers depend on the input concentration-statistic values and the runoff coefficients. Yields in pounds of TP per acre from each land cover are applied to the different areas obtained from StreamStats to calculate long-term average annual loads. Stormwater-runoff quality from undeveloped and agricultural areas were simulated by using concentrations from forest and agricultural runoff from the Washington State Department of Ecology database (*20*). Stormwater-runoff quality from developed non-highway areas were simulated by using BMP inflow concentration statistics from the September 2016 version of the International BMP database (*21*). Highway-runoff quality was simulated by using statistics from four highway-runoff sites in Oregon with TP data (*22*). The median of statistics for the average, standard deviation, and skew of the common logarithm of TP from sites in each dataset were used for the annual-yield simulations (**TABLE 1**). The geometric mean TP concentration of the forest runoff is about an order of magnitude less than the geometric means of the other land uses, which are fairly similar. The standard deviations of the TP concentrations are similar for all the different land uses.

The effect of stormwater control measure BMPs also were simulated to examine potential improvements with treatment for highways and other developed land covers (*11*,*12*). The BMP performance statistics selected by Granato and Jones (*3*) were used in these simulations. They simulated a BMP based on the median performance statistics from 7 BMP categories to represent a generic BMP. They used values of 0.116, 0.548, 0.657, and 1.233 for the minimum, lower bound of the most probable value (LBMPV), upper bound of the most probable value (UBMPV), and maximum flow reduction ratios, respectively. They used a rank correlation coefficient (rho) of 0.21 between simulated inflow volumes and flow reduction ratios. Granato and Jones (*3*) used values of 0.105, 0.226, 0.561, and 2.158 for the minimum, LBMPV, UBMPV, and maximum TP reduction ratios, respectively. They used a rho value of -0.52 between simulated inflow concentrations and concentration reduction ratios. They used a minimum irreducible concentration of 0.02 mg/L.

TABLE 1. Median of the average, standard deviation, and skew of the common (base 10) logarithms and geometric mean of event-mean concentrations of total phosphorus for different land-cover categories.

Land cover category	Number of sites	Geometric mean (mg/L)	Average[1]	Standard deviation[1]	Skew[1]	Source
Agricultural (Washington State)	4	0.193	-0.7135	0.2117	0.3221	*20*
Developed (nationwide)	95	0.159	-0.7988	0.2953	0.3296	*21*
Forest (Washington State)	4	0.02	-1.693	0.2765	1.901	*20*
Highways (Oregon)	4	0.214	-0.6687	0.2888	-0.5693	*22*

1. Statistics are for the common (base 10) logarithms of EPA parameter p00665, phosphorus water, unfiltered, milligrams per liter

GEOGRAPHIC ANALYSIS OF LAND COVER AND ROAD MILES IN STREAM BASINS WITHIN THE WILLAMETTE VALLEY, OREGON

Multiple iterations of GIS analysis were conducted to balance the allowable percentage deviation from the drainage area of interest against the number of basins that qualify for use. Early iterations resulted in too few delineated basins within the prescribed bands of allowable drainage areas. For example, only 11 basins were delineated with drainage area of 100 square miles and an allowable tolerance of 0.01 percent. Intuitively, one might expect that the number of delineated basins for all the drainage area sizes would be much larger, but several factors influence the delineation process. Physiographically, drainage area increases exponentially with increasing channel length. For example, Granato (*11*) did an analysis of drainage area and main-channel length at 845 streamgages nationwide and found that drainage area increased at a rate of 0.426 times the main channel length to the 1.74 power. Individual streamgages, however, varied from this regression line because additional drainage area is accumulated in blocks as the main channel crosses topographic crenulations and tributary areas. Furthermore, the National Hydrography Dataset used in StreamStats is discretized to a 30-meter grid, which accentuates the the step changes in drainage area with increasing channel length. For example, an increase of one grid cell (about 0.186 miles) in length would increase the drainage area by about 0.04 square miles, which is an increase of about 0.8 percent at the 5 square-mile scale. At the 100 square-mile scale each additional grid cell could be expected to increase drainage area by about 0.14 percent. Consequently, the allowable percentage deviation from the drainage area of interest was not held as a consistent percentage between small and large drainage areas during later iterations of the GIS analysis. For the last GIS analysis iteration, bands of 20 percent deviation were allowed (80-120 square miles), which resulted in 90 delineated basins within the Willamette Valley. A large percentage of these 90 basins were multiple basins nested within the same watershed. In order to avoid basins that covered the same geographic area, these basins were removed, leaving 25 basins for this analysis. These delineated basins have a wide range of basin characteristics (**TABLE 2**).

TABLE 2. Basin characteristics of 25 selected watersheds in the Willamette Valley, Oregon with delineated drainage areas from 80 to 120 square miles.

Land Cover	Minimum	Maximum	Average	Median	Standard deviation
Entire basin area, in square miles	84	120	101	101	11
Impervious areas, in percent	0.05	6.4	0.72	0.14	1.28
Agricultural areas, in percent	0.0	65	15	6.0	22
Developed areas, in percent	0.0	8.0	2.3	1.0	2.4
Undeveloped areas/ forest, in percent	16	100	82	91	25
Non-state minor roads, in miles	107	359	195	189	65
Non-state major roads, in miles	1.5	111	27	22	24
Non-state roads (total), in miles	112	470	222	222	77
State highways, in miles	0.0	37	10	7.7	11

For these selected basins, the estimated percentage of developed areas comprised of all state and non-state roadways was about 55 percent and this estimated total road area represents about 92 percent of the total impervious area (TIA). The percentage of impervious area comprised of roadways in this analysis is much greater than the literature would suggest. For example, Slonecker and Tilley (*23*) did an analysis of 11 urbanized watersheds in 5 areas of the country and found that, on average, roads represented about 28 percent of the impervious areas. They found that buildings, parking lots, driveways, sidewalks, and other anthropogenic impervious surfaces represented about 29, 25, 9, 3, and 3 percent of the total impervious area, respectively. Similarly, Roy and Shuster (*24*) examined a stream basin with 20 percent TIA and estimated that about 28 percent of TIA was buildings, 25 percent was driveways, 23 percent was streets, 12 percent was parking areas, 6 percent was sidewalks, and about 6 percent was other anthropogenic impervious surfaces. The large percentages of developed and impervious areas comprised of roads in the current study reflect the comparatively low percentages of developed and impervious areas in the Willamette Valley (averages of 2.3 and 0.72 percent, respectively). In basins with limited development, there are comparatively large stretches of roads connecting small clusters of developed area.

The amount of impervious area in a watershed is positively correlated with the total length of roads, although there is a large amount of variability for watersheds that are comprised of less than 1 percent impervious area (**FIGURE 1**). On average, within the 25 selected basins, state roads account for 4 percent of all road miles, and are less abundant than major roads (12 percent), which are in turn less abundant than minor roads (84 percent). The number of stream crossings follows the same pattern, with minor roads crossings being most abundant, and state road crossings least abundant (**FIGURE 2**).

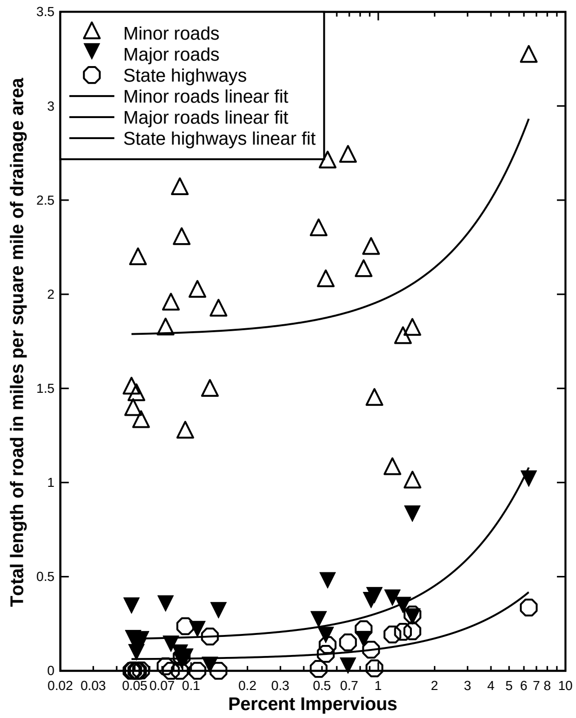

FIGURE 1. Relation between percent imperviousness and total length of roads for 25 selected Willamette Valley, Oregon watersheds with drainage areas from 80 to 120 square miles.

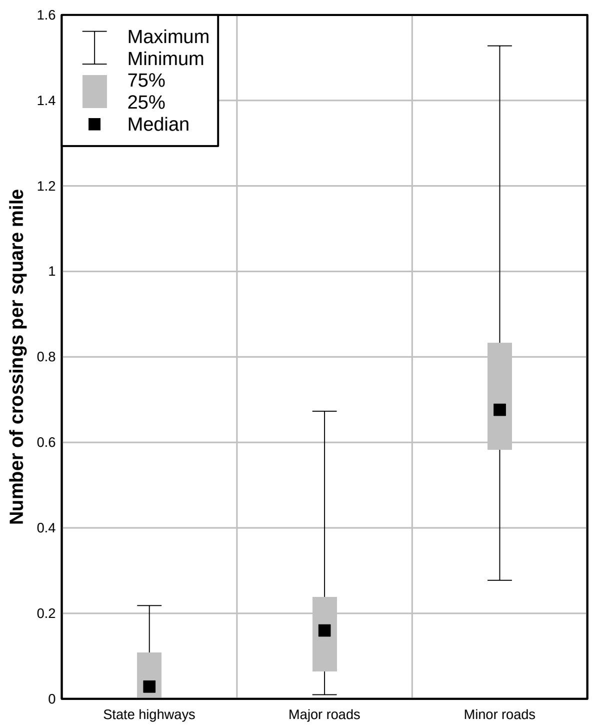

FIGURE 2. Figure plot showing the number of stream crossings per square mile of drainage area for state highways, major roads and minor roads in 25 selected Willamette Valley, Oregon watersheds with drainage areas from 80 to 120 square miles.

EXAMPLE STORMWATER-QUALITY ANALYSIS OF YIELDS AND LOADS OF TOTAL PHOSPHORUS FROM HIGHWAYS AND OTHER LAND COVERS IN THE WILLAMETTE BASIN

The first step in this example analysis was to go to the StreamStats application, navigate to the area of interest and select a point on the Willamette River for analysis (*13*); in this case the stream cell above USGS streamgage 14198000 Willamette River at Wilsonville Oregon (45.29791, -122.75033) was used for analysis. StreamStats was used to delineate the basin above this point and obtain the basin-properties report. This streamgage is located above the city of Portland, but below Salem, Albany, Corvallis, Eugene, and other small cities. Although this basin includes many highly-developed areas it is predominately undeveloped and agricultural with a total impervious area of only 1.77 percent (**TABLE 3**). Differences in land-cover and impervious percentages between this delineated basin (**TABLE 3**) and the delineated 100 square-mile basins (**TABLE 2**) are caused by the concentration of agriculture and development in the valley floor. Although the percentages of developed area and imperviousness area in this basin (**TABLE 3**) are more than twice the values for the smaller subbasin averages (**TABLE 2**), the basin is mostly a rural area with a large road network connecting the developed areas.

TABLE 3. Land-cover statistics for the entire Willamette basin above USGS streamgage 14198000 Willamette River at Wilsonville Oregon developed by using StreamStats.

Land cover	Area (square miles)	Percent of Area
Entire basin area	8,440	100
Agricultural areas	1,688	20
Developed areas (including roadways)	422	5
Undeveloped/forest areas	6,330	75
Sum of areas	8,440	100
Total impervious area	149	1.77
Non-state roads (19,010 miles)	102.5	1.21
State highways (1,220 miles)	9.7	0.11
Sum of all roads	112.2	1.32

In this basin, the long-term SELDM analyses demonstrate the effect of the selected concentration statistics and imperviousness for each land-cover type on the TP yields. The geometric mean TP concentration estimated for highway runoff (0.214 mg/L) was about 1.11, 1.35, and 10.7 times the geometric means of agriculture, developed lands and forest respectively (**TABLE 1**). The median of statistics from the 95 selected non-highway sites in the International BMP database were used for analysis of runoff quality from non-state roadways and developed areas. However, geometric mean TP concentrations ranged from 0.029 to 3.09 mg/L among sites in the International BMP database. The geometric mean concentration from the Oregon-highway dataset was greater than about 66 percent of the values for non-highway sites in the BMP database. Agricultural data from Washington State were used to calculate statistics for this analysis (**TABLE 1**), but the literature indicates that agricultural EMCs for TP may be much higher than the Washington data would suggest, with mean or median TP concentrations on the order of 0.14 to 1.56 mg/L (*25*). As such, TP yield calculations that were done by using the agricultural values in **TABLE 1** may overestimate the contribution of highway runoff. The differences in concentrations are compounded by the differences in imperviousness and therefore the runoff-coefficient statistics used for the simulations (*11*). Highway and roadway yields are for the impervious area only, whereas the yields from other land covers are attenuated by the relatively low impervious percentages used in these simulations (**FIGURE 3**).

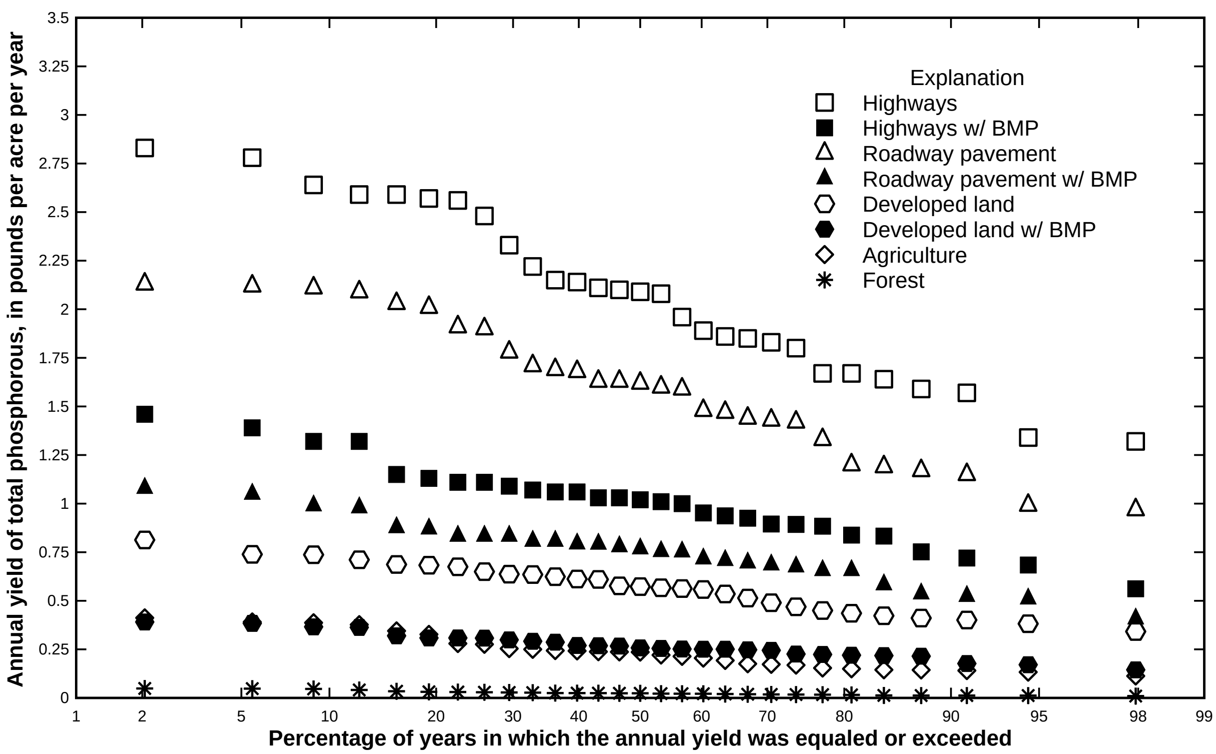

FIGURE 3. Probability plot showing annual stormwater-runoff yields of total phosphorus, in pounds per acre per year, for a 29-year simulation period.

In these simulations, the annual highway-runoff yields were higher than runoff yields from, developed, agricultural and undeveloped/forest land covers (**FIGURE 3**). The highway-runoff yields were higher than other land covers even with generic BMPs in place. This is because of the relatively large highway concentrations and the high runoff coefficients associated with the impervious pavement. If the developed-land concentration-statistics (**TABLE 1**) are applied to the impervious non-highway roadway areas, then the long-term average highway yield (**TABLE 4**) is about 1.30 times the average roadway yield without BMP treatment and about 1.33 times the roadway yield with the BMP treatment. If the developed-land concentration statistics are applied to the developed areas with an impervious percentage of 33.4 percent, then the highway and roadway yields are about 3.66 and 2.81 times the developed-area yields on average. Although the geometric mean concentration for agriculture was higher than the developed-land concentration (**TABLE 1**), the long-term average runoff yield for the developed land cover was 2.42 times the yield from the agricultural land cover (**TABLE 4**) because of the simulated difference in imperviousness (33.4 versus 0.5 percent). The long-term average runoff yield from forested land cover was about an order of magnitude less than the agricultural yield because the forest-runoff concentrations were lower than the agricultural concentrations and the impervious percentage of forest areas was simulated as zero.

TABLE 4. Average annual stormwater-runoff yields and loads of total phosphorus from different land cover areas in the entire Willamette basin above USGS streamgage 14198000 Willamette River at Wilsonville Oregon.

Land cover	Area (acres)	Average yield (pounds of total phosphorus per acre per year)	Average annual load (pounds of total phosphorus per year)
Agricultural areas[1]	1.07×10^6	0.235	2.51×10^5
Developed areas[2]	2.70×10^5	0.569	1.54×10^5
Developed areas[2] with BMPs	2.70×10^5	0.269	7.26×10^4
Undeveloped/forest areas[1]	3.99×10^6	0.0249	9.94×10^4
Non-highway roads[3]	6.77×10^4	1.60	1.08×10^5
Non-highway roads[3] with BMPs	6.77×10^4	0.758	5.13×10^4
State highways	6.21×10^3	2.08	1.29×10^4
State highways with BMPs	6.21×10^3	1.01	6.27×10^3

1. Areas are reduced by the basin-wide average road-area percentage (1.32 percent). 2. Areas include roadway but not state-highway areas. 3. Area includes non-highway roads in undeveloped and agricultural areas.

Although these simulations indicate that state highway yields are substantially larger than yields from other land covers, the state-highway contributions to long-term annual runoff loads is a small fraction of the total annual runoff loads. Without any BMPs, the simulated long-term basin-wide average annual runoff load from agricultural areas, developed areas, undeveloped areas, non-highway roads in undeveloped areas, and State highways was about 6.26×10^5 pounds per year. Runoff from State highways contributed about 2.1 percent of this long-term average annual runoff load (**TABLE 4**). Agricultural areas, developed areas, undeveloped areas, and non-highway roads in undeveloped areas contribute about 40, 25, 16, and 17 percent of the total load, respectively. Simulation results indicate that the use of generic BMPs would reduce the TP loading from state highways by about half. Alternatively, this load reduction (6.64×10^3 pounds per year) could also be achieved by adopting land management practices that result in a 2.64 percent decrease in annual runoff loads from agricultural lands, or a 4.33 percent decrease in annual runoff loads from developed lands. In comparison, application of the generic BMP performance to the developed-areas alone results in a load reduction of (8.10×10^4 pounds per year), which is more than an order of magnitude more than the highway reduction. Furthermore, application of BMP to developed clusters may be more effective than construction and maintenance of BMPs distributed along linear highway systems (*6*).

Another approach to evaluate basin-wide runoff-load reductions is to use the calculated loads to evaluate land-cover specific reductions needed to achieve specific targets (**TABLE 5**). For example, if the basin-wide reduction target is 5 percent, one approach would be to reduce the average annual runoff loads from agricultural lands by about 12 percent or to reduce the average annual runoff loads from developed lands by about 20 percent. Reductions in State highway loads alone cannot be used to meet this target because the 5 percent reduction is about 2.4 times the total highway load. Adding resource-intensive structural BMPs (*6*) to state highways or developed areas results in the highest yield reductions, but not the largest load reductions. Other land-cover treatment options, such as widespread use of agricultural best practices, do not need to be as efficient as structural BMPs to produce similar reductions in annual runoff loads (**TABLE 5**).

TABLE 5. Percentage reduction of average annual loads of total phosphorus needed to reach specific reduction targets by land cover for the entire Willamette basin above USGS streamgage 14198000 Willamette River at Wilsonville Oregon. A reduction greater than 100 percent indicates that elimination of this source alone cannot be used to reach the reduction target.

Land Cover	Target reduction value of basin-wide annual total phosphorus load, in percent				
	1	**2**	**5**	**10**	**20**
Agriculture[1]	2.5	5.0	12	25	50
Developed lands[2]	4.1	8.1	20	41	82
Undeveloped areas/ forest[1]	8.6	12	29	56	115
Non-highway roads[3]	5.8	12	29	58	116
State highways	48	97	240	480	970

1. Areas are reduced by the basin-wide average road-area percentage (1.32 percent). 2. Areas include roadway but not state-highway areas. 3. Area includes non-highway roads in undeveloped and agricultural areas.

LIMITATIONS OF THIS ANALYSIS

This analysis was designed to produce planning-level estimates of basin properties, runoff yields, and runoff loads to foster discussions about the relative contributions of different land covers and potential effectiveness of different management measures. Planning-level estimates include substantial uncertainties, which commonly are on the scale of one or more orders of magnitude (*11*). As such, more refined runoff-quality statistics may be needed to estimate yields and loads for actual TMDL analyses in Oregon and other areas. As indicated in the discussion, TP concentration-statistics for non-highway land uses were calculated with available data and may not be representative of runoff from areas in the Willamette River Basin. Highway concentration statistics were calculated by using four highway-runoff sites in Oregon, which may not be representative of typical highway-runoff in the Willamette River Basin. BMP treatment statistics represent the effects of a generic BMP rather than individual BMP designs (*3*,*12*), which may be optimized for the hydrology and water quality in this area. Pavement yields for highway and non-highway roads may substantially over estimate roadway contributions to streams because large sections of the road network drain to the local land surface rather than to connected waterbodies; this is evidenced by the low density of stream crossings (**FIGURE 2**). Furthermore, the yields and loads discussed in this paper are for stormwater runoff only; they do not include loadings from wastewater treatment plants or baseflow loading from fertilizer applications, agricultural underdrains, septic-system effluent, other commercial or industrial sources, or natural geologic sources.

CONCLUSIONS

State departments of transportation (DOTs) need ready access to quantitative information about the percentages of different land-cover categories and the amount of roadways and highways above any given highway-stream crossing. This information is needed to assess runoff-quality issues including Total Maximum Daily Loads. To this end, the U.S. Geological Survey integrated land-cover and road-length data into the web-based StreamStats tool in cooperation with the Oregon DOT and the FHWA. StreamStats is a web-based application that incorporates a Geographic Information System that enables users to derive basin characteristics, delineate drainage areas, and estimate streamflow statistics upstream from any given point along a stream. In this study, land-cover and roadway-length values from StreamStats and total-phosphorus (TP) concentration statistics from the literature were used with the Stochastic Empirical Loading and Dilution Model (SELDM) to simulate long-term runoff yields and loads from different land covers above USGS streamgage 14198000 Willamette River at Wilsonville Oregon. SELDM was used to simulate yields and loads from State highways, minor and major non-State roads, and developed land covers with and without use of stormwater best management practices (BMPs). This paper demonstrates practice-ready methods to provide planning-level load estimates.

A geographic analysis of 25 subbasins in the Willamette Valley of Oregon with drainage areas between 80 and 120 square miles was done with the StreamStats batch processing tool to evaluate land cover categories in the basin. Results indicate that these basins are primarily forest and other undeveloped lands (median value of 91 percent), and tend to have little impervious area (median value of 0.14 percent). Minor roads are more abundant in these watersheds than major roads, which are in turn more abundant than state highways (median length values of 189, 22.0 and 7.7 miles, respectively). Analysis of the number of stream crossings by road type follows the same pattern as the roadway-length analysis. The amount of impervious area for a given watershed is positively correlated with the total miles of road, although the correlation is relatively week for watersheds with less than 1 percent imperviousness.

Results of the stormwater-loading analysis with SELDM indicate that state highways produce the highest TP load per acre (the yield), followed by roadway pavement, developed-, agricultural- and forest-land covers. However, highways produce the lowest TP loading (2 percent) of the four land cover categories evaluated, because state highways constitute a relatively small percentage of the watershed. Simulated agricultural and developed land covers, which are 41 and 24 percent of the long-term average annual loads, account for the majority of average-annual TP loads in the simulated basin.

The potential effectiveness of BMPs also was evaluated in these simulations. Simulations indicate that, on average, loads from state highways could be reduced by about 50 percent if typical BMPs are used throughout the basin. Targeted BMP treatment of highway or non-highway road runoff result in the largest reduction in runoff yields, but these areas are a small part of the basin and highway and roadway loads are a small part of basin-wide runoff loads. This analysis also indicates that relatively modest runoff reductions from land-management practices in large agricultural areas or clustered developed areas could result in load reductions equal to installing structural BMPs to treat all highway and roadway runoff in the basin.

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