METHODOLOGIES FOR QUANTIFYING
NON-POINT SOURCE
CONTAMINANT LOADING
TO PUGET SOUND

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Region 10

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1.0 INTRODUCTION

Nonpoint sources of pollution may carry levels of contaminants similar to point sources. For example, urban runoff has been compared to discharge from secondary treatment systems in the concentrations of some pollutants. If the quantity of runoff is large, this source can constitute a major input to the environment, particularly over the short term, such as during storm events. Nonpoint source pollution is much more difficult to monitor than pollution from point sources due to its diffuse nature, therefore indirect methods of measurement and various modelling approaches have been devised to obtain a quantitative understanding of this contaminant source.

The objective of this report is to evaluate available methods for estimating loadings to Puget Sound from nonpoint sources and to assess whether simple and straightforward methods can provide accurate loading estimates.

Three methods which can be used to estimate nonpoint source (NPS) loading will be discussed in order of increasing complexity. These methods include:

- Estimation of nonpoint source loadings from historical measurements of flows, and concentrations

- Estimation of nonpoint source loadings from source inventories and release rates (water quality assessment method)

- Estimation of nonpoint source loadings from computer modelling of sources and drainage hydrology

For the first two methods, quantitative estimates of nonpoint source loadings for two prototype embayments have been developed for a few conventional and metal contaminants. For the more complex modelling methodologies, available models, their input data needs and implementation requirements are presented.

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1.1 PROTOTYPE DEMONSTRATION SITES

Nonpoint sources are conventionally classified according to locale as urban or agricultural. The main differences between these two types are the sources of pollution and their transport mechanisms. Urban hydrology is characterized by rapid runoff from mainly impermeable surfaces (e.g., streets) through systems designed to discharge their flows as quickly as possible. Rural hydrology generally involves sheet flow across soil surfaces into natural channels and is therefore a slower process.

Since urban and rural sources are considered differently in modelling procedures, two prototype embayments were chosen for initial application of the methods presented in this report, one urban in the character of its contributory drainage basin and the other rural. These embayments serve as test cases for the simpler computations to be discussed and as focal points for the discussion of more complicated modelling methodologies. It is our recommendation that, if work is undertaken to implement sophisticated computer modelling procedures, these embayments should be considered as the test cases for that effort as well.

The two embayments selected were:

- Elliott Bay, receiving runoff from the highly urban Seattle and Duwamish Waterway/Kent Valley areas;
- Skagit Bay, receiving runoff from the predominantly rural Skagit River Valley.

These embayments were chosen because they are representative of each source type and because water quality data are available to apply and confirm the methods. These embayments are described in more detail below.

1.1.1 Urban Embayment: Elliott Bay

Elliott Bay is a bight indentation in the eastern side of central Puget Sound. The shores of the Bay are entirely within the city of Seattle. The only substantial natural watercourse which flows into the Bay is the Duwamish River, called the Green River upstream of a short distance inland. The Duwamish drains an area of approximately 487 sq. mi. (Seaber et al. 1984) and median annual flows are 1,400 cfs (Williams 1981). The Duwamish or Green is bordered by the cities of Seattle (population 489,700, according to WSOFM 1984), Tukwilla (3600), Renton (32,700), Kent (25,500), and Auburn (29,000). Land use along the Bay is commercial (Seattle Central Business District), medium density residential, and light industrial, with shipping and shipbuilding immediately adjacent to the Bay. The land use in the Duwamish/Green River valley is predominantly light industrial (office park or warehouse) with some medium residential densities in the uplands above the valley. Upstream of about Auburn the population density is much less, with land use becoming agricultural. Howard A. Hanson Reservoir was constructed somewhat further upstream in 1961 to allow flood control.

Elliott Bay is probably the second most studied portion of Puget Sound (Commencement Bay appears to be the only site likely to have more water quality data). The availability of these studies simplified some of the difficulties of data collection. The significance of Elliott Bay for this evaluation is that it borders on the largest population in the state and is an area with some of the best available information. Its drainage area is small relative to other urbanized river basins and there are no extensive lakes which would capture sediment and complicate analysis procedures. In addition, Elliott Bay is an embayment already showing signs of impact from Man's presence in terms of elevated concentrations of some contaminants in the open water and has loadings of pollutants from both point and nonpoint sources.

1.4.3 Rural Embayment: Skagit Bay

Skagit Bay is a branch of the Whidbey Basin of Puget Sound, bounded on the west by Whidbey Island, on the south by Camano Island, and on the east by the mainland (Skagit County). The Bay is connected to the rest of Puget Sound through two outlets, Deception Pass to the northwest and Saratoga Passage to the southwest. The areas bordering the Bay are predominantly agricultural. The greatest runoff into Skagit Bay is via the Skagit River, and land use along the lower portions of the Skagit is agricultural, mainly dairy, vegetables, fruits, and flowers. Cities in this portion of the Skagit Valley include Mount Vernon (population 13,600 according to WSOFM 1984), Burlington (3,820), Sedro Woolley (6,225), Lyman (240), Hamilton (220), and Concrete (570). La Conner (645) is a slight distance north of the mouth of the Skagit River near the Bay. The upper reaches of the Skagit basin are mountainous with extensive forests (the Mt. Baker National Forest) and logging. There are only a few small, unincorporated villages in this area.

The Skagit River has a drainage area is 3218 sq. mi. (Seaber et al. 1984) and median annual flow is 18,000 cfs (Williams 1981), and is the largest river emptying into Puget Sound. Major tributaries include the Sauk, Suiattle, and Baker Rivers. Three major dams produce hydroelectric power from upper Skagit River flows. A portion of the Sauk River drainage is in Snohomish County to the south, and the Baker and upper Skagit flow down from portions of Whatcom County and British Columbia to the north, but most of this area is upstream of the dams and therefore not contributing sediment to Skagit Bay.

The Skagit River has a national stream-quality accounting network station (gage number 12200500 near Mount Vernon) with varying levels of water quality data available back to 1962 (best since 1974) and flow data available from 1940; presently sampling is conducted on a two month interval schedule. Skagit Bay has the advantage of having almost all its drainage in a single county (Skagit) with only minor contributions from Whatcom and Snohomish counties; this reduced the number of agency contacts which had to be made in data collection and coordination. The significance of Skagit Bay to this evaluation is that it is appropriate for application of NPS methodologies which were developed for rural areas. Land use and soil type data are fairly scarce, however, and may require more extensive collection schemes (e.g., aerial or satellite photography) for future studies. The water quality data available for the Skagit River is fairly comprehensive and will allow verification of the WQA model results.

1.2 APPLICATION TO OTHER SITES

The development of methodologies appropriate to urban and rural sites should allow the results to be combined for basins which are both urban and rural as long as care is taken to avoid counting an area's contribution under both methods. Embayments which are predominantly rural may allow small population centers to be left out of the analysis without significant error in the calculation. Where possible, results should continue to be checked for their accuracy using downstream water quality data, but if a methodology is proved to be correct for several areas it should be acceptable to apply it to areas without corroborating data. Some areas (e.g. Bremerton on Sinclair Inlet) do not have substantial freshwater drainage channels which could be used to confirm model predictions but these areas should not be any the less applicable for the methods presented in this report.

2.0 ESTIMATION OF NONPOINT SOURCE LOADINGS FROM HISTORICAL MEASUREMENTS OF FLOWS AND CONCENTRATIONS

Nonpoint sources are diffuse and are located at widely dispersed sites throughout the Puget Sound region. Because most nonpoint source pollution is waterborne it can often be gaged in aggregate by observing the quantities of contaminants which are carried by rivers which drain an area of concern. This is only feasible, of course, when the drainage system is concentrated in a single, or at most a few, rivers where the data collection process can be conducted for the entire area. There are Puget Sound embayments which receive their pollutant loads mainly from direct runoff into the bay rather than via collecting river systems; the estimation procedure discussed in this chapter cannot be used in such circumstances. A large majority of the drainage into Puget Sound, however, is river-borne and so this method has considerable application for the initial screening of nonpoint loadings and their comparison to other sources of pollution. It must be pointed out, however, that the total riverborne contaminant load at the river's mouth will be the result of both point and nonpoint contributions occurring upstream. Estimation of loading from contaminant concentrations at the river mouth does not distinguish between point and nonpoint source inputs.

This estimation procedure is based on historical records of flowrates and contaminant concentrations. When records of frequent, simultaneous measurement of flowrate and water quality for catchments containing major nonpoint sources are available, the accuracy of these estimates can be quite high. However, a lack of historical data necessitates approximation of data or selection of data not truly representative of actual loading, resulting in less accurate estimates. For areas which drain directly into an embayment, it is necessary to supplement any riverine contribution with the direct runoff of nonpoint pollution. Direct NPS pollution may be estimated using runoff calculations applied to the drainage area and some estimate of contaminant concentrations in that runoff.

River-borne mass loading may adequately approximate nonpoint loading when the river is directly or indirectly the major nonpoint transport pathway to the embayment. It is desirable to have water quality and streamflow data at reasonably frequent intervals (several times a year for several years) taken at a point close to the mouth of the river. When simultaneous measurements of streamflow and contaminant concentration are available, the product of the two variables gives an instantaneous mass loading value applicable to the particular pollutant at that place and time. Time-weighted or loading-weighted averages of an annual mass flux may be calculated and multiplied by a year's time to give annual loading.

This analysis was performed for the two prototype embayments. The particulars of the methods used varied according to the availability of data. The procedures and results are discussed in the following sections.

2.1 SKAGIT BAY

Since 1974, water quality and streamflow data have been measured at a USGS station located 15.7 miles upstream of Skagit Bay on the Skagit River near Mount Vernon. The drainage area for the gage is estimated by the USGS to be 3093 sq. mi., which includes all of the river's drainage basin except about 125 sq.mi. (4 %). Metal concentrations were measured 3 to 4 times a year and conventional pollutant parameters were typically measured 9 to 12 times annually, both at reasonably regularly spaced intervals. Using these data, instantaneous mass loadings were calculated, arithmetically averaged over the (water) year, and multiplied by the time factor to obtain annual loadings for selected constituents. Annual loading values were then averaged to get an overall mean and standard deviation of the annual values. The results are presented in Table 2.1.

TABLE 2.1

RIVER-BORNE LOADING OF SELECTED CONTAMINANTS IN THE SKAGIT RIVER a/

Parameter	Mass Loading (mt/yr) b/	Coefficient of Variation	Years of Data
Measured flow (10^9 ft^3)	526	21%	9
Ammonia (as N)	1,100	64%	8
NO_3 + NO_2 (as N)	2,000	17%	9
Total Kjeldahl Nitrogen (as N)	2,300	22%	3
Total Nitrogen	5,300	43%	4
Organic Nitrogen	4,100	51%	4
Total Phosphorous	520	29%	9
Total Organic Carbon	33,000	30%	4
Dissolved Solids	510,000	18%	9
Suspended Solids	1,800,000	89%	9
Arsenic	24	67%	9
Cadmium, total	51	69%	9
Copper, total	150	61%	9
Lead, total	370	73%	9
Mercury, total	1.6	75%	9
Zinc, total	400	80%	9

a/ Average annual values for water years 1974-1982 USGS gage 122005500, Skagit River near Mt. Vernon, WA.

b/ Values include "not detected" entries at one-half the detection limit. Source: USGS (1974-1982).

2.2 ELLIOTT BAY

For Elliott Bay a majority of the inflow and pollution also enters via a single river, in this case the Duwamish River. There is no USGS water quality gage on the Duwamish (or its upper reaches, called the Green River there) but the Washington Dept of Ecology (WDOE) and the Municipality of Metropolitan Seattle (Metro) have done extensive water quality sampling at many locations in the river. Harper-Owes, Inc. (1982), carried out an extensive synthesis of this sampling data, and other values contained in background literature, and their results have been used for this analysis.

The methods employed in the Harper-Owes Study to obtain and combine flows and concentrations varied according to the availability of data. The study methods are summarized briefly below. Sources were divided into the Black River, the Upper Green River, and stormwater runoff. Pollution loads from point sources, such as the Metro Renton Treatment Plant, the Combined Sewer Overflows, and industrial discharges, and other flux components such as atmospheric deposition, advective transport to and from Elliott Bay, and deposition in the Estuary, were also estimated in the Harper-Owes study in order to estimate the total loading rate to the Duwamish Estuary. The study developed a complete mass balance for the different contaminants considered, and the residuals left between the inputs and outputs were also estimated. Since data on metal concentrations were scarce for the upper Green River, the mass fluxes were estimated based upon the sediment flux and background levels of metals in Puget Sound sediment. Flow in the Black River was estimated based on a drainage-area ratio of Green River flows. Mass fluxes from stormwater runoff were calculated using runoff coefficients to calculate volume and multiplying by representative chemistry values. The contaminant loadings calculated in the Harper-Owes study are shown in Table 2.2.

TABLE 2.2

RIVER-BORNE LOADING OF SELECTED CONTAMINANTS
IN THE DUWAMISH RIVER
(Metric tons per year)

Parameter	Nonpoint Input Loads	Total Input Loads	Residual Load Unaccounted
Measured flow (10^9 ft^3)	56	64	0%
Ammonia (as N)	173	770+	ca.0%
Total Organic Carbon	220+	1200+	81%
Oil and Grease	18+	370+	58%
Suspended Solids (sediment)	243,000	244,000	1%
Arsenic	0+	1,200+	19%
Cadmium	1.02	1.3	82%
Copper	5.7	5.7	75%
Lead	6.9	9.8	91%
Mercury	0.75+	0.76+	24%
Zinc	42	48	45%
Total PCBs	0.0007+	0.241+	98%
Total Pesticides	0.0008+	0.0035+	73%

Source: Harper-Owes 1982
Notes: Nonpoint input loads include Upstream Green River, Black River, Regional Stormwater

Residual load unaccounted = (Estimated outputs - estimated inputs) /(Estimated outputs)

"+" indicates that some components of total could not be estimated

Another estimation method was also applied for the Elliott Bay site. This method used the average values of contaminant concentrations in urban runoff as determined in the National Urban Runoff Program (NURP, USEPA 1983). The results (Table 2.3) are not entirely comparable to those presented in Table 2.2 since some of the input loadings in the latter table come from rural areas along the upper Green, rather than being strictly urban sources. The runoff was estimated using an area of 136 sq.mi. which includes the central business district of Seattle, the lower Duwamish drainage, the Kent Valley, and urban upland areas which drain into those areas, subtracting out the areas served by combined sewers. The annual precipitation at Sea-Tac Airport (which is the same as that at the Urban Climatology Station at the University of Washington) of 38 inches, combined with a 75% runoff coefficient and the area as derived above, gives a runoff quantity of nine million cubic feet a year. This quantity was multiplied by the concentrations reported in the NURP report (and shown in Table 2.3) to give the total mass flux expected, assuming that the Elliott Bay area is similar to other urban areas around the country. An additional average concentration, for cadmium, was obtained from Tetra Tech (1985).

The contaminant concentrations used in the prediction of likely contaminant loading levels were the median concentration measured in the NURP study (i.e., the level which is higher than half of the sites sampled, and lower than the other half). This is a reasonable indicator of the contamination to expect at a site when there is no other indication of runoff chemistry. Also included in Table 2.3 are the concentrations and computed loadings that were found in the 90th percentile of the samples taken in the course of the NURP study. This gives an indication of the highest contaminant loading which would be expected. The NURP study also analyzed for the organic priority pollutants, but only the frequency of detection and range of detected concentrations were reported. The available data were not sufficient to develop representative concentrations of the priority pollutants in urban runoff.

TABLE 2.3

ELLIOTT BAY LOADING BASED ON PREDICTED RUNOFF
AND POLLUTANT CONCENTRATIONS FROM
NATIONAL URBAN RUNOFF PROGRAM (NURP) DATA [a,b]

Parameter	Median Site Concentration (mg/l)	Median Site Loading (Mt/yr)	90th Percentile Site Concentration (mg/l)	90th Percentile Site Loading (Mt/yr)
BOD5	9	2,300	15	3,800
COD	65	16,600	140	35,700
Phosphorus, Total	0.33	84	0.70	180
Phosphorus, Soluble	0.12	31	0.21	54
Total Kjeldahl Nitrogen	1.50	382	3.30	841
NO_3 + NO_2 (as N)	0.68	173	1.75	446
Total Suspended Solids	100	25,500	300	76,500
Cadmium	0.002[c]	0.5		
Copper	0.034	8.7	0.094	24
Lead	0.144	36.7	0.350	89
Zinc	0.160	40.8	0.500	127

Source: a/ USEPA 1983.

b/ Assumptions regarding surface runoff: Drainage area served by separated sewers: 136 mi^2; Estimated overall runoff coefficient: 0.75; Precipitation:.38 in/yr; Resulting Annual Runoff Volume = 9.0×10^9 ft^3

c/ Concentration for Cadmium from Tetra Tech, 1985.

2.3 ACCURACY OF RIVER-BORNE AND RUNOFF NPS LOADING ESTIMATES

2.3.1 River-borne Loading

The methods of estimating river-borne nonpoint source loading, using either instantaneous, average annual, or mean values from national studies require relatively little effort once the data are obtained. The accuracy of each method depends primarily on the quality of the data. The more accurate and frequent the measurements on which the estimate is based, the more reliable the estimate of river-borne loading. However, for several reasons, river-borne loading may not accurately approximate total nonpoint loading to the embayment. First, measurements of river water quality include point as well as nonpoint contributions. Second, nonpoint discharges directly into the embayment are excluded. Third, nonpoint contributions may be made downstream of the monitoring point if the measurements are not taken at the river mouth; if the measurements are made too near the mouth, concentration and flows will be inaccurate due to influences of tides and estuarine conditions. Though river-borne loading may provide an easily-obtained estimate of actual embayment loading, the values obtained must be recognized as approximate and the contributions of point and nonpoint sources will not be distinct.

2.3.2 Runoff Loading

If estimates are based on average values of concentration or runoff obtained from samplings over a larger area than that being studied (such as the NURP data), then there will be inaccuracies due to the variability of the data base and the differences between the actual and the representative sites. In addition, runoff volumes may be in error if they are not based on actual measurements. Furthermore, no provision is made for contaminant removal mechanisms prior to discharge into the embayment. It is obvious that the more specific the runoff flow and concentration data are to the study site, the more accurate this kind of methodology will be for estimating nonpoint source pollution loading.

3.0 ESTIMATION OF NONPOINT SOURCE LOADINGS FROM SOURCE INVENTORIES AND RELEASE RATES (WATER QUALITY ASSESSMENT METHOD)

A somewhat more sophisticated procedure than simply monitoring contaminant concentrations as flows leave the basin is to catalog the land uses of the basin in terms of their potential as nonpoint sources and the capacity of the hydrologic processes to deliver the contaminants to the receiving water body. Results of previous studies in which correlations have been found between contaminant loadings and various measurements of land use, precipitation, or other factors are used to develop equations and tabulated values with which to estimate nonpoint source loading. The EPA had a standardized procedure of this sort developed which has been published as the Water Quality Assessment (WQA) procedure (Mills et al., 1982).

This procedure differs from those of the previous chapter in that measurements of flow and concentration are not required. The method is therefore suitable for embayments where no such measurements have been made or, for lack of a main river system, can be made. In this sense, the WQA procedure is similar to the calculation in the previous chapter which used average concentrations from the NURP study. Although the WQA method is simple to apply, the authors emphasize that whenever possible local data should be used, if available, in lieu of the 'typical' loadings provided in the WQA manual.

The WQA method specifies separate analyses for rural and urban NPS loads and allows for the computation of both annual and single event load releases. The various contaminants which can be modelled using the method include:

- Rural watersheds:

  Sediment
  Nitrogen
  Phosphorous
  Organic Matter
  Salinity (for irrigation runoff)
  Agricultural chemicals

- Urban watersheds:

  Suspended solids (sediment)
  Biological Oxygen Demand (BOD)
  Nitrogen
  Phosphates
  Volatile Solids
  Other contaminants, available for single event calculation

The method is designed for hand calculation; however, it was implemented for this study on a conventional microcomputer spreadsheet. The WQA analyses for rural and urban sources are discussed below in relation to the two prototype embayments.

3.1 RURAL WATERSHEDS: SKAGIT BAY

For non-urban watersheds the WQA method is based on the Universal Soil Loss Equation (USLE), which is designed to predict sheet and rill erosion from croplands. The equation can be expressed as the summation:

$$Y(S)_E = \sum_{i=1}^{n} A_i \, (R \cdot K \cdot LS \cdot C \cdot P \cdot S_d)_i$$

where:

$Y(S)_E$ is the sediment yield for a drainage basin

A_i is the area in subarea "i"

R is a rainfall factor

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K is the soil-erodibility factor

L is the slope-length factor

S is the slope-steepness factor (often combined with "L")

C is the cover factor

P is the erosion control practice factor

S_d is the sediment delivery ratio

(all the factors are estimated for the subarea "i")

In its original form the USLE was based on data from a wide selection of studies, all in areas east of the Rocky Mountains. More recent studies have developed climatic and soil information for Western sites. As the form of the equation implies, data which is required in the WQA method for non-urban areas includes:

Rainfall characteristics
Land use
Cropland, woodland, pasture, etc
Soil characteristics
Canopy or ground cover
Area
Conservation practices
Characteristic slope (gradient and length)
Delivery ratios (based on distance to receiving water body)

The parameters are developed from tables and maps which are given in the WQA manual. It was necessary to confer with individuals who were more familiar with the area and its land use and soils, specifically from:

- o Soil Conservation Service (Spokane, Portland, and Mt. Vernon)
- o WSU Cooperative Extension Service (Anacortes)
- o Skagit County Planning Department (Mt. Vernon)

The USLE simply calculates the amount of sediment which is eroded from an area with the characteristics described by the parameters itemized above. The WQA procedure for non-urban areas also predicts the amount of nitrogen, phosphorus, and organic matter, based on two additional factors: the contaminant concentration in the soil and an enrichment ratio for the contaminant and the site. It would also be possible to use the method to estimate salinity and toxic agricultural chemicals carried in the runoff from an area but salinity is not a significant contaminant under the climatic conditions of the Puget Sound region, and there was not enough information to gage the amount of agricultural chemicals used on the farms of the areas being studied.

The NPS loadings calculated for Skagit Bay using the WQA procedure are presented in Table 3.1.

3.2 URBAN WATERSHEDS: ELLIOTT BAY

The Water Quality Assessment procedure for annual urban nonpoint loadings is based on the Storm Water Management Model (SWMM) Level I preliminary screening process, developed by the EPA in 1976. The basic formula for each constituent is of the form:

TABLE 3.1

NONPOINT SOURCE LOADINGS TO SKAGIT BAY
CALCULATED WITH THE EPA WATER QUALITY ASSESSMENT METHOD

Parameter	Land use	Area (acres)	Rate (lb/ac)	Loading (mt/yr)
Sediment:				
Forest, 10-30% slopes		326,636	12.6	1,867
" 30-60% "		470,498	19.2	4,098
" 60% "		153,632	66	4,600
Field Crops		17,300	206	1,610
Row Crops		53,387	260	6,277
Pasture		39,834	5.4	119
City		24,461	79	882
Total		1,085,748		19,430
Nitrogen			(0.18)[a/]	89
Phosphorus			(0.26)[a/]	127
Organic matter			(2.82)[a/]	1,387

a/ Rates back-calculated from total acreage, loading for nitrogen, phosphorus, and organic matter is based on sediment.

$$M_j = a \; P \sum_{i=1}^{n} \varepsilon_i \cdot (\alpha_{ij}) \cdot f_{2i}(PD_d) \cdot \gamma$$

where: M_j = loading of pollutant "j"

a = a units conversion factor

P = the annual precipitation

ε_i = the area in land use "i"

α_{ij} = a pollutant loading factor for land use "i" and pollutant "j"

f_{2i} = the population density function

PD_d = the population density

γ = the street sweeping frequency factor.

Each of the factors is evaluated separately for each of the following land use types (ie., each "i"):

Residential
Commercial
Industrial
Other developed uses (parks, cemeteries, schools, etc)

The pollutant loading factor also varies according to whether the sewers are separate storm sewers or combined, and depend on the pollutant type. Pollutant loading factors are given for:

Biological Oxygen Demand (BOD_5)
Nitrogen
Phosphates
Suspended solids, and
Volatile solids.

Data for the parameters is presented in the manual in the form of tables or algebraic expressions.

The Duwamish basin was analyzed according to the various census tracts in the basin, a map of which was obtained from the King County Division of Planning along with data giving population, area, and density of each tract. Each tract was categorized according to land use and sewer type. The categories were based on land use (zoning) and sewer maps from the cities in the drainage area. The populations and areas of tracts in each land use/sewer category were summed to allow an overall density (PD_d) to be determined for that land use. The summed area data (ε_i) were incorporated into a computer spreadsheet which was used to solve the above equation and also to evaluate the population density factor (f_{2i}) using equations in the manual.

The information about street sweeping was obtained from the city and county road maintenance divisions. The specified frequency is used with equations given in the manual to calculate the factor γ (this equation is also calculated in the spreadsheet program). The values of α_{ij} which are given in the manual were also incorporated into the spreadsheet program, and the NPS loading results for Elliott Bay , as reported in Table 3.2, were calculated.

3.3 ACCURACY OF WQA METHOD

In order to evaluate the accuracy of loadings calculated with the WQA procedure, the estimates obtained with this method were compared to those obtained using actual flow and concentration data as described in Section 2. A comparison of the results is given in Table 3.3. In general it can be seen that the WQA procedure greatly underestimated the quantity of contaminant flow into the two embayments which were studied. The amount by which the flux is underestimated by the WQA method is on the order of a half to almost two orders of magnitude (a factor of 4 to 93).

TABLE 3.2

NONPOINT SOURCE LOADINGS TO ELLIOTT BAY
CALCULATED WITH THE EPA WATER QUALITY ASSESSMENT METHOD

Parameter/Land use	Area (acres)	Rate (lb/ac)	Loading (mt/yr)
Biological Oxygen Demand (BOD):			
Industrial (cs)[a/]	6,726	190	581
" (ss)[a/]	3,776	46	79
Commercial (cs)	1,171	502	266
" (ss)	7,219	122	398
Residential (cs)	3,930	58	104
" (ss)	67,347	14.2	434
Other (ss)	8,365	0.6	2
Total	98,534		1,860
Nitrogen:			
Industrial (cs)	6,726	43	132
" (ss)	3,776	11	18
Commercial (cs)	1,171	46	25
" (ss)	7,219	11.2	37
Residential (cs)	3,930	9.6	17
" (ss)	67,347	2.3	71
Other (ss)	8,365	0.3	1
Total	98,534		301
Phosphates (as P):			
Industrial (cs)	6,726	3.6	11
" (ss)	3,776	0.87	1.49
Commercial (cs)	1,171	3.9	2.06
" (ss)	7,219	0.94	3.08
Residential (cs)	3,930	0.81	1.43
" (ss)	67,347	0.20	5.95
Other (ss)	8,365	0.016	0.066
Total	98,534		25
Sediment (suspended solids):			
Industrial (cs)	6,726	4560	13,930
" (ss)	3,776	1105	1,900
Commercial (cs)	1,171	3288	1,850
" (ss)	7,219	844	2,760
Residential (cs)	3,930	1194	2,130
" (ss)	67,347	290	8,850
Other (ss)	8,365	15	55
Total	98,534		31,400

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TABLE 3.2 (Continued)

NONPOINT SOURCE LOADINGS TO ELLIOTT BAY
CALCULATED WITH THE EPA WATER QUALITY ASSESSMENT METHOD

Parameter/Land Use	Acreage (acres)	Rate (lb/ac)	Loading (mt/yr)
Volatile Solids:			
Industrial (cs)	6,726	2250.	6,850
" (ss)	3,776	543.	930
Commercial (cs)	1,171	2200.	1,170
" (ss)	7,219	532.	1,740
Residential (cs)	3,930	691.	1,230
" (ss)	67,347	168.	5,130
Other (ss)	8,365	14.	53
Total	98,534		17,100

a/ (cs) = combined sewers
(ss) = separate sewers

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TABLE 3.3

COMPARISON OF ESTIMATES OF NONPOINT SOURCE LOADINGS
USING HISTORIC FLOWS AND CONCENTRATIONS (QxC)
AND
THE EPA WATER QUALITY ASSESSMENT (WQA) METHOD

Parameter	Contaminant Loading (Mt/yr) QxC method	Contaminant Loading (Mt/yr) WQA method	Ratio
	Skagit Bay (Skagit River)		
Nitrogen	5,300	89	60
Phosphorus	520	127	4.1
Organic Carbon	33,000	---	
Organic Matter	---	1,387	
Suspended Solids (Sediment)	1,800,000	19,430	93
	Elliott Bay (Duwamish River)		
$BOD_{(5)}$	2,300 (NURP)	1,860	1.2
Suspended Solids (Sediment)	243,000	31,400	7.7

Source: Tables 2.1, 2.2, 2.3, 3.1, and 3.2.

Two entries in Table 3.3 require explanation. First, since Organic Carbon is a component of Organic Matter (in soil a ratio of about 2 will give an approximate estimate of one from the other) the total organic content is underestimated with the WQA method by about an order of magnitude. Second, the biological oxygen demand estimated for the Duwamish River using median USA data from the NURP study was in good agreement with that calculated using the WQA method. However, the NURP data are not site-specific values, therefore, the calculated value is not a strict measurement of actual BOD.

The reason for the discrepancy in values for all these contaminants lies in the parameters chosen for the WQA model. The estimates could be brought into agreement by adjusting the parameter values used. For the non-urban WQA method (modelling the Skagit basin) the discrepancy would be reduced by a considerable factor if the sediment analysis alone were adjusted. The other contaminants are assumed to be carried by, and thus are proportional to, the sediment mass. Therefore, increasing the sediment flux by a factor of about 25 would bring the other estimates into much better agreement with the measured values.

No effort was made to adjust model parameters to obtain agreement with the loadings calculated from flow and concentration. At present, this adjustment (or calibration) would defeat the purpose of assessing whether the WQA method would provide a quick, simple, and accurate estimate of NPS loadings.

Although preliminary results suggest that the WQA method does not provide a simple solution it is possible the method could be calibrated to Puget Sound embayments. This would be accomplished by applying the equations to a number of embayments for which river-borne contaminants are the primary loading source (and monitoring data are available for the rivers). Particular emphasis should be placed on the sediment transport representation. If similar parameter value adjustments were found to provide satisfactory results for a number of embayments, confidence in WQA model applicability to additional embayments would be enhanced.

4.0 ESTIMATION FROM CONTINUOUS MODELLING OF SOURCES AND DRAINAGE HYDROLOGY

4.1 AVAILABLE MODELS

To estimate the release of contaminants from nonpoint sources in greater detail than on an annual basis and with greater specificity to the study site than is possible with the WQA procedure, it is necessary, to use a computer-based modelling procedure for basin hydrology and runoff quality. There are provisions in the WQA for estimating releases from individual storm events, but this is a minor component. The number of repetitious calculations involved in hydrologic analyses makes this kind of procedure ideal for computerization. Accepted procedures are sufficiently standardized that several programs are available to model any basin without modification of the program itself. The programs are generally well tested, debugged, and supported, and adequate documentation is available. Site specific input data are required and it is necessary to exercise caution in the selection of model parameters and to calibrate and verify for the specific model application.

Some of the more widely used models include:

- Storm water management model (SWMM), available from the EPA,
- Storage, treatment, overflow runoff model (STORM), from the U.S. Army Corps of Engineers,
- Areal nonpoint source watershed environment response simulation (ANSWERS) model, from Purdue University,
- Wisconsin hydrologic transport model (WHTM), from Oak Ridge National Laboratory,
- Hydrocomp simulation program (HSP), from Hydrocomp, Inc.,
- Nonpoint source (NPS) pollutant loading model, from the EPA,
- Agricultural Runoff Management (ARM) model, also from the EPA,
- Hydrological Simulation Program--FORTRAN (HSPF), also from the EPA.

These models vary in their complexity, size, and input data requirements. One (HSPF) even incorporates modules which accomplish the work of two other models (NPS and ARM). A few other models have been found in references but are either too specialized or are not widely used and will not be discussed herein. A brief description of each of the more widely used models follows.

SWMM is an extensive model developed for the EPA in 1971 by Metcalf and Eddy, Inc., the University of Florida, and Water Resources Engineers, Inc., to predict urban sewer runoff. It has been modified considerably in the years since and versions are advertised that will run on microcomputers. The program models the whole rainfall/runoff cycle, concentrating on flows (for design of storm sewer facilities), but including some aspects of water quality. It was originally a single storm event model but has had limited continuous modelling capability added.

STORM is a 1976 product of the U.S. Army Corps of Engineers' Hydrologic Engineering Center (HEC). It was designed to model both urban and rural runoff and erosion for single events. Various contaminants, besides sediment, are included in the model.

ANSWERS was originally produced by the Agricultural Engineering Department at Purdue University in 1980. It is a single event model and, though the name implies nonpoint source pollution in general, it mainly concerns itself with soil erosion and so the model is more applicable to rural than urban areas. There may also be limitations in the size of the basin being modelled.

WHTM was produced originally at the University of Wisconsin but was rewritten, documented, and expanded at Oak Ridge National Laboratory in 1974, making it more easily available for other computer systems in the process. It was designed to model the transport of toxic materials through the hydrologic process and may even be coupled with an air quality model which calculates the deposition aspects. It is general for both pervious (rural) and impervious (urban) runoff and even some consideration of subsurface flows.

HSP is a very extensive, continuous simulation, basin model first available in 1976 from Hydrocomp, Inc. and a direct descendent (as are many of the other models) from the Stanford Watershed Model (SWM) of the mid 1960's. A number of water quality parameters are available for inclusion in the model, appropriate to any land use. It had the problem of being written in the IBM computer language PL/I and so was less easily installed in other computer systems.

NPS and ARM are small watershed models (no channel transport is modelled) produced by Hydrocomp, Inc., for the EPA in 1976 and 1973 respectively, but with later enhancements. They were designed for similar general runoff situations, although ARM concentrates on agricultural aspects such as nutrients, sediment, and pesticides while NPS models general nonpoint pollution for a variety of contaminants.

HSPF is a rewriting of the HSP model in a more transportable form, accomplished by Hydrocomp, Inc., in 1980. It can be used to model both impervious and pervious runoff (incorporating the methods of NPS and ARM for these processes). Because of its generality it is appropriate to model any of the basins in the Puget Sound region and its input requirements and implementation procedures will be discussed in the following sections.

4.2 MODELING METHODOLOGY

The discussion in this section is based primarily on the general watershed model HSPF. This model is recommended for any further work on the question of Puget Sound nonpoint source delineation and quantification. An advantage of using HSPF instead of less complete models is that if further in-depth study of some pollutant and its transport or degradation is desired, the existing model can be enhanced rather than setting up a whole new model. HSPF is a comprehensive model that should reward the extensive data collection effort with considerable information about both acute and chronic contaminant fluxes of any pollutant of interest from any study site basin.

It is likely that only segments of the HSPF model would be required for simulation of most Puget Sound embayments. Model segments that could initially be simplified include channel effects. To include these would require definition of channel properties (length, cross-sectional area, roughness, slope), and data for whatever physical, chemical, or biological transformations are considered important, such as reaeration, volatilization, oxidation, nitrification, and hydrolysis. With consideration of channel effects, the hydraulics (flow in the channels) must be calibrated, using flow and contaminant data for individual storms. Another simplification that could be made is consideration of snow impacts. However, these considerations may be necessary for basins with significant flows and contaminant loadings coming from snow deposits at higher elevations and would require more meteorological data.

The documentation concerning HSPF (Donigian et al., 1984) describes the following steps involved in a complete model application:

1) Study definition,
2) Development of a modelling strategy,
3) Learning the operational aspects of HSPF use,
4) Input and management of time series data,
5) Parameter development,
6) Calibration and verification, and
7) Analysis of alternate scenarios.

In general, similar steps are required for application of any of the models described above. The first step (study definition) requires identification of the need for the study and the appropriate scale (level of detail) on which it should be addressed, investigation of available data, and evaluation of time and money resources for the study. The second step (modelling strategy) should consider the characterization of the area in climate, soils, topography, land use, pollutant sources, and historical data and should plan the investigation and overall form of the model. The third step (learning HSPF) requires time with the model for familiarization; this can be done with various sample problems which are supplied with the model. All these steps can be considered preparation for the work of modelling a particular basin, and will probably become less significant for later simulations if the effort is a continuing one.

The fourth (input time series) and fifth (parameter development) refer to data collection; the former involves climatological data (precipitation) the latter concerns soils, stream channels, topography, and land use. These steps are likely to be the most time consuming.

The sixth step (calibration and verification) is very important. It involves comparing model predictions against field observations and modifying the parameters in order to bring the model into better agreement with reality. Verification comes after calibration and is the final testing. Verification involves use of a data set independent of that used for model calibration to see whether the model will be accurate for future simulations.

The final step (analysis) is the actual use of the model. This requires both understanding of likely and useful alternatives (including continuing with the basin unchanged), applying the model to predict the results of the alternatives, and interpreting the model outputs to explain the benefits of the alternatives.

4.3 DATA REQUIREMENTS AND AVAILABILITY

The HSPF model requires a great deal of input data to specify the properties of the drainage basin, its hydrology, soils, land use, and channels, the contaminants of interest, their chemistry, and distribution around the basin, and the precipitation which drives the whole system. The HSPF Application Guide (Donigian et al., 1984) points out that there are over 1000 parameters in the entire HSPF system. However, only a small fraction of these parameters are used for most applications. The actual amount of data required depends on which options are of importance to the purpose of the project. For modelling nonpoint source pollutant loadings to an embayment of Puget Sound, required parameters would minimally include:

- o Precipitation,
- o Potential Evapotranspiration,
- o Land use,
- o Soil properties,
- o Contaminant loadings from land uses,
- o Chemical properties of contaminants,
- o Historical measurements of streamflows, chemical concentrations, and sediment loads,

These data requirements are summarized below.

4.3.1 Precipitation

Precipitation data is necessary on a daily basis (if not more often) from a minimum of three stations for the period to be modelled. The specification of three stations is based on the HSPF Application Guide (Donigian et al., 1984) recommendations for any moderately large (40 sq. mi.) basin. In the Puget Sound area, however, the precipitation varies considerably over short distances, such as the normal annual totals of 39 inches in Seattle and 93 inches at Snoqualmie Pass. It may be necessary to use more than 3 stations for a model (perhaps 7 or more for larger basins), but this should be easy to do since there are more than 60 weather stations in the Puget Sound region (NOAA, 1985). This data can be obtained in computer-readable form from the National Weather Service (NWS). Additional information on general climatic conditions is available from the State Extension Service and could be used to divide a watershed into subregions on isohyetal lines.

4.3.2 Potential Evapotranspiration

Potential evapotranspiration (PET) refers to the maximal amount of moisture which evaporates or is transpired by plants on a given day according to climatological factors; actual evapotranspiration depends on the availability of moisture in the soil. This data will be somewhat more difficult to obtain. There are relationships established for calculating PET from pan evaporation, however there are only two Puget Sound area NWS stations which measure pan evaporation (Bellingham 2 N and Puyallup 2 W Experimental Station). It should also be possible to derive estimates for PET from temperature data which is available for many of the NWS stations.

4.3.3 Land Use

Land use information appears to be somewhat problematic to obtain. Some counties do have data, if not what the land use is then at least what it is planned to be at some future date. When available, this data can generally be obtained from the County Planning Departments. Some information, especially about acreages in the various crops and the management practices used, may also be available from the County Extension Service offices or the Soil Conservation Service or, for land use in incorporated areas, City Planning Departments. Upland areas of the Puget Sound region are in National Forest land and information about these areas should be available from the National Forest Service. In some cases it may be necessary to obtain aerial or satellite photography and interpret it to provide a data base. Compilation of required data may require a considerable effort, even if some information is available in a map display format since it must be converted into numerical values of total areas in each land use type.

4.3.4 Soil Properties

Soil properties are readily available for most counties in the Puget Sound region in the form of Soil Surveys compiled by the Soil Conservation Service. Some of these are rather old (eg., the most current one for Thurston County dates back to 1958) and may not have all required information such as erosion parameters which have been developed since their publication. New Surveys are being compiled for some of these areas and may be released fairly soon. The National Forest Service has apparently also produced soil surveys for their lands which would be valuable for some of the upland areas of Puget Sound drainage basins. Some values of soil properties can also be estimated with information presented in the manuals for HSPF application. Again, as with land use, compilation of the data into tabular numerical form will be the most time-consuming part of data collection. This task will be particularly complex because the soil data and land use must be combined, and their diversity reduced to a limited number of categories appropriate to modelling.

4.3.5 Contaminant Loadings from Land Uses

Contaminant loadings due to different land uses will have to be generated from a variety of sources. For nutrients, fertilizer application rates and dates, plant uptake and scheduling of planting and harvesting, herd sizes and productivities, and various management practices will have to be obtained from Extension Service or Soil Conservation offices, and interpreted according to data from previous studies and information in manuals applicable to HSPF. In urban areas, nutrient loadings from point sources (sewage treatment plant outfalls and combined sewer outfalls, CSO's) will have to be obtained from permit data or monitoring agencies. Pesticides will be have to be estimated in a similar way in rural areas. Heavy metals and organics loadings to street surfaces will have to be estimated from studies of urban runoff, and frequency of street-sweeping will be obtained from city and county public works departments.

4.3.6 Chemical Properties of Contaminants

Chemical properties for the various contaminants can be obtained from the chemical literature and the HSPF manuals. Examples include partition coefficients (measurements of how strongly a chemical adheres to the soil) and decay rates. In some previous studies it has been found that laboratory values of some coefficients do not agree with the values under field conditions. When this occurs, the values will have to be adjusted by calibration procedures.

4.3.7 Historical Measurements of Material Discharges

Historical measurements of streamflows, contaminant concentrations, and sediment transport are extremely important for the use of HSPF, since they allow the calibration of the model. This process involves adjusting parameters in the input data to make the output approximate reality more closely. Step-by-step procedures to make the operation simpler are given in the HSPF manuals. Given the minimal nature of the modelling which is assumed at this point, monthly or annual mean values of the measurements will probably be sufficient, even though daily model timesteps are used because channel transport processes are not included in this modelling effort.

4.4 APPLICATION OF NONPOINT SOURCE MODELLING

A decision to carry out detailed modelling of one or more drainage basins contributing nonpoint source (NPS) pollution into an embayment of Puget Sound will have to be based on a number of considerations, including:

- Whether NPS pollution appears to be significant in relation to other point source loadings.
- Whether the contaminants emitted by NPS appear to be damaging to the Puget Sound ecosystem at the loadings anticipated.
- Whether detailed modelling would clarify the sources, total loadings, or other factors which would distinguish NPS from other pollution sources.
- What would modelling at the appropriate detail cost, in time and money.
- What further use would the model have beyond the initial application.

The relative significance of NPS pollution can be estimated using flow and concentration data or the WQA method and comparing the fluxes to known contaminant loadings from point sources which can be calculated from NPDES monitoring report data. Even if NPS pollution is significant relative to point sources, the question still remains whether it is actually damaging. To some extent this can be answered by considering the chemicals which are emitted by the nonpoint sources and their toxicology.

The chemical characteristics of the runoff of an area may be judged on the basis of measurements taken in rivers draining into the embayments or known chemicals associated with the land uses of the area. The diffuse nature of the NPS phenomenon makes it difficult to identify all chemicals present especially when they may be released at trace levels, however, an obvious case where nonpoint pollution would be indicated to be a problem is where there are few known point sources and yet signs of distress in the biota of the embayment are evident.

It is obvious that a detailed modelling effort would provide greater insight into the sources of NPS pollution. If done properly, modelling could point out geographic areas of greater and lesser emissions. Where preliminary screening has identified significant sources of NPS pollution that are contributing to environmental degradation, detailed modelling may be warranted to evaluate control alternatives. Detailed nonpoint source modelling would also be recommended for evaluation of different land use alternatives in regions where NPS pollution is known to be significant or proposed actions are likely to enhance/alter NPS pollution.

4.5 MODEL LIMITATIONS

The main limitations of the HSPF model, and any study predicated on it, are caused by the limitations of available data. This emphasizes the importance of the proper and complete research which must be done to get suitable parameters for the model. Calibration of the model to monitoring data which are accurate and appropriate to the assumptions used is similarly very important. For some embayments the data may be readily available, for others it may exist but be very difficult to find, while for many there is likely to be a scarcity of the kind of information required for adequate modelling. Some of this information can be obtained by field studies or remote sensing, some (such as historical contaminant concentrations) will never be available if it has not been collected. There may be a few Puget Sound areas where a considerable amount of the required data have already been gathered for a previous study; examples include the study of the Snohomish River system which was carried out by the Snohomish Country Planning Department and Systems Control, Inc. (1974) which appears to have accurate hydraulics data which would be very expensive to obtain again, or a study, using the HSPF precessor HSP, which modelled the Lower, Middle, and Upper Green River and is mentioned in Donigian and Crawford (1976). It should be noted that, even if such data are found, careful checking is necessary before it is incorporated into a new model.

4.6 ESTIMATES OF EFFORT AND COST REQUIRED FOR MODELLING

Costs associated with a detailed hydrologic modelling of Elliott and Skagit bays would range between $60,000-$100,000 depending upon the quality of input data obtained and whether channel hydraulic processes were to be modeled. These estimates are based in part on previous studies carried out with HSPF discussed in Donigian et al. (1984) and on the preliminary data collection carried out for the simpler modelling exercises discussed in this report.

For the lowest estimate ($60,000) a number of assumptions have been made; these assumptions are itemized briefly below:

- o the two prototype embayments previously discussed, Skagit and Elliott Bays, would be used
- o the preliminary estimates of data availability and adequacy are accurate for initial modelling

- the contaminants to be studied are limited to those whose levels have been monitored historically in order that calibration would be possible
- no in-stream hydraulics or transformations need be considered
- four best management practices (BMPs) would be developed and their effects on the NPS loading rates evaluated
- steps in the model development are those discussed in section 4.2 of this report

With these assumptions, it is estimated that such HSPF modelling of the Skagit and Elliott Bay embayments would require approximately 6-8 months.

The higher cost estimate is based upon extension of scope to include channel hydraulics and processes, and refined NPS loadings for critical acute conditions and upon a more extensive data collection effort. The more extensive data collection effort would include aquisition and interpretation of aerial photographs or satellite photographs to obtain more comprehensive land use data. Costs to apply the HSPF model to other embayments would depend on the size and complexity of the drainage area and the availability of data. If field collection of data were required, costs could be substantially higher than the estimates presented above.

5.0 RECOMMENDATIONS

Three procedures, of varying complexity have been described to evaluate nonpoint source pollution loadings to Puget Sound. The simplest method is based on measured flows and concentrations to estimate what loadings have historically entered an embayment via a river. The second method is the Water Quality Assessment Method developed by the EPA. The third method is simulation of a watershed using computer-based models; the EPA model HSPF was highlighted as a suitable candidate program.

The simplest method can be applied only if there are several years of good data available; it cannot be used if a river is not the main conduit of runoff to the embayment. This method does give a relatively accurate assessment of contaminant loadings, however, the contributions of upstream point and nonpoint source loadings cannot be delineated. Where there are few known upstream point sources and direct runoff is known to be minimal, this would be the preferred method for estimating nonpoint source contaminant loading.

The WQA procedure as applied here appeared to greatly underestimate the contaminant loadings. The explanation for this discrepancy appears to be that the Water Quality Assessment (WQA) method requires adjustments of its parameters to account for local conditions which are different from conditions elsewhere in the country where the method was developed. Use of historic flow and concentration measurements to calibrate the WQA procedure could result in an inexpensive method that would be applicable to Puget Sound conditions. However, limitations of available water quality data appears to make this approach somewhat doubtful in its potential benefits.

Further work, the objective of which is accurate quantitative NPS loading estimates should be based on an established methodology such as the HSPF model. The HSPF model should be able to give an accurate prediction of contaminant loadings to any embayment of Puget Sound, however, it has been the experience in other parts of the country where the method has been attempted, that model predictions can vary widely from known values even after an extensive data collection effort. Prior to implementation of a detailed modelling study, the simple screening methods discussed in this report and evaluation of available environmental data should be employed to assess the probable benefits of a more detailed NPS analysis.

Other steps which should be undertaken as part of future work in the effort to quantify nonpoint source pollutant loading must include continued support of data collection programs. The National Weather Service program to gather precipitation and temperature data, appears to be adequate at the present time (however, the variation of precipitation across the Puget Sound lowland is great enough that more data is always welcome); the U.S. Geological Survey flow monitoring system is also very good although there are many small streams and segments of major streams which do not have the density of gaging stations to determine the hydrology adequately for short-time (single event) modelling purposes.

Water quality data appears to be the greatest shortcoming which may impede future modelling and estimation efforts. For many of the rivers draining to Puget Sound, the number of stations and chemical constituents monitored are insufficient for detailed investigation of runoff water quality.

Finally, further studies to investigate runoff quality and transport mechanisms at the point of origin should be supported. The Soil Conservation Service is putting some effort in this direction, but their mandate is more to developing best management practices (BMPs) rather that to develop data indicative of the magnitude of the problem. Individual cities (particularly METRO in the Seattle area) have conducted studies of urban runoff, but few programs of a general nature appear to have been conducted in this respect. The NURP data are available as a first approximation of loading from urban runoff if land use data evaluations are available to develop estimates of runoff volume. Similar efforts to characterize agricultural and logging runoff volumes and chemistry should also be implemented.

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