Characterizing Stormwater for Total Maximum Daily Load Studies

A Review of Current Approaches

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A Review of Current Approaches

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Abstract

The Washington State Department of Ecology soon will be issuing Phase II stormwater permits for many municipalities in the state. This will require establishing wasteload allocations for stormwater discharges in Total Maximum Daily Load (TMDL) studies for waterbodies in Washington State on the federal Clean Water Act 303(d) list. TMDL wasteload allocations will be specified as permit conditions in the stormwater permit when issued.

This document provides an overview of applicable methods, models, and approaches to stormwater sampling and evaluation. Included are details about sources, sampling strategies, data needs, and results from various models used to characterize stormwater.

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Summary

The purpose of this document is to summarize peer-reviewed, stormwater water quality studies. Applicable models and critical input data are briefly examined to aid in study design planning. Approaches to the study design – such as sampling sediment versus sampling water, or correlations to predictor variables that can be monitored on a wide scale – are described. In addition, case studies of the techniques are presented.

This report has two main sections. The first part presents methods and models used in the stormwater assessment. The second part a discussion of the study design decisions each project manager will likely consider.

The appendices present a compilation of resources. Appendix A is a literature review of stormwater pollutant sources. Appendix B provides references for stormwater sampling designs. Appendix C summarizes Ecology's stormwater case studies. Appendix D provides tables of stormwater pollutant concentrations found nationwide. Appendix E is a short list of TMDL studies with stormwater loads conducted by other states.

Policy Background

TMDL Requirements

As mandated by the federal 1972 Clean Water Act, Section 303(d), the Washington State Department of Ecology (Ecology) maintains a list of waterbodies that do not meet water quality standards. A water cleanup plan, also known as a Total Maximum Daily Load (TMDL), must be developed for each of the waterbodies on the Section 303(d) list. The TMDL identifies how much pollution needs to be reduced or eliminated to achieve clean water. The most recent 303(d) list was issued for 2002/2004.

The November 22, 2002 U.S. Environmental Protection Agency (EPA) Policy Memorandum on Wasteload Allocations for Stormwater indicates that stormwater discharges from National Pollutant Discharge Elimination System (NPDES) permitted entities must be assigned a wasteload allocation for inclusion in the TMDLs.

- NPDES-regulated stormwater discharges *must* be addressed as wasteload allocations (WLAs), not as load allocations (LAs).
- Stormwater discharges from sources not currently under permit *may* be addressed as LAs.
- NPDES-regulated stormwater discharges with multiple outfall points *may* be given a single categorical WLA when data are insufficient to assign individual WLAs.
- Stormwater WLAs and LAs are to be expressed in numeric form, although "fairly rudimentary" estimates are expected when data are limited.
- Stormwater WLAs must be consistent with WLAs for other permits in the TMDL.
- EPA recommends that water-quality-based effluent limits for stormwater WLAs be in the form of best management practices (BMPs) rather than numeric limits.
- When BMPs are expected to be adequate to meet the WLA, the permit record or fact sheet must include the rationale behind the determination.
- Specific compliance monitoring or performance measures for load reductions must be included in the permit.

TMDL Policy

In 1987, Congress changed the federal Clean Water Act by declaring the discharge of stormwater from certain industries and municipalities to be a point (discrete) source of pollution requiring NPDES permits or water quality discharge permits. EPA delegated Ecology to implement the water quality permits.

The EPA stormwater regulations establish two phases for the stormwater permit program:

- Phase I stormwater NPDES permits have been issued to cover stormwater discharges from certain industries, construction sites involving five or more acres, and municipalities with a population of more than 100,000.
- The Phase II regulations expand the requirement for stormwater permits to all municipalities located in urbanized areas, or cities outside of urbanized areas that are more than 10,000 in population. On October 29, 1999, the final Phase II stormwater regulations were signed into rule by EPA.

Current NPDES permits in Washington State include Phase I, and in the near future will include Phase II. Phase I coverage includes the cities of Seattle and Tacoma; Pierce, King, Snohomish, and Clark Counties; and the Washington State Department of Transportation (WSDOT) in these areas. Phase II communities are identified under the rule as jurisdictions that (1) own and operate a storm drain system, (2) discharge to surface waters, (3) are located in urbanized areas, and (4) have a population greater than 1,000.

Under the Phase II rule, up to 115 additional municipalities in Washington may need municipal stormwater permits, not including "bubble" cities. If a city becomes regulated under the NPDES program, then other publicly-owned storm sewer systems within the city limits are also subject to the permit (e.g., universities, school districts, ports, diking and drainage districts, flood districts, hospitals, prisons). Phase II coverage maps can be found at www.ecy.wa.gov/programs/wq/stormwater/municipal/index.html.

Stormwater discharges from industries, dairies, and construction sites are regulated under separate general permits that were issued by Ecology.

- Industrial stormwater permits cover discharges from manufacturing, warehousing, processing, transportation, and recycling. Industrial permits cover refineries, pulp and paper mills, and aluminum mills.
- Separate general permits cover fruit packers, boatyards, confined animal facility operations, sand and gravel, Washington State Department of Transportation, and state parks.
- The first-phase construction stormwater general permit covers discharges at the scale of five acres and up. The second-phase construction permits, to cover one to five acres, are still under review.

Study Purpose

This report provides a review of pertinent stormwater knowledge, monitoring concepts, methods, models, and case studies for the benefit of Ecology employees. Numerous methods, technologies, and models are reviewed to (1) update stormwater study techniques, (2) minimize resources needed to characterize stormwater, (3) ensure credible analysis, and (4) meet Ecology's TMDL compliance schedule.

Preference has been given to models and methodologies for detecting toxic pollutants and fecal coliform bacteria.

The intended audience for this report is primarily TMDL project managers; however, the study design ideas could be used in broader applications to evaluate contaminant loads. Currently, a standardized technical approach for conducting stormwater analysis for TMDLs has not been developed.

Information is provided in the following areas:

1. Review approaches taken to evaluate toxic and fecal coliform pollutants in stormwater
2. Evaluate applicable models
3. Identify critical input data to incorporate into the stormwater sampling plan
4. Develop factors to relate land use to stormwater pollutant loading for toxics and, to a lesser extent, fecal coliform bacteria

Report Structure

This document is not written to provide a study design for every stormwater sampling effort. Rather this review of design approaches is intended to serve as a source of recommended options for the stormwater component in a TMDL study. The focus is on strategies and techniques for monitoring the water column and sediments within hydrologic drainage areas or stormwater conveyance systems.

The first part of this report describes different approaches used to study stormwater. The second part provides details for planning a stormwater study.

The appendices present a compilation of resources. Appendix A is a literature review of stormwater pollutant sources. Appendix B provides references for stormwater sampling designs. Appendix C summarizes Ecology's stormwater case studies. Appendix D provides tables of stormwater pollutant concentrations found nationwide. Appendix E is a short list TMDL studies with stormwater loads conducted by other states.

Stormwater Assessment

Every stormwater study will be unique due to differing research goals, financial limitations, watershed climate and physical characteristics, jurisdictional boundaries, and temporal and spatial scales. Initiating studies and monitoring storm events is resource intensive, requiring coordination between levels of government and also private sectors.

Many approaches to monitoring stormwater pollutants have been taken to satisfy individual project goals and constraints. In a TMDL study, it is difficult to accurately characterize stormwater pollutant concentrations across a large spatial scale when on a limited budget. A large number of samples would be necessary to approximate the statistical population mean because of the complex nature and variability of pollutant concentrations in stormwater. However, sampling every outfall is not a realistic option. The scale of a drainage network and number of outfalls to be monitored becomes a critical design element that often is restricted by the budget. Laboratory sample analysis alone is one of the most expensive elements in a toxics study. For example, for a TMDL study on zinc that includes municipal stormwater hydraulic modeling, wasteload and load allocations would likely be greater in scope, budget, and complexity than a zinc TMDL study based on land use without municipalities in the watershed.

Common difficulties in studying stormwater pollution include the following:

- Limited resources, personnel, or equipment
- Selecting acceptable sites
- Mapping and sampling limitations on the physical conveyance systems
- Timing and logistics of catching stormwater samples
- Gathering representative samples of highly variable discharges
- Gathering existing data from multiple jurisdictional authorities
- Modeling the highly variable concentrations and discharge rates
- Statistical analysis, particularly with missed samples and non-detects

The scale of the impaired waters, number of drains, and degree of development will help determine the method of assessment. More information and data are needed for stormwater characterization when the size of the system increases, which will often lead to more complex models to help assess the stormwater loading. Methods for sampling vary from simply taking grab samples from outfalls to flow- or time-weighted automatic samplers stationed on stormwater conveyance systems. Methods for modeling also range from simple computations to determine the load from an outfall to complex multivariate models and software to help estimate the pollutant load from the watershed.

Ecology's TMDL studies strive to maintain high quality data for future comparisons to data from biological, water, and sediment sampling. Collected data must be representative of actual conditions and comparable to historical efforts. Representativeness and comparability include elements such as seasonality and overall time-span of the study (Onwumere and Batts, 2004).

Ecology has performed several TMDL studies wherein stormwater was considered to be a contributing load. Examples are provided in detail in Appendix B.

The goal of this report is to provide examples of several systematic approaches, models, and information to be collected when designing a study to estimate stormwater loads of toxics and fecal coliform contaminants.

This document is intended for use as shown in Figure 1.

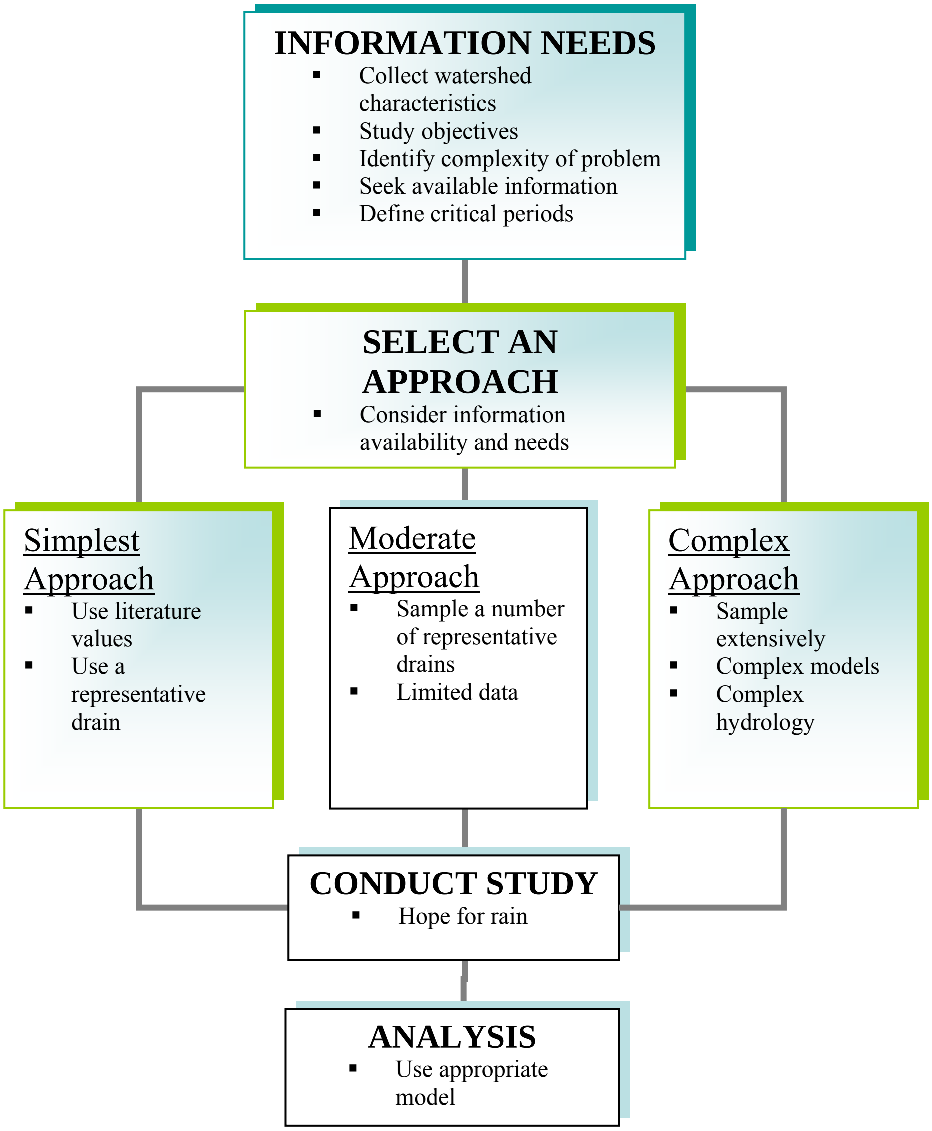


Figure 1: Decision Tree for Stormwater Characterization

Approaches to Stormwater Assessment

Among the myriad of papers on stormwater studies, there are some common approaches used to design studies, characterize stormwater constituents, and estimate pollutant concentrations. These approaches are presented from easiest and least expensive to more complex and expensive. In each of the approaches listed below, there is the option to use literature values or measured contaminant values.

Simple and Empirical Models

- Land Use Characterization
- Impervious Area Characterization
- Simple Method
- Rollback Method
- Regression Equations

Increasingly Complex Models

- Integrative
- Continuous Simulation

In a comparison between simple and complex models, Chandler (1994) found that, with four case studies, there was little reason to choose a complex model when estimating annual nonpoint (diffuse) source loads for urban areas because almost three-fourths of the data loading comparisons were within a factor of 2 or less. However, larger amounts of data tend to require more complex models to process and understand. Complex models are often used for TMDLs, load allocations, and studies of urban pollutants vs. erosion or natural background sources.

It appears that approaches to quantify stormwater pollutant loads can generally be grouped into empirical associations or models with increasingly complex systems. Table 1 from Ohrel (2000) gives insight on the importance of scale when choosing a method or model for stormwater monitoring.

Table 1: Utility of Stormwater Study Scale (from Ohrel, 2000).

When To Use	When Not To Use
Simple	
Small urban watersheds (< 640 acres)	Baseflow runoff/pollutant loads are desired
Only stormwater runoff and pollutant load estimates are desired	Large watersheds (>640 acres)
Need for quick and reasonable load estimates	Non-urban land uses (e.g., construction sites, industrial areas, rural development, agricultural uses), as reliable “C” values, are unavailable
Only percent impervious and runoff pollutant concentrations are available	Ambiguity about watershed’s percent imperviousness
Only planning level estimates are needed	
Complex	
Large and complex watersheds	Limited by time
Want a time history of runoff flow rate and pollutant concentration	Limited by funds
Want defining channel segments, bridges, culverts, etc., subject to erosion	High accuracy needed for dissolved pollutant parameters
Want determining maximum water elevations (for identifying floodplains)	Uncertain whether complex model can provide more accurate information than simple model
Want to provide hourly or daily load inputs to lake, river, or estuary water quality model	

Land Use Categorization

General Description

Land use characteristics can greatly influence the concentrations of pollutants carried by stormwater. Many studies have investigated the variability within a land use category based on a range of pollutant concentrations and degrees of imperviousness. A careful review of the land use and drainage systems in the study area will yield several locations that appear to represent the primary land uses. Two approaches are generally taken at this point. The first is to sample single land uses by catching stormwater runoff from relatively small homogenous catchments and then extrapolate the data to other similar land uses within the study area. The second approach is to locate the stormwater station to capture relatively large catchments of mixed land uses. The composition of the land uses should be similar to the project area as a whole.

Land use classifications are used to explain what types of pollutants are expected from the land. For example, residential runoff will be presumed to carry pollutants from landscaping, animals, septic systems, trash, and automobiles.

Land use is sometimes used to describe land cover such as paved vs. forested, and this may be confusing. The next section *Impervious Area Categorization* describes land cover in terms of water infiltration and pollutant export potential.

Applicability

Useful at the watershed, subwatershed, and catchment scale.

Data Needs

Language and definition of terms are critical to comparing studies and results. Table 1 defines terms as applied to the scale of study, and Table 2 defines terms as applied to land use.

Table 2: Common Terms Used for Different Sized Parcels and Management Areas

Watershed Management Unit	Typical Area (mi^2)	Influence of Impervious Cover	Sample Implementation Measures
Catchment	0.05 to 0.50	Very strong	Best management practices and site design
Sub-watershed	1 to 10	Strong	Stream classification, best management practices, and site design
Watershed	10 to 100	Moderate	Watershed-based zoning and Environmental restoration
Sub-basin	100 to 1,000	Weak	Basin planning: Land use zoning and ordinances
Basin	1,000 to 10,000	Very weak	Basin planning: Land use zoning and ordinances

Adapted from www.stormwatercenter.net/Slideshows/rapid_files/frame.htm October 2006.

This land use method requires areas of the stormwater catchment, which in turn may require knowledge of the stormwater conveyance systems, topology, land use, jurisdictional boundaries, watercourses, and aerial photos. Pollutant concentrations from a given land use category are also variable within a certain predictable range. Table 3 presents commonly used descriptions of land use designations.

These definitions provide definitions and examples, and are based in part on the definitions from the Growth Management Act (RCW, 1990) and Growth Management Hearings Board (GMHB) rulings (WAC, 2006). Clarification for a particular project may be left to the judgment of local ordinances, particularly between light industrial and commercial, or during ground-truthing field visits.

The goal of land use assessment is to determine a land use category, acreage, and range of concentration values for each category. Knowing the land uses in a watershed will help determine where to locate study sites, aid in hydraulic modeling, and likely be a critical component of a study design.

Heavy metals, polychlorinated bi-phenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs) are more commonly found in urban settings, particularly associated with traffic, parking lots, industrial areas, and commercial areas. For example, a paved parking lot is far more likely to produce stormwater carrying petroleum products and heavy metals than an agricultural field which would likely produce stormwater with sediment and pesticides. Fecal coliform bacteria are often found in the highest concentrations from residential and agricultural land uses, followed by commercial and mixed-use areas.

Table 3: Typical Land Use Categories

Category	Description
Commercial	Predominantly commercial businesses such as the downtown area. Examples would include stores, offices, hotels, restaurants, hospitals, and universities. These areas tend to have high turnover traffic, parking lots, and buildings.
Industrial	Predominantly industrial businesses and activities. Examples include ports, lumber and steel yards, mills, manufacturing, and warehouses.
Light Industrial	Local ordinances may have a zoning called light industrial. This category may be a slight mixture of commercial and industrial. It is typically a structure with one use, little office space, and relatively few workers. Example uses might include, but is not limited to, storage units, printing, electronic equipment assembly, or kennels.
Rural Residential	The minimum density by the GMHB is 1 dwelling unit (du) per 5 acres. There may be less dense areas (1du/10acre or 1du/20acre) that are surrounded by forest or pastures.
Low Density Residential	Single-family homes at densities ranging from 1 to 4 dwellings per acre are the predominant land use. Typically open space, water, or forest surrounds the spaces in-between.
Medium Density Residential	Housing densities range from 4 to 10 dwellings per acre. Dwellings consist of single-family, duplexes, and mobile homes. Sometimes a multi-housing unit with a large area around it free from pavement could be considered medium density. Other examples would include convalescent care, community centers, child care, bed-and-breakfasts, places of worship.
High Density Residential	Housing at densities of 10 to 20 dwelling units per acre, including multi-family units (four-plex and higher). Can also include mobile home parks, senior housing, offices, live-work houses, and dormitories.
Open Space	Areas of land free from pavement and buildings. May or may not contain trees, sidewalks, small roads, and small parking lots. Examples include grasslands, city and county parks (not developed), and vacant lots.
Forest	Wooded lands. The hydrologic response of a conifer forest differs from a deciduous or mixed forest. Land use zoning generally refers to a conifer forest for timber production.
Agriculture	Lands used to raise crops or livestock.
Roadway	Typically roadways with two or more lanes in each direction. It is assumed that the other categories account for the occurrence of two-lane or one-lane roads.
Mixed	An area that combines one or more of the other categories listed above in somewhat similar proportions such that separating the areas would be difficult. An example is an area of town that is well mixed with medium density residential, commercial, and potentially agriculture or small industrial at the same time.

The best way to obtain land use information is to ask the city or county engineers and planners for drawings or GIS layers of the stormwater conveyance system, subwatersheds, land use, jurisdictional boundaries, watercourses, and aerial photos. It is critical to visit the area and get assistance from those knowledgeable about the local stormwater conveyance systems. The construction materials and location of these systems are highly variable, partly a result of the period when the systems were laid. Land use (i.e., residences, commercial, industrial, agriculture, forests, and water) can be estimated from aerial photographs, ground-truthing trips, AutoCAD files, or Ecology's Landsat photos.

Pros/Cons of the Method

Pros: Use to locate stormwater sampling locations at likely hotspot areas. Compare "like" catchments to each other by land use.

Cons: GIS style maps of stormwater conveyance system, subwatersheds, land use, jurisdictional boundaries, watercourses, and aerial photos may be old or non-existent. But these data are part of the Phase II requirements, and availability is improving.

Examples of Land Use Classifications

1. Ecology presented an article (Yake et al., 2000) on the concentration of dioxins in soils across Washington State by land use. The purpose of the study was to assess the typical (or background) concentrations of dioxins in TEQ equivalents, the sum of the detected polychlorinated dioxins and furans (PCDD/PCDFs). Of 84 soil samples, dioxins were detected in every sample.

   The following land use patterns were observed (Table 4); however, the significance of these relationships was not assessed.

   Table 4: Summary of Dioxin Concentrations in Washington State Soils by Land Use (reported as TEQ, ng/kg = pptr)

Land Use	Range	Mean	Median	Geometric Mean	Number of Samples
Urban	0.13 – 19	4.1	1.7	1.9	14
Forest	0.03 – 5.2	2.3	2.2	1.2	8
Open	0.04 – 4.6	1.0	0.27	0.24	8
Agricultural	0.008 – 1.2	0.14	0.05	0.062	54

   TEQ =2,3,7,8-TCDD toxicity equivalent

2. The *Stormwater Management Manual for Eastern Washington* (Ecology, 2004) outlines a few of the source relationships between toxic pollutants and land use:
    - Runoff from roads and highways is contaminated with pollutants from vehicles. Typical pollutants in road runoff include oil and grease, PAHs, lead, zinc, copper, cadmium, sediments (soil particles), and road salts and other anti-icers.
    - Runoff from industrial areas typically contains even more types of heavy metals and sediments, as well as a broad range of manmade organic pollutants including phthalates, PAHs, and other petroleum hydrocarbons.
    - Runoff from commercial areas contains concentrated road-based pollutants and may also contain other pollutants typical of industrial and residential areas.
    - Residential areas contribute the same road-based pollutants to runoff, and also herbicides, pesticides, nutrients (from fertilizers and animal wastes), as well as bacteria, viruses, and other pathogens (from animal wastes).

3. A study in Tennessee demonstrated that a relationship between urban land uses and bacterial loading rates may exist. The fecal coliform bacteria counts in urban tributaries were much higher in sewered basins than in non-sewered basins. The fecal bacteria densities were related to the density of housing, population, development, percent impervious area, and apparent domestic animal density (Young and Thackston, 1999).

Impervious Area Categorization

General Description

Natural impervious cover includes soil types such as exposed bedrock or thick clay layers. Accessing local knowledge on subwatershed soils is helpful to assign the degree of imperviousness for each land use category. For example, in western Washington a common Puget Sound basin soil is called glacial till. This soil type is well drained in an undisturbed area; however, upon residential development, glacial till is easily compacted to the point of 100% imperviousness (same as pavement).

Human influences often reduce stormwater percolation with activities that include (1) covering the soil (e.g., paving and building), (2) compacting the soil (e.g., holding livestock, building trails and roads, and trampling sensitive soils, and (3) retarding infiltration (e.g., reducing vegetation and filling wetlands). All of these human influences can be present in a wide range of intensities for any given land use category. The importance of maintaining pervious surfaces is not only limited to reducing flows. Pollutant export to sensitive environments such as riparian areas or waterways is minimized when impervious surfaces are minimized or regularly cleaned. Infiltrating stormwater is considered a priority because it carries pollutants. Infiltration is one way to achieve natural treatment and reduce flow simultaneously.

Schueler (2000) defines impervious area as the sum of roads, parking lots, sidewalks, rooftops, and other impermeable surfaces in the urban landscape. The majority of the impervious area composition is from transport and rooftops. The transport component is predominant in the suburban environment, at 63-70% of the total impervious cover for residential, multi-family, and commercial areas (City of Olympia, 1995). Imperviousness can be estimated with a minimal effort in ground truthing, and is an important foundation for more effective stormwater study.

In typical rainfall runoff, hydrograph in subwatersheds with impervious areas has become earlier and more intense, with a shorter overall life span. The effects of stormwater runoff into streams has increased the frequency and severity of flooding, accelerated channel erosion, altered streambed substrate-size composition, reduced baseflow, altered energy inputs to streams, and altered the natural temperature regime (Schueler, 2000). A one-acre parking lot impervious cover will increase the annual volume of stormwater runoff over a one-acre undeveloped meadow by up to 16 times (Schueler, 2000).

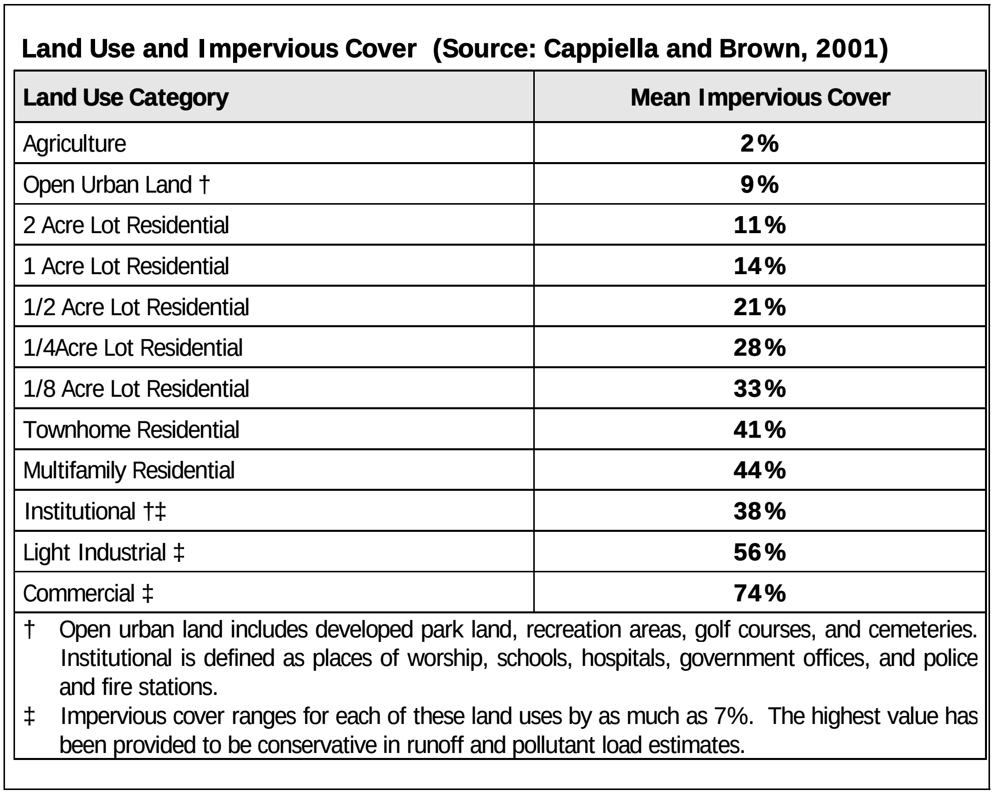
Over the long term, the hardened surfaces and shortened travel times for rainwater have had sustained impacts to stream hydrology, geomorphology, and water quality. Variability is due to several factors such as annual climate, historical uses, infiltration rates, soil types, human use influences, and population. A 40% loss in infiltration to groundwater has been measured in watersheds with land use changes (Paul and Meyer, 2001).

Given a medium density residential area…."*larger events can generate more runoff from pervious areas than impervious areas. However it is likely that most of the runoff during the*

[Municipal Separate Storm Sewer Systems] (MS4) monitoring activities was associated with more common small events, and hence, impervious areas were more important" (Maestre et al., 2004).

The following table was developed by the Center for Watershed Protection in 2001, based on a GIS analysis within the Chesapeake Bay watershed.

Figure 2: Stormwater Center Impervious Cover Table by Land Use.



Land Use and Impervious Cover (Source: Cappiella and Brown, 2001)

Land Use Category	Mean Impervious Cover
Agriculture	**2%**
Open Urban Land †	**9%**
2 Acre Lot Residential	**11%**
1 Acre Lot Residential	**14%**
1/2 Acre Lot Residential	**21%**
1/4Acre Lot Residential	**28%**
1/8 Acre Lot Residential	**33%**
Townhome Residential	**41%**
Multifamily Residential	**44%**
Institutional †‡	**38%**
Light Industrial ‡	**56%**
Commercial ‡	**74%**

† Open urban land includes developed park land, recreation areas, golf courses, and cemeteries. Institutional is defined as places of worship, schools, hospitals, government offices, and police and fire stations.

‡ Impervious cover ranges for each of these land uses by as much as 7%. The highest value has been provided to be conservative in runoff and pollutant load estimates.

Copied from www.stormwatercenter.net/Slideshows/rapid_files/frame.htm. October 2006.

"*Applying th[ese] factors to the areas of the different land use polygons …will generate a composite imperviousness for the subject watershed.*"

Applicability

Any watershed.

Data Needs

Imperviousness of the area
Land use
Aerial maps
Land use maps
Landsat imagery

Impervious cover is also a critical input variable for the following models:

- Storm Water Management Model (SWMM)
- Hydrologic Simulation Program Fortran (HSPF) model
- Source Loading and Management Model (SLAMM)
- Simple Method
- TR-55
- TR-20

Pros/Cons of the Method

Pro: Useful at the study planning level and can be done as a desktop exercise.
Con: Assigned impervious may be subjective and is only as good as the source map.

Examples of Use

1. Impervious Cover and Land Use in the Chesapeake Bay Watershed (CWP, 1998)

The Center for Watershed Protection developed the "Impervious Cover Model," which is illustrated in Figure 3 below, based on more than 40 scientific studies. The relationship identifies the threshold of impervious cover that corresponds to general stream health. The Impervious Cover Model is a planning tool that correlates an initial screening of impervious cover to management options for the protection and mitigation needs of a watershed. Local communities use impervious cover as an indicator tool in their planning, zoning, and watershed analysis efforts as a result of the compelling scientific evidence.

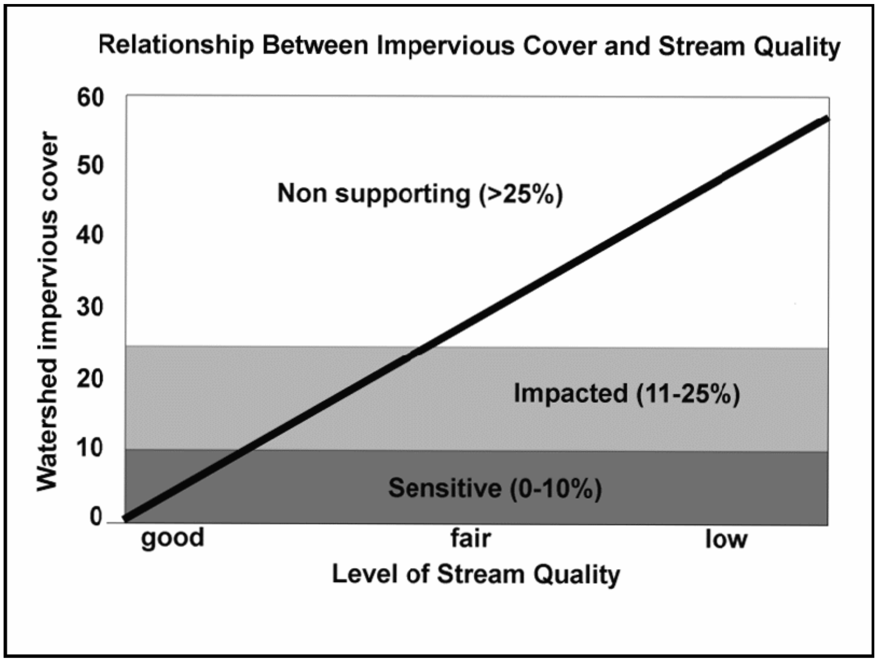


Figure 3: The Impervious Cover Model (CWP, 1998)

Estimating imperviousness in a given landscape is usually done from a combination of source maps and ground-truthing trips around the watershed. Source maps should be kept up to date. Sleavin et al. (2000) compared various base map sources and mapping techniques to determine percent impervious cover. Creating GIS coverage from various source maps was compared to on-the-ground impervious cover in four Connecticut towns. Municipal zoning designations, parcel sizes, and jurisdictional defined areas were poorly correlated to actual impervious areas. In addition, these data sets often fail to include road impervious areas. The most accurate measure was ground truthing; however, not far behind was aerial photograph interpretation, which was a much quicker assessment. However, the seasonal effects of leaf-out could cause error, if not taken into account.

Using satellite-derived land cover (such as Landsat) and published impervious cover of particular land uses is the most common and least expensive method to estimate percent impervious cover. Landsat Thematic Mapper series is a continuous data set that provides a fairly accurate means to estimate impervious cover.

2. Landsat Imagery

Using 1998 Landsat imagery, an urban land cover and impervious area study of the Puget Sound lowlands was conducted by Hill et al. (2003). Using an algorithm, the Landsat satellite imagery is used to produce GIS land use data into seven land cover categories at 30m resolution. This method is reproducible as it does not rely on individual aerial photo interpretations. The algorithm and GIS land use data produced are available to Ecology by contacting K.Z. Hill at the University of Washington.

Total impervious area was determined for seven land covers: urban (intense, grassy, forested), vegetated (grass/shrub, deciduous, and coniferous), and open water. This method was found to systematically overestimate and underestimate two types of cover. Overestimated impervious areas were small islands of imperviousness where runoff probably infiltrates in the vegetation near them. Underestimated impervious areas were those that appear as pervious by photographs, but were found to be compacted or otherwise nearly impervious upon ground truthing. Hill wrote that *total impervious area* is not equivalent to *effective impervious area.* Hill recommended that Table 5 be used for the Puget Sound Lowlands.

Table 5 provides literature values for imperviousness of land use designations used in various studies.

Table 5: Comparative Impervious Percentages by Land Use

Land Use	Hill et al., 2003[a]		NSQD[b]	Palouse Study[c]
	TIA[d] (%)	EIA[e] (%)	TIA (%)	TIA (%)
Low density res. (1 unit per 2-5 acres)	10	4	-	20
Medium density res. (1 unit per acre)	20	10	-	35
"Suburban" density (4 units per acre)	35	24	42-45	
High density and Institutional (multi-family or 8+ units per acre)	60	48		40
Commercial / Industrial	90	86	83/70	80
Open Space			4	8

[a] Compiled by Dinicola (1989) and referenced by Hill et al. (2003).
[b] Maestre et al. (2004). National Stormwater Quality Database (NSQD).
[c] Lubliner et al. (2005). Compilation of local conditions and literature values.
[d] Total Impervious Area.
[e] Effective Impervious Area.

3. Hood Canal, WA

Currently, Washington State is using land use as a method to assess pollution risk from nitrogen to Hood Canal in Puget Sound. The *Preliminary Assessment and Corrective Action Plan* (PACA) was developed to provide an estimate of the main nutrient sources to Hood Canal, initiate corrective actions to prevent fish die-offs from low dissolved oxygen that have repeatedly been occurring. A scientific model based on UW –DSHVM (see complex models below) was developed and currently being used to revise corrective actions and improve effectiveness in restoring dissolved oxygen to the Canal.

The methods used in *PACA* development were fairly simple at first. Land cover based on land use was estimated from Landsat TM satellite images into four land cover categories. Landsat data have a "pixel" size of 30 meters, roughly a 100-foot circle, which likely underestimates the land cover due to the rural character of the watershed. The four categories were summed to find the total amount of commercial, high-density residential, medium-density residential, and low-density residential land cover in the Hood Canal watershed. Nitrogen loading was estimated based on the land cover classification and on literature values. This method, for calculating loading from stormwater runoff, projects that roughly 48,000 pounds (24 tons) of nitrogen per year is discharged into Hood Canal (Fagergren et al., 2004).

4. TMDLs for toxic pollutants in California and Pennsylvania

California's San Francisco Bay PCB TMDL and Pennsylvania's Oxon Run PCB TMDL provide a comprehensive look at sources and sinks for PCBs. Both of these studies are much larger than any of Ecology's TMDLs for toxics constituents.
www.waterboards.ca.gov/sanfranciscobay/TMDL/sfbaypcbstmdl.htm
www.epa.gov/reg3wapd/tmdl/dc_tmdl/OxonRun/OxonO&M&Bact_DR.pdf

Simple Method

General Description

The Simple Method (Schueler, 1987) takes into account the hydrology of the subwatershed by several terms in the model that are generally referenced values. These terms include the average annual rainfall, percent impervious, and the fraction of runoff.

Average annual rainfall can be found from isohyet figures contained in the Ecology stormwater manuals.

Average annual rainfall, overall imperviousness, and pollutant concentrations are used in the Simple Method to estimate pollutant loads. The Simple Method provides a general planning estimate of likely storm pollutant export from areas at the scale of a development site, catchment, or subwatershed. More sophisticated modeling may be needed to analyze larger and more complex watersheds.

Data needs, pollutant concentrations, rainfall, percent impervious, or land use estimates are elementary. These can usually be found from other studies. Using a range of published concentrations will provide a generalized range in pollutant loads. The drainage area scale and land uses should closely resemble the referenced watershed. This is, by far, the roughest estimate that can be used and done very quickly as a desktop exercise. Clearly using literature values yields no information about a particular study area. See Appendix D for literature values of stormwater pollutant concentrations.

Often very little is known about the study area; therefore, the pollutant concentration, land use, hydrology, rainfall, or degree of imperviousness are studied (or estimated) to gain a cursory estimate of the stormwater pollutant loads to the receiving water of interest. The instantaneous pollutant load from each outfall can be calculated as the concentration times the discharge rate. Often budget constraints restrict sampling programs and parameters.

Applicability

Perhaps the most useful aspect of this approach is that a tiered study design can be easily implemented; wherein water, sediment, or stormwater samples from strategic locations in a watershed could be used to get a rough “first glimpse” at the pollutant concentrations at different locations. A few key stormwater samples will help produce a range of concentrations for which the annual load can be estimated. The goal is usually to identify sediment or water concentrations, locate hot spots, calculate relative loads, and gather descriptive statistics to better plan a larger study on the site or watershed.

Data Needs

Pollutant concentrations, discharge, and average annual rainfall are needed to use the Simple Method. Impervious or land use percentage estimates are also potentially useful.

Schueler's Simple Method (1987) is based on annual runoff volume and pollutant concentration, as follows:

$$L = 0.226 * R * C * A$$

Where: L = Annual load (lbs)
R = Annual runoff (inches)
C = Pollutant concentration (mg/l)
A = Area (acres)
0.226 = Unit conversion factor

The annual runoff is a product of annual runoff volume and a runoff coefficient. The runoff coefficient is calculated based on impervious cover in the subwatershed. Runoff volume is calculated as:

$$R = P * Pj * Rv$$

Where: R = Annual runoff (inches)
P = Annual rainfall (inches)
Pj = Fraction of annual rainfall events that produce runoff (usually 0.9)
Rv = Runoff coefficient $Rv = 0.05+0.9(Ia)$
Ia = Impervious fraction

Pros/Cons of the Method

Pro: Ohrel (2000) wrote: "Most appropriate for smaller (<640 acres) watersheds when quick, reasonable estimates suffice…[and] with some refinement of the "C" [concentration] values for current local conditions, the Simple Method would provide reasonable water quality and pollutant load estimates quickly and cheaply – provided recognition of the method's limitations were made."

Con: The Simple Method model is never more than a unit-area loading model. Refinement can be achieved by reducing the scale and assigning land uses with differing imperviousness; however, it remains a steady-state constant loading model.

An Example of Use

The Draft Spokane River PCB TMDL, Stillaguamish River TMDL, and Palouse Pilot Project had their stormwater components analyzed by use of the Simple Method with measured pollutant concentrations and stormwater discharge, and relied on tabulated rainfall estimates. See Appendix C.

Rollback Method

General Description

The Statistical Rollback Method (Ott, 1995) uses the statistical characteristics of a known data set to predict the statistical characteristics of a data set that would be collected after pollution controls have been implemented and maintained. In applying the rollback method, the target fecal coliform geometric mean value (GMV) and the target 90th percentile are set to the corresponding water quality standard. The reduction needed for each target value to be reached is determined. The rollback factor, f_{rollback}, is

$$f_{\text{rollback}} = \text{minimum } \{\ (100/\text{sample GMV}), (200/\text{sample } 90^{\text{th}} \text{ percentile})\ \}$$

The percent reduction ($f_{\text{reduction}}$) needed is

$$f_{\text{reduction}} = (1 - f_{\text{rollback}}) \text{ x } 100\%$$

which is the percent reduction that allows both GMV and 90th percentile target values to be met.

The result is a revised target value for both the GMV and the 90th percentile. In most cases, a reduction of the 90th percentile is needed, and application of this reduction factor to the study GMV yields a target GMV that is usually less (i.e., more restrictive) than the water quality criterion. The 90th percentile is used as an equivalent expression to the “no more than 10%” criterion found in the second part of the water quality standards for fecal coliform bacteria. The method is well described in the South Prairie Creek Bacteria TMDL by Roberts (2003).

Applicability

The rollback method (Ott, 1995) has been used by Ecology staff on numerous TMDL allocations to determine the necessary reduction for both the GMV and 90th percentile bacteria concentration to meet water quality standards (Cusimano and Giglio, 1995; Pelletier and Seiders, 2000; Joy, 2000; Joy and Swanson, 2005; and Coots, 2002).

Data Needs

- Bacteria counts and flow data.
- Enough data to have a statistically sound data set.
- In most areas, at least a year to capture seasonal effects to accurately describe the 10th and 90th percentiles.

Pros/Cons of the Method

Pro: The data result format matches the language of Ecology’s surface water quality criteria for bacteria.

Con: This method is time-consuming in that many data points over several different conditions are required.

An Example of Use

The modeling approach uses the Statistical Rollback Method to determine the load reduction necessary to achieve the fecal coliform water quality standard in South Prairie Creek, Spiketon Creek/Ditch, and the unnamed tributary at the town of South Prairie. Compliance with the most restrictive of the dual fecal coliform criteria determines the bacteria reduction needed. Fecal coliform sample results for each site in this study were found to follow lognormal distributions, and the 90th percentile was calculated as the antilog of the mean of the log-transformed data plus 1.28 times the standard deviation of the log-transformed data. (Roberts, 2003).

Regression Equations

General Description

Statistical regression of a water quality indicator on one or more predictor variables can be a simple and useful model for developing water quality studies. Endreny et al. (2004) evaluated the robustness of nine water quality export-load estimators to predict pollutant loads with data reduction schemes. This study focused on the residential environment and dissolved constituents. When select data were removed from the overall data set, some estimators (such as regressions) out-performed in some scenarios due to concentration responsiveness to discharge, sampling frequency, data randomness, and normality. Data collected from slightly more baseflow events with some storm-event data provided the best estimate of the actual load using a regression estimate method. The best scenario in terms of reduced data to predict a load most accurately was to be sure the data set had samples from both baseflow and storm event, and was richer in storm event data.

Applicability

Pollutant concentrations and loads are often correlated to other constituents (i.e., total suspended solids) or to physical characteristics of the watershed such as runoff volume or impervious area.

Data Needs

Pollutant concentrations, discharge rates, and other predictor variables.

Pros/Cons of the Method

Pro: Easier and less expensive analysis of surrogate compounds. Regression equations are fairly simple mathematical relationships and can be readily used in a broad range of applications.

Con: Sometimes a direct correlation with the pollutant of interest is not made.

Examples of Use

1. **Simple Regression**
2. **Load Duration Curve**
3. **Regression Analysis and Use of Surrogates**
4. **Walla Walla TMDL**
5. **Grays Harbor Fecal Coliform TMDL**

1. Simple Regression

Driver, N.E. and G.D. Tasker, 1990. Techniques for Estimation of Storm-Runoff Loads, Volumes, and Selected Constituent Concentrations in Urban Watersheds in the Unites States. USGS Water Supply Paper 2363.

Using complementary datasets from EPA and USGS, linear regression models were optimized on the basis of mean annual rainfall to estimate storm-runoff constituent loads, storm-runoff volumes, storm-runoff mean concentrations of constituents, and mean seasonal or mean annual constituent loads. The best explanatory variables were total storm rainfall and contributing area, followed by impervious area, land use, and mean annual climatic characteristics in some cases. Stormwater loads for dissolved solids, nitrogen, and ammonia were modeled the most accurately, whereas suspended solids were the least accurate. In general, the least accurate regression models were for areas such as the Pacific Northwest with a large annual rainfall.

2. Load Duration Curve

Hydrologists commonly characterize stream values (e.g., flow, load) using a duration curve, which is the percentage of time during which the value of a given parameter is equaled or exceeded. Discharge rates are typically sorted from the highest value to the lowest. Using this convention, flow duration intervals are defined, which are expressed as a percentage with zero corresponding to the highest stream discharge in the record (i.e., flood conditions) and 100 to the lowest (i.e., drought conditions) (Cleland, 2002).

Duration curves can also add value to the TMDL process by expanding the characterization of water quality concerns, linking concerns to key watershed processes, prioritizing source assessment efforts, and identifying potential solutions. Duration curves can strengthen watershed assessments and enhance the TMDL development process (Cleland, 2003). For access to Load Duration Curve methodology and example TMDLs from several states, follow the link: www.tmdls.net/tipstools/flowdc.htm.

As a key part of its TMDL development process, the state of Kansas has used the load duration curve method for more than five years, www.kdheks.gov/tmdl/basic.htm#data. Initially, the focus was on a way to identify whether point or nonpoint sources were the main pollutant source. The load duration curve has become widely used for nonpoint source pollution due to the ease of assessing water quality across a range of flow conditions.

3. Regression Analysis and Use of Surrogates

Christensen, Victoria G.; Xiaodong Jian; and Andrew C. Ziegler, 2000. Regression Analysis and Real-Time Water-Quality Monitoring to Estimate Constituent Concentrations, Loads, and Yields in the Little Arkansas River, South-Central Kansas. Water-Resources Investigations Report 00-4126. http://ks.water.usgs.gov/Kansas/pubs/reports/wrir.00-4126.html#HDR1

The Little Arkansas River is used as source water for artificial recharge to the Equus Beds aquifer, which provides water for the city of Wichita in south-central Kansas. The water quality was monitored by both real-time and periodic samplings to develop surrogate relations between physical properties (turbidity) and constituents of concern.

Identification of seasonal trends was especially important because high streamflows have a substantial effect on chemical loads and because concentration data from manually collected samples often were not available. Monitoring surrogates to estimate selected chemical constituents in streamflow can increase the accuracy of load and yield estimates and can decrease some manual data-collection activities.

Regression equations for each field site were developed to estimate alkalinity, dissolved solids, total suspended solids, chloride, sulfate, atrazine, and fecal coliform bacteria concentrations. Generally, two years of data (35 to 55 samples) collected throughout 90 to 95% of the stream's flow duration were sufficient to define the relation between a constituent and its surrogate(s).

The estimated constituent loads relative percent difference (RPD) were less than 25% for alkalinity, dissolved solids, chloride, and sulfate, and greater than 25% for total suspended solids, atrazine, and bacteria loads. Even with a RPD greater than 25%, there are advantages of real-time information over manual sampling. The timely availability of bacteria and other constituent data may be important when considering recreation, aquifer recharge for water suppliers, and prevention of negative effects on fish or other aquatic life.

Constituent loads calculated from the regression equations may be useful for calculating TMDLs for determining in which subbasin to concentrate efforts with regard to land-resource, best management practices. These results have applications anywhere constituent concentrations, loads, or transport are of concern.

4. A Total Maximum Daily Load Evaluation for Chlorinated Pesticides and PCBs in the Walla Walla River

The Walla Walla PCB TMDL study (Johnson et al., 2004) was able to correlate total DDT with total suspended solids (TSS) and set instream targets for TSS reduction to meet DDT criteria for aquatic life. TSS was, in turn, linked to the state turbidity standard and to fish habitat requirements. This work was based heavily on an earlier TMDL in the Yakima River basin (Joy and Patterson, 1997) that first explored the relationship between TSS and DDT.

In both TMDLs, a strong positive correlation between TSS concentrations and the predictor variable was found. In the Walla Walla River and tributaries, the semipermeable membrane devices (SPMD) data showed the relative amounts of DDT, DDE, and DDD are fairly constant, with DDE accounting for 50 ± 4% of the t-DDT. Therefore the DDE-based TSS target of 100 mg/L should be reduced to 50 mg/L to meet a t-DDT criterion (divide by a factor of 2).

Turbidity is easier to monitor than TSS, and because state standards for turbidity already exist, turbidity was selected as a surrogate measure of TSS where sampling *both* TSS and turbidity was not practical. In light of chronic violations of the turbidity standard and the link between turbidity and TSS, a regression equation was developed to calculate turbidity levels that corresponded to the TSS targets for t-DDT.

The Walla Walla TMDL effort proposed TSS as the surrogate for chlorinated pesticides, and no wasteload allocations for TSS were set for stormwater from the wastewater treatment plants. wasteload allocations for PCBs were placed on the wastewater treatment plants on Garrison and Mill Creeks as the human health water quality criteria times the NPDES permit limit for the average monthly effluent flow.

Land use changes directed at meeting DDE-based targets would also effectively address other problem pesticides identified in this report. PCBs, like chlorinated pesticides, have a strong affinity for soil particles, so it is thought that meeting the TSS/turbidity targets in the Walla Walla River drainage will also reduce PCB concentrations in the river and its tributaries. The water quality targets proposed for pesticides may also result in compliance with the Washington State human health criterion for PCBs.

5. Grays Harbor Fecal Coliform TMDL

Pelletier, G. and K. Seiders, 2000. Grays Harbor Fecal Coliform Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. 110 pgs. Publication No. 00-03-020. www.ecy.wa.gov/biblio/0003020.html

A multiple regression model was found to explain most of the variability in fecal coliform concentrations in tributaries to Grays Harbor. The regression model required estimation of several parameters: a constant; a linear and quadratic fit to the logarithm of flow; and sinusoidal (Fourier) functions to remove the effect of annual seasonality.

To estimate daily and annual loading of fecal coliform, the regression model is first used to predict daily fecal coliform concentrations from the record of daily flows. Daily loads were estimated as the product of daily flow and estimated daily concentration. Seasonal or annual loads were estimated as the sum of estimated daily loads.

The resulting regression equations for tributaries to Grays Harbor, and comparisons of predicted and observed concentrations and loads, are presented in the Grays Harbor report. The model calibration results showed that Ecology's model predictions represented the observed data very well, and implicitly accounted for the contribution of wildlife to fecal coliform loads.

Complex Modeling Approaches

There are many papers on methods, models, and literature reviews for stormwater pollution in the last two decades. In preparing this section, the websites of the group or agency that authored or currently maintain the following models were visited. In most cases, the model overview and description was directly copied to this document to maintain both the clarity of writing and accuracy at the highest level. The web link is provided along with the copied text for direct reference.

Three resources for model comparisons that are more extensive than this document are:

1. James (1996) edited a book over-viewing 18 papers dealing with the modeling aspects of urban stormwater. These papers discuss use of the models as well as the effects of highly influential watershed parameters such as percent impervious area, hydrologic soil drainage characteristics, flow lengths, surface characteristics, slope, and site-specific rainfall intensity.

2. The Watershed and Water Quality Modeling Technical Support Center of EPA (www.epa.gov/athens/wwqtsc/index.html) provides access to a variety of tools and mathematical models to support TMDL development, wasteload allocations, and watershed protection plans.
    - Watershed Models (BASINS, Watershed Characterization System, Loading Simulation Program, HSPF, WAMView)
    - Water Quality Models (WASP, QUAL2K, EPD-RIV1, AQUATOX)
    - Hydrodynamic Models (EFDC, EPD-RIV1)

3. Ohrel (2000) reviewed and compared various models to estimate the stormwater loads from watersheds. He stated that “when choosing models to compute stormwater pollutant loads, managers seek a blend of accuracy, reliability, and timeliness, while minimizing the cost of obtaining such information”.

Most of the models discussed have web links from Ecology’s website: www.ecy.wa.gov/programs/eap/models.html.

A select number of models are discussed below as either integrative models or complex continuous simulation models. Case studies are described as examples of the model.

Integrative Models

1. **WASP**
2. **PRMS**
3. **QUAL2Kw**
4. **CORMIX**
5. **Equilibrium Partitioning**
6. **AQUATOX**
7. **DHSVM**

1. WASP

www.epa.gov/athens/wwqtsc/html/wasp.html

General Description

This model helps users interpret and predict water quality responses to natural phenomena and manmade pollution for various pollution management decisions. WASP is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. WASP allows the user to investigate 1, 2, and 3 dimensional systems, and a variety of pollutant types. The state variables for the given modules are in the table below. The time varying processes of advection, dispersion, point and nonpoint (diffuse) mass loading, and boundary exchange are represented in the model. WASP also can be linked with hydrodynamic and sediment transport models that can provide flows, depths velocities, temperature, salinity, and sediment fluxes.

WASP has been used to examine eutrophication of Tampa Bay, FL; phosphorus loading to Lake Okeechobee, FL; eutrophication of the Neuse River Estuary, NC; eutrophication of the Coosa River and Reservoirs, AL; PCB pollution of the Great Lakes; eutrophication of the Potomac Estuary, kepone pollution of the James River Estuary, volatile organic pollution of the Delaware Estuary; heavy metal pollution of the Deep River, NC; and mercury in the Savannah River, GA.

Applicability

WASP Model Information	
Current Version	7.2
Release Date	July 31 , 2006
Operating System	Windows 95/98/ME/2000/XP
Intended Audience	Environmental Engineers/Scientists, Regulatory Agencies
Key Words	aquatic biology, assessment, compliance, discharge, environmental effects, hydrology, metals, nonpoint source related, NPDES, point source(s), surface water, test/analysis, TMDL related
Media	Surface Water
Pollutant Types	Conventional Pollutants (Nitrogen, Phosphorus, Dissolved Oxygen, BOD, Sediment Oxygen Demand, Algae, Periphyton), Organic Chemicals, Metals, Mercury, Pathogens, Temperature

Data Needs

- Parameter concentrations, flows, and mixing coefficients.
- Each of the modules has different requirements, but in general, the following are needed for toxics: partitioning, 1st Order decay, fate processes, reaction products, ionization, sediment sizes, and time scale.

Pros/Cons of the Method

Pros: The modules [simple toxicant; non-ionizing organic toxicant; organic toxicant; mercury] contain a range of reasonable values, which can be experimented with if the field value is unknown.

Cons: WASP cannot perform the following: mixing zone processes, NAPLs (oil spills), sediment drying, potentially large hydraulic files, separate eutrophication, or toxicant fate models. Also, WASP cannot be run in batch mode such as a Monte Carlo simulation.

An Example of Use

The Oxon Run watershed had a sub-model component that used WASP as a toxics screening level model to simulate the loading, fate, and transport in the tidal portion of the river (EPA, 2004). It is a 1-D model that simulates processes in the river by idealizing the river as a long channel where conditions may vary along the length of the channel but are assumed to be uniform throughout any channel transect.

Sub-models were used for sediments, arsenic, (copper, lead, zinc), chlordane/heptachlor epoxide, DDT, dieldrin, PAH, and PCBs. Chlordane and DDT are bound in sediment. WASP used a high-water, low-water, and average-flow years-calculated harmonic mean flow. Sediment management was the main priority in the cleanup plan because resuspension of bed sediment would cause the PCB levels to always be high.

2. PRMS

http://smig.usgs.gov/cgi-bin/SMIC/model_home_pages/model_home?selection=prms

General Description

PRMS (Precipitation-Runoff Modeling System) is a distributed watershed model that simulates precipitation- and snowmelt-driven movement of water through the basin via overland flow, interflow, and baseflow. Watershed response can be simulated at a daily time step or, more frequently, over the course of a storm. Kinematic routing of the unidirectional flow and the transport of sediments through a receiving network of well-mixed channel reaches can be simulated when the model is in "storm mode".

Simulation of the energy balance in the snowpack and the water balance is based on many theoretically- and empirically-developed relations. The model contains procedures for parameter optimization and sensitivity analyses.

Applicability

Water Quality Constituents Modeled	Sediment
Status	The FORTRAN model code is not proprietary. Support provided by U.S. Geological Survey Hydrologic Analysis Software Support.
Graphical User Interface	A Unix-based GUI is available through the modeling framework.
Pre and Post Processors	PRMS uses Watershed Data Management (WDM) format, see ANNIE and IOWDM.
Developer	U.S. Geological Survey (USGS)
Contact	USGS Hydrologic Analysis Software Support Team (HASS) 437 National Center Reston, VA 20192 (electronic mail: h2osoft@usgs.gov)
Users Manual	Leavesley, G.H., Lichty, R.W., Troutman, B.M., and Saindon, L.G., 1983, Precipitation-Runoff Modeling System: Users Manual: U.S. Geological Survey Water-Resources Investigations Report 83-4238, 207 p. *Available online*.

Data Needs

Data Type	PRMS
Domain	▪ basin delineated into land areas of similar hydrologic response ▪ elevation, latitude, aspect, and slope of each land area ▪ vegetation cover of each land area
Flow	▪ routing coefficients for storage reservoirs OR function tables of storage vs. outflow
Meteorology	▪ daily minimum/maximum air temperature ▪ precipitation (daily, or more frequently for storm mode) ▪ solar radiation (daily) ▪ pan evaporation (daily, required for 1 PET option)
Hillslope Hydrology	▪ interception capacity of vegetation (pervious) ▪ retention storage (impervious) ▪ Manning's *n* for overland flow plane (storm mode only) ▪ parameters regulating groundwater recharge from soil and subsurface reservoirs ▪ maximum recharge rate of groundwater from excess soil moisture ▪ nominal storage in soil zone ▪ parameters regulating evapotranspiration potential of soil zones and groundwater ▪ parameters regulating infiltration and runoff
Snow Pack	▪ lapse rate correcting air temperature at gages to elevation ▪ threshold temperature for precipitation as snow ▪ density of new snow ▪ average maximum snowpack density ▪ sublimation as fraction of potential evapotranspiration ▪ water holding capacity of snowpack ▪ coefficient relating latent and sensible heat flux to air temperature
Sediment	▪ coefficients relating rainfall to soil detachment ▪ coefficients relating sediment transport to surface water outflow ▪ coefficients relating scour of soil matrix to surface water outflow
Channel Routing	▪ Manning's *n* for channel segments (storm mode only)

Pros/Cons of the Method

Pro. The model is comprehensive and flexible.

Con. The model requires a large number of parameters.

An Example of Use

http://smig.usgs.gov/SMIC/model_pages/prms.html#WILLAMETTE
Precipitation-Runoff and Streamflow-Routing Models for the Willamette River Basin, Oregon. (Copied from the abstract; U.S. Geological Survey Water-Resources Investigations Report 95-4284)

The following is copied from the above website:

“Precipitation-runoff and streamflow-routing models were constructed and assessed as part of a water-quality study of the Willamette River Basin….. Routing models are needed to estimate streamflow so that water-quality constituent loads can be calculated from measured concentrations and so that sources, sinks, and downstream changes in those loads can be identified. Runoff models are needed to estimate ungaged-tributary inflows for routing models and to identify flow contributions from different parts of the basin. The runoff and routing models can be run either separately or together to simulate streamflow at various locations and to examine streamflow contributions from overland flow, shallow-subsurface flow, and ground-water flow.

The 11,500-square-mile Willamette River Basin was partitioned into 21 major basins and 253 subbasins. For each subbasin, digital data layers of land use, soils, geology, and topography were combined in a geographic information system (GIS) to define hydrologic response units (HRU's), the basic computational unit for the Precipitation-Runoff Modeling System (PRMS). Spatial data layers were also used to calculate noncalibrated PRMS parameter values. Other PRMS parameter values were obtained from 10 nearby calibrated subbasins of representative location and character.

About 760 miles of the Willamette River system were partitioned into 4 main-stem networks and 17 major tributary networks for streamflow routing. Data from time-of-travel studies, discharge measurements, and flood analyses were used to develop equations that related stream cross-sectional area to discharge and stream width to discharge. These relations were derived for all 21 stream networks at approximately 3-mile intervals and used in the Diffusion Analogy Flow model (DAFLOW) in streamflow routing.

Ten representative runoff models and 11 network-routing models were calibrated for water years 1972-75 and verified for water years 1976-78…. Observed and estimated daily precipitation and daily minimum and maximum air temperature were used as input to the runoff models. The resulting coefficient of determination (R2) for the representative runoff models ranged from 0.69 to 0.93 for the calibration period and from 0.63 to 0.92 for the verification period; absolute errors ranged from 18 to 39 percent and from 27 to 51 percent, respectively. Bias error for the runoff modeling ranged from +13 to -32 percent. Observed daily streamflow data were used as input to the network-routing models where available, and simulated streamflows from runoff model results were used for ungaged areas. Absolute error for the network-routing models ranged from about 21 percent for the Molalla River model, for which 70 percent of the subbasin was ungaged, to about 4 percent for the Willamette main-stem model (Albany to Salem), for which only 9 percent of the subbasin was ungaged.

With an input of current streamflow, precipitation, and air temperature data the combined runoff and routing models can provide current estimates of streamflow at almost 500 locations on the main stem and major tributaries of the Willamette River with a high degree of accuracy. Relative contributions of surface runoff, subsurface flow, and ground-water flow can be assessed….”

3. QUAL2Kw

www.epa.gov/athens/wwqtsc/html/qual2k.html

General Description

QUAL2Kw has been used extensively by Ecology's TMDL staff for dissolved oxygen, pH, temperature, and nutrients. It is a modernized version of EPA's QUAL2E river and stream receiving water quality model. The QUAL2Kw framework has updated science and new features to be more flexible in the simulation of fate and transport of conventional (non-toxic) pollutants.

Because this document is mostly focused on toxic constituents, and to a lesser extent bacteria, this approach is only mentioned for the pathogen modeling capacity.

The QUAL2Kw framework has the following characteristics:

- One dimensional. The channel is well-mixed vertically and laterally.
- Steady flow. Non-uniform, steady flow is simulated.
- Diel heat budget. The heat budget and temperature are simulated as a function of meteorology on a diel time scale.
- Diel water-quality kinetics. All water quality state variables are simulated on a diel time scale for biogeochemical processes.
- Heat and mass inputs. Point and nonpoint loads and abstractions are simulated.
- Phytoplankton and bottom algae in the water column, as well as sediment diagenesis, and heterotrophic metabolism in the hyporheic zone are simulated.
- Variable stoichiometry. Luxury uptake of nutrients by the bottom algae (periphyton) is simulated with variable stoichiometry of nitrogen and phosphorus.
- Automatic calibration. Includes a genetic algorithm to automatically calibrate the kinetic rate parameters.
- New to EPA's QUAL2K: Pathogen removal is determined as a function of temperature, light, and settling.

QUAL2Kw is programmed in the Windows macro language: Visual Basic for Applications (VBA). Excel is used as the graphical user interface.

Applicability

Current Version	2.04
Release Date (QUAL2K)	March 2006
Operating System	Windows ME/2000/XP / MS Office 2000 or Higher
Intended Audience	Environmental Engineers/Scientists, Regulatory Agencies
Key Words	Aquatic biology, assessment, compliance, discharge, environmental effects, hydrology, NPS related, NPDES, point source(s), surface water, test/analysis, TMDL related
Media	Surface Water
Pollutant Types	Conventional Pollutants (Nitrogen, Phosphorus, Dissolved Oxygen, BOD, Sediment Oxygen Demand, Algae), pH, Periphyton, Pathogens

Data Needs – Critical Input Values

Overall data needs include:

- Flow balance of all inputs and withdrawals
- Hydraulic conditions: Weir dimensions, rating curve coefficients, or Manning equations
- Shade
- Wind speed over the watercourse
- Pollutant concentrations:

  TEMP = temperature (C)
  TKN = total kjeldahl nitrogen (µgN/L) or
  TN = total nitrogen (µgN/L)
  NH4 = ammonium nitrogen (µgN/L)
  NO2 = nitrite nitrogen (µgN/L)
  NO3 = nitrate nitrogen (µgN/L)
  CHLA = chlorophyll a (µgA/L)
  TP = total phosphorus (µgP/L)
  SRP = soluble reactive phosphorus (µgP/L)
  TSS = total suspended solids (mgD/L)
  VSS = volatile suspended solids (mgD/L)
  TOC = total organic carbon (mgC/L)
  DOC = dissolved organic carbon (mgC/L)
  DO = dissolved oxygen (mgO2/L)
  PH = pH
  ALK = alkalinity (mgCaCO3/L)
  COND = specific conductance (µmhos)
  CBOD Variables

- Filtered BOD5 with nitrogen BOD suppression

Pros/Cons of the Method

Pro: QUAL2Kw has been used by Ecology with success for several conventional parameter TMDLs.

Con: Unknown

An Example of Use

The best information about QUAL2Kw is from Ecology’s website:
www.ecy.wa.gov/programs/eap/models.html

Greg Pelletier published details about QUAL2Kw in the Journal of Environmental Modelling & Software (Pelletier et al., 2006).

Ecology has not used the pathogen portion of QUAL2Kw, due to the very recent release date.

4. CORMIX

www.cormix.info/picgal/rmixingz.php

General Description

CORMIX is an EPA-supported mixing zone model and decision support system for environmental impact assessment of regulatory mixing zones resulting from continuous point source discharges. The system emphasizes the role of boundary interaction to predict steady-state mixing behavior and plume geometry.

Applicability

CORMIX can predict mixing behavior from diverse discharge types ranging from power plant cooling waters, desalinization-facility or drilling-rig brines, municipal wastewater, or thermal atmospheric plumes. CORMIX can also be applied across a broad range of ambient conditions ranging from estuaries, deep oceans, and swift shallow rivers to density-stratified reservoirs and lakes.

Data Needs – Critical Input Values

Special Regulatory Mixing Zone Requirements for Toxic Discharges.

EPA maintains two water quality criteria for allowable concentrations of toxic discharges:

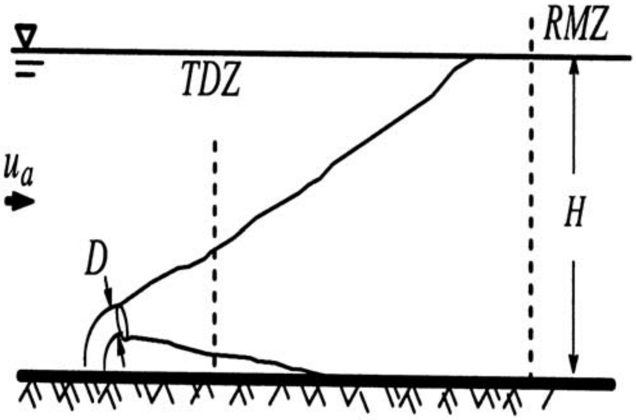
1. Criterion Maximum Concentration (CMC) - Protective of acute or lethal effects.
2. Criterion Continuous Concentration (CCC) - Protective of chronic effects.

CMC is spatially more restrictive than the CCC. The CCC is often treated like a water quality standard; it must be met at the edge of the same regulatory mixing zone specified for conventional or toxic pollutants.

Toxic Dilution Zone (TDZ) Requirements

EPA allows a toxic dilution zone within the regulatory mixing zone, but it must comply with one of four of the following criteria:

1. Meet the CMC within the discharge pipe.
2. Exit velocity must exceed 3 m/s (10 ft/s).
3. Geometric restrictions.
4. Show that a drifting organism will be exposed less than 1 hour to CMC no more than once in 3 years.



The toxic dilution zone (based on CMC) for toxic substances is located within the regulatory mixing zone (based on CCC).

Geometric Restrictions within the Toxic Dilution Zone (TDZ)

1. The CMC must be met with 10% of the distance from the edge of the outfall structure to the edge of the regulatory mixing zone in any spatial direction.
2. The CMC must be met with a distance of 50 times the discharge length scale in any spatial direction. The discharge length scale (LQ) is defined as the square-root of the cross-sectional area of any discharge outlet (LQ ~ D).
3. The CMC must be met within a distance of 5 times the local water depth in any horizontal direction.

Advanced CORMIX Tools for Regulatory Mixing Zone Visualization

In practical application, the regulatory mixing zone may occur in the near-field or in the far-field after boundary interaction occurs. In practice, regulatory mixing zones may be specified by a length, area, or volume around the discharge source.

Within the regulatory mixing zone, CCC values may be specified for conventional and toxic discharge, while a more restrictive spatial region for toxic discharges (called a toxic dilution zone or TDZ) with CMC values may be specified.

Pros/Cons of the Method

Unknown

An Example of Use

No Ecology examples of use.

5. Equilibrium Partitioning Model

General Description

The equilibrium partitioning (EP) model is often used to predict bioaccumulation in benthic invertebrates. It is based on the premise that a contaminant distribution has reached thermodynamic equilibrium between the three environmental phases (sediment, water, and biota) (Shea, 1988).

Applicability

Almost every bioaccumulation model uses the equilibrium partitioning technique.

Data Needs

Water quality and chemical concentration data.

Pros/Cons of the Method

Morrison et al. (1996) stated the limitations to the EP model are threefold: (1) Overlooks biomagnifications, wherein chemical contaminants are transported against their thermodynamic gradient via the food chain, (2) Assumes the biota sediment accumulation factor (BSAF) is constant and independent of the chemical, organism, and sediment properties, and (3) Feeding strategies (e.g., filter vs. detritus) are not distinguished which may result in significant differences between BSAFs in organisms.

An Example of Use

Crunkilton and Devita (1997): *Abstract:* "The concentrations of freely dissolved polycyclic aromatic hydrocarbons (PAHs) in an urban stream at high-flow and base-flow were estimated by an equilibrium partitioning model (EPM), and by use of lipid-filled semipermeable membrane devices (SPMDs), then compared to direct measurements made on bulk (unfiltered) water samples. The SPMD method was slightly more effective in detecting smaller three- and four-ring PAHs and the EPM method was slightly more effective in detecting five and six-ring PAHs. Although the SPMDs sequestered slightly fewer of the large PAHs, they sampled more compounds of a size range likely to be bioavailable to aquatic organisms. Estimates of the concentrations of freely dissolved PAHs for the EPM and the SPMD methods were similar when compared under the same flow regimes. The SPMD method also provided a time-integrated average measure of freely dissolved PAHs that cannot be easily duplicated with conventional sampling procedures. Concentrations of freely dissolved PAHs (EPM method) as well as concentrations of total PAHs at high-flow averaged about 20 times greater than at base-flow. This suggests the potential for immediate toxicological impacts on stream biota is greater at high-flow because of increased concentrations of bioavailable PAHs. For individual PAHs, differences between bulk and freely dissolved concentrations were most evident at high-flow for high K_{ow} compounds strongly partitioned to suspended solids. Thus, in hazard assessments for aquatic biota it is important to employ measures of freely dissolved PAHs during storm water runoff events."

6. AQUATOX

www.epa.gov/waterscience/models/aquatox/about.html

General Description

"AQUATOX is a freshwater ecosystem simulation model. It predicts the fate of various pollutants, such as nutrients and organic toxicants, and their effects on the ecosystem, including fish, invertebrates, and aquatic plants. AQUATOX is a valuable tool for ecologists, water quality modelers, and anyone involved in performing ecological risk assessments for aquatic ecosystems."

Applicability

AQUATOX simulates multiple environmental stressors (including nutrients, organic loadings and chemicals, and temperature) and their effects on the algal, macrophyte, invertebrate, and fish communities. The model has the capability to evaluate the spatial and temporal relationship of various pollutants, such as nutrients and organic chemicals, and their effect on the organisms that reside within the waterbodies. The model is widely applicable and a valuable tool for water quality modelers, aquatic ecologists, biologists, and water resource managers.

Within the AQUATOX users manual, Imhoff et al. (2004) is referenced in the inset Table 3.2 for a comparison of bioaccumulation state variables and the models that best represents them, with AQUATOX (Release 2) clearly winning against the other models as representing more plants and animals as state variables.

Ecological Understanding and Problem Analysis

- Evaluate which of several stressors is causing observed biological impairment. For example: Are nuisance levels of attached algae in streams controlled primarily by nutrients, sediments, grazing by snails, or flow conditions?
- Predict effects of pesticides and other toxic substances on aquatic life. For example: Will sublethal concentrations eventually cause game fish to disappear? Will reduction of one group of organisms reduce the food supply for other, more beneficial species, or lead to increases in nuisance species?
- Evaluate potential ecosystem responses to invasive species.
- Explore how changes in land use or agricultural practices in a watershed might affect aquatic life, by using the new linkage to BASINS.

Environmental Management

- Compare differences in biological responses to control alternatives.
- Develop targets for nutrients in lakes and reservoirs with nuisance algal blooms.
- Estimate time to recovery of fish or invertebrate communities after reducing pollutant loads.
- Calculate bioaccumulation factors for organic toxic chemicals.
- Estimate how long before tissue levels of toxic organics in fish will return to safe levels, following removal of contaminated sediments.

Data Needs

Unknown

Pros/Cons of the Method

Pro: AQUATOX will link to continuous simulation models (including Basins, HSPF, and SWAT).

Con: AQUATOX is not a usable model for metals and pathogens.

An Example of Use

The AQUATOX model is a relatively new model; therefore, limited work has been done to test the application of this model at the watershed scale.

7. DHSVM [Distributed Hydrologic Soil-Vegetation Model]

www.hydro.washington.edu/Lettenmaier/Models/DHSVM/index.shtml

Developed in the early 1990s by Mark Wigmosta while at the University of Washington, the model code has been further developed by the University of Washington and Pacific Northwest National Laboratory. DHSVM is a distributed hydrologic model that explicitly represents the effects of topography and vegetation on water fluxes through the landscape at a regional scale. It is typically applied at high spatial resolutions on the order of 100 m for watersheds of up to 104 km^2 and at sub-daily timescales for multi-year simulations. It consists of four main elements: vegetation, unsaturated soil, saturated soil flow, and surface channel flow. It has been applied predominantly to mountainous watersheds in the Pacific Northwest in the United States. As a spatially distributed hydrological model, DHSVM is input intensive. In broad terms, the following input is needed for the implementation of the model in a specific area:

- Digital Elevation Model (DEM) of the basin
- Soil textural and hydraulic information
- Vegetation information
- Meteorological conditions at a subdaily timestep, in particular precipitation, air temperature, humidity, wind speed, incoming shortwave radiation, and incoming longwave radiation
- Information about the stream and road network (e.g., location, width).

Soil and vegetation information is needed at the same resolution as the resolution at which the model is implemented. For each pixel, a soil and vegetation type is specified, and a lookup table is used to store the associated soil and vegetation properties.

Pro: DHSVM includes a sediment module. With so many toxics that bind strongly to sediment, this may prove valuable.

Con: DHSVM does not (at this time) incorporate water quality parameters; however, there is talk of adding this capability.

Examples of Use

1. The DHSVM model is a relatively new model and is being used in the Hood Canal Dissolved Oxygen Project. www.hoodcanal.washington.edu/
2. Vanshaar, J., and D.P. Lettenmaier, 2001. Effects of land cover change in the hydrologic response of Pacific Northwest forested catchments, Water Resources Series, Technical Report 165, University of Washington, Seattle. www.ce.washington.edu/pub/WRS/WRS165.pdf
3. Burges, S.J., M.S. Wigmosta, and J.M. Meena, 1998. Hydrological Effects of Land-Use Change in a Zero-Order Catchment, ASCE J. Hydrol. Eng., 3, 86-97. http://scitation.aip.org/heo.

Hydrologic modeling and relatively simple monitoring were used to estimate the hydrologic balance for two geographically close and, in the undisturbed state, hydrologically similar, zero-order basins: one undeveloped forest and the other suburban. Continuous precipitation and streamflow were measured in each basin; the model was used to estimate time series of evapotranspiration and groundwater recharge over a 40-yr period. The suburban catchment was denuded of forest cover, soil thickness was reduced, and 30% of the area was covered with impervious surfaces. The amount of annual precipitation that becomes runoff ranged from 12 to 30% in the forested catchment and 44 to 48% in the suburban catchment where runoff from pervious areas accounts for 40–60% of the annual total. The peak flow rate per unit area for an approximate 24-hr, 50-yr rainfall was more than 10 times higher from the pervious area at the suburban site than at the forested site. These findings emphasize the need to consider surface flow from all sources in the catchment when considering mitigation measures.

Continuous Simulation Models

1. **SWMM**
2. **HSPF**
3. **GEMSS**
4. **BASINS**

A comparative study of nine un-calibrated runoff models and their ability to predict the storm volume and peak streamflows with identical data revealed that the models based on the SCS curve number (HEC-1 and TR20) had the poorest fit. Other models in the study include CASC2D, CUHP, CUHP/SWMM, DR3M, SSPF, and SWMM (Zarriello, 1999).

1. SWMM

www.epa.gov/ednnrmrl/models/swmm/index.htm
www.epa.gov/athens/wwqtsc/SWMM.pdf

General Description

"The EPA Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of sub-catchment areas on which rain falls and runoff is generated. The routing portion of SWMM transports this runoff through a conveyance system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each sub-catchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps."

Applicability

SWMM continues to be widely used throughout the world for planning, analysis, and design related to stormwater runoff, combined sewers, sanitary sewers, and other drainage systems in urban areas, with many applications in non-urban areas as well.

Typical applications include:

- Designing and sizing of drainage system components for flood control
- Sizing of detention facilities and their appurtenances for flood control and water quality protection
- Flood plain mapping of natural channel systems (SWMM 5 is a FEMA-approved model for NFPI studies)
- Designing control strategies for minimizing combined sewer overflows
- Evaluating the impact of inflow and infiltration on sanitary sewer overflows
- Generating nonpoint source pollutant loadings for wasteload allocation studies
- Evaluating the effectiveness of BMPs for reducing wet weather pollutant loadings

Data Needs

Information to be gathered for use in the SWMM model depends on the complexity of the system; however, data needs generally include catchment area, precipitation, runoff volume, pollutant concentrations, and specifics of the stormwater transporting system (i.e., pipes, channels, storage/treatment devices, pumps, and regulators).

Pros/Cons of the Method

Pro:

In addition to modeling the generation and transport of runoff flows, SWMM can also estimate the production of pollutant loads associated with this runoff. The following processes can be modeled for any number of user-defined water quality constituents:

- Dry-weather pollutant buildup over different land uses
- Pollutant washoff from specific land uses during storm events
- Direct contribution of rainfall deposition
- Reduction in dry-weather buildup due to street cleaning
- Reduction in washoff load due to best management practices (BMPs)
- Entry of dry weather sanitary flows and user-specified external inflows at any point in the drainage system
- Routing of water quality constituents through the drainage system
- Reduction in constituent concentration through treatment in storage units or by natural processes in pipes and channels

Con: Unknown.

An Example of Use

Alaska Case Study for SWMM: Chester Cr. Bacteria TMDL
www.dec.state.ak.us/water/tmdl/pdfs/chestercrwatershedTMDLEPAFinal.pdf

The following paragraphs are copied from the above website:

"Due to the water quality criteria being based on a 30-day geometric mean, the urban character of the watershed, previous modeling efforts made by MOA (Municipality of Anchorage), and availability of USGS flow data, the Storm Water Management Model (SWMM) (EPA, 2000) was selected to estimate existing and potential future fecal coliform counts in the Chester Creek watershed. SWMM simulates the quantity and quality of runoff produced by storms, as well as during baseflow conditions, and is one of the most advanced tools available for evaluating water quality in urban watersheds. SWMM simulates real storm events based on rainfall and other meteorological inputs, such as evaporation and temperature, and watershed transport, storage and management practices to predict runoff quantity and quality. At the subwatershed scale, SWMM provides predictions of daily fecal coliform counts, which allows for a direct comparison with Alaska's water quality standards.

The SWMM model was first calibrated to observed hydrology and fecal coliform counts for the period 1987 to 1993 and was then used to assess the effectiveness of various implementation options. Seven "analysis points" were identified to evaluate conditions at various points along Chester Creek and in University Lake and Westchester Lagoon. The following nine tables summarize the results of the TMDL analysis. They indicate that significant reductions in existing loads throughout the watershed are necessary to meet water quality standards. Areas of the watershed with the highest fecal coliform loading rates tend to be residential land uses with a high degree of imperviousness and located in close proximity to the stream. The municipality of Anchorage released a report in 2003 stating that likely sources associated with these land uses are warm blooded animal sources including domestic pets (particularly cats and dogs) and wild animals.

Through an evaluation of information collected in developing this TMDL and in a fecal coliform assessment of Chester Creek done through a DEC grant to the University of Alaska (to be published in July 2005), DEC believes three potential sources of fecal coliform contribute little or insignificant loads of fecal coliform bacteria to the Chester Creek system: onsite septic systems, illegal campsites, and leaking sewage lines. DEC believes that waterfowl and wildlife contribute little fecal coliform through most of the watershed, but at some locations may contribute higher amounts at certain times of the year.

As any contributions they provide are not resulting from human actions, they are not included in the TMDL loading allocations. This TMDL focuses on stormwater discharges as the main component. These municipal discharges are regulated by a National Pollutant Discharge Elimination System (NPDES) stormwater permit for municipal separate storm sewer systems (MS4), watershed loads delivered to Chester Creek are addressed through the wasteload allocation component of this TMDL.

Although the SWMM scenarios in this TMDL did not show that fecal coliform bacteria will be reduced to levels meeting state water quality standards, DEC believes the standards will be met because of the following mitigating issues: (1) although SWMM is considered the best model for the type and amount of data available, it was not designed for Alaska's extreme northern climate and could have predicted conservative reductions under the implementation scenarios; (2) the data used are 10-15 years old and do not reflect improvements in stormwater management known to have occurred since the data was collected; and (3) recent monitoring data1 consistently shows fecal coliform levels are considerably lower than levels seen in data used to develop the TMDL, translating into fewer reductions needed to meet state water quality standards than projected by the model. DEC will continue to monitor these waters for levels of fecal coliform bacteria and if sampling results show the actions are not achieving the target levels, DEC will, in coordination with the MOA, consider and take other actions to adjust and meet the targets.

In 2004, DEC contracted with the University of Alaska, Anchorage to collect temporal and spatial fecal coliform data on Chester Creek. Unfortunately the data collected could not used in developing the TMDL because there wasn't any corresponding flow data need for SWMM."

Western Washington Continuous Simulation Hydrology Model (WWHM)

The Department of Ecology has funded the development of an HSPF-based continuous runoff model for western Washington using the best available precipitation data and mathematical algorithms. It is referred to as the Western Washington Hydrology Model (WWHM).

In the 2001 manual update, Ecology changed the flow control standard from a peak-flow-rate matching basis to a flow-duration matching basis. The 2005 manual continues to use a duration-based standard. Designers must use a continuous simulation hydrologic model to comply with the flow control standard, to design flow control facilities, and to size flow-rate-based treatment facilities.

The current version of the model and the user's manual can be downloaded from this website www.ecy.wa.gov/programs/wq/stormwater/wwhm_training/wwhm/wwhm_v2/instructions_v2.html.

2. HSPF

http://smig.usgs.gov/cgi-bin/SMIC/browse_models
To find model information, select HSPF from the list.

General Description

Hydrologic Simulation Program-Fortran (HSPF) is a distributed watershed model that simulates precipitation- and snowmelt-driven movement of water through the basin via overland flow, interflow, and baseflow. Kinematic routing of the unidirectional flow through a receiving network of well-mixed channel reaches is also simulated. The transport of a wide variety of constituents through the watershed and the receiving network can be simulated. Time scales from storm events to many years can be simulated.

Simulation of the physical, chemical, and biological processes included in the model is based on many theoretically- and empirically-developed relations. The resulting model is comprehensive and flexible, but also very complex and requires a large number of parameters.

Applicability

Water Quality Constituents Modeled	▪ temperature ▪ inorganic suspended sediments ▪ biochemical oxygen demand ▪ algae ▪ phosphorus ▪ nitrogen ▪ dissolved oxygen ▪ pH ▪ total inorganic carbon ▪ zooplankton ▪ detritus ▪ pesticides
Status	The FORTRAN model code is not proprietary. Support provided by U.S. Geological Survey Hydrologic Analysis Software Support (HASS).
Graphical User Interface	HSPF has been incorporated into GENSCN and BASINS.
Pre-processors	HSPF uses the Watershed Data Management (WDM) format (e.g., ANNIE).
Post-processors	Utility modules within HSPF can be used to generate plot files and display tables, compute statistics, and also perform frequency, duration, and excursion analyses.
Developer	U.S. Environmental Protection Agency (EPA)
Contact	U.S. Geological Survey Hydrologic Analysis Software Support Team, 437 National Center, Reston, VA 20192 (electronic mail: h2osoft@usgs.gov)
Users Manual	Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., Donigian, A.S., Jr., and Johanson, R.C., 1997, Hydrological Simulation Program--Fortran, Users manual for version 11: U.S. Environmental Protection Agency, National Exposure Research Laboratory, Athens, GA., EPA/600/R-97/080, 755 p.
Project Abstracts	Salt Creek, IL | Truckee and Carson Rivers, CA/NV | King and Snohomish Counties, WA | Truckee River, CA/NV | Comparison of Nine Runoff Models | Ipswich River, MA | Du Page County, IL | Comparison of Nine Runoff Models | Ninemile Creek, NY

Data Needs

Data needs, depending on desired model functions:

- watershed soils
- land use
- slope
- surficial geology
- bedrock geology
- precipitation
- groundwater
- snow melt
- wetlands

Pervious/impervious area

Channel dimensions

Pros/Cons of the Method

Pro: Unknown

Con: "Runoff models such as HSPF are highly sensitive to precipitation volume and intensity, which can differ appreciably over small areas." (Zarriello, 1999).

Examples of Use

King County

Dinicola (1999) presented recent efforts to develop regionalized HSPF parameters for King and Snohomish Counties in Washington State that were useful for urbanizing watersheds. King County has already employed an HSPF-based model (King County Runoff Time Series, KCRTS) to estimate runoff flow rates and volumes in their jurisdiction.

ENVVEST

Sinclair Inlet and Dyes Inlet were listed on the 1998 303(d) list of impaired waters because of fecal coliform contamination in the marine waters and metals and other contaminants in bottom sediments. In addition, a number of creeks that discharge to these inlets were listed for fecal coliform contamination. To address all the contamination issues using a watershed approach, a partnership was established between Department of Ecology as the state agency that establishes TMDLs (Water Cleanup Plans), the Puget Sound Naval Shipyard, and the U.S. Environmental Protection Agency working together on Project ENVVEST (an acronym for ENVironmental InVESTment).

Background on the Project ENVVEST can be found at www.ecy.wa.gov/programs/wq/tmdl/sinclair-dyes_inlets/.

The storm-event sampling plan developed for this project is a well-funded and comprehensive sampling plan to characterize pollutants, model watershed hydrology, and the impacts on receiving waters. Ecology is only one participant in this project that is being led by the U.S. Navy and EPA. The objectives of the sampling plan are to:

1. Collect flow and water quality data from representative stormwater outfalls
2. Obtain modeling data such as ambient conditions and boundary conditions
3. Collect preliminary data for nonpoint source runoff contaminants
4. Assess the storm-event runoff water quality impacts
5. Screen a subset of streams and stormwater outfalls for pesticides and herbicides

Historical precipitation and flow data and current flow monitoring have been combined to develop an extensive hydrologic record for the project area. Stream and stormwater outfall volumes are modeled with HSPF. This watershed model is then linked to a receiving water quality model, Curvilinear Hydrodynamics in 3 Dimensions (CH3D), for the inlets.

For an example of a detailed sampling program, the ENVVEST sampling for one winter (2002-03) is described: Stormwater sampling was initiated after 0.25” of rain in a 24-hr period. Discrete grab samples and automated composite samplers were used to estimate the “event mean” concentrations for conventional parameters, nutrients, metals, and toxic organics (PAHs, PCBs, and phthalates). ISCO automatic samplers collected 150-ml aliquots of sample water every 15 minutes continuously during the storm. About four 6-hr composite samples were combined “post-hoc” to create a composite that best represented the flow hydrograph and avoided tidal intrusion and low-to-no-flow samples. Composite samples from selected streams were analyzed for some parameters to obtain data on “first flush” and “peak flow” conditions of the storm hydrograph. The final report on this study is expected to be made available in early 2007.

3. GEMSS

www.erm-smg.com/gemss.html

GEMSS, a Generalized Environmental Modeling System for Surface waters, was developed by J.E. Edinger Associates, Inc. as an integrated hydrodynamic and water quality model package with GIS and environmental data management.

Applicability

The GEMSS software is designed in a modular fashion for easy coupling of existing and other user defined models. Currently the system has eight modules:

- HydroDynamic and Transport Module - HDM
- Thermal Analysis Module - TAM
- Water Quality Module - WQM
- Sediment Transport Module - STM
- Particle Tracking Module - PTM
- Chemical and Oil Spill Module - COSIM
- Bio Organisms Entrainment Module - ETM
- Toxicity Module – TXM

Data Needs

Meteorology data, hydrodynamic data, and water quality data.

Pros/Cons of the Method

Pros:
GEMSS® is a model Ecology uses day-to-day, built to work on surface water problems the way Ecology approaches them.

GEMSS can be used when variable flow conditions exist (unsteady flow).

Con:
Although it is an excellent productivity tool, GEMSS is a "work in progress" and does not have the level of perfection of mass-market software packages.

Examples of Use

GEMSS is a fully hydrodynamic, time-variable, water quality model which has been considered for unsteady flows conditions by Ecology TMDL study leads. The parameters to be modeled include flow (Bilhimer, 2006; Pelletier and Sullivan, 2006), dissolved oxygen and pH (Carroll and Mathieu, 2006; Pelletier and Sullivan, 2006; Roberts et al., 2004), and fecal coliform bacteria (Ahmed and Sullivan, 2004).

4. BASINS

http://smig.usgs.gov/cgi-bin/SMIC/model_home_pages/model_home?selection=basins

General Description

Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) is a customized ArcView GIS application designed to be used by regional, state, and local agencies in performing watershed-based and water-quality-based studies. BASINS was also conceived as a system for supporting the development of Total Maximum Daily Load (TMDL) studies. GIS data (by EPA region) and meteorological data (by state) are available for download with the software.

The system is designed to support analysis at a variety of scales using the assessment tools that are integrated into the software (TARGET, ASSESS and Data Mining). Through the use of GIS, BASINS has the flexibility to display and integrate a wide range of information (e.g., land use, point source discharges, water supply withdrawals) at a scale chosen by the user. Utilities include local data import, land use and DEM reclassification, watershed delineation, and management of water quality data. Through the graphical user interface, users can access national environmental information, apply assessment and planning tools, and run a variety of nonpoint loading and water quality models.

Models that have been incorporated into BASINS include HSPF, TOXIROUTE, and QUAL2E. Post-processing tools for use in visualizing and interpreting the results of the water quality modeling are integrated into the software.

Applicability

Status	The software is not proprietary. BASINS requires a Windows 95/98/NT/ME/2000, XP operating system, and ArcView 3.1/3.2/3.3 with Spatial Analysis extension. Support, training, and listserver are available.
Developer	U.S. Environmental Protection Agency (EPA), Office of Water
Contact	EPA BASINS support team (e-mail: basins@epa.gov) Modeling and Information Technology Team Standards and Health Protection Division Office of Science and Technology U.S. Environmental Protection Agency Mailcode - 4305T 1201 Pennsylvania Ave. NW, Washington, DC 20460 fax: 202-566-0409
Users Manual	Better Assessment Science Integrating Point and Nonpoint Sources, BASINS, Version 3.0, U.S. Environmental Protection Agency Report EPA-823-B-01-001. A printed copy of the documentation can be ordered from EPA National Service Center for Environmental Publications (1-800-490-9198).

Originally introduced in 1996 with subsequent releases in 1998 and 2001, BASINS is a multipurpose environmental analysis system designed for use by regional, state, and local agencies in performing watershed and water-quality-based studies. This system makes it possible to quickly assess large amounts of point source and nonpoint source data in a format that is easy to use and understand. This invaluable tool integrates environmental data, analytical tools, and modeling programs to support development of cost-effective approaches to watershed management and environmental protection, including TMDLs.

Data Needs

- GIS information such as land use, watershed delineation, and DEM reclassification
- Water quality data
- Water supply and withdrawal information.

Pros/Cons of the Method

Unknown

An Example of Use

No Ecology examples of use.

Sample Collection and Data Evaluation

Wet weather events, such as rainfall and snowmelt, in urban landscapes have received much attention as the mechanisms for transporting pollution to the nation's waters. EPA's 1996 National Water Quality Inventory reported that urban runoff was a leading cause of water quality problems in the country, causing impairment in (1) 469 of the nation's estuaries, (2) 21% of the lakes, ponds and reservoirs, and (3) 13% of the rivers and streams. Stormwater quality is on the forefront of environmental policy decisions and environmental research in the United States as well as the rest of the world.

The typical urban sources of pollutants include streets, lawns, driveways, parking lots, gas stations, bus depots, golf courses, construction sites, marinas, trash, sand/salt, commercial and industrial areas, highway yards, atmospheric fallout, direct rainfall (i.e., acid rain), and a variety of other sources such as landfills, recycling facilities, transportation, and manufacturing and industrial facilities.

The quality of stormwater runoff tends to be extremely variable (EPA, 1983). Many studies, nationally and locally, have attempted to characterize stormwater sources of pollution and the relationships between variables such as rainfall, drainage area, climatic variables, and land use. Stormwater runoff from urban areas has been shown to contain many different types of pollutants.

Depending on the nature of the activities in those areas, these pollutants can include suspended solids, sediment, bacteria, nutrients, pesticides, herbicides, toxics, floatables, oil, grease, heavy metals, synthetic organics, petroleum hydrocarbons, and oxygen-demanding substances. The adverse impacts of these pollutants in stormwater discharges include closed beaches, closed shellfish areas, fish consumption bans, beach and shoreline litter and floatables, siltation of marina and shipping channels, habitat/wetland degradation, and streambank erosion.

Sample Representativeness

Stormwater samples, like other environmental samples, are prone to investigator sampling error. For example, safety concerns may preclude sampling from certain outfalls, confined entry locations, or submerged outfalls, which may have an effect on the data distribution. Stormwater sample representativeness is also challenged due to the high variability in the pollutant concentrations between storms and even at single sampling stations during the same storm. Confidence in the data can be no better than how well the sample represents the system sampled. The definition of a representative sample (i.e., flow-weighted or grab) has not been specified by Ecology or EPA, and is left to the study designer to consider.

The definition of the populations should be considered at the outset of the sampling study design. A representative sample defines a particular population, but the definition of the population of interest is important. Is the population the maximum concentration over one hour or four hours? Is it the event mean concentration (EMC) or the average concentration over the whole storm, or some other regulatory criterion? The monitoring objectives determine what kind of population the investigator wants to characterize and what intensity and type of sample the investigator will need to take. For example, the fecal coliform water quality standards are based on the geometric mean, which is calculated as the nth root of the product of n numbers.

Often a fecal coliform TMDL will use the EMC, a common conventional parameter calculation that requires a discrete series of samples with concentrations associated with identifiable flow rates over the course of the event as well as a measure of the total flow volume over the course of the storm.

$$\text{EMC} = \frac{\text{mass of pollutant during event}}{\text{flow volume during event}} = \frac{\text{sum } Qi*Ci}{\text{sum } Qi}$$

Another example of how to define the population may be criteria violations. If the goal is to determine the rate of criteria violation over a particular season, then storms of several magnitudes should be monitored. On the other hand, if peak storm concentrations are of interest, then the first major storm of the season and all other storms of a particular intensity are needed.

In contrast to fecal coliform sampling designs, some of the toxic organic parameters (i.e., PCBs) preferentially bind to organic matter or sediments and, therefore, have very low water column concentrations. A single grab sample for PCBs analysis may yield a non-detect. Therefore, composite water sample techniques have been developed to improve data usefulness.

Regardless of study approach, a sample taken properly from the study population with a high degree of quality assurance will lead to accurate conclusions about the study population.

Sample Collection Techniques

Every study should give consideration to (Othmer and Berger, 2002):

- General characteristics of the aqueous system.
- Variability between storm events – at least 3 storm events as a recommended minimum to begin capturing the range of values from a study site.
- Composite sampling for highly variable contaminants bound to the particulate matter in the water column, such as PCBs and pesticides
- Flow modes (e.g., intermittent, highly variable, base and peak flows, hydrology, and hydraulics).
- Variability of the pollutant concentrations
  - Time (e.g., first flush, whole event).
  - Cross-section (e.g., turbulent/laminar flow, velocity, density, lateral dispersion, stratification).

Ecology has used a minimum of three storm events to begin characterizing an average storm concentrations for toxic parameters (Johnson et al., 2006; Lubliner et al., 2006); however, a larger number of storm events are sampled for many of the bacteria TMDLs (Pelletier and Seiders, 2000; Roberts et al., 2004; Carroll and Mathieu, 2006).

Whole Water

Sample *type* refers to the kind of sample taken (grab, composite), and sample *technique* refers to the method by which the sample was collected (manually or by automatic sampler). Composite sampling is more likely than grab sampling to catch episodic stormwater contamination. Using an automatic sampler, a sample could be collected that would be representative of the entire week rather than a point in time. For example, a flow-compositing sampler can be set to take proportionally larger samples during periods of higher flows.

Sample Types (Othmer and Berger, 2002).

Grab Sample:	A discrete, individual sample taken within approximately 15 minutes.
Composite Sample:	A combined series of individual aliquots that will reflect a mean concentration. The four types of composites are as follows Constant Time – Constant Volume (TcVcv) Constant Time – Volume Proportional to Flow Rate (TcVvq) Constant Volume – Time Proportional to Flow Volume Increment (TcVvv) Constant Time – Volume Proportional to Flow Increment (VcTvv)

This following four figures graphically illustrate these composite techniques (Othmer and Berger, 2002). These figures are reproduced with the author's permission.

Figure 4: Constant Volume (TcVcv)

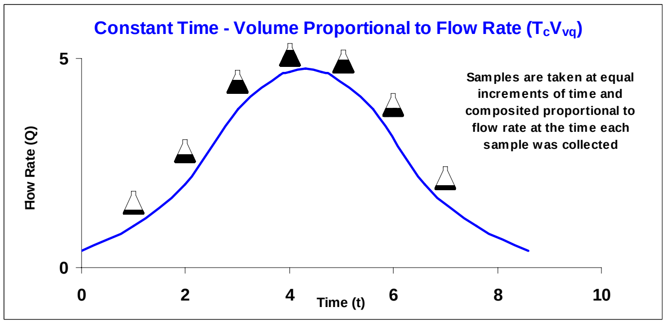


Figure 5**:** Volume Proportional to Flow Rate **(**TcVvq)

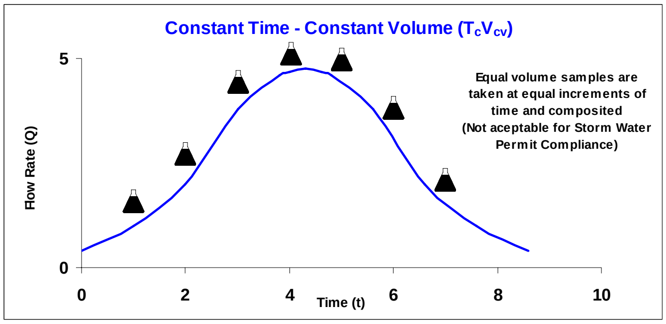


Figure 6: Time Proportional to Flow Volume Increment (TcVvv)

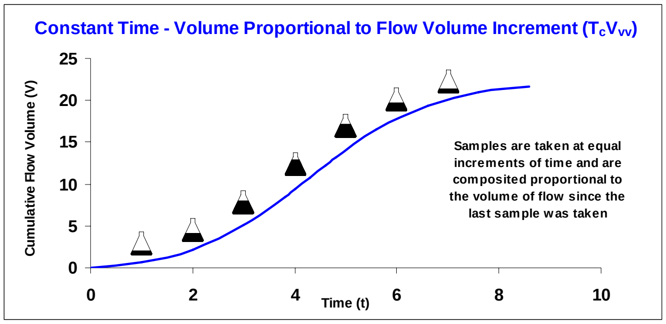
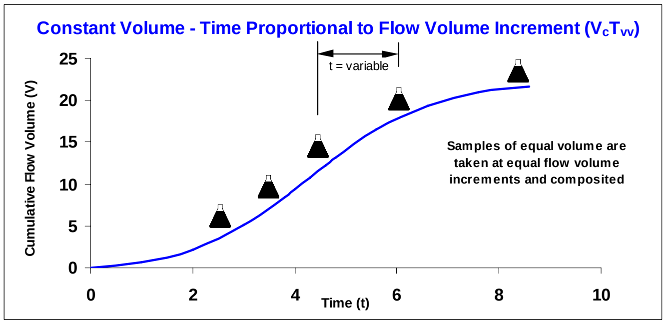


Figure 7: Volume Proportional to Flow Increment (VcTvv)



The graphs show that the relative sample aliquot volume is dependent on the compositing scheme.

In 1975, the EPA performed an evaluation of these four composite sampling schemes as an Assessment of Automatic Sewer Samplers. The results indicated the best composite for four flow scenarios and five concentration scenarios tested were the TcVvq followed by TcVvv (which were very similar), then VcTvv and TcVcv. The differences were not found to be large.

It is difficult to collect a *wide* range of storm magnitudes with an automatic sampler using flow-weighted sampling, largely due to the volume of samples taken during higher flows. A solution used in the Nationwide Urban Runoff Program (NURP) project in 1982 in California was to suspend a 10 L jar in a larger drum container as the base. With larger rain events, the 10 L jar used to collect the sub samples was allowed to overflow into the large drum container (Burton and Pitt, 2002). They suggest that alternatives to this technique to accommodate a wider range of runoff events include:

- Use time-composite techniques
- Use two samplers
- Visit, reprogram, and switch out bottles when the storm intensity changes
- Manually sample

The variable nature of stormwater discharges would require a large number of grab samples to accurately characterize the mean; therefore, composite samples are preferred from large or medium MS4s during rainfall events.

Roa-Espinosa and Bannerman (1995) compared four sampling modes at outfalls at five industrial sites to evaluate the sampling techniques for average stormwater pollutant concentrations. The four methods were flow-weighted composite, time-discrete sampling, time-composite sampling, and "first-flush" sampling during the first 30 minutes of runoff. Overall, they found that time-composite sampling of outfalls was simpler, cheaper, and comparable to flow-weighted composite sampling. Although first-flush sampling was cheaper, results were not as reproducible as time-composite results (cited from Maestre et al., 2004).

However, Othmer and Berger (2002) concluded that studies today are generally flow-weighted to provide an EMC or mass loading of a storm event. Not all NPDES permits require composite sampling. Although the technique can be useful to develop load reductions required by TMDLs, some pollutants require individual samples such as oil, grease, volatile organic carbons (VOCs), and depending on the length of the sampler time period, fecal coliform bacteria.

In 1992, EPA published the *NPDES Storm Water Sampling Guidance Document* that details collection types and techniques, measuring flow, sample handling, and other related stormwater sampling information. Table 6 is adapted from the document's Exhibit 3.3.

Table 6: Comparison of Manual and Automatic Techniques (EPA, 1992)

Sample Method	Advantages	Disadvantages
Manual Grabs	▪ Appropriate for all pollutants ▪ Minimum equipment required	▪ Labor intensive ▪ Environment possibly dangerous to field personnel ▪ May be difficult to get personnel and equipment to the storm outfall within the 30-minute requirement ▪ Possible human error
Manual Flow-Weighted Composites (multiple grabs)	▪ Appropriate for all pollutants ▪ Minimum equipment required	▪ Labor intensive ▪ Environment possibly dangerous to field personnel ▪ Human error may have significant impact on sample representativeness ▪ Requires flow measurements taken during sampling
Automatic Grabs	▪ Minimizes labor requirement ▪ Low risk of human error ▪ Reduced personnel exposure to unsafe conditions ▪ Sampling may be triggered remotely or initiated according to present conditions	▪ Samples collected for oil & grease may not be representative ▪ Automatic samplers cannot properly collect samples for VOCs analysis ▪ Costly if numerous sample sites require the purchase of equipment ▪ Requires equipment installation and maintenance ▪ Requires operator training ▪ May not be appropriate for pH and temperature or parameters with short holding times (fecal coliform, fecal streptococcus, chlorine) ▪ Cross-contamination of aliquot if tubing/bottles not washed
Automatic Flow-Weighted Composites	▪ Minimizes labor requirements ▪ Low risk of human error ▪ Reduced personnel exposure to unsafe conditions ▪ Sampling may be triggered remotely or initiated according to on-site conditions	▪ Not acceptable for VOCs sampling ▪ Costly if numerous sample sites require the purchase of equipment ▪ Requires equipment installation and maintenance ▪ Requires operator training ▪ Requires accurate flow measurement tied to sampler ▪ Cross-contamination of aliquot if tubing/bottles not washed

Passive Sampling or Biological Compositing

Other innovative methods for compositing are passive or biological methods that are commonly employed to concentrate organic contaminants. These include using resident fish or mollusks, placing study fish or mollusks, or using semi-permeable membranes devices (SPMDs) to sample the water column for contaminants.

In a report of PCB mitigation at an energy plant in Kansas, several recommendations for PCB monitoring were made that were general enough in nature to be useful to stormwater sampling anywhere (Department of Energy, 2003).

- To source track contaminants, water or mollusks samples could be gathered at multiple locations under steady-state flow conditions. If elevated levels were found, samples from further up the outfall would continue to be analyzed until the contamination was isolated. This would probably be an iterative process, identifying and removing the more significant sources of PCBs as a first priority.
- Semi-permeable membrane sampling could also be used to determine toxic pollutant concentrations at specific locations integrated over time. Flow rates from various waste streams that contribute to this outfall would need to be measured. With these data, the proportional amount of PCBs in each part of the system would be quantified. This could assist in targeting future corrective actions in those areas that will do the most good.

A recent study in New Jersey compared the passive SMPD technique to whole water composite and grab sample techniques for tracking down PCB contamination to the Camden County stormwater collection system. The detection of PCBs in the single grab samples indicates an advantage over the more expensive and time-consuming 24-hour composite technique for a quick-source, track-down study. The composite technique was used for congener fingerprinting due to the longer exposure times. The SPMD results were skewed to the lower chlorinated PCBs, since the higher chlorinated PCBs are particulate-bound and do not cross the semi-permeable membrane. This may be due, in part, to the fact that they only measure the dissolved fraction. Estimates of the total concentrations can be obtained based on equilibrium partitioning. The advantage of the SPMD technique is the ability to integrate PCB concentrations over an extended sampling period (14 days), which was useful in New Jersey to compare storm drain locations to each other (Belton et al., 2005).

A disadvantage in using SMPD technology is that the SPMD must be submerged at all times which may be a problem in the highly variable discharges of the stormwater environment. AUSGS tutorial on SPMDs can be found at
http://wwwaux.cerc.cr.usgs.gov/spmd/SPMD-Tech_Tutorial.htm
as well as in Huckins et al. (2006) and Chimuka and Cukrowska (2006).

Sample Timing

Stormwater flow rate and pollutant concentrations vary during an individual storm and between storms. Constituent fluctuations are a result of deposition; buildup during dry weather, intensity, and length of the storm; and time between storms. The stormwater study design should be tailored to the pollutant characteristics, with the understanding of the bias introduced by the study.

Sample timing is often planned to capture the highest concentration of the pollutant. Sampling small storms (0.1 to 0.2 in) is important because they are frequent and commonly exceed numeric water quality criteria for bacteria and heavy metals. Moderate rains (0.5 to 2 in) represent the majority of flow (and pollutant mass) discharges (Burton and Pitt, 2002).

The actual travel time of pollutants from a catchment was evaluated by Kirchner et al. (2000) using chloride tracers. They found many catchments had flushing times that followed a power-law distribution, where contaminants initially were flushed rapidly, but then low-level contamination was delivered to the streams for a long time after the initial flush. For example, metals are often found highest in the first half hour and detected throughout the entire length of the storm (Golding, 2005); see *Zinc in Mill Creek* below.

First Flush

A typical practice is to measure the pollutants near the beginning of the storm, usually the first half hour, the so-called “first flush”, when the concentrations for soluble pollutants are expected to be the highest. Usually the first flush is observed with discrete samples taken at short intervals over 30 minutes, and another sample taken each hour thereafter. Alternatively with more expensive analyses, such as PCB congener analysis, the first hour may be a composite sample of short intervals, and every “n” hour(s) thereafter would start a new composite sample.

The first-flush effect would be expected to occur in a watershed with a high level of imperviousness, but the National Stormwater Quality Database (NSQD) data (Maestre et al. (2004) indicated the highest concentration in first flushes occurred less than 50% of the time for the most impervious areas. They noted that if the timing of the peak flow and highest rain energy occur at the beginning of the event, then the first-flush effect is exaggerated. However, if the peak occurs late in the event then the first flush may be unnoticeable.

Sampling the first flush as the “worst-case” scenario for pollutant concentrations works well for pollutants that follow the build-up/wash-off pattern. The interval between storms may be a critical factor in sampling for first-flush contaminants, particularly in western Washington where storm fronts commonly overlap and are of low intensity.

In the NSQD study, they used 417 paired samples from storm events from eight communities, mostly located in the southeast USA, and found statistically significant relationships between first-flush and total storm-composite pollutant concentrations from different land uses.

Paired data helped to isolate constituents that exhibited a first-flush pattern: chemical oxygen demand (COD), BOD5, total dissolved solids (TDS), total Kjeldahl nitrogen (TKN), and zinc from all land uses except open space. Zinc, lead, and copper always had a first flush. Pollutants that exhibited no statistically significant first flushes in any category were suspended solids, turbidity, pH, phosphorous, fecal coliforms, fecal streptococcus, total nitrogen, dissolved phosphorus, and orthophosphate.

The NSQD study found that, for bacteria, the seasonal variations and geographic locations were important predicting variables for water concentrations; bacteria values were lowest in the winter and highest in summer.

The following list of first-flush pollutants by land use is adapted from the NSQD (Maestre et al. (2004):

No First Flush

- Open Space – total suspended solids, cadmium, chromium, copper, lead, zinc
- Industrial – cadmium, chromium, nickel
- Commercial – fecal coliform, fecal streptococcus, turbidity
- Residential – fecal coliform, fecal streptococcus, turbidity, chromium, nickel
- All Combined – fecal coliform, fecal streptococcus, turbidity

First Flush

- Open Space – no pollutants measured
- Industrial – copper, lead, zinc
- Commercial – total suspended solids, cadmium, chromium, copper, lead, nickel, zinc
- Residential – total suspended solids, cadmium, copper, lead, zinc
- All Combined – total suspended solids, cadmium, chromium, copper, lead, nickel, zinc

Other factors besides land use (e.g., rain intensity, seasonality) are suggested to better explain some observed conflicts such as TKN (first flush) and total nitrogen (not first flush). The largest effect was found for land uses with large paved areas such as commercial and industrial. About 70% of the constituents in the commercial land use category had elevated first-flush concentrations, 60% for the residential and mixed, 45% for industrial, and no first flush for open space. Line et al. (1997) found zinc and copper were the most common metals found in the first-flush stormwater at 20 sites covering 10 different industrial groups. Other first-flush contaminants included volatile and semi-volatile organics, pesticides, nutrients, and solids.

For some stormwater constituents, the first-flush studies may underestimate the entire storm load for contaminants that are heavier or have low water solubility and are flushed from pervious surfaces. Maestre stated that the first flush did not have the highest concentration for particulate-bound pollutants or those derived from erosional forces. It seems logical that some pollutants would exhibit a first flush from commercial or industrial land uses with easily washed pavements, but not from pervious soils where a higher rain intensity, saturation effect, or erosional forces are necessary to suspend pollutants such as PCBs, chlorinated pesticides, metals, and sediments. Lubliner et al. (2005) found the highest PCB concentrations from three storm events in Pullman, Washington, occurred five days into a storm at two of three storm drains studied.

If budget restrictions limit the study to only a few samples, which part of the storm should be sampled? The answer would probably be revealed by considering the imperviousness, land uses, likely storm variability, applicable impairment criteria, and the storm conveyance layouts.

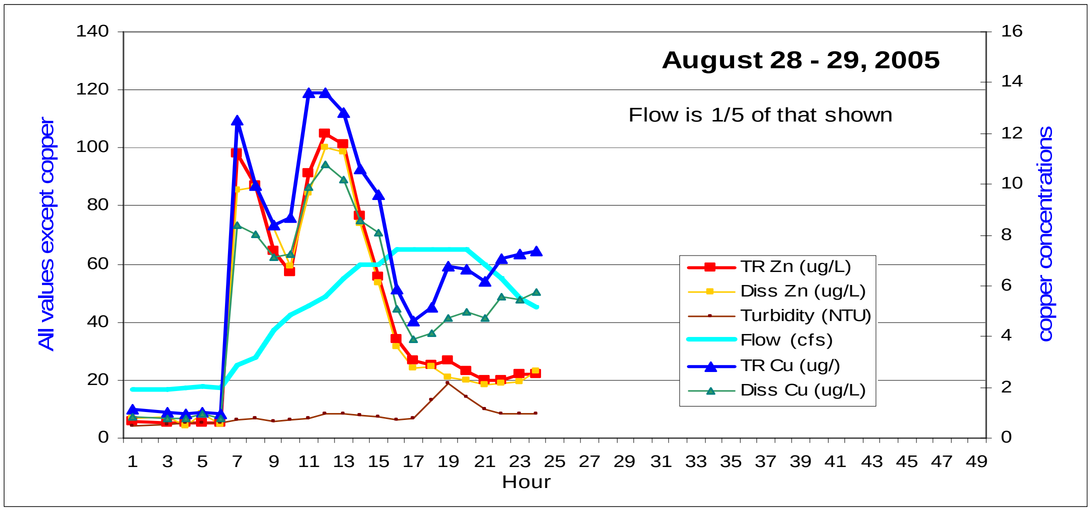
Zinc in Mill Creek

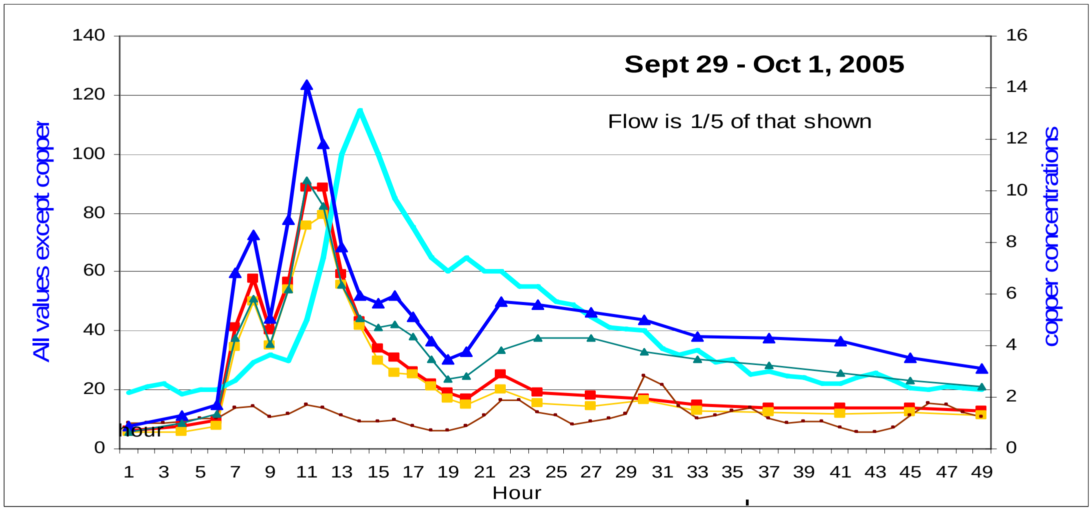
An Ecology study (Golding, 2005) for zinc in Mill Creek in Kent, Washington, was initiated due to (1) the creek's listing on the federal Clean Water Act section 303(d) list for zinc and copper, and (2) exceedances in the self-monitoring data, required under the Industrial Stormwater General Permit (ISGP). The self-monitoring data showed greater than 55% of industrial stormwater discharge samples had exceeded the zinc benchmark of 117 µg/L, with 21% exceeding the action level of 372 µg/L. The Mill Creek drainage has a high density industrial area, with 28 facilities within its 8-square-mile drainage area.

The hourly composite samples of this study provided dissolved zinc and copper data to compare directly with acute (one-hour) water quality criteria, during the worst-case condition of first flush of stormwater runoff from exposed surfaces after a period of no precipitation, as well as throughout the storm. Zinc and copper concentrations in Mill Creek climbed as streamflow increased during a storm event. At the same time, water quality criteria, which are dependent on hardness, began to drop.. Acute water quality criteria for dissolved zinc were exceeded for 2 of the 3 sampled storm events. A time series of at least 24 hours or longer was also tracked for each storm event.

As shown in Figure 8, zinc and copper concentrations peaked well before peak streamflow during the first monitored storm event of the season in August. The September/October event saw the gap between the peaks narrow. The December event, unlike the other two, was preceded by considerable rainfall and rises in streamflow in the month before monitoring. For the December event, all peaks for flow, metals concentrations, hardness, and turbidity coincided. The final monitored event in December saw a less rapid rise in metals concentrations and the smallest overall rise compared with the other two monitored events. This supports the assumption that critical pollutant concentrations are found in early-season, first-flush storm events.

Findings from the NSQD (Maestre et al., 2004) support industrial land use as a major source of zinc and copper in stormwater runoff. A median value of 112 µg/L dissolved zinc from industrial land use is higher than from other land uses evaluated in the study: residential, commercial, freeways, and open space. Three land uses were associated with similar median concentrations of dissolved copper: 8 µg/L for industrial land use, 7.6 µg/L for commercial, and 10.9 for freeways.





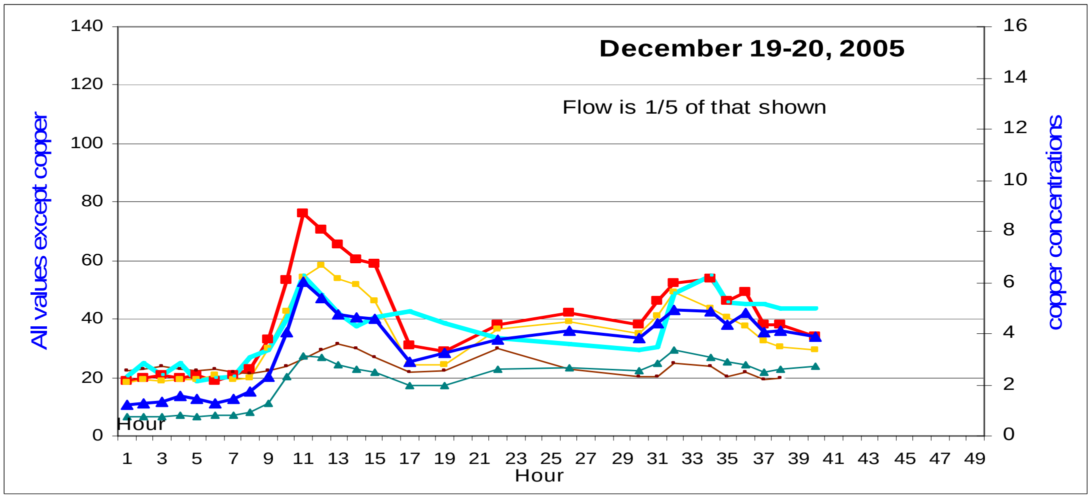


Figure 8. Complete Time Series of All Data Collected During Three Storm Events (Golding, 2005).

Rainfall

Measuring rainfall at the study site is always recommended. Simple tipping bucket rain gages are easy to install and, if electronically situated, can be real-time. Average rainfall statistics can be found in Ecology's stormwater manuals if actual field collection is not possible.

Each of the nationwide studies presented rainfall as an important and explanatory variable in stormwater monitoring. The Nationwide Urban Runoff Program (NURP) study by USGS divided the nation into three rain zones and found that the amount of rainfall was directly proportional to the stormwater pollutant load carried for all parameters. The municipal NPDES data in NSQD contained rainfall depth information, but about half of the events had serious data gaps for runoff volume data.

Given the difficulty of timing, weather variations, and logistics of storm weather sampling, the "representative" storm definition is basic and flexible. It is usually a good idea to monitor a broad range of storm conditions. Ecology regulations specify the "representative" storm as at least 0.1 inch of precipitation, preceded by only a trace of rainfall or less for a specified time period.

Examples of the minimum rainfall to initiate storm event sampling from previous Ecology studies range from 0.3 inches in western Washington to 0.1 inches in eastern Washington. Stormy weather in western Washington is usually characterized by long-duration, low-intensity storms over a wide geographical area. Often the storm fronts overlap, and there are few days with zero precipitation. On the other hand, eastern Washington storms have a more familiar storm pattern with higher rain intensities followed by periods of dryness. Consideration should be given to the imperviousness of the drainage area.

The typical "representative" storm criteria

Volume:	No fixed maximum. 0.1 inch minimum. Typical range is 0.2 to 0.75 inch
Duration:	Typical range is 6 to 24 hours
Antecedent Dry Period:	24 hours minimum
Inter-event Dry Period:	6 hours

Drainage Area

Surface water drainage from the landscape typically follows topography in most areas, with a common exception being urban areas. Coordination and information gathering from the local government is critical. Stormwater conveyance is sometimes pumped up hill to tie into drain pipes. Delineation may be necessary from source maps in USGS topography, GIS files, and Auto CAD files.

Delineating the project area will help to locate field sites, identify sources, reduce the effect of confounding pollutant sources, and help to establish jurisdictional authority. This will likely be a important part of identifying stakeholders in the watershed.

A site visit will be needed to identify storm drain outfalls and site peculiarities. The ideal field site may need access permission and have equipment storage. Some sites may be ruled out because of an inadequate staging area, the outfall would be underwater in the winter, or the site would be unsafe for field personnel.

Data Analysis

Stormwater Statistics

The large nationwide studies have agreed that most stormwater constituent data follow a lognormal distribution (EPA, 1983; Van Buren et al., 1997; Maestre et al., 2004). However, each researcher must check the data distribution.

A lognormal distribution means that the data do not follow a normal bell curve shape, nor do the data have small variances around the mean. Environmental data tend to be lognormal due to (1) the asymmetric shape of the data curve (usually positively skewed) with several high value data points, and (2) large variances around the mean.

Use of the lognormal distribution has the advantage of easily being transformed to a normal distribution for use in further statistical tests such as ANOVA. Typically, the log-transformed event mean concentration (EMC), median, and 5th and 95th percentiles are reported.

Studies that have characterized the data distributions are summarized in Table 7.

Table 7: Studies That Have Characterized Stormwater Data Distributions

Normal	Dissolved constituents are sometimes better described by a normal distribution (Van Buren, 1997).
Lognormal	All constituents in the NSQD study, minus total ammonia and chromium in freeway areas and NO_2+NO_3 in industrial areas, were well represented by the lognormal distribution (Maestre et al., 2005); PCB, DDE, dieldrin, fecal coliforms (Lubliner, 2006); and most *but not all* fecal coliform studies done by Ecology.
Gamma	Total solids, total Kjeldahl nitrogen (TKN), total phosphorous, chemical oxygen demand (COD), barium, and copper are best described by a gamma distribution (Behera et al., 2000). NO_2+NO_3 in industrial land uses and chromium in freeway areas were best fit to the gamma distribution (Maestre et al., 2004).
Exponential	Suspended solids, nitrates, and aluminum were best described by an exponential distribution (Behera et al., 2000). The exponential distribution better fit total ammonia in freeway areas (Maestre et al., 2004).

In most cases, the NSQD data provided acceptable levels of confidence and power using the Kolmogorov-Smimov “goodness of fit” test. Behera et al. (2000) in Toronto, Canada, found EMCs in both separate and combined sewer systems followed the gamma, exponential, and lognormal probability distributions.

High value data points often influence the mean and variance, and are in most cases real data points that cannot be treated as outliers. Knowing that the likely data distribution is lognormal, for example, is important so that the infrequent, yet truly high, value in the data set is not labeled an outlier and tossed. The high value data have a tremendous effect on the mean and variance, and therefore the validity, of the data set. Small sampling efforts or seasonally restrictive data sets may exclude these high value data points and improperly represent the range in stormwater pollutant concentrations.

Equally important is the effect of non-detects in a water quality data set. The number of non-detects and the methods of data analysis used were found to cause differences from 1 to 70% of the mean value, which would have significant impacts on estimations of constituent mass loading (Kayhanian et al., 2002).

Sample Number “N”

The variability in stormwater concentrations is high between outfalls and between storms. For example, Woodward-Clyde (1995) state that EPA regulations for municipal NPDES applicants must monitor three storm events; however, to obtain reasonably representative results, five storm events should be monitored. Statistical analysis for paired watershed measurements, differences between upstream vs. downstream, or trends over time will require even more data than a basic generalization study. Descriptive statistics can, however, reveal much about the samples even if the investigator cannot perform a more detailed examination.

Descriptive Statistics

- Mean and Median
- Variance
- Standard Deviation
- Coefficient of Variation
- Normality or Log Normality
- Skewness
- Kurtosis

If the standard deviation is large (or the coefficient of variation is 3 or more), going beyond the initial statistical analysis to hypothesis testing is probably not worthwhile. Instead the investigator should collect more samples or talk with a statistician about what question the data can answer.

Ecology has published several resources and protocols to ensure quality data and results. Following are websites listing documents and staff available to help in the study design, data management, and statistical analysis.

- Quality Assurance and Standard Operating Procedures:
  www.ecy.wa.gov/programs/eap/quality.html

- TMDL Modeling:
  www.ecy.wa.gov/programs/eap/models.html

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Appendices

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Appendix A.
Sources of Stormwater Pollutants

Review of National Studies

Impervious surface cover of the environment alters hydrology and geomorphology and, therefore, increases contaminant loading which results in predictable changes in stream habitat such as declines in the richness of algal, invertebrate, and fish communities in urban streams (Paul and Meyer, 2001).

The first nationwide stormwater study was published by EPA in 1983 based on data collected as part of the Nationwide Urban Runoff Program (NURP) that was established by the 1977 Clean Water Act. NURP sampled about 2300 storms from 1978 through 1982 to characterize runoff and nonpoint sources of pollution from urban areas. The NURP concluded that the amount of directly connected impervious surfaces to the drainage system is the most important factor affecting runoff volumes. Another conclusion was that pollutant concentrations of stormwater constituents did not vary significantly by land use. A large study by Camp, Dresser, McGee (CDM) used the NURP data and reached the same conclusion (Smullen and Cave, 2002).

On the contrary, the United States Geological Survey (USGS) found stormwater pollutant concentrations were significantly explained by several variables in regression models, including land use. Linear regression models were developed to estimate stormwater constituent loads, volumes, mean concentrations, and seasonal loads. Explanatory variables included total storm rainfall, impervious area, drainage area, land use, and climatic and physical characteristics. In descending order of significance, the explanatory variables were total storm rainfall, total contributing area, impervious area, land use, and mean annual climatic characteristics (Driver and Tasker, 1990).

A more recent study by Maestre et al. (2004), based on results from the National Stormwater Quality Database (NSQD, version 1.1), found that pollutant concentrations could be differentiated by land use, which counters the CDM and NURP findings. The NSQD was compiled from a portion of the Phase I NPDES (National Pollutant Discharge Elimination System) MS4 (municipal separate storm sewer system) stormwater permit holders. The data set covers, over a ten-year period, more than 200 municipalities throughout the U.S. NSQD uses a different data set from NURP, and 20 years separates the data (Pitt et al., 2003). Overall, the data ranges and event mean concentrations (EMCs) are similar to those found in NURP, with one clear exception: lead. An order of magnitude decrease in lead concentrations was attributed to the ban on leaded gasoline. In addition, the more recent data found that seasonal variations were not as important as geographical variations, except bacteria values were lowest in the winter and highest in summer.

Toxic Pollutants

Toxic pollutants can refer to a wide array of constituents that may affect biotic health in the environment, and ultimately human health. Often included are heavy metals, PCBs, PAHs, herbicides, pesticides, and many breakdown products. Bannerman et al. (1996) found that urban stormwater had high enough concentrations to degrade stream water quality in a study for the USGS in conjunction with the Wisconsin Department of Natural Resources. The pollutants monitored in the stormwater runoff were from four urban water quality monitoring projects for toxic constituents (lead, zinc, copper, silver, cadmium; nine PAHs; bis(2-ethylhexyl) phthalate; DDT; atrazine; Alachlor; and 2,4-D) and some conventional pollutants (suspended solids; chlorides; total phosphorus; BOD5; and bacteria) between 1989 and 1994.

Some toxic constituents are ubiquitous due to common historical use and atmospheric transport. Others occur only locally where released into the environment. Historical and current use of the environment may provide clues as to the suspected toxic constituents found in the local sediments, air, or water column. Land use may provide a reasonably confident explanation as to the sources of some toxic pollutants. For example, Smith (2000) found elevated PAH concentrations in stormwater runoff from (in decreasing order): gas stations, high-volume parking lots, highway off ramps, and low-volume parking lots. In a study by Qian and Anderson (1999) in the Willamette River basin, concentrations of four common pesticides and herbicides in stormwater were significantly related to land use, followed by geographic location, intensity of agriculture, and size of the watershed.

In the context of land use, the air-shed must also be considered, particularly for volatile or sprayed toxic pollutants such as PAHs, PCBs, herbicides, and pesticides. Several studies in the last decade have concluded that PCBs and PAHs in stormwater are atmospherically delivered, and should be considered an important source pathway (Datta et al., 1998; Atasi et al., 2000; Blanchard et al., 2001). PAHs appear to vary significantly by season both in the stormwater and atmospheric concentrations (Ozaki et al., 2001). The first flush has been observed for PAH (Smith et al., 2000; Shinya et al., 2000) and metals (Shinya et al., 2000). High-flow conditions were 20 times higher in PAH concentrations than baseflow concentrations (Crunkilton and Devita, 1997).

Fisher et al. (1999) found polychlorinated dioxins and furans (PCDD/Fs) in urban runoff entering Santa Monica Bay, California, peaked during storms, but the congener and isomer profiles resembled profiles found in lake sediments and rainwater more than they resembled profiles found in urban sources such as dioxins from incinerators or in contaminated commercial products. Wenning et al. (1999) found similar concentrations of PCDD/Fs in stormwater from areas adjacent to and distant from petroleum refineries. Industrialized areas and non-industrialized urban locations may represent important sources of PCDD/Fs to San Francisco Bay.

Many toxic pollutants exist preferentially bound to particulate matter. The Washington State Department of Ecology (Ecology) used the surrogate measure of total suspended solids for chlorinated pesticides in the wasteload and load allocations in the Yakima and Walla Walla River TMDL studies. PAH concentrations, particularly the higher molecular weight PAHs, are particulate bound (Shinya et al., 2000) and highest in the sediment layer, but Kucklick et al.

(1997) could not tie the concentrations directly to total organic carbon or grain size. The toxicity of stormwater runoff and sediments following four significantly-sized storms was monitored in Santa Monica Bay. The toxicity of offshore water samples was proportional to the concentration of runoff in the plume. Changes in grain size and total organic carbon (TOC) were also evident (Bay et al., 1998).

Fecal Coliform Bacteria

Fecal coliform bacteria are used by the state of Washington as indicators of pathogens associated with fecal contamination. Fecal pathogens are microorganisms capable of causing disease through ingestion and exposure to skin, eyes, ears, nose, and urinary orifices. Ingestion of fecal contaminated water is possible via direct consumption from contaminated water supplies or during recreation activities. Other indicators, such as E. coli and enterococci, have been evaluated as alternative or additional surrogates for pathogens under the triennial review of Washington State water quality standards. However, at the time of publication, fecal coliform bacteria remain the designated indicator (Roberts, 2003).

During precipitation events, rainwater washes the surface of the landscape, impervious surfaces, saturates soils, and raises water tables. Runoff of the stormwater can accumulate and transport fecal matter and deliver the load via stormwater drains to receiving waters and potentially degrade water quality.

Nonpoint (diffuse) Sources of Bacteria

Fecal coliform bacteria are produced in the intestines of warm-blooded mammals and are present in high concentrations in feces. Potential sources of fecal coliform bacteria include humans, domestic animals, and wildlife. Non-human sources in the urban environment range from non-commercial farms, equestrian centers, game farms, and manure-spreading operations to waterfowl rookeries, roosting pigeons, and rats.

Human wastes in stormwater runoff may come from surfaced wastewater from failing septic tank systems, broken sewer lines, or combined sewer overflows. Improperly maintained, poorly located, or failing septic systems prevent proper treatment of human waste by not allowing solids to settle to the bottom of a tank where they are decomposed through biological activity. When a system fails, the treatment process is incomplete and nutrients, bacteria, and other contaminants in sewage can reach groundwater, streams, or lakes. Leaks in sewer systems occur as the infrastructure ages and as surrounding soils are disturbed by construction or by tree roots. Human feces may enter recreational waters due to a lack of or improperly maintained toilet facilities. Moorage facilities such as marinas may be sources of bacteria due to improper boat toileting practices or faulty connections to the marina system.

Permitted Point Sources of Bacteria

- Municipal and industrial wastewater treatment plants
- State parks
- Boatyards

- Food packers and processors
- Washington State Department of Transportation
- Sand and gravel operations
- Dairy operations
- Stormwater, including stormwater from construction sites

Fecal coliform bacteria contaminants from municipal, industrial, and stormwater sources are regulated by various National Pollution Discharge Elimination System (NPDES), EPA, and general permits issued by Ecology.

A statewide general NPDES permit for the Washington State Department of Transportation (WSDOT) is currently under development at Ecology. The new general NPDES permit will require WSDOT to develop, implement, and enforce a Stormwater Management Program (SWMP). The SWMP will describe the procedures and practices WSDOT will use to reduce the discharge of pollutants from their existing stormwater system to the maximum extent practicable to protect water quality and make progress towards meeting water quality standards. The permit will also include requirements for implementing approved TMDLs applicable to WSDOT discharges statewide.

WSDOT currently applies their technical management manual, the Highway Runoff Manual (HRM), for designing stormwater control systems as part of transportation improvement projects. The HRM is the guidance document used by WSDOT, engineering consultants, and many local transportation agencies. The manual provides tools for highway design engineers to develop functional designs for stormwater collection, conveyance, and treatment systems for state highways, ferry terminals, park-and-ride lots, and other transportation-related stormwater utilities.

Ecology administers the Dairy Operations General Permit to cover dairy operations. On July 1, 2003, jurisdiction for the dairy waste program was transferred to the Washington State Department of Agriculture (WSDA) under the Livestock Nutrient Management Program. However, until EPA delegates permit authority to WSDA, Ecology will continue to administer the permit, with inspections performed by WSDA. The current general permit does not include specific provisions relating to a TMDL, but dairies are not allowed to discharge dairy waste to surface waterbodies except under catastrophic conditions. Waste storage facilities must be "… designed, constructed, and operated to treat all process-generated wastewater plus the runoff from a 25-year, 24-hour rainfall event…."

The construction stormwater general permit, effective December 2005, does have provisions for discharges to impaired waterbodies (which are listed for turbidity, fine sediment, high pH, and phosphorus). Specifically, Condition S8 requires these dischargers to conduct water quality sampling to verify that construction site discharges do not cause violations of water quality standards. If stormwater sampling shows that water quality standards are violated, then the construction site is assigned an effluent limit; see pages 18-21 in the construction stormwater general permit.
www.ecy.wa.gov/programs/wq/stormwater/construction/construction_final_permit.pdf

Appendix B.
Websites for Sampling Design

Delineating a Subwatershed

Center for Watershed Protection Slideshow presented at the Storm Center website:
www.stormwatercenter.net/

There are six basic steps to delineating the boundary of a subwatershed:

1. Define the origin
2. Evaluate surrounding topography
3. Identify breakpoints
4. Connect breakpoints
5. Double check
6. Measure the area

EPA Water Quality Supported Models

- BASINS: A Powerful Tool for Managing Watersheds

- AQUATOX: A Simulation Model for Aquatic Ecosystems

  www.warrenpinnacle.com/prof/AQUATOX/AQUATOX.html
  www.epa.gov/waterscience/models/aquatox/
  www.epa.gov/waterscience/models/aquatox/training/

- CORMIX for Mixing Zones
  A mixing zone model that can be used to assess water quality impacts from point source discharges at surface or sub-surface levels.

- WASP6
  WASP6 is an enhanced version of the Water Quality Analysis Simulation Program (WASP). This version runs more quickly than previous versions of WASP, and allows for graphical presentation of results. This version includes kinetic algorithms for (1) eutrophication/conventional pollutants, (2) organic chemicals/metals, (3) mercury, and (4) temperation, fecal coliform, and conservative pollutants.

- QUAL2K model

- EPA Center for Exposure Assessment Modeling
  The Center for Exposure Assessment Modeling (CEAM) was established in 1987 to meet the scientific and technical exposure assessment needs of the United States Environmental Protection Agency (EPA) as well as state environmental and resource management agencies. CEAM provides proven predictive exposure assessment techniques for aquatic, terrestrial, and multimedia pathways for organic chemicals and metals. www.epa.gov/ceampubl/

- Council for Regulatory Environmental Modeling (CREM) Models Knowledge Base

- EPA Watershed/Water Quality Modeling Technical Support Center
  The Watershed/Water Quality Modeling Technical Support Center assists EPA regions, state and local governments, and their contractors by providing access to technically defensible tools and approaches that can be used to develop Total Maximum Daily Loads (TMDLs), wasteload allocations, and watershed protection plans. The Center also provides a pathway for bringing ORD research efforts into "real world" applications.

Load Duration Curves

www.tmdls.net/index.htm

Models and Tools Supported by Ecology for TMDL Studies

www.ecy.wa.gov/programs/eap/models/index.html

USGS Table of Model Characteristics

http://smig.usgs.gov/cgi-bin/SMIC/gen_table?dimensions=all&domains=all&constituents=all&models=all&list_gen=SMIChtml

	Name	Type	GUI	Domains
Flow Only	BRANCH	1-D	no	rivers, estuaries, channel networks
	CH3D-WES	3-D	yes	rivers, lakes, estuaries, reservoirs, coastal areas
	DAFLOW	1-D	U	rivers, channel networks
	DR$_3$M	watershed	no	watersheds, channel networks
	DYNHYD5	1-D	W	rivers, estuaries
	FEQ	1-D	W	rivers, channel networks
	FESWMS	2-D (h)	U/W	rivers, lakes, estuaries, reservoirs, coastal areas
	FourPt	1-D	no	rivers, channel networks
	HEC-HMS	watershed	W	watersheds, channel networks
	HEC-RAS	1-D	W	rivers, channel networks
	RMA2	2-D (h)	U/W	rivers, lakes, estuaries, reservoirs, coastal areas
	TOPMODEL	watershed	U/W	watersheds, channel networks
	UNET	1-D	W*	rivers, channel networks
Transport Only	BLTM	1-D	no	rivers, estuaries
	CE-QUAL-ICM	1,2,3-D	U/W*	rivers, lakes, estuaries, reservoirs, coastal areas
	CE-QUAL-R1	1-D (v)	no	reservoirs, lakes
	OTEQ	1-D (l)	no	rivers
	OTIS	1-D (l)	no	rivers
	RMA4	2-D (h)	U/W	rivers, lakes, estuaries, reservoirs, coastal areas
	SED-2D	2-D (h)	U/W	rivers, lakes, estuaries, reservoirs, coastal areas
	WASP5	1, 2, 3-D	W	rivers, lakes, estuaries, reservoirs, coastal areas
Flow and Constituent Transport	CE-QUAL-RIV1	1-D (l)	no	rivers, channel networks
	CE-QUAL-W2	2-D (v)	U/W*	rivers, reservoirs, estuaries
	EFDC/HEM3D	1,2,3-D	W*	rivers, lakes, estuaries, reservoirs, coastal areas
	HSPF	watershed	W	watersheds, channel networks
	MIKE 11	1-D (l)	W	estuaries, rivers, channel networks
	MIKE 21	2-D (h)	W	estuaries, coastal areas
	MIKE 3	3-D	U/W	rivers, lakes, estuaries, reservoirs, coastal areas
	MIKE SHE	watershed	W	watersheds, channel networks
	PRMS	watershed	U	watersheds, channel networks
	QUAL2E	1-D (l)	W	rivers, channel networks
	RMA10	3-D	U/W	rivers, lakes, estuaries, reservoirs, coastal areas
	SNTEMP	1-D (l)	no	rivers, channel networks
	SSTEMP	1-D (l)	W	rivers, channel networks
Model Systems	BASINS	System	W	watersheds, rivers, channel networks
	GenScn	System	W	watersheds, rivers, channel networks
	MMS	System	U	watersheds, channel networks
	SMS	System	U/W	rivers, lakes, estuaries, reservoirs, coastal areas

Type: (l)=longitudinal, (v)=vertical, (h)=horizontal
GUI: W, runs on Windows OS; U, runs on Unix OS; *, not currently available but in progress

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Appendix C.
Ecology's Stormwater Case Studies

The following studies were conducted by the Department of Ecology. These are presented as examples of study decisions that have been made in the past. As more information about stormwater models, land use data, and new technologies become available, there will undoubtedly be an evolution in the way studies are conducted by Ecology.

Toxics Studies

Draft Spokane PCB TMDL - by *Posteriori* Simple Method

Serdar, D., K. Kinney, and P. Hallinan, 2006 (draft). Spokane River PCBs Total Maximum Daily Load Study (draft report). Washington State Department of Ecology, Olympia, WA. Publication No. 06-03-024. www.ecy.wa.gov/biblio/0603024.html

Four storm drain catch basins were sampled during one storm event to ascertain the PCB load contributions made to the Spokane River by stormwater from the City of Spokane. Although these stormwater samples were collected during this one-time event and carry no weight as a 'representative' sample, the concentrations in the four samples indicate the potential for stormwater to be a PCB source to the Spokane River. The Simple Method (Schueler, 1987) was used. The average pollutant concentration of the four drains was multiplied by the impervious fraction, annual rainfall, and area draining to the Spokane River. This resulted in the largest reduction of PCBs being aimed at the stormwater load (~90%). This study is in draft form; therefore, the above recommendations may change.

Palouse Pilot Project - by Simple Method

Lubliner, B., 2006. Pullman Stormwater Pilot Study for Pesticides, PCBs, and Fecal Coliform Bacteria, 2005-2006. Washington State Department of Ecology, Olympia, WA. Publication No. 06-03-034. www.ecy.wa.gov/biblio/0603034.html

A pilot study was undertaken to determine the concentrations of chlorinated pesticides, PCBs, and fecal coliform bacteria in stormwater from three storm drain outfalls in Pullman. The outfalls were sampled using simple grabs during three storm events from December 2005 to April 2006.

PCBs, fecal coliform bacteria, and 4,4′-DDE were detected in all stormwater samples from Pullman storm drain outfalls. Dieldrin and heptachlor epoxide were detected in all but one stormwater sample. These detections and estimated loads will be considered in the upcoming Palouse River Toxics TMDL study.

Many of the toxic pollutant detections were near the reporting limits, and all detections were qualified as estimates due to the interfering "dirtiness" of the stormwater matrix. Individual stormwater concentrations for dieldrin and PCBs were below aquatic life criteria. The highest dieldrin concentration, 5.0 ng/L, was 2000 times lower than the acute instream criteria. The highest measured PCB concentration, 45.3 ng/L, was roughly 23 times lower than the acute instream criteria. There is undoubtedly a cumulative load from many storm drains to the same waterbody that may affect the river concentrations of these toxic compounds. However, neither the South Fork Palouse River nor Missouri Flat Creek were sampled as part of this stormwater pilot study. The Palouse River Toxics TMDL study, which is in progress, will assess the risk to aquatic life and human health criteria from these pollutants. The chronic aquatic life criteria are not appropriate for stormwater samples without year-round sampling from the storm drains to assess the chronic exposure.

The bacterial concentrations from the three Pullman storm drains were highly variable (39 – 4900 cfu) which was anticipated from stormwater. The data followed a lognormal distribution.

The annual mass loads of the toxic 303(d) listed pesticides, PCBs, and fecal coliforms were estimated from the measured concentrations using the Simple Method (Schueler, 1987). The impervious cover was estimated from city maps, literature values, and the density of development as visually estimated. The developed portions of the city center are around the university and close to the downtown area. However, large housing developments are expanding into the open areas; therefore, the imperviousness of Pullman is expected to rapidly change in the near future.

Table C-1: Comparative Imperviousness by Land Use and Assigned Values (%) Used in the Palouse Stormwater Pilot Study.

Land Use	Hill et al., 2003[a]		NSQD[b]	Palouse Pilot Study
	TIA	EIA	TIA	TIA
Low density residential (1 unit per 2-5 acres)	10	4	-	15
Medium density residential (1 unit per acre)	20	10	-	35
"Suburban" density (4 units per acre)	35	24	42-45	
High density (multi-family or 8+units per acre)	60	48		40
Commercial / Industrial/ Institutional	90	86	83/70	50
Open Space			4	15

[a] Hill et al. (2003), originally compiled by Dinicola (1989).

[b] National Stormwater Quality Database (Maestre et al., 2004).

TIA - total impervious area

EIA - effective impervious area

A weighting factor was developed by multiplying the literature-based impervious percentage by the percent of coverage in Pullman to find the percentage of area that has each degree of imperviousness. This weighting factor was then summed to find the imperviousness of the city as a whole. The overall imperviousness of 25% seems relatively low for a town of Pullman's population. This may be a result of large agricultural or undeveloped areas within the city limits.

The total annual load was calculated based on the mean concentration for each 303(d) listed pollutant and the annual runoff, calculated using the Simple Method. A non-detect was included in the mean as one-third of the reporting limit, to avoid overestimation by simply averaging the detected values.

Table C-2: Simple Method Load Estimations for 303(d) Listed Toxics in Pullman Stormwater.

303(d) Listed Pollutants	Mean Pollutant Concentration[1] (ng/L)	Daily Load (mg/day)	Annual Load (lbs/yr)
4,4'-DDE	2.16	18.7	0.015
alpha-BHC	0.27	2.4	0.002
dieldrin	1.18	10.2	0.008
heptachlor epoxide	0.23	2.0	0.002
total PCBs	15.23	132.1	0.106

[1] Mean concentration from all stormwater samples taken during the pilot study, 2005-06.

High variability in fecal coliform bacteria counts from nonpoint (diffuse) stormwater sources was expected, given that only three storm events were sampled. These loads ranged from 3.4x10^4 to 1.8x10^6 cfu/year. There does not appear to be a clear cause-and-effect relationship between discharge and bacterial concentration. More samples are needed to gain statistical confidence in the mean value.

Walla Walla TMDLs - Toxics and Fecal Coliform Bacteria

Johnson et al. (2004)[1] developed a TMDL for chlorinated pesticides/breakdown products and PCBs in the Walla Walla River drainage. Much of the work was based on a TMDL evaluation of the lower Yakima River basin in 1994-95 (Joy and Patterson, 1997)[2], that found a strong correlation between total suspended sediment (TSS) and DDT loads from irrigated agricultural areas during the irrigation season. In the Walla Walla TMDL, no stormwater monitoring was done, and no phase II areas existed. A PCB wasteload allocation was restricted to the wastewater treatment plants (WWTPs), and the load allocation was considered to be the nonpoint sources. The Mill Creek and College Place WWTPs need to meet the instream criteria for PCBs at the end-of-pipe.

Joy and Swanson (2005)[3] conducted a fecal coliform TMDL study on the Walla Walla River. The following waterbodies were given fecal coliform load reduction targets: the Walla Walla and Touchet rivers; the west branch of the Little Walla Walla River; and Dry, Pine, Mud, Mill, Garrison, Yellowhawk, Russell, and Cottonwood creeks. The WWTPs for the cities of Dayton, College Place, and Walla Walla, as well as potential Phase 2 municipal stormwater permittees, were given fecal coliform wasteload allocations.

To reduce the impact of stormwater runoff for permit holders in the Walla Walla basin (cities, county, and WSDOT), EPA suggested that the fecal coliform wasteload allocations be equivalent to the reduction needed in the receiving water reach. For example, runoff from Highways 125 and 12 would be required to have best management practices (BMPs) in place to ensure fecal coliform bacteria reductions of 6% at the Walla Walla River crossing, 94% at Mill Creek, and 42% on Yellowhawk Creek. Any future municipal stormwater permits will require specific plans and evaluations of stormwater BMPs to meet instream fecal coliform targets.

References

[1] Johnson, A., B. Era-Miller, R. Coots, and S. Golding, 2004. A Total Maximum Daily Load Evaluation for Chlorinated Pesticides and PCBs in the Walla Walla River. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-032. www.ecy.wa.gov/biblio/0403032.html

[2] Joy, J. and B. Patterson, 1997. A Suspended Sediment and DDT Total Maximum Daily Load Evaluation Report for the Yakima River. Washington State Department of Ecology, Olympia, WA. Publication No. 97-321. www.ecy.wa.gov/biblio/97321.html

[3] Joy, J. and T. Swanson, 2005. Walla Walla River Basin Fecal Coliform Bacteria Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication No. 05-03-041. www.ecy.wa.gov/biblio/0503041.html

Stormwater Toxics Source Tracking Study (Non-TMDL)

Cubbage, J., 1995. Drainage Basin Tracing Study: Phase II Chemicals Found in Storm Drains and Outfalls to Sinclair and Dyes Inlets, Washington. Washington State Department of Ecology, Olympia, WA. Publication No. 95-342. www.ecy.wa.gov/biblio/95342.html

This study used previously collected sediment quality data to investigate pollutant sources in particularly polluting drainages. Cubbage investigated more storm drains (both new and old) and compared concentrations in sediments and water. He delineated some branching storm drain systems to find high concentration branches relative to the others:

- Sediment samples from near end-of-line catch basins were collected with a pivoting scoop or Ponar grab sampler. Field personnel did not enter any manholes or catch basins.
- A continuous centrifuge was used in one case where there was no residual or accumulating sediment at the catch basin.
- Water samples were collected using a common stainless steal beaker on a pole, and the device was cleaned between sites.

Because all these storm drains were discharging to marine waters, Cubbage compared the sediment and water concentrations in the storm drains to the marine standards.

Bacteria Studies

East Fork Lewis River Bacteria TMDL

Bilhimer, D., L. Sullivan, and S. Brock, 2005. Quality Assurance Project Plan: East Fork Lewis River Temperature and Fecal Coliform Bacteria Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication No. 05-03-110. www.ecy.wa.gov/biblio/0503110.html

The objectives of a TMDL study are usually met through characterizing annual and seasonal pollutant concentrations, using both a fixed network and a seasonal network of field sites. Fecal coliform monitoring often spans one year so that data will represent all seasonal conditions. For example, 16 months of fecal coliform and flow data were collected in the East Fork Lewis River TMDL to calculate basic fecal coliform concentration and loading data in various reaches of the watershed (Bilhimer et al., 2005). Seasonal sampling isolates critical conditions for water quality impairments.

In the ongoing Palouse River Fecal Coliform TMDL study (Carroll and Mathieu, 2006), data from the fixed-network is sampled bi-monthly to provide fecal coliform data sets to meet the following needs:

- Provide an estimate of the annual and seasonal geometric mean and 90th percentile fecal coliform counts.
- Provide reach-specific fecal coliform load and concentration comparisons to define areas of increased fecal coliform loading (e.g., malfunctioning on-site sewage systems, livestock, wildlife, or manure spreading) or fecal coliform decreases (e.g., settling with sediment, die-off, dilution, or diversion). With accurate streamflow monitoring, tributary and source loads also can be estimated.
- Help delineate jurisdictional responsibilities for fecal coliform sources.
- Determine the impact of various land uses on instream changes of fecal coliform concentrations.

Stillaguamish TMDL - by *Posteriori* Simple Method

Joy, Joe, 2004. Stillaguamish River Watershed Fecal Coliform, Dissolved Oxygen, pH, Mercury, and Arsenic Total Maximum Daily Load Study. Publication No. 04-03-017. www.ecy.wa.gov/biblio/0403017.html

The Stillaguamish Basin TMDL (2004) project originally covered fecal coliform bacteria, dissolved oxygen, pH, and arsenic issues on both major forks, the mainstem Stillaguamish River, several tributaries, and Port Susan. Many reaches of the Stillaguamish River, most tributaries, and Port Susan had seasonal fecal coliform problems. Freshwater fecal coliform load reductions recommended in the TMDL assessment should bring both freshwater reaches and Port Susan back into compliance with criteria.

The EPA's directive to include stormwater as a wasteload allocation came in 2002, just after all data collection efforts for the TMDL were completed. To comply with the EPA directive, stormwater fecal coliform loads from the five jurisdictions were estimated using the Simple Method model (Stormwater Center, 2004). The model requires the sub-basin drainage area and impervious cover, stormwater runoff pollutant concentrations, and annual precipitation. The land uses in each sub-basin were categorized as residential, commercial/industrial, agricultural, forest, and roadway. Fecal coliform loads were calculated for each category to judge its relative importance to fecal coliform loading.

Assumptions were made about the landscape complexity or scales. The researchers used available local data and the upper quartile range of mean concentrations. A Margin of Safety for imperviousness was incorporated. Wasteload allocation estimates for Snohomish County and WSDOT (both Phase I) were calculated on roadway areas, and Arlington (Phase II) wasteload allocations were estimated from all land uses within the city limits. Stormwater from all land uses within the city of Arlington boundary was used for the wasteload allocation because the infrastructure of the city was assumed to be dense enough to carry all runoff.

Assumptions

- All parcels of land in a land-use category contribute same pollutant load
- Land uses have not significantly changed since coverage was made
- Adjacent land is not contributing pollutants to roadway
- Base-flow pollutant load is insignificant compared to storm load
- There is no die-off or treatment between source and receiving water

Lag-time of pollutant delivery over relatively large geographic areas is not important.

The TMDL evaluation demonstrated that fecal coliform bacteria criteria violations are prevalent throughout the lower Stillaguamish River basin, especially during storm events.

South Prairie Creek Bacteria TMDL

Roberts, M., 2003. South Prairie Creek Bacteria and Temperature Total Maximum Daily Load Study. Washington State Department of Ecology. Publication No. 03-03-021
www.ecy.wa.gov/biblio/0303021.html

Historical fecal coliform bacteria concentrations along lower South Prairie Creek exceeded water quality standards, resulting in inclusion on the 1996 and 1998 federal Clean Water Act section 303(d) lists. This study identifies and quantifies the sources of fecal coliform bacteria from Spiketon Road in Buckley to the confluence with the Carbon River. The South Prairie Creek load allocations call for fecal coliform load reductions downstream of the town of South Prairie.

In addition, fecal coliform loads must be reduced in Spiketon Creek/Ditch and in the unnamed tributary leaving the town of South Prairie. The unnamed tributary originates in the town of South Prairie and conveys groundwater and stormwater; this tributary is covered under NPDES permit number WASM11002.

The tributary had very high concentrations of fecal coliform bacteria during the 2001 monitoring program. Because the ditch is part of Pierce County's stormwater infrastructure, the reduction factor (calculated using the Rollback method) is considered a wasteload allocation. Bacteria levels must be reduced by 63% at State Route 162 and by 90% at the tributary mouth.

Deschutes River/Capitol Lake Bacteria TMDL

Roberts, M., B. Zalewsky, T. Swanson, L. Sullivan, K. Sinclair, and M. LeMoine, 2004. Quality Assurance Project Plan: Deschutes River, Capitol Lake, and Budd Inlet Temperature, Fecal Coliform Bacteria, Dissolved Oxygen, pH, and Fine Sediment Total Maximum Daily Load Study. Washington State Department of Ecology. Publication No. 04-03-103. www.ecy.wa.gov/pubs/0403103.pdf

A TMDL study is in progress to study fecal coliform concentrations (among other pollutants) in the Deschutes River watershed. Roberts et al. (2004) planned to conduct two rounds of dry-weather stormwater outfall monitoring in late summer 2004 at up to 25 locations. A subset of sites was planned to be sampled over three to six storm events, two to four times over the storm.

This sampling protocol is based on an earlier 2003 reconnaissance study that had identified 12 stormwater outfalls representing a variety of catchment land uses. Ten stormwater outfalls were visited on October 14, 2003 to verify locations and to collect a sample of the pipe-carried water. Three of ten pipes had flowing water, but fecal coliform levels were low.

Deschutes Wet Weather Survey Observations, So Far

Storms were difficult to catch during the wet season:

- Too low intensity at too frequent recurrence intervals (western Washington) or geographically limited cloudbursts (eastern Washington).
- Too short duration.
- Weekend occurrence without lab support.
- Sampling more than twice at each site for fecal coliform was not possible, even when the geographic scope was reduced.

Other References

Ecology, 2004. Stormwater Management Manual for Eastern Washington. Washington State Department of Ecology, Olympia, WA. Publication No. 04-10-076. www.ecy.wa.gov/biblio/0410076.html

Schueler, T.R., 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Publication No. 87703. Metropolitan Washington Council of Governments, Washington, DC.

Schueler, T.R., 2000. The importance of imperviousness. Watershed Protection Techniques 1(3):100-111.

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Appendix D.
National Pollutant Concentrations

Pollutant Median Concentration by Land use, from the NSQD Version 1.1 results published by Pitt et al. (2004).

Table 1, Summary of Available Stormwater Data Included in NSQD, version 1.1, presents 11 land uses and 39 parameters. The number of observations, the number of samples above detection, median value, and the coefficient of variation are provided. The table is not shown in this report; however, it can be accessed through the following link: http://unix.eng.ua.edu/~rpitt/Research/ms4/Paper/MS4%20Feb%2016%202004%20paper.pdf

A summary of the following land uses and measured parameters is available from the following link, www.cwp.org/NPDES_research_report.pdf.

Land Uses (Number of Observations)

- Overall Summary (3765)
- Residential (1042)
- Mixed Residential (611)
- Commercial (527)
- Mixed Commercial (324)
- Industrial (566)
- Mixed Industrial (218)
- Institutional (18)
- Freeways (185)
- Mixed Freeways (26)
- Open Space (49)
- Mixed Open Space (168)

Measured Parameters

- Area (acres)
- % Impervious
- Precipitation Depth (in)
- Runoff Depth (in)
- Oil and Grease (mg/L)
- pH
- Temperature (C)
- BOD5 (mg/L)
- COD (mg/L)
- TDS (mg/L)
- TSS (mg/L)
- Conductivity (µS/cm 25ºC)
- Hardness (mg/L CaCO3)
- Fecal Coliform (mpn/100 mL)
- Fecal Streptococcus (mpn/100 mL)
- Total Coliform (mpn/100 mL)
- Total E. Coli (mpn/100 mL)
- NH3 (mg/L)
- N02+NO3 (mg/L)
- Nitrogen, Total Kjeldahl (mg/L)
- Phosphorus, filtered (mg/L)
- Phosphorus, total (mg/L)
- Sb, total (µg/L)
- As, total (µg/L)
- As, filtered (µg/L)
- Be, total (µg/L)
- Cd, total (µg/L)
- Cd, filtered (µg/L)
- Cr, total (µg/L)
- Cr, filtered (µg/L)
- Cu, total (µg/L)
- Cu, filtered (µg/L)
- Pb, total (µg/L)
- Pb, filtered (µg/L)
- Hg, total (µg/L)
- Ni, total (µg/l)
- Ni, filtered (µg/L)
- Zn, total (µg/L)
- Zn, filtered (µg/L)

From an additional paper accessed from the same parent websites, several summary tables of selected PAH and pesticide data from the NSQD database were compiled as in Table D-1 below. The dataset for toxic organic measurement was much smaller. The authors noted that several hundred events were compiled to produce these overall summary values. The detection rate for these samples ranged from 15 to 35%.

Table D-1: Summary of Selected Organic Information in NSQD, version 1.0 (ug/L).

	Methylene chloride	Bis (2-ethylhexyl) phthalate	Di-n-butyl phthalate	Fluor-anthene	Phen-anthrene	Pyrene	Diazinon	2,4-D
Number of observations	251	250	93	259	233	249	79	101
% of samples above detection	36	30	16	19	13	14	22	35
Median of detected values	11.2	9.5	0.8	6	3.95	5.2	0.06	3
Coefficient of variation	0.77	1.13	1.03	1.31	1	1.24	1.9	0.86

Copied from www.cwp.org/NPDES_research_report.pdf and also presented http://rpitt.eng.ua.edu/Research/ms4/Paper/NSQD%20ver%201%20aug%206%202003.pdf

Table D-2: Median Comparisons between NSQD and NURP (1983).

Parameter	Overall		Residential		Commercial		Open Space	
	NSQD	NURP	NSQD	NURP	NSQD	NURP	NSQD	NURP
Area (acres):	56	68.5	57.3	57.5	38.8	27.5	73.5	3,775
BOD5 (mg/L)	8.6	9	9	10	11.9	9.3	NA	NA
COD (mg/L)	53	65	55	73	63	57	21	40
TSS (mg/L)	58	100	48	101	43	69	51	70
Pb, total (ug/L)	16	144	12	144	18	104	5	30
Cu, total (ug/L)	16	34	12	33	17	29	NA	NA
Zn, total (ug/L)	116	160	73	135	150	226	39	195
Nitrogen, Total Kjeldahl (mg/L)	1.4	1.5	1.4	1.9	1.6	1.18	0.6	0.97
N02+NO3 (mg/L)	0.6	0.68	0.6	0.74	0.6	0.57	0.6	0.54
Phos., filtered (mg/L)	0.27	0.33	0.3	0.38	0.22	0.2	0.25	0.12
Phos., total (mg/L)	0.12	0.12	0.17	0.14	0.11	0.08	0.08	0.03

Copied from www.cwp.org/NPDES_research_report.pdf.

NSQD –National Stormwater Quality Database
NURP – Nationwide Urban Runoff Program

The Stormwater Center has put together a table of concentrations found for a variety of parameters across the country to be used in the Simple Method model. These concentrations are averaged across different land uses. This table can be found at the website www.stormwatercenter.net, following the monitor/assess bullet and selecting the Simple Method link.

Table D-3: Urban "C" Values for Use with the Simple Method (mg/l)

Pollutant	New Suburban NURP Sites (Wash., DC)	Older Urban Areas (Baltimore)	Central Business District (Wash., DC)	National NURP Study Average	Hardwood Forest (N. Virginia)	National Urban Highway Runoff
Phosphorus						
Total	0.26	1.08	-	0.46	0.15	-
Ortho	0.12	0.26	1.01	-	0.02	-
Soluble	0.16	-	-	0.16	0.04	0.59
Organic	0.10	0.82	-	0.13	0.11	-
Nitrogen						
Total	2.00	13.6	2.17	3.31	0.78	-
Nitrate	0.48	8.9	0.84	0.96	0.17	-
Ammonia	0.26	1.1	-	-	0.07	-
Organic	1.25	-	-	-	0.54	-
TKN	1.51	7.2	1.49	2.35	0.61	2.72
COD	35.6	163.0	-	90.8	>40.0	124.0
BOD (5 day)	5.1	-	36.0	11.9	-	-
Metals						
Zinc	0.037	0.397	0.250	0.176	-	0.380
Lead	0.018	0.389	0.370	0.180	-	0.350
Copper	-	0.105	-	0.047	-	-

Copied from the www.stormwatercenter.net website on 11/28/2006.

NURP – Nationwide Urban Runoff Program

Ecology published the *Stormwater Management Manual for Eastern Washington* in 2004 which created two references (Table 1.1 and Table 1.2 in the manual) for typical concentrations of a limited number of pollutants found in urban stormwater runoff. The pollutant concentrations in stormwater runoff from arid watersheds tend to be higher than concentrations from humid watersheds, since rain events are infrequent and pollutants have more time to accumulate on impervious surfaces. Pervious areas in arid and semi-arid regions also tend to produce higher sediment and organic carbon concentrations because the sparse vegetative cover does little to prevent soil erosion in uplands and along channels when it does rain. There is not likely to be data for some parameters, and stormwater runoff sampling may be required.

Table D-4: Mean concentrations of selected pollutants in urban stormwater runoff across the United States and in arid and semi-arid regions.

Location	Total Suspended Solids (mg/L)	Total Copper (ug/L)	Total Zinc (ug/L)	Total Lead (ug/L)	Total Phosphorus (ug/L)
National Average	78	14	162	68	320
Phoenix, AZ	227	47	204	72	410
Boise, ID	116	34	342	46	750
Denver, CO	384	60	350	250	800
San Jose, CA	258	58	500	105	830
Dallas, TX	663	40	540	330	780

Original Source: Several studies summarized in Watershed Protection Techniques, Vol. 3 No. 3, March 2000.

Table D-5 shows typical concentrations of a limited number of pollutants from stormwater runoff generated by different land uses. This table is also found in the *Stormwater Management Manual for Eastern Washington* (Table 1.2).

Table D-5: Mean concentrations of selected pollutants in stormwater runoff from different land uses in the state of Oregon.

Land Use	Total Suspended Solids (mg/L)	Total Copper (ug/L)	Dissolved Copper (ug/L)	Total Zinc (ug/L)	Total Phosphorus (ug/L)
In-pipe industry	194	53	9	629	633
Instream industry	102	24	7	274	509
Transportation	169	35	8	236	376
Commercial	92	32	9	168	391
Residential	64	14	6	108	365
Open	58	4	4	25	166

Note: In-pipe industry means the samples were taken in stormwater pipes. Instream industry means the samples were taken in streams flowing through industrial areas. Samples for all other categories were taken from within stormwater pipes. Original Source: Strecker et al., 1997.

References

Ecology, 2004. Stormwater Management Manual for Eastern Washington. Washington State Department of Ecology. Publication No. 04-10-076. www.ecy.wa.gov/pubs/0410076.pdf

EPA, 1983. Results of the Nationwide Urban Runoff Program. Water Planning Division, U.S. Environmental Protection Agency, Washington, D.C. PB 84-185552, December 1983.

Maestre, A., Pitt, R.E., and R. Morquecho, 2004. "Nonparametric statistical tests comparing first flush with composite samples from the NPDES Phase 1 municipal stormwater monitoring data." Stormwater and Urban Water Systems Modeling. In: Models and Applications to Urban Water Systems, Vol. 12 (edited by W. James). CHI. Guelph, Ontario. http://unix.eng.ua.edu/~rpitt/Research/ms4/Paper/MS4%20Feb%2016%202004%20paper.pdf

Pitt, R., A. Maestre, and R. Morquecho, 2003. The National Stormwater Quality Database (NSQD, version 1.0). Water Environment Federation Technical Exposition and Conference, Los Angeles.
http://rpitt.eng.ua.edu/Research/ms4/Paper/NSQD%20ver%201%20aug%206%202003.pdf

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www.cwp.org/NPDES_research_report.pdf.

Strecker, E.W. et al., 1997. Analysis of Oregon Urban Runoff Water Quality Monitoring Data Collected from 1990 to 1996, Oregon Association of Clean Water Agencies.

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Appendix E.
TMDL Studies with Incorporated Stormwater Loads Conducted by Other States

Organic Toxics

San Francisco Bay - PCB
- www.waterboards.ca.gov/sanfranciscobay/TMDL/sfbaypcbstmdl.htm
- www.waterboards.ca.gov/sanfranciscobay/TMDL/SFBayPCBs/pcbs_tmdl_project_report 010804.pdf
- www.ecoatlas.org/help/arcimshowtopcb.html

Oxon Run (Anacostia River Watershed), Penn - Chlordane, DDT
- www.epa.gov/reg3wapd/tmdl/dc_tmdl/OxonRun/OxonO&M&Bact_DR.pdf
- EPA, 2004. Decision Rational Total Maximum Daily Loads Oxon Run (Anacostia River Watershed) For Organics, Metals and Bacteria. USEPA Region III. Philadelphia, Penn. 19103-2029. December 15, 2004

Delaware River and Estuary - PCB
- www.epa.gov/reg3wapd/tmdl/pa_tmdl/DelawareRiver/index.htm
- www.epa.gov/reg3wapd/tmdl/de_tmdl/Zone6DelRvPCB/index.html

Metals

San Francisco Bay - Mercury
- www.waterboards.ca.gov/sanfranciscobay/TMDL/sfbaymercurytmdl.htm
- www.waterboards.ca.gov/sanfranciscobay/TMDL/walkermercurytmdl.htm

Great Lakes - Mercury
- www.epa.gov/glnpo/bnsdocs/hgsbook/

Pesticides

San Francisco Bay Urban Creeks - Diazinon
- www.waterboards.ca.gov/sanfranciscobay/TMDL/urbancrksdiazinontmdl.htm

Bacteria

Kansas Load Duration Curve Method
- www.kdheks.gov/tmdl/basic.htm#data

Oxon Run (Anacostia River Watershed), Penn
- www.epa.gov/reg3wapd/tmdl/dc_tmdl/OxonRun/OxonO&M&Bact_DR.pdf