United States
Environmental Protection
Agency

Office Of
The Administrator
(A-101F6)

EPA 101/F-90/046
January 1991

EPA

Urban Storm Water Runoff And Ground-Water Quality

#90-2304

Printed on Recycled Paper

URBAN STORM WATER RUNOFF AND GROUND-WATER QUALITY

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November 26, 1990

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National Network for Environmental Management Studies
U.S. Environmental Protection Agency

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ABSTRACT

Urban storm water runoff is a form of nonpoint source pollution which is intimately tied to the hydrologic cycle, human activities, and urbanization. Traditionally, scientific research, water resource management, and regulations have focused on the effects of urban storm water on surface water quality, and seldom on ground-water quality. The Safe Drinking Water Act and other narrowly focused federal legislation, along with state and local laws and ordinances, provide a legislative patchwork that attempts to protect the nation's ground-water quality. A clear and enforceable comprehensive federal policy protecting ground-water quality is needed to provide direction to state and local governments.

The purpose of this report is to provide a summary of information and key references on urban storm water in relation to ground-water protection for United States Environmental Protection Agency (EPA) staff and others responsible for protecting ground-water quality. This report presents a brief overview of the major literature describing: 1) the quality and chemistry of urban storm water runoff, 2) its effects on ground-water resources, and 3) current management practices, strategies, and regulations that attempt to reduce ground-water contamination from urban storm water. Also included is a selected bibliography and list of contacts at the federal, state, and local levels of government.

PREFACE

This report was made possible by a fellowship grant from the National Network of Environmental Management Studies Program of the U.S. Environmental Protection Agency. This grant provided the author funding for a three month internship at U.S. EPA Region 10 which fulfilled the internship degree requirement for a Masters of Public Affairs from the Lyndon B. Johnson School of Public Affairs. I would especially like to thank Jonathan Williams at U.S. EPA Region 10 for his invaluable guidance and help in writing and editing this report.

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EXECUTIVE SUMMARY

Urban storm water runoff is a form of nonpoint source pollution which is intimately tied to the hydrologic cycle, human activities, and urbanization. Pollutants such as nutrients, heavy metals, and pesticides are commonly found in urban storm water. The quality and chemistry of urban storm water is highly variable and dependent on many factors, including rainfall characteristics and land use. Urban storm water pollutants can have both short and long term ecological and human health effects, and thus represent a major environmental concern.

Traditionally, scientific research, water resource management, and regulations have focused on the effects of urban storm water on surface water quality (rivers, lakes, and estuaries), and seldom on ground-water quality. The Clean Water Act of 1987 and the current EPA ruling regarding the issuance of National Pollution Discharge Elimination System permits for urban storm water discharges are only for those point discharges into surface water bodies.and not ground water. In the last few years more notice has been given to possible ground-water contamination from urban storm water because of increasing urbanization and dependence on ground water for drinking water. However, there is no comprehensive national legislation or policy that protects ground water quality.

The Safe Drinking Water Act and other narrowly focused federal legislation, along with state and local laws and ordinances, provide a legislative patchwork that attempts to protect the nation's ground water quality. To fill the void, some states are using the National Drinking Water Regulations as ground-water quality standards for lack of federal standards. Other federal programs such as the Sole Source Aquifer Program are severely limited in their scope and effectiveness in protecting ground-water quality. A clear and enforceable comprehensive federal policy protecting ground-water quality is needed to provide direction to state and local governments. This could take the form of a broad policy of nondegradation of the existing quality of a given aquifer or a specific set of ground-water quality standards similar to the National Drinking Water Regulations.

The purpose of this report is to provide a summary of information and key references on urban storm water in relation to ground-water protection for United States Environmental Protection Agency (EPA) staff and others responsible for protecting ground-water quality. This report presents a brief overview of the major literature describing: 1) the quality and chemistry of urban storm water runoff, 2) its effects on ground-water resources, and 3) current management practices, strategies, and regulations that attempt to reduce ground-water contamination from urban storm water. Also included is a selected bibliography and list of contacts at the federal, state, and local levels of government.

CHAPTER 1

INTRODUCTION

1.1 General Description of Nonpoint Source Pollution

Nonpoint source water pollution is typically defined as pollution that originates from sources that are diffuse and difficult to pinpoint. Another broad definition of nonpoint source pollution is when the rate of materials entering receiving waters (such as sediments, nutrients, or toxicants generated from land use or the atmosphere) exceeds natural levels (Novotny and Chesters, 1981, p. 541). In contrast to point source pollution (such as municipal wastewater effluent), nonpoint source pollution is intermittent, highly variable, and closely related to human alterations to the landscape and the watershed hydrology of an area.

Nonpoint pollution sources fall into two broad categories related to land use, rural and urban. Rural sources include agriculture, logging, and mining activities. Urban sources include street litter, automobiles, animal wastes, combined sewer overflows, street salting, construction, and industrial activities.

Nonpoint source pollution is hard to identify and monitor, and its full impact is not yet well known. Nevertheless, pollutants from nonpoint sources can have both short and long term ecological and human health effects, and thus represent a major environmental concern. Two examples of short term or "shock" effects are fish kills due to the input of oxygen consuming organic material that drastically decrease dissolved oxygen levels and closures of shellfish beds due to bacterial contamination from combined sewer overflows. Long term cumulative effects include the eutrophication of surface waters from nutrient overloading or possible contamination of a drinking water aquifer. Another concern is the accumulation of pollutants in sediments and their possible continual release into receiving waters.

1.2 General Description of Urban Storm Water Runoff

Urban storm water runoff usually consists of surface runoff from such nonpoint sources as streets, parking lots, and yards; but it may also have point source contributions from accidental spills and leaks or illegal dumping of commercial and household wastes into storm drains. Urban runoff commonly discharges as a point source of pollution, such as a storm sewer outfall or injection well. However, urban runoff may also percolate to ground water as a nonpoint discharge of contaminants.

One example of urban storm water containing nonpoint source pollutants that are possibly contaminating ground water exists in Spokane, WA. Spokane's drinking water supply comes from the Spokane-Rathdrum Aquifer, which is recharged in some vulnerable areas by urban runoff. An estimated 75% of urban storm water in Spokane is disposed of in Class V injection wells (Miller, 1990). Calcium chloride is used for de-icing roads in Spokane and is found in urban runoff during the winter. During the winter, elevated levels of chloride and calcium were found in ground water, and were attributed to recharge from contaminated urban runoff in dry wells (Miller, 1985).

An example of ground-water contamination by urban storm water from point source pollutants was discovered in Vancouver, WA. In 1989, tetrachloroethylene or perchloroethylene (PCE) from a dry cleaners contaminated the water table via dry wells. It is theorized that 15 to 20 years ago, accidental or intentional dumping of PCE occurred.

Storm water that collected in a storm drain and infiltrated the ground through a dry well helped disperse the PCE into the ground water. PCE is thought to be a "probable" carcinogen by U.S. EPA and does not dissipate very rapidly (Westfall, 1989, sec. A, p. 1). One estimated cost of the ground-water cleanup in 1989 was approximately $2 million (Ryll, 1989, sec. A, p. 1).

1.2.1 Hydrologic Cycle

Urban storm water represents only a portion of the hydrologic cycle in which water circulates on the earth. A simplified explanation of the hydrologic cycle is illustrated in Figure 1. Water reaches the land surface as precipitation. Precipitated water may runoff, collect in surface waters, evaporate, infiltrate the ground to be either held or transpired by plants, or percolate to the saturated zone. Once in an aquifer, water eventually moves towards a discharge point, but can remain in the ground anywhere from several hours to thousands of years.

1.2.2 Quantity of Urban Storm Water

The quantity or volume of storm water runoff is related to the amount of precipitation and degree of urbanization. Therefore, storm water quantity is very variable and specific to an individual storm event and site. Storm events are highly dynamic and the amount of rainfall varies tremendously from storm to storm. Total rainfall volume depends on the intensity and duration of the rain, which in turn depend on the geographic location and climate.

Urbanization markedly alters natural drainage patterns. Pavement, buildings, and compacted soils form impervious layers that do not allow rainfall to infiltrate the ground; instead it collects and forms surface runoff (Novotny and Chesters, 1981, p. 7; Canning, 1988, pp. 1, 5). Therefore, increased urbanization and the amount of impervious ground cover increases the volume and the rate surface runoff (See Figure 1-2). Mar et al. also discovered that the quantity of runoff can vary significantly on elevated and curbed sections.of highways (1982, p. 18).

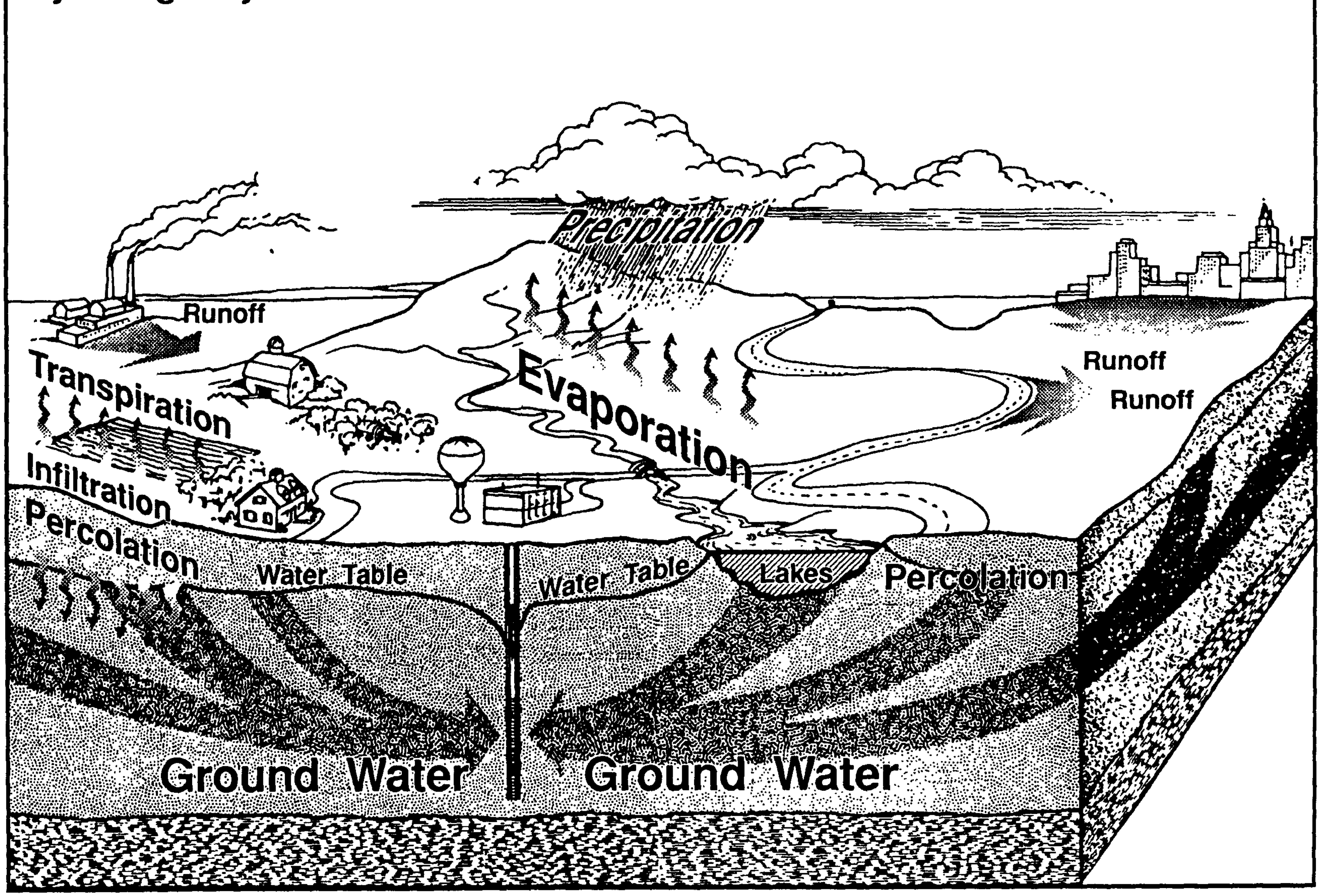
In contrast, overland water flow in forests is very limited because water is slowed and trapped by the leaf duff and thick organic topsoils which allow it to filter into the ground (Eckel, 1990). Grassland and cultivated agricultural areas generally yield less runoff than urban areas, but more than forest land.

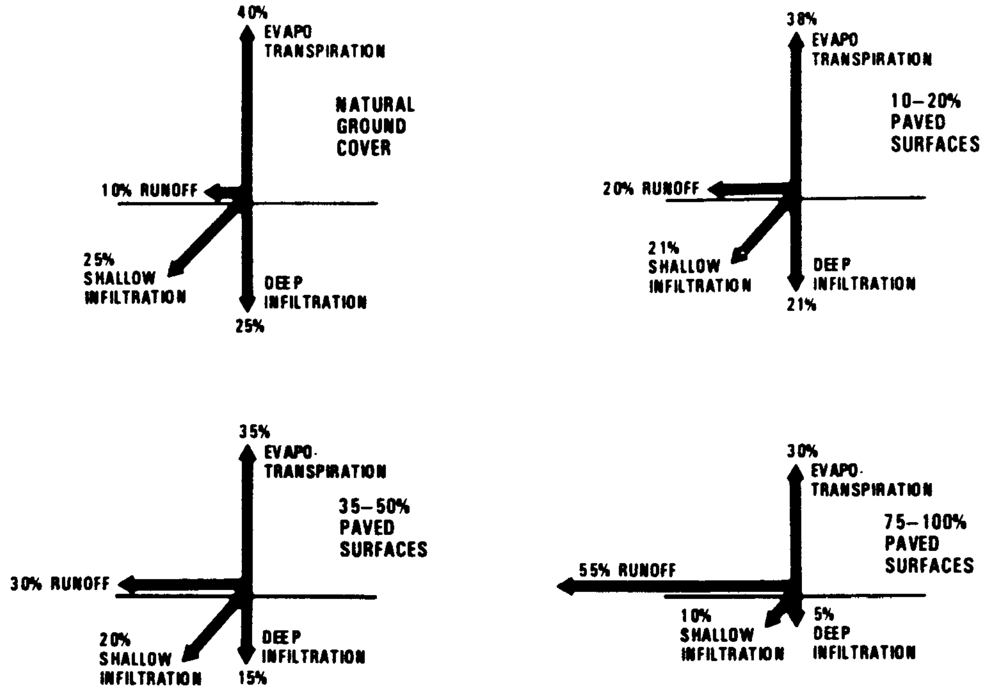
Increases in the quantity of urban storm water usually cause increased frequency and volume of flooding, which can threaten human lives and property. Also, the quality of storm water or concentrations of pollutants in storm water is intimately tied to storm water quantity which is discussed in the following section.

1.2.3 Quality of Urban Storm Water

The quality of storm water is also extremely variable, hard to generalize, and specific to particular sites and storm events. Concentrations of contaminants may range in several orders of magnitude at any given site. Pollutant "mass loadings are very strongly influenced by the amount of precipitation and runoff, and estimates of mass loads will be biased by the size of monitored storm events."(U.S. EPA Nationwide Urban Runoff Program (NURP), 1983, p. 9-2). Novotny and Chesters state that "It is a known fact that there is a close relationship of pollutant loadings from areal sources to the rain volume and intensity, infiltration and storage characteristics of the watershed, and other hydrologic parameters."(1981, p. 77). Other factors such as the frequency of storm events, land use,

Figure 1
Hydrologic Cycle





Source: J.T. Tourbier and R. Westmacott, *Water Resources Protection Technology: A Handbook of Measures to Protect Water Resources in Land Development*, p. 3.

Figure 1-2. Typical Changes in Runoff Volume Resulting from Paved Surfaces.

traffic density, and human and animal population densities affect the presence and concentrations of pollutants found in urban storm water (Randall and Grizzard, 1983, p. 59). In performing regression analyses on the NURP data, Driver and Lystrom concluded that "Total storm rainfall and total contributing drainage area are the most significant variables in all of the storm-runoff-load relations."(1986, p. 132). Other important variables sited were land use, impervious cover, population density, rainfall duration, and other storm event characteristics (Driver and Lystrom, 1986, p. 132).

Pollutant loadings in highly urbanized areas are also controlled by the amount and composition of pollutants in the atmosphere and refuse accumulated on impervious surfaces, which eventually end up in surface runoff. "Impervious areas accumulate pollutants during dry periods, and then pollutants are washed off of the surfaces during rainfall events, thus adding to the quantities washed out of the atmosphere." (Randall and Grizzard, 1983, p. 63). Urban storm water can contain pollutants with concentrations on the same order of magnitude'or greater than municipal secondary wastewater effluent (Novotny and Chesters, 1981, p. 11; NURP, 1983, p. 9-4). (See Table 2-1 of this report for comparisons of concentrations.) In suburban and less urbanized areas soil erosion and soil-adsorbed pollutants may play a greater role in the quality of storm water runoff (Novotny and Chesters, 1981, p. 312). The NURP Study found that the only statistically significant difference in urban storm water quality was between urban and open/non-urban land use categories (Athayde, Myers, and Tobin, 1986, p. 221).

1.3 Urban Storm Water Runoff and Ground-Water Quality

Urban storm water poses three types of problems: 1) flooding from the increased volume and scouring; 2) sediment deposition; and 3) chemical and biological pollutants (Puget Sound Water Quality Authority (PSWQA), 1986, p. 4-92). Unmanaged or uncontrolled urban storm water poses a significant threat to the quality of receiving waters which include rivers, lakes, streams, estuaries, wetlands, and ground water. The NURP study adopted a useful three-level definition of when urban nonpoint source pollution becomes a problem: 1) impairment or denial of beneficial uses; 2) water quality criterion violation; and 3) local public perception (1983, p. 3-5).

Ground-water contamination may occur from urban storm water recharge. Contaminated urban storm water recharge of ground water may be either natural or artificial. Natural infiltration occurs when the landscape has not been altered by humans. Artificial recharge results when urban storm water is trapped by control devices such as detention/retention basins, grassy swales, injection wells, and reservoirs, and allowed to infiltrate the ground.

Surface water contaminated by urban storm water may also enter ground water. Whenever surface water is at a higher hydraulic head than surrounding ground water, the surface water will migrate toward the ground water. The rate of migration depends upon the type(s) of earth materials between the surface water body and ground water.

From a public health standpoint, the most serious threat to ground water quality is to drinking water sources. Ground water could be contaminated by heavy metals or organic compounds in vulnerable areas where urban storm water recharges a drinking water aquifer. Contaminated ground water that contributes to base flow of surface water could also be a source of pollutants such as nutrients that cause eutrophication, and threaten aquatic life. If contaminated ground water were used for irrigation in agriculture, toxicants could enter the food supply or excessive amounts of salts could damage crops.

Urban storm water management techniques which reduce ground water recharge may adversely impact drinking water supplies. Canning notes that "...the diminishment of infiltration to the ground water reduces aquifer recharge which results in low summer stream flows and water well levels."(1988, p. 5). This could be significant for communities that depend heavily on ground water for drinking water if an aquifer could not sufficiently recharge because of water lost to surface runoff and receiving waters. Furthermore, water quality could suffer in coastal areas subject to saltwater intrusion if ground water recharge rates decline.

Ground-water quality can be difficult and expensive to monitor. Once polluted, aquifers are generally very difficult and expensive to clean up. In fact, technological or financial constraints render some ground-water resources impossible or impractical to clean up. Therefore, efforts should focus towards reducing the amount of contaminants entering urban storm water, and then effectively managing storm water to prevent ground-water pollution.

1.4 Background

Up until the late 1960s and 1970s, nonpoint source pollution and the quality of urban storm water runoff was not a widespread public concern. Historically, the focus of urban storm water management has been to drain flood waters as quickly as possible (PSWQA, 1986, p. 4-92; NURP, 1983, p. 1-1; Novotny and Chesters, 1981, p. 2). This practice sometimes causes degradation to wildlife habitat and even increased flooding downstream.

The next focus of storm water management was to control runoff on-site, but was still mainly concerned with the quantity of storm water (Canning, 1988, p. 1).

Currently, storm water quality issues are also being examined because of increased knowledge about the possible harmful effects of contaminants found in urban storm water, and subsequent federal regulatory involvement. The 1972 amendments to the Federal Water Pollution Control Act, (referred to as the Clean Water Act), prohibits the discharge of any pollutant to navigable waters from a point source unless the discharge is authorized by a National Discharge Pollution Elimination System (NPDES) permit. Traditionally, the NPDES program has concentrated on reducing pollutants in industrial and municipal wastewater point source discharges, but now also includes nonpoint source pollution. Urban storm water is unusual because it often discharges as a point source, but contains contaminants derived from point and nonpoint sources.

The U.S.EPA NURP study collected and analyzed urban storm water quality data in 28 cities and evaluated available management controls. The study found that urban storm water is extremely variable in quality, and can contain pollutants with concentrations on the same order of magnitude of secondary wastewater effluent. The "National Water Quality Inventory, 1986 Report to Congress" concluded that "pollution from diffuse sources as runoff from agricultural and urban areas is cited by the States as the leading cause of water quality impairment." (53 FR, 1988, p. 49417). In 1987, Congress reauthorized the Clean Water Act and added Section 402, which requires EPA to develop regulations to issue NPDES permits for urban storm water discharges, treating them as a point discharges. EPA is expected to issue the final rule on storm water discharges by municipalities over 250,000 in population and industry in November 1990.

The effects of urban storm water runoff on surface water have been studied at length, however, there has been little research published on the impacts of urban runoff on ground-water quality. Nonetheless, available information on the quality and chemistry of urban runoff may be useful to those responsible for protecting ground-water quality and managing urban runoff. Urban runoff management practices are still evolving and have ground-water implications, even if flood control and surface water quality are the focus of concern.

CHAPTER 2

QUALITY AND CHEMISTRY OF URBAN STORM WATER RUNOFF

2.1 Introduction

The quality and chemistry of urban storm water has been characterized in detail over the past twenty years by many researchers with similar results and conclusions about the constituents and their concentrations in urban storm water (Sartor and Boyd, 1972; Miller and McKenzie, 1978; U.S. EPA, 1983; Pitt and Bissonette, 1983; Galvin and Moore, 1982; Wang, et.al., 1983; Merrill, 1989). The urban storm water quality section of this report will: 1) identify the types of parameters and ranges of contaminant concentrations generally found in urban storm water; 2) discuss possible sources of pollutants, and their toxic effects, with an emphasis on data collected in the Pacific Northwest region of the United States.

2.1.1 How Pollutants Are Reported

Pollutants and other parameters, such as pH and conductivity, can be broken down into two broad categories: 1) standard or conventional and 2) toxicants. In turn, these categories can be broken down further into subgroups. Pollutants concentrations are usually reported either as concentrations of pollutants in discrete samples or as loading estimates of total inputs of pollutants to receiving environments.

Concentrations of pollutants are reported in milligrams per liter (mg/L) which equals parts per million (ppm) or micrograms liter (ug/L) which equals parts per billion (ppb). The concentrations and the amount of runoff are the basis on which pollutant mass loadings in the water column and sediments can be estimated (NURP, 1983, p. 9-2; Hvitved-Jacobsen, 1985, p. 347).

Pollutant mass loadings can be used to characterize present loadings and future loadings under expected changes in land use (Randall and Grizzard, 1983, p. 83). The estimation of pollutant loadings are reported in many different units. Some examples are as kilograms per hectare per year (kg/ha/y), pounds per acre (lbs./acre), lbs./acre/inches of rainfall, and pounds per curb mile (lb./curb mi.). This lack of standard unit usage makes comparison of studies more difficult.

In recognition of the growing concern about the effects of urban storm water, the United States Environmental Protection Agency's (U.S. EPA) Nationwide Urban Runoff Program (NURP) from 1978-1983 set out to characterize the quality of urban storm water, its effects on receiving waters, and the effectiveness of management controls of removing pollutants. Data mainly on conventional pollutants was collected from sites in 28 cities with a variety of climates, geologic settings, land use types, and population densities. The primary water quality statistic the NURP study used to compare data was the event mean concentration (EMC), which is based on flow weighted composite samples for each storm event at each site. EMC equals the total constituent mass discharge divided by the total runoff volume. The major conventional constituents reported in the NURP study were total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), total phosphorous (TP), soluble phosphorous (SP), total Kjedahl nitrogen (TKN), and nitrate-nitrite (NO_2-NO_3). The ranges of the site median EMC values are presented in Table 2-1 of this report.

2.1.2 Problems Comparing Data

It is difficult to compare urban storm water quality data in a precise and quantitative manner because of wide variation in storm events, sites, and methodologies. Inherent factors controlling urban storm water quality include land use, geographic location, climate, and water resource management controls of any given area. These inherent factors are discussed in more detail in section 2.4 of this chapter. The high methodological variability in sampling, analytical techniques, units of measure, and different forms or species of pollutants employed to describe urban storm water, make comparisons between studies difficult (Galvin and Moore, 1982, p. 3-6; Canning, 1985, p. 69).

Site characteristics dictate what type of field sampling techniques will be used to sample urban storm water, and often are not fully described in final reports. A crucial point to consider is whether the sampling took place before or after the runoff reached receiving waters, i.e. whether the data represents diluted or undiluted runoff.

Analytical techniques can also vary widely and laboratory quality assurance and control data details, including detection limits, regarding this are rarely supplied in published reports. When comparing data it is useful to know exactly what form or species of a particular constituent was measured and whether it was in its solid or soluble form. It is also very useful to know what the detection limits of the instrumentation were and what type of quality control was used in order to insure the validity of the data.

In comparing pollutant concentrations with water quality criteria or standards, percentages of samples exceeding a certain level are often given. Care must be taken to discern whether the percentage is derived from the total number of samples or the number of samples that the pollutant was detected in. Another important fact to consider is that water quality standards are for receiving waters and urban storm water runoff data are usually reported as undiluted concentrations. Galvin points out that comparison of water quality standards and actual urban runoff data for metals is "very rough and even possibly misleading guide to significance of the levels seen, since the runoff values are undiluted storm water and total metal analysis, while the criteria are ambient water, supposedly bioavailable levels." (Galvin, 1987, p. 11).

2.2 Conventional Parameters

Conventional parameters are those most commonly measured by communities and researchers to characterize water quality. They have historically been used to describe wastewater treatment effluent and in water resource planning. Conventional parameters can be grouped into five categories: **physical, chemical, oxygen demand, nutrients, and bacteria/viruses.** Tables 2-1 and 2-2 compare data for conventional parameters reported in the Nationwide Urban Runoff Program, three studies conducted in the Pacific Northwest, secondary wastewater effluent, and National Drinking Water Regulations.

Table 2-1.

Summary of Major Conventional Parameters of Urban Storm Water Runoff Compared to Water Quality Standards and Secondary Waste Water Effluent

PARAMETER (mg/L)	EPA NURP[1] 1978-1983	Bellevue, WA[2] NURP 1983	Portland, OR[3] USGS 1978	Spokane, WA[4] 1983	Metro Secondary Waste Water Effluent	NDWR[5]
TSS	100 (14-1247)	50 (1-2740)	(1-2,220)		13.0	500[c]
BOD_5	9 (2-23)	6.6 (<0.01-40)	28[a]		13.0	
COD	65 (23-146)	60 (8-780)	(8-120)	89.0-2711.0	53.0	
TP	0.33 (0.02-2.83)	0.15 (0.01-40)	(0.01-1.1)	0.28-0.70	3.8	
Soluble P	0.12 (0.005-0.39)					
TKN	1.5 (0.3-9.9)	1.1 (0.21-45)	(0.25-5.4)[b]	1.65-2.31	15.6	
NO_2-NO_3	0.68 (0.20-5.17)	0.21 (<0.01-4.5)	(0.08-7.0)	0.78-0.83	0.06	10[d]
Coliform Bacteria (Colonies/100mL)	Summer: 63,000 Winter: (4,600-281,000)	Mean: 980 Min-Max: (1-66,000)	(5-27,000)		50.0	

1 U.S. EPA. 1983. Nationwide Urban Runoff Program. Summary Data from 28 cities.
Site EMC for median urban site; ( ) = Min-Max of site.
EMC = Event median concentration = Total constituent mass discharge / Total runoff value.

2 Pitt and Bissonette. 1984. Bellevue,WA. NURP. Summary data from Table 25.

3 Miller and McKenzie. 1978. Summary data from Tables 4 and 5.
( ) = Min-Max of all samples.
a = Max only; b = Total organic nitrogen

4 Miller. 1983. Spokane, WA. Summary data from flow weighted averages.

5 U.S. EPA National Drinking Water Regulations.
c = Secondary standard; d = Primary standard

Table 2-2.

Summary of Minor Conventional Parameters of Urban Storm Water Runoff Compared to Water Quality Standards

PARAMETER (mg/L)	Bellevue, WA[1] NURP 1983	Portland, OR[2] USGS 1978	NSDWR[3]	U.S. EPA Surface Water Quality Criteria 1986 Fresh Acute	Fresh Chronic	Marine Acute	Marine Chronic	Water & Fish Ingestion
Temp. (°C)	8.0 (2.6-14.8)			------------Species dependent criteria--------------				
Conductivity (umhos/cm)	41 (12-1480)	32-284						
pH (pH units)	6.7 (3.4-7.9)	6.4-8.2	6.5-8.5		6.5-9		6.5-8.5	
Alkalinity as $CaCO_3$	12 (0-25)	8-120			20			
Hardness	24 (7-170)							
Dissolved Oxygen		7.8-12.2						
TDS		20-180	500					250
Ammonia as N	0.14 (<0.01-7.2)	0.02-0.41		------Temperature and pH dependent criteria-----				
Chlorine								
Chloride	4.5 (0.8-380)		250	0.019	0.011	0.013	0.0075	
Flouride	0.1 (0.1-0.4)		a					
Sulfate	9.4 (2.6-61)		250					
Calcium	7.9 (2.3-34)							
Magnesium	1.1 (0.3-20)							
Sodium	2.3 (0.9-210)							
Potassium	1.0 (0.6-11)							
Iron			0.3		1			
Silica	3 (0.1-15)							
Manganese			0.05					

1 Pitt and Bissonette. 1984. Bellevue,WA. NURP. Summary data from Table 25.

2 Miller and McKenzie. 1978. Summary data from Tables 4 and 5.
( ) = Min-Max of all samples.

3 U.S. EPA National Secondary Drinking Water Regulations.
[a] = National Primary Drinking Water Regulation standard that varies with temperature.

2.2.1 Physical

Solids

Solids found in urban storm water are composed mostly of relatively inert minerals such as quart and feldspar, and are referred to interchangeably as sediments. The amount of solids found in storm water is a function of how much exposed ground, construction activity, or soil disturbance is occurring in a specific area. These solids can be divided into two classes based on size and transport mechanism (Sartor and Boyd, 1972, p. 46). Settlable solids are those sediments that are only partially suspended in the storm water and are dragged or bounced along the surface of the street, parking lot, etc. These sediments tend to be in the sand and silt particle size range and will settle out rapidly at low current velocities. Suspended sediments on the other hand remain suspended in the storm water until the energy of the flow has been decreased enough to allow settling, such as in a detention/ retention pond or grassy swale. These particles tend to be the smaller silts and clays and are more of a public health concern, because they can have pollutants attached to them (adsorbed) such as phosphorous, heavy metals, and organic compounds. Randall and Grizzard state that "The principal pollutant in storm water runoff, i.e. the pollutant present in the largest amount, is nearly always suspended sediment." (1983, p. 60).

Solids are most commonly reported as total suspended solids (TSS) in mg/L. The Bellevue, WA NURP study reported a range of 1-2740 mg/L TSS (Pitt and Bissonette, 1984, p.75). Mar, et al. concluded in highway runoff study that pollutant loadings are proportional to TSS (1982, p.18).

Dissolved solids are the minerals, metals, and other compounds in solution in water, and usually are reported as total dissolved solids (TDS) in mg/L. This measurement gives a rough indication of possible water quality deterioration such as "excessive hardness, seawater intrusion, corrosive characteristics, and other mineral concentrations." (Turney, 1984, p.17). TDS is commonly thought of as a gross measurement of the major cations and anions.

Alkalinity

The acidity or alkalinity is reported in pH units. pH is the negative logarithm of the hydrogen ion concentration of a solution. Neutral water has a pH of 7.0. Urban storm water tends to be slightly to moderately acidic. Hydrogen activity has a great affect on the solubility of some metals and other constituents which, in turn, determines their biological availability and toxicity levels. pH can also determine the survival rate of pathogens associated with animal and human excrement. In general, increased acidity (lower pH), increases the solubility of metals, and decreases survival rates of pathogens.

Another measure of alkalinity is the equivalent concentration of calcium carbonate ($CaCO_3$) needed to neutralize a strong acid, (usually up to pH of 4.5), (Freeman, 1984, p. 37). Highly alkaline waters may have an unpleasant taste and cause salt build up problems in industrial processes. "The alkalinity in irrigation water in excess of alkaline earth concentrations may increase the pH of the soil solution, leach organic material and decrease permeability of the soil, and impair plant growth." (Freeman, 1984, p. 37). Calcium carbonate in water acts as a buffer which maintains an elevated pH, which decreases most metals' solubility. This fact is significant in areas such as the Pacific Northwest, where there is little or no naturally occurring calcium carbonate (limestone) contributing to the buffering capacity of ground waters. Metals in these areas are probably likely to be more soluble and therefore more bioavailable. Davies also notes that increases in alkalinity and hardness generally decrease the toxicity of metals to aquatic organisms (1986, p. 61).

Hardness
"Hardness is related to the ability of soap to produce a lather in water; soft water reacts favorably with soap to produce an abundant lather with no residue, and hard water produces less lather and leaves a soapy residue. Hardness is caused primarily by the presence of calcium and magnesium in water; however, iron, manganese, and strontium also may contribute to water hardness."(Turney, 1986, p. 14). Calcium, magnesium, and iron are widely found in soils and rocks in the Earth's crust. "Hardness of waters in contact with limestone commonly exceed 200 mg/L." (Freeman, 1984, p. 39).

Conductivity
Conductivity or specific conductance measures the ability of water to carry an electrical current and is sometimes used as gross estimate of total dissolved solids (Freeman, 1989, p. 39). It is typically reported as micro-ohms per centimeter (umhos/cm) and ranged from 12-1480 umhos/cm in the Bellevue NURP and 32-284 umhos/cm in the USGS Portland, OR study.

Temperature
Temperature is almost always reported in degrees Centigrade. Temperature controls the level of dissolved oxygen in water and is more of a concern when surface water is the receiving water for urban storm water. Increased temperature raises the pH, by releasing the CO_2 out of solution, which generally decreases the availability or level of toxicity of metals. Davies, however notes that increases in temperature can increase metal toxicity as a result of increasing an organism's metabolism (1986, p. 61).

2.2.2 Chemical

The elements included in this category are commonly referred to as the major cations and anions. These elements occur in more than trace amounts and are not considered toxic or harmful in small quantities. A few of these elements are included in the secondary drinking water standards and are considered more of an aesthetic problem. Table 3 compares concentrations of some of these elements found in urban storm water to water quality standards and criteria.

Major anions
Chloride, flouride, and sulfate are anions that are commonly measured in urban storm water and other water quality determinations. These anions are minor constituents in the Earth's crust and pose problems in industrial processes if occurring in excessive amounts (Freeman, 1984, p. 37). Excessive chloride and sulfate may give drinking water an objectionable taste. A common source of chloride in urban storm water is rock salt that is used for de-icing roads in the winter.

Major cations
Calcium, magnesium, sodium, potassium, iron, and silica are major cations that are abundant and widely distributed in the Earth's crust and natural waters. All of the major cations may precipitate out of solution, forming deposits or scale in pipes and boilers. These cations are generally undesirable in industrial processes.

Sodium in excessive amounts can be harmful to humans with cardiac, renal, and circulatory diseases, and to women with toxemias of pregnancy. With regard to agriculture, large amounts of sodium are toxic to plants, may decrease soil permeability, and increase the pH of the soil solution. Calcium and magnesium are the main constituents that commonly contribute to the total hardness of water. Magnesium, present in drinking water in large concentrations, can act as a cathartic or diuretic. Excessive amounts of iron in domestic water supplies "may adversely affect the taste of water and beverages and stain laundered clothes and plumbing fixtures."(Freeman, 1984, p. 36).

2.2.3 Oxygen Demand

Dissolved oxygen (DO) in water is commonly used to characterize receiving waters' ability to sustain aquatic life. Generally, increases in oxygen consuming pollutants, temperature, and salinity decrease the amount of dissolved oxygen in water. DO levels naturally vary greatly among ground waters. Decreased levels of DO could indicate possible contamination problems if a ground water normally had high levels of DO.

Oxygen demanding or consuming pollutants are organic materials that decrease dissolved oxygen in receiving waters. Substantial loads of oxygen consuming materials can cause fish kills, foul odors, discoloration, and algae growth (Sartor and Boyd, 1972, p. 50). Biological oxygen demand (BOD) and chemical oxygen demand (COD) are both analytical techniques and discrete measures of these organic pollutants that include animal and human excrement, oil and grease, and pesticides. BOD and COD are usually reported in mg/L.

BOD measures pollutants that consume oxygen through bacterial degradation processes over a measured period of time, such as aerobic bacteria decomposition of organic material. BOD^5 is the BOD for five days and ultimate BOD is all the oxygen a substance could possibly consume. Chemical oxygen demand measures pollutants that consume oxygen through both bacterial and chemical degradation processes (Canning, 1988, p. 65-66). The ranges of BOD^5 found in the 1983 NURP study were comparable to those concentrations found in secondary wastewater discharge (p. 9-4).

2.2.4 Nutrients

Nutrients of primary interest found in urban storm water are the various forms of nitrogen and phosphorous. These compounds encourage the growth of algae in surface water, and in large amounts can drastically decrease dissolved oxygen to very low levels that can induce massive fish kills and the eutrophication of surface waters. The major sources of nutrients in urban storm water include yard fertilizers, animal wastes, eroded soil, organic debris, and atmospheric fallout (Canning, 1988, p. 68). Prych and Ebbert concluded that one third of total nitrogen in storm water is from rainfall (1986, p. 1).

<u>Nitrogen</u>
Nitrogen concentrations are most commonly reported either as total nitrogen or as nitrate-nitrite. Nitrates and ammonium nitrogen are of primary interest with respect to bioavailability and eutrophication. Since nitrogen is readily transformed to either of these forms, a measure of total nitrogen reflects nitrogen nutrient availability (Sartor and Boyd, 1972, p.59). Total nitrogen is usually reported as either total Kjedahl nitrogen (TKN) or total nitrogen (TN). TKN is a specific analytical technique used to measure organic nitrogen plus ammonia. Ammonia is also a common measure of nitrogen

Nitrate-nitrite (NO_2-NO_3) is commonly thought of as a measure nitrate, because the nitrite concentrations are generally small in comparison to nitrate (Turney, 1984, p. 19). Concentrations of 0.3 mg/L or more are generally thought to promote algal blooms. Nitrate is extremely soluble in water and almost always found in its dissolved form (Canning, 1988, p. 68). With respect to ground water and drinking water, excessive levels of nitrate (> 10 mg/L) can cause a blood disease methemoglobinemia in infants ("blue babies") which deprives them of oxygen (Sartor and Boyd, 1972, p. 60).

Phosphorous

Phosphorous also exists in several forms and is most often reported as total phosphorous (TP) and soluble phosphorous. A recent Metro study on phosphorous in Lake Sammamish, WA reported phosphorous concentrations as bioavailable phosphorous (BAP). Orthophosphate (PO_4) occurs both as particulates adsorbed onto sediments and in dissolved form. Phosphate is thought to be the growth-limiting nutrient in freshwater and algal blooms are likely to occur if concentrations exceed 0.01 mg/L (Canning, 1988, p. 68).

2.2.5 Bacteria/Viruses

Fecal coliform

Fecal coliform bacteria is a relatively harmless group of bacteria found in the intestines of warm blooded animals, including humans, and is usually reported in colonies/100mL. Fecal coliform, in particular Esherichia coli (E. coli), is used as an indicator organism of pathogenic or disease-causing bacteria and viruses that are associated with human or animal excrement (Canning, 1988, p. 63; Turney, 1984, p. 20). Fecal streptococci are used as an indicator of human waste contamination usually from combined sewer overflows and septic systems. Ratios of total fecal coliform to fecal streptococci of 2:1 or more, generally indicate contamination by sewage; ratios of 1:1 or less indicate an animal source of wastes (Novotny and Chesters, 1981, p. 407-408).

Bacteria and viruses can remain suspended in water or can adsorb onto sediments which can increase their rates of survival. With regard to ground-water contamination, Yates and Yates noted that microorganisms have been found to migrate considerable distances in the subsurface. "Viruses, in particular, due to their small size (20 to 200 nm) and long survival times can migrate very large distances in soil and ground water; as much as 1600 m have been reported for certain viruses in karst terrain (Gerba, 1984b) and up to 400 m in sandy soil (Keswick and Gerba, 1980)." (Yates and Yates, 1989, p. 202).

The main source of bacteria and viruses in urban storm water is pet animal and bird excrement washed off of street surfaces and yards. The ranges of fecal coliform found in undiluted storm water by the 1983 NURP study were 4600-281,000 colonies/100 mL in summer and 120-330,000 colonies/mL in winter. The primary drinking water standard for coliform is 1 colony/100 mL monthly average with individual measurements allowed to exceed this.

2.2.6 Studies

The U.S. EPA NURP study focused more on the short term effects of conventional pollutants on receiving waters, rather than cumulative effects, and concluded that nutrients and oxygen demanding pollutants do not pose a significant problem in most instances. This is probably an inaccurate interpretation because it ignores the long term accumulation of these pollutants. However, it did conclude that "coliform bacteria are present at high levels in urban runoff and can be expected to exceed EPA water quality criteria during and immediately after storm events in many surface waters, even those providing high degrees of dilution." (p. 9-3). TSS was also noted to be fairly high in comparison to wastewater treatment effluent and could have detrimental physical effects to aquatic life and build up toxic sediments (p. 9-5).

The Bellevue, WA NURP study reportedthat approximately two-thirds of the total solids and phosphorous loads, and one-third of the TKN, TN, and organic carbon loads were in suspended rather than dissolved forms (Pitt and Bissonette, 1984, p. 74).

Miller and McKenzie concluded in the Portland, OR study that "In general, constituent concentrations of storm-water runoff exceed domestic sewerage-treatment standards for settlable solids, suspended sediments, and fecal coliform.", but that "BOD concentrations were not high enough to indicate that treatment would be necessary." (1978, p. 43).

2.3 Toxicants

In recent years more attention has been given to describing toxicants in urban storm water because of the increasing awareness of their possible deleterious impact on public health and the environment. Advances in technology have also made it possible to measure toxicants in urban storm water at trace levels. However, toxicant levels remain difficult and expensive to quantify because concentrations often occur at the detection levels of complex analytical instrumentation. "Toxicant" is a general term for inorganic and organic chemicals that are either carcinogenic, mutagenic, teratogenic, or otherwise harmful to organisms and humans in both lethal and sub-lethal concentrations.

Toxicants are generally classified into two broad categories of metals and organics. It is commonly recognized that many of these pollutants are for the most part not soluble, but instead exist in solid or colloidal forms or adsorbed onto sediments (usually silts and clays), which eventually accumulate in receiving waters. The long term accumulation and effects rather than the short term effects of these pollutants (especially metals), in receiving waters and sediments may be a more serious hazard to human and aquatic life (Galvin, 1987, p. 14).

In an expanded companion study to the NURP study, the NURP Priority Pollutant Monitoring Program (PPMP), urban storm water was analyzed for 127 out of 129 priority pollutants identified by EPA in 1980. 14 inorganic and 63 organic of these pollutants were detected and of these lead, selenium, and 2 pesticides (alpha-hexachlorocyclohexane (alpha-BHC) and gamma-hexachlorocyclohexane (gamma-BHC) were thought to represent a potential risk to humans in undiluted runoff (1983, p. vi). (See Appendix A for the summary of the NURP PPMP findings.)

2.3.1 Metals

Metals found in urban storm water are a major concern because of their high prevalence and potential toxicity. The term "heavy metals" is used loosely and can be confusing because it sometimes includes both very common elements such as iron and zinc, and trace elements such as lead and arsenic. Metals are represented in several water quality regulations and classifications according to their varying degrees of toxicity and environmental impacts. These classifications include the National Primary and Secondary Drinking Water Regulations, U.S. EPA Priority Pollutant classification, U.S. EPA Water Quality Criteria for freshwater and marine aquatic life, and various state water quality standards. It is worth pointing out again that criteria are also for receiving waters and not undiluted runoff. These standards are listed in Table 2-3, along with summary data from various toxicants studies.

From a ground-water perspective, the National Drinking Water Regulations are the most pertinent. The primary maximum contaminant levels are concerned with the "contaminants that may have a significant direct impact on the health of the consumer and are enforceable by EPA."(Freeman, 1984, p. 40). Most of the EPA priority pollutant metals are represented in this list. The secondary maximum contaminant levels "deal with contaminants that may not have a significant direct impact on the health of the consumer, but their presence in excessive quantities may affect the aesthetic qualities and discourage the use of a drinking-water supply by the public."(Freeman, 1984, p. 40). (See Figures 2-1, 2-2, and 2-3 for comparisons of metals concentrations found in urban storm water runoff and the National Drinking Water Regulations.)

The toxicity of a metal depends on its form or state, which dictates it's mobility and availability for uptake and accumulation in organisms (Sartor and Boyd, 1972, p. 68). A metal's form or state includes its valence (electrical charge), and whether it exists in solution or is tied up in a complex organic or inorganic solid compound. Many metals are adsorbed to particles through a complex electro-chemical bonding that is controlled by the pH of the water and sediments (Canning, 1988, p. 69). Low pH, oxidation-reduction potential (Eh), and DO favor metal solubility (NURP PPMP, 1983, p. 83). "The dissolved metal fraction is most directly related to toxicity, however, water quality criteria and standards are based on total fractions because they provide an indication of the amount of metal available for dissolution." (NURP PPMP, 1983, p. 63).

Galvin and Moore found that metals are "almost completely associated with storm water particles," except for copper and zinc, which showed significant dissolved concentrations (1984, p. 3-3). A serious concern is that physical disturbances such as dredging and flood scouring can resuspend contaminated sediments that may re-release pollutants into the water column.

The NURP PPMP Special Metals Project tried to differentiate between three different fractions or forms of metals. Dissolved or "soluble" metals were defined as those metals that passed through a 0.45 micron membrane filter. This fraction is sometimes referred to as the ionic fraction which is considered to be the most available for uptake by organisms. Total recoverable or "extractable" metals are those metals in an unfiltered sample following treatment with hot dilute mineral acid. Total metals are those metals in an unfiltered sample following vigorous digestion with concentrated nitric acid.

Lead, zinc, and copper are the metals most often reported because of higher frequencies and concentrations in urban storm water. In the NURP PPMP, lead and zinc were detected in 94% of the samples and copper was detected in 91% of the samples in the NURP PPMP study. All three metals were detected in 100% of the Metro toxicant study samples. The NURP PPMP reported that "Levels of cadmium, copper, lead, and zinc in undiluted runoff exceeded EPA 1980 acute criteria for protection of aquatic life by a factor of 2 to 8. Consequently these pollutants could cause harm to aquatic life, depending upon receiving stream dilution, storm duration, and whether the metal was in the more toxic soluble form." (NURP PPMP, 1983, p. vi).

Lead

Lead is probably the most notable heavy metal because of its high toxicity and bioaccumulation in humans and other organisms. The NURP PPMP reported total lead concentrations in undiluted urban storm water runoff ranged from 6-460 ug/L with an EMC of 144 ug/L, which exceeded the 50 ug/L drinking water standard in 73% of the samples (1983, p. 6-47). Concentrations ranged from 60-460 ug/L with an EMC of 210 in the Metro Toxicant study (1984, p. 3-8), also exceeding the 50 ug/L drinking water standard (See Figure 2-1). In 1989, Merrill reported an EMC of 57 ug/L in Seattle storm water, which supports the notion that the concentration of lead in urban storm water has significantly decreased, reflecting the phasing out of leaded fuels.

Lead was reported to almost exclusively exist in its solid form by Galvin and Moore (1984, p. 3-3) and the NURP PPMP (1983, p. vi). Sartor and Boyd also found that lead had a strong tendency to be associated with fine particles, with almost 90% of the total lead found with particles smaller than 246 microns (1972, p. 75). "The sources of lead include gasoline products, by-products of their combustion, and exterior paints and stains." (Marsalek, 1986, p. 53).

Zinc

Zinc is the most prevalent heavy metal in street surface contaminants (Sartor and Boyd, 1972, p. 68) and occurs in the highest concentrations by far. Concentrations ranged from 10-2400 ug/L with an EMC of 160 ug/L in the NURP PPMP (1983, p. 6-47) (See Figure 2-3), and approximately 40% of the total zinc was in soluble form (p. vi). Sartor and Boyd discovered that zinc was not associated with any particular size range of sediments (1972, p. 74). "The most significant sources of zinc in urban runoff include atmospheric fallout, corrosion processes (particularly galvanized metal sewers), tires, pavement wear, automobile exhausts, exterior paint, road salt and possibly some terrestrial sources." (Marsalek, 1986, p. 53). Most zinc compounds are not particularly toxic in low-to-moderate concentrations to humans and are considered more toxic to aquatic organisms.

Copper

Copper is the other highly prevalent metal found in urban storm water. Total copper concentrations ranged from 1-100 ug/L with and EMC of 34 ug/L in the NURP PPMP study (See Figure2-3). Like zinc, 40 % of the total copper was in soluble form (1983, p. vi). Copper is not particularly toxic to humans and other higher organisms, but can be to lower ones. It also does not have the cumulative effect that other heavy metals exhibit. Copper compounds in low concentrations are sometimes used to control algae and aquatic weeds (Sartor and Boyd, 1972, p. 74), and are frequently associated with fish kills and degraded aquatic habitat (Canning, 1988, p. 71). "The sources of copper include corrosion of copper plumbing, electroplating wastes, some algicides, brake linings, and asphalt pavement wear." (Marsalek, 1986, p. 53).

Other Trace Metals

Other trace metals found less frequently in urban storm water include antimony, arsenic, beryllium, cadmium, chromium, nickel, and selenium. (See Table 2-3 for specific ranges of concentrations and detection frequencies and Figures 2-1 and 2-2 for comparisons of metals concentrations to the drinking water standards.) In the NURP PPMP study **selenium** concentrations ranged from 2-77 ug/L and exceeded the 10 ug/L drinking water standard in 10% of the samples it was detected in. Nickel concentrations ranged from 1-182 ug/L and exceeded the human health criterion of 13.4 ug/L in 21% of the samples. **Nickel** is not a significant health risk in water when ingested, but "Ni compounds are suspected of acting synergistically with some carcinogens to increase mutagenic effects" (Sunderman, 1981, in NURP PPMP, 1983, p. 44). **Arsenic** concentrations frequently exceed EPA human carcinogenic criterion (10 to the minus 5 risk level) of 0.022 ug/L. Only one sample, however, exceeded the 50 ug/L EPA drinking water standard. 12% of samples that **beryllium** was detected in exceeded the carcinogenic criterion. **Mercury** ranged from 0.6-1.2 ug/L and did not exceed the drinking water standard.

The NURP PPMP study concluded that dilution in receiving waters and wastewater treatment would probably decrease these concentrations, but these levels could be hazardous in the following worst case scenarios: 1) if runoff was most of the total receiving water flow in a dilution of less than 1 to 10; 2) if these concentrations occur above drinking water intakes; 3) lead and selenium removal by wastewater treatment is minimal (1983, p. 44).

Table 2-3.

Summary of Metals Found in Urban Storm Water Runoff Compared to Water Quality Standards.

PARAMETER (ug/L)	EPA NURP[1] PPMP 1983	Metro Toxicant[2] Bellevue, WA 1982	Seattle, WA[3] 1989	NDWR[4]	U.S. EPA Water Quality Criteria 1986 Fresh Acute	Fresh Chronic	Marine Acute	Marine Chronic	Water & Fish Ingestion
Antimony	2.6-23				9,000*	1,600*			146
Arsenic	1-50.5	13 (3-37,		50[a]					0.0022 **
Arsenic (Pent)					850*	48*	2,139*	13*	
Arsenic (Tri)					360	190	69	36	
Barium				1,000[a]					
Beryllium	1-49				130*	5.3*			0.0068**
Cadmium	0.1-14	0.7 (0.2-1.9)	0.8	10[a]	3.9+	1.1+	43	9.3	10
Chromium	1-90	7' (2-19)	6.2	50[a]					
Chromium (Hex)					16	11	1,100	50	50
Chromium (Tri)					1,700+	210+	10,300*		170,000
Copper	34 (1-100)	20 (4-46)		1,000[b]	18+	12+	2.9	2.9	
Cyanide	2-300				22	5.2	1	1	200
Lead	144 (6-460)	210 (60-460)	57	50[a]	82+	3.2+	14	5.6	50
Mercury	0.6-1.2			2[a]	204	0.012	2.1	0.025	0.144
Nickel	1-182				1,400+	160+	75		8.313.4
Selenium	2-77			10[a]	260	35	410	54	10
Silver	0.2-0.8	0.6		50[a]	4.1+	0.12	2.3		50
Thallium	1-14				1,400*	40*	2,130*		13
Zinc	160 (10-2,400)	120 (28-250)	117	5,000[b]	120+	110+	95	86	

1 U.S. EPA. 1983. Nationwide Urban Runoff Program. Priority Pollutant Monitoring Program.

2 Galvin and Moore. 1982. Metro Toxicant Program. Bellevue,WA. NURP. Tables 7 and 8, pp.3-8, 3-9.

3 Merrill. 1989. Table 1, p. 9.

4 U.S. EPA National Drinking Water Regulations.
a = Primary standard; b = Secondary standard

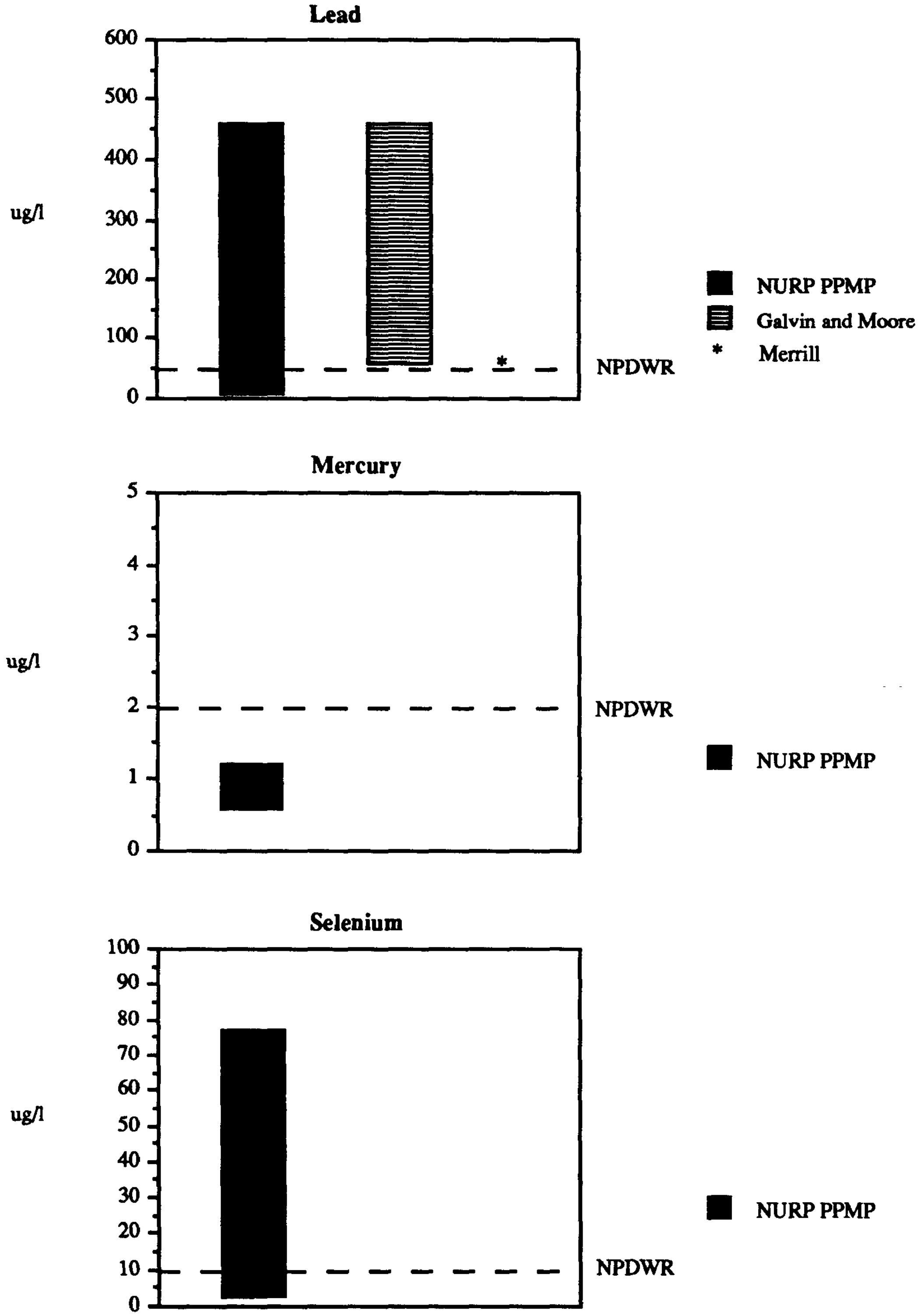
( ) = Min-Max

* = Insufficient data to develop criteria. Value presented is the Lowest Observable Effect Level (L.O.E.L.)

** = Human health criteria for carcinogens reported for three risk levels. Value presented is the 10^{-6} level.

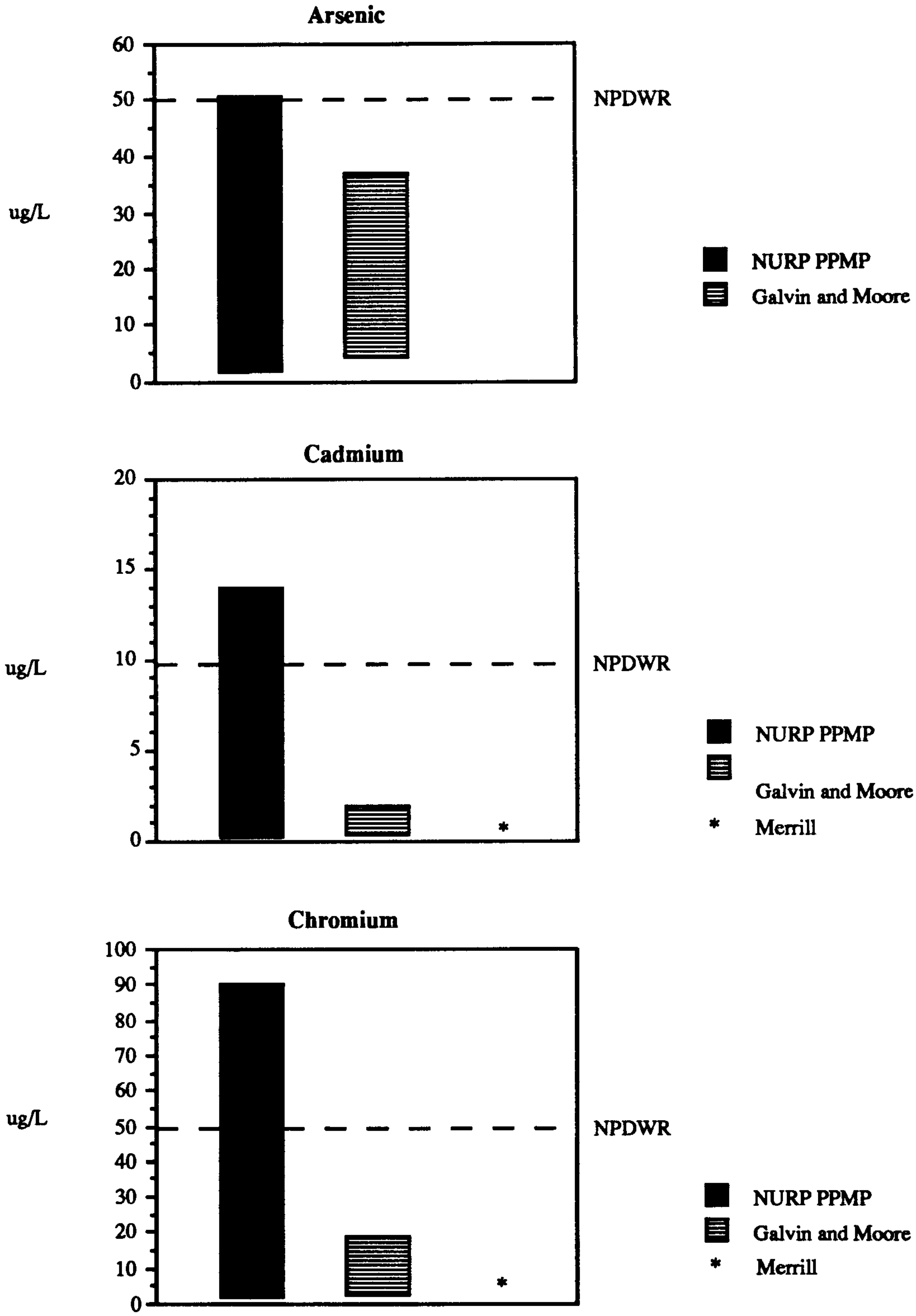
\+ = Hardness dependent criteria (100 mg/L).

Figure 2-1. Comparison of Ranges of Metals Concentrations Found in Urban Storm Water to the National Primary Drinking Water Regulations (NPDWR).



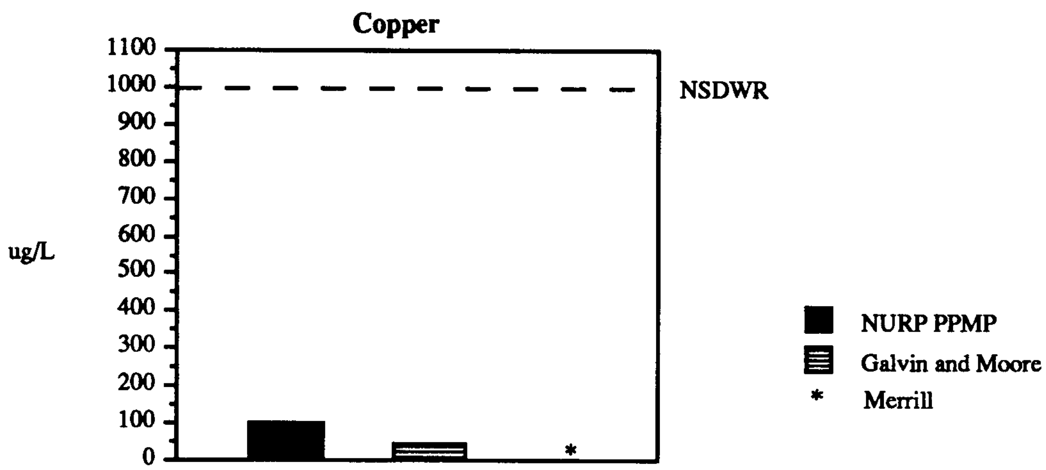
Sources: NURP PPMP. 1983. Summary data from Table 6-19, p. 6-47.
Galvin and Moore. 1982. Tables 7 and 8, pp. 3-8 and 3-9. Metro Toxicant Program. Bellevue, WA.
Merrill. 1989. Table 1, p. 9. Seattle, WA.

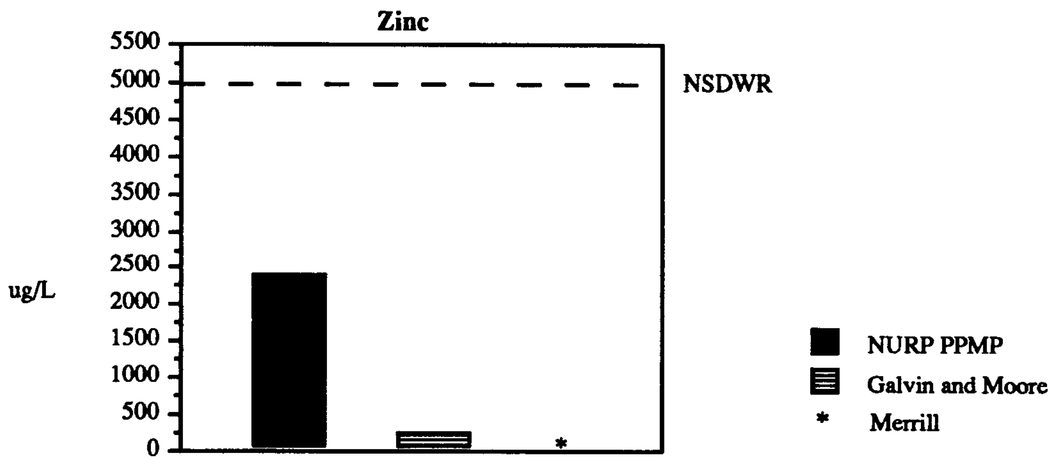
Figure 2-2. Comparison of Ranges of Metals Concentrations Found in Urban Storm Water to the National Primary Drinking Water Regulations (NPDWR).



Sources: Summary data from NURP PPMP. 1983. Summary data from Table 6-19, p. 6-47.
Galvin and Moore. 1982. Tables 7 and 8, pp. 3-8 and 3-9. Metro Toxicant Program. Bellevue, WA.
Merrill. 1989. Table 1, p. 9. Seattle, WA.

Figure 2-3. Comparison of Ranges of Metals Concentrations Found in Urban Storm Water to the National Secondary Drinking Water Regulations (NSDWR).





Sources: NURP PPMP. 1983. Summary data from Table 6-19, p. 6-47.
Galvin and Moore. 1982. Tables 7 and 8, pp. 3-8 and 3-9. Metro Toxicant Program. Bellevue, WA.
Merrill. 1989. Table 1, p. 9. Seattle, WA.

2.3.2 Organics

Oil and Grease and Total Organic Carbon
The two most common and crudest measurements of organic materials in urban storm water runoff are oil and grease and total organic carbon (TOC) (Galvin, 1987, p. 14). However, not all the organic materials in oil and grease and TOC measurements are considered toxicants. Oil and grease concentrations ranged from <1 to 10 mg/L and dissolved organic carbon concentrations ranged from 0.2 to 120 mg/L in the Bellevue, WA NURP study. Specific groups of organic materials that are commonly measured include polycyclic aromatic hydrocarbons (PAHs), pesticides, and polychlorinated biphenals (PCBs). These groups are composed of very specific compounds, each with their own chemical signature that can be detected by complex analytical instruments. See Appendix A for specific ranges of concentrations of these organic compounds found in the NURP PPMP study.

PAHs
Polycyclic aromatic hydrocarbons are "products of incomplete combustion and are found in everything from cigarette, coal and wood stove smoke to gasoline and diesel exhaust. They are major components in air-suspended particulates (e.g.,soot) and are common in street dust, tightly bound up in fine particles." (Galvin, 1987, pp. 19, 21). PAH's are commonly found in highway runoff and can be traced to combustion byproducts (Marsalek, 1986, p. 53).

Refractory organics
Refractory organics are chemicals that are man-made and highly resistant to chemical and biological degradation. These chemicals include pesticides, herbicides, PCBs, cleaning solvents, and photofinishing chemicals. The long term accumulation of these pollutants from constant low level inputs (especially from atmospheric fallout), is more of a problem with respect to acute or sub-lethal toxicity.(Canning, 1988,p. 69).

Pesticides
Organic pesticides are a major public health and environmental concern because of their widespread presence and high persistence in the environment. Most pesticides and herbicides in urban runoff are washed from landscaping foliage, lawns, and gardens, with the majority adsorbed onto sediments. (Canning, 1988, p. 69). "The two most prevalent pesticides, alpha-BHC and gamma-BHC, are used commonly in soil treatment to eliminate nematodes and other pests." (Marsalek, 1986, p. 53).

PCBs
PCBs are chlorinated organic compounds that are extremely stable and persistent in the environment, similar to organochlorine pesticides. These compounds are not very mobile in soils and tend to adsorb onto soil particles (Novotny and Chesters, 1981, p. 243). "Because PCBs are soluble in lipid tissue, these components have been found to accumulate in the fat of living organisms including man."(Novotny, 1981,p. 15). The major sources of PCBs are leaks from fire-resistant transformers, insulating condensers, hydraulic systems, spills and losses in manufacturing of PCBs, vaporization or leaching from PCB-containing formulations, and disposal of waste PCBs (Novotny and Chesters, 1981, p. 15; Marsalek, 1986, p. 53).

Studies
The NURP PPMP study detected 63 of the possible 106 organic priority pollutants at lower concentrations than the inorganic pollutants and at frequencies of 22% or less. This study concluded that:

> The organic priority pollutants found most frequently pose little risk to humans at detected levels, except possibly for alpha-hexachlorocyclohexane (alpha-BHC) and chlordane. These pesticides and the three polycyclic aromatic hydrocarbons (PAHs), chrysene, phenanthrene, and pyrene were found in 5 to 20 percent of the urban runoff samples at concentrations exceeding the EPA criteria for the protection of human health from carcinogenesis for 10 to the minus 5 risk level....At the 10 to the minus 7 risk level, gamma-hexachlorocyclohexane (lindane) also exceeded the carcinogenic activity carcinogenic criteria in at least 10 percent of the samples.(1983, p. 43).

The study sited pesticides, fossil fuel combustion, plastic products, and automobile-related activities.as the main sources of the priority pollutant organics (1983, p. 40). (See Appendix A for list of organic priority pollutants.)

The Metro Toxicant study detected 19 of 111 organics at detection frequencies of 20% or less. The "most frequently detected were lindane (tentative), alpha-BHC (tentative), pentachlorophenol, fluoranthene, phenanthrene, and pyrene." (Galvin and Moore, 1982, p. 3-20). Merrill found low and high molecular weight polycyclic hydrocarbons, phthalate esters, and 2-methyl naphthalene ranging in concentrations from 0.1 to 25 ug/L in greater than 33 percent of samples of Seattle storm water in 1989 (p. 8).

2.4 Factors Affecting Urban Storm Water Quality

Sartor and Boyd hypothesized that "The principal factors affecting the loading intensity at any given site include the following: surrounding land-use, the elapsed time since streets were last cleaned (either intentionally or by rainfall), local traffic volume and character, street surface type and condition, public works practices, season of the year, etc." (1972, p. 6). However, several studies have concluded that concentrations of urban storm water pollutants do not appear to vary significantly with land use, except perhaps some cases where metals concentrations in highway runoff seem to be higher (Galvin and Moore, 1982, p. 3-3; NURP, 1983, p. 9-5). The NURP study concluded the following:

> As a result of extensive examination, it was concluded that geographic location, land use category (residential, commercial, industrial park, or mixed), or other factors (e.g., slope, population density, precipitation characteristics) appear to be of little utility in consistently explaining overall site-to-site variability in urban runoff EMCs or predicting the characteristics of urban runoff discharges from unmonitored sites. Uncertainty in site urban runoff characteristics caused by high event-to-event variability at most sites eclipsed any site-to-site variability that might have been present. (1983, p. 9-5).

2.4.1 Urban Land Use

Although general land use types by themselves are not particularly valuable in explaining specific variations in urban storm water quality, it is useful to understand the activities taking place in them that generate pollutants found in urban storm water runoff. For the purposes of this report the sources of urban storm water pollutants will be discussed according to individual activities or sites occurring in one or more of these land use categories.

Urban land use types are generally grouped into four categories: residential, commercial, industrial, public/government.

Residential
Residential land use encompasses both single-family housing and multi-family housing. Sources of storm water pollutants from residential land use include: streets, driveways, yards and landscaping, woodburning, automobile maintenance, disposal of household chemicals, and pets.

Commercial
Shopping centers, parking lots, highly urbanized downtown areas, warehousing, storage, office parks, gasoline service stations, and small businesses represent some commercial land uses that generate pollutants found in urban storm water.

Industrial
Industry can discharge pollutants during the production, storage, and transportation of raw materials, products, and wastes used in manufacturing.

Public/Government
Public activities which generate urban runoff pollutants include: 1) transportation systems (rail, highways, roads); 2) public facilities (parks, boat launches); 3) port facilities (air terminals, off-loading facilities); 4) internal government facilities (automobile maintenance and fuel stations); and 5) landfills (PSWQA, 1986, p. 4-98). The most widespread and studied of these has been highways.

2.4.2 Sources of Pollutants

Refuse and fine particulate matter that accumulate on impervious surfaces such as streets, highways, parking lots, yards, and roofs are major sources of pollutants in urban storm water. This material has a variety of sources that include atmospheric deposition, litter, road traffic, animal fecal waste, dead leaves, grass, and animals (Novotny,1981,p.313). (See Table 2-4 for a summary of urban storm water pollutant sources.) Most street refuse is very coarse litter, however most pollutants are associated with the finer fraction (Novotny and Chesters, 1981, p. 324; Galvin and Moore, 1982, pp. 3-42, 3-62).

Atmospheric Deposition
Dust particles from soil and urban litter, is always present in the air. Most dust particles are fairly large and are deposited near their source. Industrial emissions, motor vehicle traffic, and motor vehicle exhaust probably contribute the majority of air-born pollutants found in urban storm water. "Fly ash from industrial coal burning operations and disintegration of urban litter is another significant source of atmospheric deposition, especially in or near urban and industrial centers." (Novotny and Chesters, 1981, pp. 152, 154). The NURP PPMP study concluded that "Predominant sources of the priority pollutants are thought to be gasoline and other fossil fuel combustion, metal alloy corrosion and other automobile-related activities." (1983, p. 40).

Motor Vehicles
Sartor and Boyd sited the following motor vehicle sources of street surface contaminants: 1) leakage of fuel, lubricants, hydraulic fluids, and coolants; 2) fine particulates worn off of tires and clutch and brake linings; 3) particulate exhaust emissions; 4) dirt, rust, and decomposing coatings which drop off of fender linings and under carriages; 5) vehicle components broken by vibration or impact (glass, plastic, metals, etc.) (1972, p. 28). "Each year more than one billion pounds of tire matter is worn off in the United States." (Randall and Grizzard, 1984, p. 61). This tire matter contains such pollutants as zinc, oil, and oxygen-demanding organic polymers. Automobile exhaust contains lead, hydrocarbons, phosphorous, and nitrous oxides that are deposited dry or washed out of the air by rainfall. Automobile parts wear contributes copper and chromium to street surfaces.

Table 2-4.

Sources of Urban Storm Water Pollutants.

Pollutant	Urban Sources	Water Quality Impacts on Receiving Waters
Solids	Soil erosion Automobile wear Automobile exhausts Industrial emissions	Carries organic and inorganic toxicants. Decreases drinking water quality. Degrades habitat and decreases the viability and variability of aquatic species Decrease in value for recreational and commercial activities.
Salts	De-icing salts	Decreases drinking water quality. Degrades habitat and decreases the viability and variability of aquatic species Damages crops.
Nutrients & Oxygen Demand	Fertilizers Decomposing plants and animals Soil erosion Combined sewer overflows Pet and bird fecal matter Industrial emissions Atmospheric deposition	Nitrates can cause infant health problems. Eutrophication of lakes and estuaries.
Metals	Automobile exhausts Automobile wear Industrial discharges Atmospheric deposition Soil erosion Combined sewer overflows	Bioaccumulation and biomagnification. Decreases drinking water quality. Accumulates in bottom sediments, posing risks to bottom-feeding organisms and their predators. Disrupts aquatic food chains. Can affect reproduction rates and life spans of aquatic species.
Organics		
PAHs	Automobile exhausts Automobile wear Industrial discharges Atmospheric deposition	Carcinogenic Bioaccumulation and biomagnification. Toxic to marine life.
PCBs	Fire-resistant transformers Insulating condensors Hydraulic systems Disposal of waste PCBs Transformer oil reprocessing	Carcinogenic Bioaccumulation and biomagnification. Persistance in the environment is generally greater than that for most chlorinated pesticides. Predominant fate is adorbtion onto sediments.
Pesticides	Pest and weed control Soil erosion	Bioaccumulation and biomagnification. Some are carcinogenic, mutagenic, or teratogenic. Persistance in the environment is generally greater than that for most chlorinated pesticides. Human health hazard via consumption of contaminated fish and water. Degrades habitat and decreases the viability and variability of aquatic species
Bacteria	Combined sewer overflows Pet and bird fecal matter	Associated pathogens and disease-bearing organisms. Human health hazard. Reduced recreational usage. Decreased drinking water quality.

Sources: Puget Sound Water Quality Authority, 1989; U.S. EPA, 1984; Randall and Grizzard, 1984; Novotny and Chesters, 1981.

Highways and Streets
Like other urbanized areas, highways interrupt natural drainage patterns and have distinct linear form. Highway and street surfaces contribute significant amounts of pollutants to urban storm water. "The nature, conditions, and gradient, of the contributing surface is of major significance in controlling pollutant delivery to the sewer system."(Ellis, 1986, p. 6). Other factors that affect pollutant loadings on road surfaces are the speed and the frequency of the traffic flow.

"Street surface characteristics were found to have an effect on the contaminant loadings observed at a given site"; asphalt surfaces and those in fair-to-poor conditions contributed significantly higher loadings (Sartor and Boyd, 1972, p. 9). The weathering of asphalt and pavement contributes solids that contain lead, chromium, copper, nickel, zinc, grease, and petroleum to urban storm water (PSWQA, 1986, p. 4-98). Mar et al., discovered that levels of solids and metals in highway runoff were similar and nutrient concentrations were lower compared to those concentrations found in other urban runoff and treated sewage (1982, p. 19). This study also found that most of the pollutants were insoluble and bound to particles. In particular, the majority of metals in highway runoff are in unavailable forms and can be immobilized in soils and vegetation (Mar, et al.,1982, pp. 19, 23). High density and heavy stop-and-go traffic will generate the greatest amount of pollutants from highways (PSWQA, 1986, p. 4-98).

Higher speed travel significantly impacts atmospheric deposition of pollutants generated by automobile exhaust. Traffic-generated winds are very effective in removing pollutants from highways and "the steady-state volume of solids on a highway is controlled by the width of the distress land, the height of the curbing, and the speed of the traffic."(Mar et al., 1982, p. 12). Wang, et al. concluded that "A significant fraction of the solids generated by the highways is blown and deposited within 15 meters of the roadway and is incorporated in the vegetation and top soil. The remainder is widely dispersed at low concentrations. Metals associated with the soils can be leached by runoff waters with pH lower than 5; otherwise metals appear to be immobile."(Mar, et al., 1982, p. 23).

Yards
Yards and other urban vegetated areas contribute suspended solids, nutrients, pesticides, fecal coliform, and oxygen-consuming pollutants to urban storm water. Lawn fertilizers are a major source of nitrogen and phosphorous. Lawn and garden products such as pesticides, insecticides, and herbicides contribute refractory organic chemicals to urban storm water, which persist in the environment for long periods of time. Domestic animals and birds in the urban environment are sources of pathogens associated with fecal matter. Leaves, grass clippings, other organic lawn wastes, and animal fecal matter are major contributors of phosphorous and other oxygen demanding materials.

Construction Sites
Construction sites in any land use setting are a major contributor of sediments to urban storm water. Unlike other urban activities, construction activities are short-lived events. Soil disturbance and subsequent erosion by precipitation, wind, or gravity, generate sediments that are pollutants themselves and also serve as transport mechanisms for pollutants generated elsewhere.

Spills, Leaks, and Dumping
Accidental or intentional point source discharges also contribute pollutants to urban storm water that are more likely to cause acute environmental problems when combined with cumulative nonpoint source effects. Possible point sources may include spills or leaks from households, small businesses, large industries, trucks, and railroad cars.

Household chemicals entering urban storm water include: 1) automobile oils, coolants, and other fluids; 2) household cleaning wastes; 3) lawn and garden chemicals; and 4) paints and solvents. Typical entryways into urban storm water are directly through disposal into storm drains and sewers or dumping on the ground or street.

Small businesses that use products containing hazardous chemicals, (such as dry cleaners and gasoline service stations), are potential sources of pollutants in urban storm water. The example of PCE contaminated ground water attributed to a dry cleaning business described in the introduction of this report, serves as an illustration. Gasoline service stations and automobile repair shops are sources of petroleum products that, if spilled, eventually wash into storm sewers or dry wells.

Industrial discharges
Industrial discharges can result from spills, storage leaks, or atmospheric releases. Metal smelters are notorious for emitting toxic metals such as lead and arsenic into the atmosphere and into storm water runoff from slag piles. Other examples are petroleum refineries and gasifiers that discharge hydrocarbons through atmospheric emissions, leaking storage tanks, etc.

Combined sewer overflows
Combined sewers in older urban areas are those systems that collect and treat both storm water and sanitary sewerage. Combined sewers represent a significant source of pollutants because in most instances the "pipes and the treatment plants are not designed to handle all of the storm water from large storms. During heavy rainfall, the sewage system discharges some of the excess flow of raw sewage and storm water through combined sewer overflows (CSOs) into nearby water bodies such as lakes, rivers, or Puget Sound." (PSWQA, 1986, p. ii.). The main pollutant concerns seem to be: 1) high fecal coliform and associated pathogen concentrations and 2) possible accumulation of toxicants in receiving water sediments and their effects on aquatic organisms around CSO outfalls.

2.4.3 Geographic Location

Climate
Rainfall intensity, duration, and frequency explains a large majority of the variation in urban storm water quality, and at times will overshadow any variations in land use. "The rate at which rainfall washes loose particulate matter from street surfaces depends upon three primary factors: rainfall intensity, street surface characteristics, and particle size." (Sartor and Boyd, 1978, p. 9).

In developing regression relationships, Driver & Lystrom hypothesized that "total storm rainfall and the size of the drainagé area are the most significant variables affecting storm-runoff-load relations." (1986, p. 132). Miller and McKenzie also concluded that total rainfall frequently explained most of the variation of the dependent variable in multiple regression analysis performed on their storm water data (1978, p. 1). Ellis also notes that the quantity of storm water or "the flow factor plays a dominant role in urban runoff pollution dynamics, as it is the driving force in the mobilisation, transport, and deposition of pollutants." (1986, p. 6). Pitt and Bissonette found wide variations in major ion concentrations in Bellevue storm water and speculated that "these variations are most likely caused by the large variations in storm flows represented in these samples." (1984, p. 71).

Antecedent conditions, particularly the time between storm events is a variable controlling the amount of pollutants found in urban storm water. The longer the time between storm events, the more pollutants are allowed to build up on impervious surfaces such as streets. This may be significant, because housekeeping practices such as intensive street sweeping could be effective in reducing pollutant deposition during dry periods when rainfall is infrequent.

"First flush" Phenomenon
Surface runoff that occurs right after a storm begins, often contains higher concentrations of pollutants than what is found later during the same storm event or closely following storms (Canning, 1988, p. 9). This phenomena is commonly know as the "first flush" which concentrates pollutant loads in the first part of runoff waters. This results in a small portion of the total runoff volume containing a large fraction of the total pollutant load (Randall and Grizzard, 1983, p. 68). Randall and Grizzard noted that "extractable metals exhibited the greatest propensity toward the first flush effect, followed by total nitrogen and total phosphorous." (1983, p. 69). Prych and Ebbert concluded that when "discharge is high, concentrations of constituents in suspended form tend to be higher and those in dissolved forms tend to be lower than when discharge is low." (1986, p. 2).

Some researchers, however, speculate that in regions like western Washington, which experience low intensity and long duration rainfall, there is a "less noticeable first flush effect" except perhaps during the winter rainy seasons when storms are more intense (Canning, 1988, p. 10). "A large initial flush of runoff to wash accumulated solids from the drainage system is uncommon. Instead, the runoff volume slowly increases and any accumulated solids are gradually carried from the system." (Mar, 1982, p. 15).

Geology
The topography or slope of the landscape directly affects the quantity of urban storm water, and in turn the quality of storm water. An increase in slope increases the amount and the rate of flow of surface runoff. In terms of storm water quality, an increase in slope translates into a greater capacity of runoff to loosen and transport pollutants. Also, the degree of urbanization and amount of impervious ground cover determines the amount of surface runoff, as discussed in chapter 1. The amount and flow rate of runoff, along with pervious ground cover characteristics also controls how fast the runoff is able to infiltrate the ground.

Permeability (the rate of water movement through the soil column under saturated conditions) and infiltration (the rate at which water percolates from the surface storage into the soil zone) are determined by ground cover and soil characteristics (Novotny and Chesters,1981, p. 82). In addition, the ability of soils to retain, modify, decompose, or sorb pollutants are dependent on chemical and physical soil parameters that are extremely interrelated.

Chemical soil parameters include mineral composition, organic content, clay mineral content, pH, exchangeable cation and anion content and capacity, and total concentration of salts. Particle size, texture, compaction, and cultivation represent some of the major physical soil parameters (Novotny and Chesters, 1981, pp. 82-83). Soil moisture and vegetation also affect permeability rates.

Soils with high clay content are not very permeable, but have a high pollutant retention capability, as do soils high in organic matter. Pollutants such as phosphorous, most toxic metals, and pesticides are largely immobile in these type of soils because they are adsorbed onto soil particles with available cation/anion exchange sites. These pollutants are not likely to be leached from these soils unless very acidic water percolates through or all the available cation/anion exchange sites are filled up. Nitrates and chloride, which are extremely soluble, are not likely to be retained by these soils.

Sandy soils on the other hand are more permeable, but do not have a great capacity to retain pollutants. This is a cause for concern because pollutants which permeate the topsoil might migrate down to ground water and possibly contaminate drinking water (Novotny and Chesters, 1981, pp. 82-83).

CHAPTER 3

URBAN STORM WATER RUNOFF AND GROUND-WATER QUALITY

Increasing numbers of people in the United States are obtaining their drinking water from ground water, both through public water supplies and from private wells. Urban areas and associated impervious ground cover often expand over crucial aquifer recharge zones, possibly affecting the quantity and quality of ground water.

The normal recharge of ground water is often altered because of impervious ground cover that disrupts natural drainage patterns and channels runoff away from recharge areas to other receiving waters. Aquifers may become depleted because stormwater runoff is not allowed to infiltrate the surface and eventually percolate down. Depleted aquifers in turn are not able to naturally discharge to surface waters such as smaller lakes and streams that depend primarily on ground water for their sources of water. Conversely, human-made structures such as retention basins are sometimes used deliberately to recharge ground water.

3.1 Ground-Water Recharge from Urban Storm Water

The quality of ground water could be degraded by either natural or artificial recharge from polluted storm water. Undiluted storm water may naturally infiltrate topsoils and percolate down to an aquifer. Diluted storm water in surface waters may also seep through cracks and pores in the bottom of lakes and streams. Artificial recharge may occur in a variety of settings, including settling basins (detention or retention), biofiltration strips, dry wells, or cracks in the pavement or sidewalk. These artificial pathways are discussed in more detail in chapter 4 of this report. For a general discussion of hydrology and ground-water protection, see "Ground Water Resource Protection: A Handbook for Local Planners and Decision Makers in Washington State" published by the Washington State Department of Ecology and King County Resource Planning.

3.2 Studies

There has been very little quantitative research done linking urban storm water pollutants and ground-water contamination. Ground-water monitoring is both very complex and expensive; therefore, local governments have been reluctant to implement ground-water monitoring because they often lack the necessary financial and personnel resources. Local governments are slowly starting to move towards monitoring urban storm water and its effects on ground water because of increasing risks to drinking water supplies and the advent of federally mandated storm water permitting.

3.2.1 Nationwide Urban Runoff Program (NURP, 1983)

The NURP study concluded that ground water was not imminently threatened by deliberate recharge from urban stormwater at the two sites where it was investigated (Long Island, New York and Fresno, California). The Long Island, NY and Fresno, CA NURP projects studied recharge basins, ranging from newly installed basins, to basins exceeding 20 years in age. The primary focus of these studies was to find out whether urban storm water pollutants were migrating into ground water. The following were the general findings from these two studies (NURP, 1983, p. 7-24):

Heavy metals, coliform bacteria, pesticides, and many of the organic priority pollutants were intercepted in soils during infiltration and prevented from reaching ground water aquifers.

Chlorides were not attenuated by soils.

Pollutants accumulate in the upper soil layers in higher concentrations near the surface and none were found several meters below the surface. All soil types tested retained pollutants, both clays and sands. Pollutant concentrations were found to be a function of the length of time a basin has been in service.

"The limit of the ability of the soil to retaining the pollutants of interest is unknown... However given the long service periods of a number of the recharge basins studied, this does not appear to represent an imminent concern."

Ground-water surfaces were at least 20 feet in depth at both study sites, so these findings may not be appropriate for sites with shallow ground water.

"No significant differences in interception/retention of pollutants is apparent for basins with bare versus vegetated recharge surfaces. However, vegetation does apparently help to maintain infiltration rates normal for the soil type."

Priority pollutants accumulated in soils in basins used for both recharge and recreation may present health risks or require special maintenance and warrant further investigation.

3.2.2 Long Island, NY NURP (1982)

The Long Island area has glacially derived soils similar to those in parts of the Puget Sound area. These soils are mostly classified as either loamy soils or sandy soils (p. 39). Five artificial recharge basins were studied and a total of 46 storm events were sampled in the Long Island, NY NURP study. This study had the following general conclusions:

> The limited results of this study indicate that the continued use of recharge basins is justified and warranted. Coliform and fecal streptococcal bacteria were found in runoff but not in the groundwater beneath the recharge basins. The concentrations of other pollutants, which were generally relatively low in runoff, were even lower in the groundwater beneath the basins. It appears that infiltration through the soil is an effective mechanism for the attenuation of some of the heavy metals and organic compounds... It also appears that, contrary to the widely held view, the removal of vegetation from the basin floor is not necessary, and that the vegetation may actually facilitate the infiltration of storm waters (L.I.NURP, 1982, p. xxiii).

Most inorganic constituent concentrations detected were relatively low in urban storm water samples and within permissible levels for drinking water. However, median lead concentrations in storm water draining from a major highway consistently exceeded drinking water standards and chloride concentrations were generally higher during the winter months (p. 115). Researchers concluded that "Coliform and fecal streptococcal indicator bacteria are removed from stormwater as it infiltrates through the soil." (p. 116). No conclusions about possible contamination of ground water by organic priority pollutants in normal surface runoff were made, but it was noted that illegal discharges of organic chemicals that runoff may carry into storm drains or recharge basins could be significant (p. 116).

3.2.3 Fresno, CA NURP (1984)

The Fresno, CA NURP study had similar conclusions as the Long Island, NY NURP:

> Soils results showed that the soils in the recharge basins provide a high degree of removal of storm runoff contaminants, thereby protecting groundwater quality. Although there is some evidence of downward movement of some contaminants in the soil, no contamination of the soil water or groundwater has occurred in any of the five basins studied (p. 1-3). Lead concentrations in the soil water and groundwater underlying the recharge basins were very comparable to background levels found in the regional ground water. This shows that the soil layer is an excellent mechanism for removing the lead from the percolating runoff water (Fresno, CA NURP, 1984, p. 1-4).

3.2.4 Spokane, WA (1985)

Spokane, located in eastern Washington, has a large number of dry wells (approximately 6,000) that are used to dispose of storm water runoff, which may in turn be contaminating ground water. A study by the city of Spokane in the early 1980s monitored ground water quality in a monitoring well adjacent to three of these dry wells.

Miller and others found that aquifer water levels along with calcium and chloride concentrations demonstrated a one to two week lag time between precipitation events. Contaminants in general seemed to be "stratified" in ground-water samples. These generalizations applied to very gravelly soils with a total depth to water of about 20 meters (65 ft.), (1985, pp. 60, 61). It was also discovered that:

> Calcium concentrations are generally lower in storm water runoff than in groundwater. This is not true however for winter runoff events occurring following extensive use of de-icing salts. The use of calcium chloride results in both elevated chloride and calcium. This feature can potentially indicate the effect of a specific storm on groundwater and, for at least one event during this study, does (Miller, 1985, p. 60).

3.3 Contamination Risks to Ground Water

With respect to ground-water quality, the major concern is the possible contamination of drinking water supplies from recharge by polluted urban storm water. Ground-water supplies seem to be at risk in both the short and long term.

The short term profound risks appear to stem more from point source discharges such as leaks or spills of undiluted pollutants into storm drains. These short term risks are extremely unpredictable and present acute toxicity or "shock effects" to ground water. Once introduced into ground water these pollutants are diluted slower than in surface waters and are harder to clean up.

The long term effects of "normal" or diluted urban storm water runoff composed primarily of pollutants washed off of impervious surfaces is unkown at this point. Heavy metals and organic chemicals that are adsorbed onto sediments accumulate in the upper layers of soils, where their fate is uncertain. Researchers have demonstrated that soils have a great capacity to immobilize and retain a large number of the pollutants found in urban stormwater. The major unanswered question is how long will these contaminants remain relatively immobile in soils and whether they will eventually migrate down to aquifers. Two possible transport mechanisms for re-release into the environment could be erosion or leaching by acidic water infiltrating and percolating these soils.

CHAPTER 4

URBAN STORM WATER QUALITY MANAGEMENT PRACTICES

4.1 Introduction

The ultimate goal of urban storm water quality management is to prevent the pollution of receiving waters and sediments. This goal can be achieved through numerous structural and non-structural methods. A comprehensive local storm water management plan is comprised of the following components : 1) information, 2) monitoring, 3) ordinances, 4) spill response, 5) engineering design, operations, and maintenance, 6) funding and staffing, 7) agreements with neighboring jurisdictions, 8) education and public involvement, and 9) enforcement (Hubbard and Galvin, 1989). The three basic tools of storm water management are storm water utilities, ordinances, and drainage manuals. Storm water utilities are also called surface water or drainage utilities. Their purpose is to finance, develop and implement storm water drainage ordinances and management plans, and educate the public. Storm water ordinances specifically address such things as non-storm water discharges, permits, spill control, erosion and sedimentation plans, storm water standards for new development and retrofitting existing development, privately-owned systems, and sensitive areas such as wetlands or wildlife habitat (Hubbard and Galvin, 1989, p. 27-29). Storm water or drainage technical manuals provide the engineering details for choosing and designing the appropriate water quality and quantity controls for a given site.

As the chemistry of urban storm water runoff is unique to a given site, so are the quality controls used to reduce the pollutants contained in storm water. The type of storm water quality controls used depend on: 1) whether quantity control is also a goal; 2) size of the drainage basin; 3) rainfall characteristics; 4) what maximum size storm is chosen to control; and 5) geology and hydrology of the area. This report will give a brief overview of these approaches, and describe basic principles, and consider their possible effects on ground-water quality. Details on the specific engineering aspects of these designs can be found in the Washington State Department of Ecology (WDOE) Stormwater Management Manual for the Puget Sound Basin - Draft; Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs by Thomas Schueler, Biofiltration Systems for Storm Runoff by Richard Horner, and Urban Runoff Quality: Effects and Management Options by Douglas Canning.

Up until recently, urban storm water control techniques have focused on the quantity rather than the quality aspects of storm water management. Improvements in quality were only incidental to controlling the volume of runoff, as in the case of some detention/retention ponds. Conversely, some quantity control methods actually decrease the quality of storm water when the primary goal is to channel runoff away as quickly as possible. This increases the volume and velocity of storm water and its ability to carry pollutants.

The three basic approaches to improving urban storm water quality are: 1) preventing pollutants from entering runoff through "housekeeping" practices; 2) reducing the volume of runoff by decreasing the amount of impervious surfaces; and 3) treating contaminated runoff before it reaches receiving waters. Storm water treatment is the most widely practiced, but is usually incidental to flood control. Storm water is detained in some manner, which allows pollutants to settle out or become immobilized by natural processes (PSWQA, 1986, p. 4-100). However, Canning points out that "The problem of pollution is not solved by this approach; the site of the problem is merely displaced unless the pollutants can be retrieved. Retrieval is often possible then necessitating proper disposal of the material." (1988, pp. 13-14).

Other factors to consider besides pollutant removal in considering storm water quality management controls or best management practices (BMPs) include: 1) quantity control; 2) construction and maintenance costs; 3) destruction or creation of wildlife habitat; 4) potential safety hazards; 5) aesthetic value; and 6) recreational benefits (Schueler, 1987, p. 2.16-17).

Urban storm water quality management can be classified as either structural or non-structural. Structural controls are natural or human-made physical features and structures that are used to prevent pollutants from entering or remove pollutants from storm water. These controls can be on-site or regional and include detention/retention ponds, grassy swales, or infiltration structures. Non-structural controls are activities, policies, and regulations that attempt to improve the quality of urban storm water and mitigate its effects on the environment.

4.2 Structural Controls

4.2.1 Detention/Retention

Detention and retention ponds or basins are the two basic types of traditional facilities used to impound water for flood control and/or remove pollutants from storm water. The strict definition of a detention pond is one that only temporarily detains storm water and then later re-releases it as surface runoff, with little or no water infiltrating the ground (WDOE, 1990, p. III-4-1; Canning, 1988, p. 17). Retention ponds are generally classified as those which retain storm water that is only released through infiltration and evaporation processes (URS, 1988, p. 3-15). There are many gray areas in between these two types and sometimes the term "detention/retention" pond is used because infiltration, evaporation, and temporary detention processes take place in most ponds.(URS, 1988, p. 3-15). Detention/retention facilities are discussed below and retention facilities that are strictly infiltration devices are discussed in the following section.

Detention ponds have historically been used to control flooding, and whatever water quality improvements occurred due to settling of contaminants were incidental. Dual purpose detention basins provide both quantity and quality control. Quantity control is achieved by briefly detaining large storms to prevent flooding. Quality control is achieved through the prolonged detention of small storms for at least 18 to 24 hours, to allow settling of suspended solids is necessary for water quality control (Canning, 1988, p. 18). "Detention basins are widely used in the Puget Sound area where low permeability subsoils preclude the use of retention-infiltration basins." (Canning, 1988, p. 17).

Detention ponds can remove storm water pollutants through sedimentation of particulates or biological uptake of dissolved pollutants. The detention pond design will determine the degree to which each process operates and its efficiency in removing pollutants.(WDOE, 1990, p. III-4-1). WDOE classifies detention facilities either as "wet" ponds that maintain a permanent pool of water or "dry" ponds that drain after a relatively short period of time. These facilities can also be either above ground or underground.

The NURP study found that pollutant removal ranged from "insignificant to quite poor" for dry basins investigated. Wet basin performance ranged from poor to excellent because of differences in the size of the basin relative to the drainage basin and local storm characteristics. Detention basins in which the "runoff from an individual storm displaces all or part of the prior volume, and the residual is retained until the next storm event" were shown to have high pollutant removal capabilities (NURP, 1983, p. 8-3).

Surface "wet" ponds are thought to be the most effective in improving storm water quality because they maintain a permanent pool of water which promotes particulate removal and biological uptake of pollutants. Particulate removal is improved in both above ground and underground ponds by: 1) decreasing the energy of storm water as it enters the basin; 2) preventing scour and resuspension of material on the bottom; and 3) allowing exchange of incoming storm water with previously captured water, thus providing additional time between storms to settle pollutants (WDOE, 1990, p. 4-2). However, biological assimilation of dissolved pollutants is only promoted in above ground wet ponds. In above ground ponds, aquatic plants and algae can take up soluble pollutants such as nutrients and some metals, and bacteria are allowed to decompose some of the organic pollutants (URS, 1988, p. 33-16).

Canning notes that: "The principal faults with current detention basin design are (1) an often inadequate outlet structure and detention period for effective sedimentation, (2) the stirring up and resuspension of sediments by inflowing storm water, and (3) inadequate maintenance." (1988, p. 17). Scouring and resuspension of contaminated sediments, which could then re-release pollutants to receiving waters, is a major concern in designing detention basins. Regularly scheduled removal of sediments is necessary for detention basins to remain as effective water quality control facilities (PSWQA, 1986, p. 4-103). Another concern is the disposal of contaminated sediments which accumulate in these basins and possible leaching of pollutants into ground water from landfills.

Extended detention wet ponds were ranked first in treatment efficiency of storm water by detention facilities in the WDOE Puget Sound Stormwater Management Manual - Draft. Schueler notes that:

> Extending the detention time of dry or wet ponds is an effective, low cost means of removing particulate pollutants and controlling increases in downstream back erosion. If stormwater is detained for 24 hours or more, as much as 90% removal of particulate pollutants is possible. However, extended detention only slightly reduces levels of soluble phosphorous and nitrogen found in urban runoff. Removal of these pollutants can be enhanced if the normally inundated area of the pond is managed as a shallow marsh or a permanent pool.(1987, p. 3.1)

Schueler recommends a two stage detention pond design with an upper and lower stage. The upper stage is designed for flood control for larger infrequent storms and remains dry most of the time. This can prevent the resuspension of contaminated sediments by initially reducing the energy of the water entering the lower stage. The lower stage is designed for water quality control and allows the fine particles and pollutants to settle out. This stage maintains a permanent pool and could be an artificial wetland in which plants could help stabilize sediments uptake soluble pollutants (1987, p. 3.16)

Routine maintenance of detention facilities may include mowing, inspections, debris and litter removal, erosion control, and nuisance control (odors,mosquitos,weeds,litter). Non-routine maintenance of detention facilities may include structural repairs and replacement, and sediment removal (Schueler, 1987, pp. 3.21-3.23).

4.2.2 Infiltration

Infiltration facilities are structures that directly infiltrate storm water into the ground. These facilities include large off-site retention basins, small on-site units such as infiltration pits and trenches, percolating catch basins, dry wells, and porous pavement (NURP, 1983, p. 8-15). Most infiltration structures except for porous pavement also provide storage volume and flood control capabilities (NURP, 1983, p. 8-15). The two basic principles behind improving stormwater quality through infiltration are 1) attenuation (immobilization) of pollutants by soils and 2) dilution of stormwater with large amounts of uncontaminated ground water.

Pollutants such as soluble heavy metals, phosphorous, and pathogens can be attenuated by soils. Attenuation processes are very complex and include adsorption, precipitation, trapping, straining, and bacterial degradation or transformation. Attenuation rates for individual pollutants depend on their solubility and biochemistry, and the physical and chemical properties of the soils and ground water (Schueler, 1987, p. 5.13).

Infiltration devices are a viable water quality control option in medium textured soils with moderate permeability where the water table is well below the soil surface (URS, 1988, p. 3-18; Schueler, 1987, p. 6.2). However, infiltration facilities are generally not designed to trap coarse sediments that can sometimes clog the soil pores on the pond floor, thus preventing infiltration. "Fine soils are subject to clogging, while coarse soils can pass pollutants to groundwater. Excessively rapid percolation through coarse soils allows insufficient time and soil surface contact for effective pollutant removal. Therefore, whether a rate is too rapid depends on whether an aquifer lies relatively near the surface."(URS, 1988, p. 3-18).

Clogging is a major drawback of infiltration devices which results in significantly reduced or no infiltration. Infiltration structures are most vulnerable to clogging during their own construction because of soil disturbance and erosion. Pre-settling basins or biofiltration can sometimes be used to trap coarser sediments and prevent clogging. The NURP study noted that:

> Pollutant removals are reduced in direct proportion to the runoff volume which is intercepted and recharged. Load reductions will be further enhanced if quality improvements occur in the portion of the runoff which is not captured. The combination of soil infiltration rate and percolating area provided determines the "treatment rate" of a specific recharge device... Overall performance will be related to the size of the recharge device relative to the urban catchment it serves and the permeability (infiltration rate) of the soil (1983, p. 8-15).

Of all the storm water quality control methods, infiltration probably has the greatest potential to contaminate ground water with pollutants found in urban storm water, especially in soils with high permeability. Careful site-specific considerations should be made when determining whether infiltration methods are appropriate for a given area. Other site conditions that could preclude the use of infiltration methods include steep slopes, shallow depth to ground water, and close proximity to water supply wells (NURP, 1983, p. 8-14). "SEEPAGE", a qualitative system to evaluate sites for infiltration facilities has been developed by the Soil Conservation Service and is included in the WDOE Stormwater Management Manual for the Puget Sound Basin - Draft.

Infiltration basins
Infiltration basins are generally large off-site retention basins that can serve two purposes. With respect to water quantity, retention basins can control flooding and also store runoff for later infiltration into the ground; ground waters in turn recharge rivers and streams. Schueler notes that "Infiltration basins divert a significant fraction of the annual runoff volume back into the soil. This enhanced recharge can maintain flow levels in small headwater streams during critical dry weather periods."(1987, p. 6.7). The other purpose is related to water quality. Retention basins are effective in removing both fine contaminated sediments and soluble pollutants found in urban runoff through soil adsorption processes (Schueler, 1987, p. 6.1).

Infiltration trenches
Infiltration trenches are usually on-site and are basically smaller versions of infiltration basins. These structures can also facilitate removal of soluble and particulate pollutants, and can provide ground water recharge and flood control depending on their size and infiltration capacity. (Schueler, 1987, p. 5.1)

Porous pavement
Porous pavement is asphalt or concrete pavement that has sufficient voids or pore space to allow water to infiltrate into the ground. Schueler describes porous pavement as having a "high capability to remove both soluble and fine particulate pollutants in urban runoff, and also provides ground-water recharge, low flow augmentation, and stream bank erosion control. Its use is generally restricted to low volume parking areas...The major drawback associated with porous pavement is that if is becomes clogged it is difficult and costly to rehabilitate. The risk of premature clogging of the pavement is fairly high, and can be prevented only if sediment is kept off of the pavement before, during, and after construction." (Schueler, 1987, pp. 7-1, 7-2).

Injection wells
Underground injection wells, also known as dry wells, are also a form of infiltration used to dispose of storm water runoff on-site. Schueler classifies dry wells as "underground infiltration trenches". Dry wells are probably the most likely to contaminate ground water because they "provide little pretreatment and act as a direct conduit for stormwater to enter the unsaturated zone and the aquifer, bypassing soil column attenuative processes..."(Goldstein, 1987).

Dry wells are used in all types of land use areas. Spills and leaks of undiluted hazardous chemicals that eventually find their way to dry wells are the most serious threat posed to ground water. The contamination of ground water by PCE given in the introduction is an example of this hazard. The potential impact of "normal" urban storm water on ground water via dry wells is still relatively unknown. The WDOE "Guidelines for Stormwater Disposal Via Dry Wells" recommends the following:

> Dry wells are not generally an acceptable method of disposing of stormwater. Grassy swales, percolation areas, and wet and dry ponds provide better treatment and protection to ground water. Use dry wells only where alternatives, such as retention basins or storm sewers, are not practical or feasible (1989, p. 4).

If dry wells are used, it is generally recommended that some sort of pre-treatment occur before stormwater enters the well. This may consist of biofiltration, a pre-settling basin, or oil-water separator.

Detention/retention versus infiltration
The Puget Sound Water Quality Authority provides an excellent discussion of the tradeoff between detention and retention (infiltration) facilities in its 1986 Nonpoint Source Pollution issue paper. A portion of this discussion is quoted below.

> The choice between detention and retention basins involves tradeoffs between risking contamination of ground water, adding pollutants to surface waters, and preventing damage to fish habitat. Retention basins reduce contamination of surface waters (because contaminants remain in the basin or enter the ground water instead of flowing with stormwater into streams), reduce the volume of streams during and after flooding, and "save" the water as ground water for later recharge of streams during dry seasons. Retention, therefore, provides greater protection to both spawning and rearing habitat for salmon. Unfortunately, retention basins can potentially cause contamination of ground water as dissolved contaminants from stormwater filter down. Detention basins, on the other hand, do not contaminate ground water. However, they do not reduce the total volume of stormwater to streams nor do they help to prevent streams from drying out during the summer (p. 4-102).

4.2.3 Biofiltration

Biofiltration can be defined as "processes in which a wastewater stream receives treatment through interaction with vegetation and the soil surface."(Horner, 1988, p. i). The basic principle of biofiltration is that vegetation acts as a physical and chemical filter to immobilize pollutants and prevent them from entering receiving waters. Biofiltration processes include sedimentation, infiltration, adsorption, and biological uptake of pollutants (WDOE, 1990, p. III-6-1). There are three basic types of biofiltration: 1) grassed swales, 2) filter strips, and 3) wetlands.

Grassy swales
A grassy swale is a vegetated channel similar to a storm drain channel (WDOE, 1990, p. III-6-2-). "Grassed swales function primarily by sedimentation of suspended solids and pollutants. The velocity of water flowing through a grassed swale is reduced sufficiently to promote sedimentation. Additionally, as the runoff infiltrates porous ground, pollutants are also filtered out by the root mat and upper soil horizon. Some dissolved pollutants may also be adsorbed onto the surface of the vegetation, the root mat, or soil particles." (Canning, 1988, p. 23). To be effective, the flow of stormwater should not exceed the height of the vegetation in the grassed swale (WDOE, 1990, p. III-6-2).

In Washington Department of Transportation sponsored highway studies, University of Washington researchers found grassy swales to be the most cost effective means of removing solids and associated pollutants from highway runoff, but were not as effective removing soluble metals.(Canning, 1988, p. 21). In that particular study Wang et al. concluded that "a slightly sloped channel of hydraulically sufficient cross-sectional area and 60 m in length is capable of removing 60-80 percent of the Pb, Zn, and Cu, in highway runoff." (1982, p. 28).

The NURP study concluded that grassy swales moderately improved urban runoff quality. The authors cited slope, vegetation type and maintenance, control of flow velocity and residence time, and enhancement of infiltration as factors to consider in the design of grassed swales (1983, p. 9-14). A major concern of biofiltration systems is maintaining vegetation. If swales have standing water for prolonged periods of time or excessive sedimentation occurs, vegetation will die off and its benefits cease.

Filter strips

Filter strips are smaller versions of grassed swales. The main difference between the two is that filter strips are used when runoff is a sheet flow, grassy swales or channels are used when runoff volume is sufficient to form channels (Horner, 1990). "Filter strips provide a vegetated buffer around streams, lakes, and wetlands" and "also protects the water body from litter, bank erosion, and other impacts of intense use. Close-growing, fine grasses provide the best pollutant removal action, but woody vegetation offers other buffering advantages."(URS, 1988, p. 3-17).

In a 1988 review of biofiltration systems in the region Horner noted that:

> A minority had poor vegetation coverage, and some exhibited persistent pooling of water, perhaps due to the prevalent shallow slopes, as well as high water tables. Saturation can kill grasses and be an aesthetic drawback near homes and businesses. Little siltation was evident, except at construction sites, although few biofilters are preceded by settling devices. Therefore, maintenance could be limited in most cases to mowing.(Horner, 1988, p.ii).

Wetlands

Wetlands include bogs, shallow marshes, shrub/scrub wetlands, and forested wetlands, and are classified as either natural or artificial. Some of their functions include flood storage and desynchronization, sediment trapping, and nutrient retention and removal (Canning, 1988, p. 27). Canning describes their primary water quality function as being sedimentation:

> The principal water quality improvement mechanism is sedimentation. As storm water enters a wetland, flow velocities are diminished by obstructing vegetation and shallow depths. To the extent that flow velocity is diminished, suspended solids settle to the bottom of the wetland. Since many of the contaminants are adsorbed to sediments, sedimentation clears the runoff not only of the solids but also of some heavy metals, phosphorous, refractory organics, petroleum hydrocarbons, and bacteria and viruses (1988, p. 33).

"The use of natural wetlands for storm water control is highly controversial because of the possible cumulative effects of pollutants in storm water on wetland vegetation and wildlife. These effects are still not clear from the literature."(PSWQA, 1986, p. 4-101). Stockdale points out that:

> It should be kept in mind that wetlands are not final sinks for nutrients, heavy mental and other substances that are discharged to them. Wetlands improve water quality by transforming, removing, storing and releasing those substances, at modified rates and times. (1986, p. 17).

As with other urban storm water quality controls using infiltration processes, caution must be taken in areas with highly permeable soils and shallow ground water to avoid possible ground-water contamination.

Artificial wetlands

Artificial wetlands can be thought of as modified retention/detention ponds because they have many similar design principles .(URS, 1988, p. 3-17). Location and vegetation are two key considerations in designing artificial wetlands for storm water quality control. Location considerations include proper elevation relative to the ground water table, soils, geology, and ground-water hydrology (Canning, 1988, p. 36). A design should have a pre-settling basin, maintain a permanent pool with a minimum of open water, and preferably use native and dense-growing species of vegetation (Canning, 1988, pp. 36, 38). (See Canning and the Puget Sound Stormwater Management Design Manual for specific details on artificial wetland design).

4.2.4 Oil-water Separators

Traditional oil-water separators work on the principle that oil floats on water and typically use a "T" outlet which traps the oil. However, oil-water separators are effective only if they are regularly maintained by removing the oil and grease between each storm event. If this is not done the oil becomes resuspended or re-emulsified and then discharged during subsequent storms. Another problem with oil-water separators is that very intense storms may flood and not allow the oil enough time to separate (PSWQA, 1986, p. 4-100).

Another type of oil-water separator is a coalescing plate separator, which "uses packs of corrugated plates to coalesce small oil and grease droplets into larger droplets which can be skimmed off the top." (PSWQA, 1986, p. 4-100). These separators can also be effective if properly functioning and maintained.

Normal urban storm water has relatively low concentrations of oil and grease which available devices cannot remove to any significant degree. Horner and Wonacott studied a detention pond/coalescing plate separator system at Boeing Computer Services, a light industrial site. They discovered that the coalescing plate oil/water separator was not utilized because oil and grease concentrations in the storm water were very low to begin with and the detention pond removed the vast majority of pollutants found (1985, p. iv). Land treatment of detention pond effluent such as through a grassy swale could be used to remove these small amounts.

Areas that are vulnerable to spills or leaks from vehicles would justify using oil and grease separators. These include areas where there is a large amount of heavy industrial traffic (e.g., trucking bases) or in areas prone to spills. Vehicles tend to leak most when their seals contract upon cooling. Therefore, large parking lots with considerable in-and-out traffic can be significant source, while high-speed highways operating normally may not be (URS, 1988, p. 3-19).

4.2.5 Prevention of Erosion on Construction Sites

Construction sites are a major source of sediments that enter urban storm water and often carry adsorbed pollutants. The theory behind erosion control is to minimize bare areas, especially on steep slopes, through vegetation and also to prevent sediment in runoff from leaving the site by straw bales and other filtering devices.

4.3 Non-Structural Controls

4.3.1 Housekeeping

Prevention and removal of pollutants from impervious surfaces such as streets, before they enter urban storm water is the main principle behind housekeeping practices. General "housekeeping" practices such as spill prevention, cleaning practices, and regular inspection of storage areas can greatly reduce the amount of pollutants entering urban storm water form all land use areas. Street sweeping, however has generally been ineffective in removing contaminants and improving storm water quality, because it does not remove the finer particles which have pollutants adsorbed onto them (NURP, 1983; Sartor and Boyd, 1972; Pitt and Bissonette, 1984; Galvin and Moore, 1983).

4.3.2 Primary or Secondary Treatment of Urban Storm Water

Primary or secondary treatment of urban storm water in wastewater treatment facilities is technically possible, but the variability and sometimes large volumes of runoff make this option economically infeasible (URS, 1988, p. 3-19). Low volume storms or the first few hours of a storm could be routed to be treated. "However, generally the volume of storm water exceeds the capacity of the sewer lines resulting in an overflow of storm water exceeds the capacity of the sewer lines resulting in an overflow event of combined storm and sanitary sewage."(PSWQA, 1986, p. 4-105).

4.3.3 Investigative Monitoring and Site Visits

Investigative monitoring and site visits are also a means to reduce point source pollutants in urban storm water. "This technique is a method for an enforcement agency to identify the source of a pollutants in storm water in order to require control. Storm drains are sampled and when more than typical amounts of pollutants are found, the pollutant is tracked up the line until, by process of elimination, the source is identified. Sampling sediments in storm drains is effective because, unlike water samples, sediment samples integrate pollutant inputs over time." (PSWQA, 1986, p. 4-104).

CHAPTER 5

POLICIES AND REGULATIONS

5.1 Introduction

In 1972 and 1977 Congress amended the Federal Water Pollution and Control Act, also known as the Clean Water Act (CWA). The CWA prohibits the discharge of any pollutant to navigable surface waters from a point source unless the discharge is authorized by a National Pollution Discharge Elimination System Permit (NPDES), but does not specifically address discharges to ground water. There is no federal program that addresses ground water protection in a comprehensive manner. The NPDES program has focused predominantly on reducing pollutants from point source discharges, such as industrial and municipal wastewater, in order to improve surface water quality (53 FR, 1988, p. 49417).

Although EPA was given the legal authority to implement this Act, the primary responsibility for water pollution control has fallen on the states and local governments. Section 208 of the CWA required states to develop comprehensive water quality plans to protect its surface water bodies from both point and nonpoint sources of pollution. In terms of storm water discharges, the Safe Drinking Water Act indirectly addresses possible ground water contamination through the National Drinking Water Standards, the Underground Injection Control Program, Sole Source Aquifer Program, and the Wellhead Protection Program.

EPA issued its first storm water regulations on May 22, 1973 in 38 FR 13530. These regulations exempted most storm water discharges from permitting except for storm water from industrial and commercial activities identified as being a significant contributors of pollution (53 FR, 1988, p. 49419). Reluctance to regulate storm water was probably due to the great difficulty in how to defining and regulating storm water. EPA's reasoning behind this decision was that: 1) storm water discharges were not suited to the NPDES permitting program and traditional end-of-pipe wastewater treatment because of the inherent variable quantity and quality of storm water; 2) it was thought that storm water could be better managed at the local level through source controls; 3) requiring individual permits for the hundreds of thousands storm water outfalls "would create an overwhelming administrative burden and would divert resources away from control of industrial process wastewater and municipal sewage."(53 FR, 1988, p. 49419).

Over the last eighteen years there has been much debate over which storm water discharges should be regulated and how they should be regulated. The rules have been alternately broadened and narrowed after a series of court challenges from both environmentalists and industry. However, in general the movement has been slowly towards increasing regulation of urban storm water. EPA has had the difficult task of balancing "the environmental concerns associated with such discharges with the practical limitations of individual NPDES permits and the reality of limited resources."(53 FR, 1988, p. 49419).

5.2 Water Quality Act of 1987

5.2.1 Section 402

To further clarify its intent to improve the nation's water quality, Congress reauthorized and amended the Clean Water Act by passing the Water Quality Act of 1987 (WQA). Sections 402, 401, and 503 of the WQA specifically address the issue of storm water. In Section 402(p)(1),(2), and (4) Congress laid out the following regulatory timetable for industrial and municipal storm water discharges:

	Cities over 250,000 & Industry	Cities 100,000 to 250,000	Cities under 100,000
EPA Regulations	2/4/89	2/4/91	10/92
Applications	2/4/90	2/4/92	?
Permitting	2/4/91	2/4/93	?
Compliance	2/4/94	2/4/96	?

The WQA also gives the Administrator considerable discretion to regulate any discharge that "contributes to the violation of a water quality standard or is a significant contributor of pollutants to the water of the United States."(WQA, Section 402(p)(2)(E), 1987).

Industrial
Section 402(p)(3)(A) on industrial discharges requires that "permits for discharges associated with industrial activity must meet all of the applicable provisions of section 402 and section 301 including technology and water quality based standards for discharges from municipal storm sewers."(53 FR, 1988, p. 49424).

Large- and medium-sized municipalities
Section 402(p)(3)(B) on municipal storm water discharges provides that permits:

(i) May be issued on a system- or jurisdiction-wide basis.

(ii) Shall include a requirement to effectively prohibit non-storm discharges into the storm sewers.

(iii.) Shall require control to reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques and system, design and engineering methods, and such other provisions as the Administrator or the State determines appropriate for the control of such pollutants.

Part (i) of this section is very significant because it gives EPA the discretion to issue system-wide permits for municipalities that have hundreds or even thousands of storm water discharges. "This should reduce significantly the monitoring, data, and information requirements for permit application, but permit application requirements will still be substantial." (Tucker, 1989, p. 114). This system-wide approach will probably alleviate only some of the administrative burden at all levels of government, but it will take time to figure out how to issue system-wide permits efficiently and realistically.

Part (ii) totally prohibits non-storm water discharges which includes combined sewers and illegal hookups to storm sewers. These connections are difficult to find and very costly to correct. In older urban areas with combined sewers this could be very significant problem to correct.

Part (iii) is written very vaguely, and the term "maximum extent practicable" has caused much concern, because it is left open to interpretation. This vagueness could work in a positive or a negative way. It could provide the flexibility needed for local governments and industry to be innovative in managing storm water or provide a loophole for inaction and noncompliance. EPA and State permit writers will have to decide what constitutes "maximum extent practicable" for each site. Interpretation of this term will likely be tested in the judicial system.

Small municipalities
Section 402(p)(5) requires EPA to perform two studies on storm water discharges, potential impacts, and management controls from municipalities under 100,000 in population. Based on those studies, section 402(p)(6) requires EPA in consultation with States and local officials to issue regulations and deadlines for issuing permits for those discharges by no later than October 1, 1992.

5.2.2 Sections 401 and 503

Section 401 excludes "discharges of storm water runoff from mining operations or oil and gas exploration, production, processing, or transmission facilities if the storm water discharge is not contaminated by contact with, or does not come into contact with any overburden, raw material, intermediate product, finished product, byproduct, or water product located on the site of such operations."(53 FR, 1988, p. 49424). Section 503 excludes agricultural storm water discharges from the definition of point sources.

5.2.3 Current EPA Ruling on Urban Storm Water

The final EPA rule on regulating storm water discharges from municipalities over 250,000 in population and industry is expected in November 1990. Some of the issues involved in the current ruling are: 1) what type of sampling and data collection should be required in the permitting process; 2) whether to issue group permits for industrial facilities of the same type, and if so, how it would be done; 3) whether industrial facilities or municipalities should be responsible for providing storm water quality control for industrial discharges into a municipal storm sewer system; 4) allowing a system- or jurisdiction-wide approach for municipalities, where one permit instead of individual permits would be issued; 5) flexibility in permitting municipal storm water management programs which reflect site-specific characteristics and impacts associated with these discharges (Gallup and Weiss, 1989, pp. 104-105).

5.3 Safe Drinking Water Act

The main goal of the SDWA of 1974 was to ensure public health by improving the quality of the nation's drinking water. Congress directed EPA to establish minimum national drinking water standards which set limits on the concentrations of chemicals sometimes found in drinking water. These standards apply to water supplies with at least 15 connections or serving 25 or more people. Suppliers must also inform the public if their drinking water does not meet these standards and what precautions to take. Enforcement of the SDWA is carried out either by the States or by EPA on request by the States or when the States are slow to act.

The four major components of the SDWA are the 1) National Drinking Water Standards (1974), 2) Underground Injection Control Program (1974), 3) Sole Source Aquifer Program (1974), 4) Wellhead Protection Program (1986). The 1986 Amendments to the SDWA further clarified Congressional intent to improve drinking water by specifically: 1) prohibiting the use of lead-containing materials in drinking water supply systems; 2) accelerating the regulation of drinking water pollutants by setting a specific schedule with deadlines for EPA to develop and enforce drinking water standards; 3) expanding and/or improving federal water quality programs.

5.3.1 National Drinking Water Regulations

Congress first required EPA to establish national drinking water standards through the SDWA of 1974 to ensure the quality of the nation's drinking water at the tap. The 1986 amendments to the SDWA require EPA to strengthen these standards, which apply to both surface water and ground-water sources of drinking water. The National Drinking Water Regulations consist of primary and secondary standards that reflect both human health and aesthetic concerns with regard to public water supplies.

The purpose of the primary drinking water standards is to protect public health. The concentrations of chemical constituents in these standards are levels in drinking water that EPA has determined as being safe for human consumption. Under the authority of the SDWA, EPA is required to issue a Maximum Contaminant Level Goal (MCLG) and an Maximum Contaminant Level (MCL) for various chemical constituents found in drinking water.

A maximum contaminant level goal (MCLG) is a nonenforceable health goal. EPA issues maximum contaminant level goals for substances only included in the primary drinking water standards. MCLGs are set at a level at which "no known or anticipated adverse effects on the health of persons occur and which allow an adequate margin of safety."(GAO, 1988, p. 52). MCLGs are usually set at a risk level of one-in-one-million risk of cancer to humans. A maximum contaminant level (MCL) is an enforceable primary drinking water standard. MCLs are set as close as possible to MCLGs as feasible and achievable through available technology.

The secondary drinking water standards are not concerned with public health, but are designed to protect public welfare. Their purpose is to "provide guidelines regarding the taste, odor, color, and other aesthetic aspects of drinking water which do not present a health risk." (EPA, 1989, p. 18).

5.3.2 Underground Injection Control Program

Created in 1974, the Underground Injection Control (UIC) Program focuses on preventing the underground injection of waste that could cause ground water contamination and subsequent violations of national drinking water standards. The UIC program requires EPA to establish minimum requirements for state regulation and permitting of deep well injection of wastes or "subsurface emplacement of fluids into underground wells".

The simple definition of "injection well" is a hole in the ground that is deeper than it is wide. EPA classifies injection wells into five broad categories based on the type of injected material and the location of the injected material in relation to an aquifer (Barrett, 1987, p.13). These five categories are also subdivided into more specific types of injection wells. Congress exempted oil, natural gas production and associated petroleum development brines from extensive regulation, only requiring states to prove that the brines would not endanger drinking water (Gordon, 1984, p. 97).

5.3.3 Sole Source Aquifer Program

The purpose of the Sole Source Aquifer Program is to protect aquifers which serve as the primary drinking water supply for a large portion of the population of a given area. Current EPA policy requires that some person or organization petition EPA to designate an aquifer as a sole or principal source of drinking water. Once an area has been designated as a sole source aquifer, EPA has the authority to review and approve any federally funded projects that could threaten ground-water quality within the sole source aquifer area (Barrett, 1987, p. 13). This program is very limited in scope because it does not include federal projects themselves or any projects without federal financial assistance. However, local attention given to designated sole source aquifer areas may in a indirect may serve to help state and local governments develop laws and ordinances protecting ground water and the impetus to implement existing laws.(Gordon, 1984, p. 97).

5.3.4 Wellhead Protection Program

The goal of the Wellhead Protection Program is to prevent the contamination of public water supply wells through the protection of recharge areas surrounding ground-water wells. This program makes the link between land use and human activities near wellhead areas and ground-water quality, and provides another mechanism for ground-water protection.

5.4 Other Federal Statutes - FIFRA, TOSCA, RCRA, CERCLA

Other federal statutes that indirectly protect ground-water resources include the Federal Insecticide, Fungicide, Rodenticide Act (FIFRA), Toxic Substances Control Act (TOSCA), Resource and Conservation and Recovery Act (RCRA), and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or "Superfund".

Both FIFRA and TOSCA regulate toxic chemicals that could harm human health and the environment. FIFRA "establishes procedures for governing the registration, classification, sale, use, research, monitoring , and disposal of pesticides"(Barrett, 1987, p.15). TOSCA gives EPA authority to "review new chemical substances and mixtures prior to manufacture, develop rules for industry testing of chemicals, assess risks, and control existing toxic chemicals."(Barrett, 1987, p. 15). In terms of ground water, a benefit of regulating these chemicals in a prudent manner is the prevention of underground drinking water supply contamination.

A primary goal of the Hazardous Waste Management Program under RCRA is to protect ground-water resources from potential contamination of existing hazardous waste facilities. RCRA requires generators of hazardous wastes to track it from generation to disposal and regulates hazardous waste storage and disposal facilities (Barrett, 1987, p. 14).

The CERCLA or Superfund program in contrast is response oriented and designed to mitigate the past and current releases of hazardous substances at hazardous waste sites. In nominating sites for the National Priority List for Superfund eligibility, the Washington State Department of Ecology and EPA rank them according to the: 1) potential for contaminating drinking water supplies or other pathways that can affect human health and 2) potential for destruction of sensitive ecosystems (Barrett, 1987, p. 14). "To date, federal response actions under CERCLA have principally addressed ground water contamination problems."(Barrett, 1987, p. 15).

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

Currently, there is no comprehensive federal legislation or program which protects ground-water quality from all potential or existing sources of contamination,(including urban storm water runoff), or that establishes national ground-water standards (Barrett, 1987, p. 15). The Safe Drinking Water Act and other narrowly focused federal legislation, along with state and local laws and ordinances, provide a legislative patchwork that attempts to protect the nation's ground-water quality. To fill the void, some states are using the National Drinking Water Regulations as ground-water quality standards for lack of federal ground-water standards. Other federal programs, such as the Sole Source Aquifer Program are severely limited in their scope and effectiveness in protecting ground-water quality.

6.2 Assessment of the Water Quality Act of 1987

"The long term goal of EPA appears to be to force the development of comprehensive storm water management plans at the local level that will in time reduce the discharge of pollutants into and from storm waters." (Tucker, 1989, p. 120). Currently, a few local jurisdictions are moving ahead in developing storm water or surface water utilities in anticipation of EPA's final rule on storm water discharges. The City of Bellevue in Washington state was the first city in the country to develop a storm water utility, ordinances, and water quality drainage plan. This may be an instance of local government taking initiative in the absence of national or state guidance, which may significantly influence national policy in the future.

Only urban storm water discharges to surface water will require NPDES permits under the WQA of 1987. However, the issuance of these NPDES permits may have a indirect positive effect on the quality of urban storm water discharges to ground water. Management controls used to improve the quality of urban storm water in order to prevent surface water contamination may also have a byproduct effect of preventing ground-water contamination.

The WQA of 1987 excludes the regulation of mining, and petroleum industry storm water runoff that does not come into contact with any materials produced at the operations site. It is very unrealistic to think that storm water emanating from mining operations or petroleum refineries does not contain significant amounts of toxicants. Some of these activities, especially refining processes certainly take place in or near urban areas. Why should storm water from these industries be excluded? Even if they are located in rural or semi-rural settings, contaminated storm water could pollute surface water that reaches urban areas or recharge an aquifer with pollutants possibly migrating underground to public drinking water supply wells.

All levels of government will have a tough time implementing this massive program that will require additional staffing and funding. Small municipalities will probably be especially hit hard because of lack of trained staff and no established drainage plans. The capital and operating expenses necessary to comply with these regulations will cost an enormous amount of money. Who will pay for it? The federal government is currently having serious budgetary problems and is not in a position to provide as much financial aid to local governments as in the past. Tucker points out that "The financial burden of the municipal storm sewer permitting program will fall primarily on local governments, i.e., cities, counties, flood control districts, etc. The permitting program is not voluntary and there are no grants or federal funding support to assist with meeting permit requirements."(1989, p. 112).

6.3 Assessment of the Safe Drinking Water Act

Although EPA does not explicitly support the adoption of national ground-water standards, the agency is implicitly supporting the use of the national drinking water standards as ground-water standards through its ground-water protection programs.(GAO, 1988, p. 3). A 1988 General Accounting Office (GAO) report found that both EPA and some states are encouraging the use of drinking water standards as ground-water standards.

GAO found four EPA programs that encourage the use of drinking water standards as ground-water standards at the local level. To prevent ground-water contamination, the Sole Source Aquifer program implicitly encourages states and municipalities to designate aquifers used as a primary source of drinking water sources. Section 1424 (e) allows EPA to make such designations, but the Agency only responds to petitions, and does not explicitly encourage the submission of petitions. The EPA Office of Pesticide Programs also takes a preventative stance in that actions should be taken before concentrations of pesticides in ground water reach the drinking water standard MCLs. Both the RCRA and Superfund programs rely heavily on MCLs in the drinking water standards to instigate remediation actions at hazardous waste sites (GAO, 1988, p. 3). The GAO report states that:

> An assumption common to all of these policies is that MCLs play a key role in helping to determine the need and scope of regulatory actions, and when coupled with appropriate control techniques and programs, their use will result in an acceptable level of groundwater protection.(1988, p. 3).

Gordon points out the major flaw behind this reasoning is that "...a drinking water supply could be severely contaminated by toxic substances for which there are no MCLs and still meet the federal requirements for safe drinking water."(Gordon, 1984, p. 89).

In the absence of national ground-water quality standards, 26 states have numeric ground-water standards that rely heavily on the EPA national drinking water MCLs. Both the substances chosen and their allowable levels found in these states' ground-water standards were based on the drinking water standards.(GAO, 1988, p. 4-6). The states are essentially implementing a policy of limited degradation of ground water up to the legally enforceable MCLs set in the drinking water standards. GAO found that ground-water quality at 92 percent of the locations studied met all the drinking water standard MCLs and that 71 percent met the MCLGs for all substances measured.(1988, pp. 1, 38).

Should there be national ground-water standards? If so, should the goal of ground-water standards be nondegradation or limited degradation up to the point of the drinking water standards? Another option could be a policy of antidegradation similar to the urban storm water discharge requirements in Section 402(p)(3)(B)(iii) of the CWA of 1987. This policy would require that the best management practives be used to reduce ground-water pollution to the maximum extent practicable.

In addition to drinking water, ground water is used for irrigation and livestock. Ground water also affects the habitat of aquatic life because it flows into surface water. Allowing limited degradation through application of the drinking water standards for ground-water protection could jeopardize other uses that require standards higher than those for drinking water. EPA MCLs for drinking water were at least as stringent as levels recommended for livestock and irrigation, but MCLs for 17 substances were less stringent than levels set for aquatic life (GAO, 1988, p.9). GAO concluded that the adoption of drinking water standards as ground water standards "would allow the potential for degradation of a considerable amount of groundwater (to the level of contamination allowed by drinking water standards)."(GAO, 1988, pp. 1, 38).

Most states lack a comprehensive ground-water protection strategy, and instead have disjointed statutes that are implemented by several states agencies. These regulations generally fall into four broad categories: 1) regulation of contaminants; 2) classification of aquifers; 3) ground-water quality standards; and 4) control of land use in aquifer-recharge zones.(Gordon, 1984, p.48). Variability in regional ground-water quality and contamination sources, along with the absence of comprehensive federal ground-water regulations account for the great diversity in state ground-water regulations. At the local level, jurisdiction over ground water is also often split between different departments, such as the public works and engineering department, health department, and water utility. Development pressures and the fact that aquifers often extend over governmental boundaries also add to the difficulties in protecting ground water (Gordon, 1984, p. 49).

6.4 Recommendations

In order for local governments to succeed in managing storm water and protecting ground-water quality, guidance must come from EPA and the states to show local governments how to develop comprehensive storm water management plans and ordinances. Instead, EPA and the states seem to be waiting to see what happens at the local level before proceeding further, especially in the area of ground-water protection.

A clear and enforceable comprehensive federal policy protecting ground-water quality from all sources of contamination, (including urban storm water), is needed to provide direction to state and local government. This policy could take the form of the nondegradation or antidegradation of existing ground-water quality of any given aquifer. Another option would be to develop a specific set of national ground-water quality standards similar to the National Drinking Water Standards. A regional approach could also help local governments cope with implementing both storm water management and ground-water protection. Development of regional ground-water management authorities with the authority to both plan and enforce rules because of the regional nature of ground water and the multiplicity of governmental interests (Gordon, 1984, p. 49).

Sharing information between all levels of government could expedite the development of storm water management plans and avoid duplication of work. Aggressively developing information networks could play a key role in providing much needed information to local jurisdictions where the actual implementation of water quality control takes place. An example of this the Municipality of Metropolitan Seattle's current development of an computer database of annotative bibliography of publications related to urban storm water quality and management.

Urban storm water quality and its management is an extremely complex and variable issue. It will take a collective and innovative effort at all levels of government and by the public to practically and effectively control urban storm water and mitigate its effects on the environment.

APPENDIX A

TABLE 6

SUMMARY OF ANALYTICAL CHEMISTRY FINDINGS FROM NURP PRIORITY POLLUTANT SAMPLES[a]
(includes information received through 9/30/83)

Pollutant	Cities where detected[b]	Frequency of detection (%)[c]	Range of detected concentrations (μg/l)[d]
I. PESTICIDES			
1. Acrolein	Holding times exceeded		
2. Aldrin	4, 7, 26	6	0.002T-0.1M
3. α-Hexachlorocyclohexane (α-BHC) (Alpha)	7, 8, 22, 26	20	0.0027-0.1M
4. β-Hexachlorocyclohexane (β-BHC) (Beta)	7, 8	5	0.018-0.1M
5. γ-Hexachlorocyclohexane (γ-BHC) (Gamma) (Lindane)	7, 8, 12, 26	15	0.007-0.1M
6. δ-Hexachlorocyclohexane (δ-BHC) (Delta)	7, 26	6	0.004-0.1M
7. Chlordane	2, 8, 21, 26	17	0.01L-10
8. DDD	Not detected		
9. DDE	26	6	0.007-0.027
10. DDT	7	1	0.1M
11. Dieldrin	26, 27	6	0.007-0.1
12. α-Endosulfan (Alpha)	7, 26, 27	19	0.008-0.2
13. β-Endosulfan (Beta)	Not detected		
14. Endosulfan sulfate	Not detected		
15. Endrin	Not detected		
16. Endrin aldehyde	Not detected		
17. Heptachlor	7, 8, 27	6	0.01-0.1M
18. Heptachlor epoxide	7, 26	2	0.003T-0.1M
19. Isophorone	7	3	10M
20. TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin)	Not included in NURP program		
21. Toxaphene	Not detected		
II. METALS AND INORGANICS			
22. Antimony	7, 24, 26	13	2.6-23A
23. Arsenic	2,3,7,12,19,20,21,22,26,27	52	1-50.5
24. Asbestos	Not included in NURP program		
25. Beryllium	7, 12, 20, 21	12	1-49
26. Cadmium	1,2,3,7,12,20,21,27	48	0.1M-14
27. Chromium	1,2,7,8,12,17,19,20,21,22,26,27,28	58	1-190
28. Copper	1,2,3,4,7,8,12,17,19,20,21,22,23,26,27,28	91	1L-100
29. Cyanides	4,8,19,22,26,27	23	2-300
30. Lead	1,2,3,4,7,8,12,17,19,20,21,22,26,28	94	6-460
31. Mercury	7,20,28	9	0.6-1.2
32. Nickel	2,3,7,12,20,21,26,27	43	1-182
33. Selenium	7,19,23	11	2-77
34. Silver	3,17,27	7	0.2M-0.8
35. Thallium	7	6	1-14
36. Zinc	1,2,3,7,12,17,19,20,21,22,23,27,28	94	10-2400

(continued)

TABLE 6. (Continued)

Pollutant	Cities where detected[b]	Frequency of detection (%)[c]	Range of detected concentrations (μg/L)[d]
III. PCBs AND RELATED COMPOUNDS			
37. PCB-1016 (Aroclor 1016)	Not detected		
38. PCB-1221 (Aroclor 1221)	Not detected		
39. PCB-1232 (Aroclor 1232)	Not detected		
40. PCB-1242 (Aroclor 1242)	Not detected		
41. PCB-1248 (Aroclor 1248)	Not detected		
42. PCB-1254 (Aroclor 1254)	Not detected		
43. PCB-1260 (Aroclor 1260)	2	1	0.03
44. 2-Chloronaphthalene	Not detected		
IV. HALOGENATED ALIPHATICS			
45. Methane, bromo- (methyl bromide)	Not detected		
46. Methane, chloro- (methyl chloride)	Not detected		
47. Methane, dichloro- (methylene chloride)	4, 17, 22	11	5-14.5A
48. Methane, chlorodibromo-	28	1	2
49. Methane, dichlorobromo-	28	1	2
50. Methane, tribromo- (bromoform)	28	1	1
51. Methane, trichloro- (chloroform)	4,17,20,22,23,27,28	9	0.2T-12L
52. Methane, tetrachloro- (carbon tetrachloride)	4, 28	3	1-2
53. Methane, trichlorofluoro-[e]	2,4,24,28	5	0.6T-27
54. Methane, dichlorodifluoro- (Freon-12)[e]	Not detected		
55. Ethane, chloro-	Not detected		
56. Ethane, 1,1-dichloro-	4,28	3	1.5A-3
57. Ethane, 1,2-dichloro-	28	1	4
58. Ethane, 1,1,1-trichloro-	4,2,7,22,24	6	1.6-10M
59. Ethane, 1,1,2-trichloro-	28	2	2-3
60. Ethane, 1,1,2,2-tetrachloro-	4	2	2G-3
61. Ethane, hexachloro-	Not detected		
62. Ethene, chloro- (vinyl chloride)	Not detected		
63. Ethene, 1,1-dichloro-	28	2	1.5-4
64. Ethene, 1,2-*trans*-dichloro-	20,28	4	1-3
65. Ethene, trichloro-	2,4,8,24,28	6	0.3T-12
66. Ethene, tetrachloro-	8,17,22,28	5	1M-43
67. Propane, 1,2-dichloro-	28	1	3
68. Propene, 1,3-dichloro-	28	2	1-2
69. Butadiene, hexachloro-	Not detected		
70. Cyclopentadiene, hexachloro-	Standard methods inappropriate		
V. ETHERS			
71. Ether, bis(chloromethyl)[e]	Not detected		
72. Ether, bis(2-chloroethyl)	Not detected		
73. Ether, bis(2-chloroisopropyl)	Not detected		
74. Ether, 2-chloroethyl vinyl	Not detected		
75. Ether, 4-bromophenyl phenyl	Not detected		
76. Ether, 4-chlorophenyl phenyl	Not detected		
77. Bis(2-chloroethoxy) methane	Not detected		

(continued)

TABLE 6. (Continued)

Pollutant	Cities where detected[b]	Frequency of detection (%)[c]	Range of detected concentrations (μg/l)[d]
VI. MONOCYCLIC AROMATICS (EXCLUDING PHENOLS, CRESOLS, PHTHALATES)			
78. Benzene	4,17,27	5	1-13
79. Benzene, chloro-	7,20,26,28	5	1G-10M
80. Benzene, 1,2-dichloro-	Not detected		
81. Benzene, 1,3-dichloro-	Not detected		
82. Benzene, 1,4-dichloro-	Not detected		
83. Benzene, 1,2,4-trichloro-	Not detected		
84. Benzene, hexachloro-	Not detected		
85. Benzene, ethyl-	4,8,17,20,26,28	6	1-2
86. Benzene, nitro-	Not detected		
87. Toluene	4,17	3	3-9
88. Toluene, 2,4-dinitro-	Not detected		
89. Toluene, 2,6-dinitro	Not detected		
VII. PHENOLS AND CRESOLS			
90. Phenol	4,7,26	14	1L-13T
91. Phenol, 2-chloro-	28	1	2
92. Phenol, 2,4-dichloro-	Not detected		
93. Phenol, 2,4,6-trichloro-	Not detected		
94. Phenol, pentachloro-	4,8,19,20,26,27,28	19	1T-115
95. Phenol, 2-nitro-	8	1	1M
96. Phenol, 4-nitro-	4,7,8,20,26,28	10	1T-37
97. Phenol, 2,4-dinitro-	Not detected		
98. Phenol, 2,4-dimethyl-	4,7,8,26	8	1T-10M
99. m-Cresol, p-chloro-	4	1	1.5A
100. o-Cresol, 4,6-dinitro-	Not detected		
VIII. PHTHALATE ESTERS			
101. Phthalate, dimethyl	8	1	1L
102. Phthalate, diethyl	3,4,17,20,21	6	1-10M
103. Phthalate, di-n-butyl	4,22,24	6	0.5T-11
104. Phthalate, di-n-octyl	8,20,26,27,28	6	0.4T-2G
105. Phthalate, bis(2-ethylhexyl)	4,12,19,22,21,26	22	4T-62
106. Phthalate, butyl benzyl	2,8,26	6	1-10M
IX. POLYCYCLIC AROMATIC HYDROCARBONS			
107. Acenaphthene	Not detected		
108. Acenaphthylene	Not detected		
109. Anthracene	2,17,20,21,26,28	7	1-10M
110. Benzo(a)anthracene	2,21,27	4	1-10M
111. Benzo(b)fluoranthene	26,27	5	1-5

TABLE 6. (Continued)

Pollutant	Cities where detected[b]	Frequency of detection (%)[c]	Range of detected concentrations (μg/l)[d]
112. Benzo(k)fluoranthene	2,21,27	3	4-14
113. Benzo(g,h,i)perylene	21	1	5
114. Benzo(a)pyrene	2,21,26,27	6	1-10M
115. Chrysene	2,7,17,21,26,27	10	0.6T-10M
116. Dibenzo(a,h)anthracene	21	1	1T
117. Fluoranthene	2,8,12,17,21,26,27,28	16	0.3T-21
118. Fluorene	28	1	1
119. Indeno(1,2,3-c,d)pyrene	21	1	4
120. Naphthalene	4,24,26,28	9	0.8T-2.3
121. Phenanthrene	2,8,17,20,21,26,27,28	12	0.3T-10M
122. Pyrene	2,3,8,12,17,21,26,27,28	15	0.3T-16
X. NITROSAMINES AND OTHER NITROGEN-CONTAINING COMPOUNDS			
123. Nitrosamine, dimethyl (DMN)	Standard methods inappropriate		
124. Nitrosamine, diphenyl	Standard methods inappropriate		
125. Nitrosamine, di-n-propyl	Not detected		
126. Benzidine	Standard methods inappropriate		
127. Benzidine, 3,3'-dichloro-	Not detected		
128. Hydrazine, 1,2-diphenyl-	Standard methods inappropriate		
129. Acrylonitrile	Holding times exceeded		

[a] Based on 121 sample results received as of 9/30/83, adjusted for quality control review.

[b] Cities from which data are available:

1. Durham, NH
2. Lake Quinsigamond, MA
3. Mystic River, MA
4. Long Island, NY
7. Washington, DC
8. Baltimore, MD
12. Knoxville, TN
17. Glen Ellyn, IL
19. Austin, TX
20. Little Rock, AR
21. Kansas City, KS
22. Denver, CO
23. Salt Lake City, UT
24. Rapid City, SD
26. Fresno, CA
27. Bellevue, WA
28. Eugene, OR

Numbering of cities conforms to NURP convention.

[c] Percentages rounded to nearest whole number.

[d] Some reported concentrations are qualified by STORET quality control remark codes, to wit: A = Value reported is the mean of two or more determinations; G = Value reported is the maximum of two or more determinations; L = Actual value is known to be greater than value given; M = Presence of material verified but not quantified; T = Value reported is less than criteria of detection. One value in this column indicates one positive observation or that all observations were equal.

[e] No longer included as a priority pollutant.

APPENDIX B

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APPENDIX C

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