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METHODS FOR DETECTION OF INAPROPRIATE DISCHARGES TO STORM DRAINAGE SYSTEMS

Background Literature and Summary of Findings

by

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Notice

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Foreward

Abstract

A number of past projects have found that dry-weather flows discharging from storm drainage systems can contribute significant pollutant loadings to receiving waters. If these loadings are ignored (by only considering wet-weather stormwater runoff, for example), little improvement in receiving water conditions may occur with many stormwater control programs. These dry-weather flows may originate from many sources, the most important sources may include sanitary wastewater or industrial and commercial pollutant entries, failing septic tank systems, and vehicle maintenance activities. After identification of the outfalls that are affected by polluted dry-weather flows, additional survey activities are needed to locate and correct the non-stormwater entries into the storm drainage systems.

This report contains background information for the design and conduct of local investigations of non-stormwater entries into storm drainage systems. It also includes details associated with the development of the previously published User's Guide (Pitt, *et. al*, 1993) along with a description and the results of the later field verification study. In addition, the evaluation of numerous field and laboratory procedures is also presented, along with a review of emerging technologies that may be useful during future investigations. This is the first phase of a three year project. Future project activities will include summarizing the efforts that various communities have used to meet the inappropriate discharge investigation requirements contained in the Phase I NPDES stormwater permit program, and will present a recommended procedures for Phase II communities.

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Contents

Figures

Tables

Acknowledgments

This report contains information that has been developed and tested in a number of separate research reports investigating inappropriate pollutant entries, or discharges, into storm drainage systems. Many case studies were reviewed during early parts of this research to identify the most appropriate methods of investigation. Information that was obtained from these cities is gratefully acknowledged.

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Section 1
Introduction

Overview

Current interest in illicit or inappropriate connections to storm drainage systems is an outgrowth of investigations into the larger problem of determining the role urban stormwater runoff plays as a contributor to receiving water quality problems. Urban stormwater runoff is traditionally defined as that portion of precipitation which drains from city surfaces exposed to precipitation and flows via natural or man-made drainage systems into receiving waters. Urban stormwater runoff also includes waters from many other sources which find their way into storm drainage systems. For example, Montoya (1987) found that slightly less than half the water discharged from Sacramento's stormwater drainage system was not directly attributable to precipitation. Sources of some of this water can be identified and accounted for by examining current NPDES (National Pollutant Discharge Elimination System) permit records, for permitted industrial wastewaters that can be discharged to the storm drainage system. However, most of the water comes from other sources, including illicit and/or inappropriate entries to the storm drainage system. These entries can account for a significant amount of the pollutants discharged from storm sewerage systems (Pitt and McLean 1986).

The U. S. Environmental Protection Agency's Office of Research and Development's Storm and Combined Sewer Pollution Control Program and the Environmental Engineering & Technology Demonstration Branch, along with the Office of Water's Nonpoint Source Branch, have supported the development of this research for the investigation of inappropriate entries to storm drainage systems. This report is designed to provide information and guidance to local agencies by meeting the following objectives:

1. Identify and describe the most common potential sources of non-stormwater pollutant entries into storm drainage systems.
2. Describe an investigative procedure that will allow a user to determine whether significant non-stormwater entries are present in a storm drain, and then to identify the particular source, as an aid to the ultimate location of the source.

This research identified three categories of non-stormwater outfall discharges: pathogenic/toxicant, nuisance and aquatic life threatening, and clean water. The most important category is for outfalls contributing pathogens or toxicants. The most likely sources for this category are sanitary or industrial wastewaters. The outfall analyses should have a high probability of identifying all of the outfalls in this most critical category. High probabilities of detection of other contaminated outfalls are also likely when using these procedures. After identification of the contaminated outfalls, their associated drainage areas are then subjected to a detailed source identification investigation. The identified pollutant sources are then corrected.

Section 402 (p)(3)(B)(ii) of the 1987 reenactment of the federal Clean Water Act requires that National Pollutant Discharge Elimination System (NPDES) permits for municipal separate storm sewers shall include a requirement to effectively prohibit problematic non-stormwater discharges into storm sewers. This research report can be used by local governments to evaluate and help locate these non-stormwater discharges.

This report includes a brief summary of the magnitude of the problems that may be associated with dry-weather flows discharged from separate storm sewer systems. It also discusses the potential sources and associated characteristics of these flows from a variety of land use activities. This source flow information is then used to present a method to investigate and evaluate the potential contributions of these sources, based on dry-weather flow observations.

Procedures to statistically describe the likelihood and magnitude of the potential flow components are also presented, along with statistically based procedures to help in the selection of the analysis methodology. A large-scale demonstration of these procedures, carried out in Birmingham, Alabama, is also described in this report.

Many of the proposed methods are based on the experiences of a number of non-stormwater flow investigations conducted in many locations throughout North America. However, the specific techniques that should be used at any location should be strongly based on local conditions, especially the characteristics of potential non-stormwater flow components and the land uses in the watershed areas served by the storm sewer outfalls under investigation.

Background

Urban stormwater runoff has been shown to contain many pollutants. There are cases where pollutant levels in storm drainage are much higher than they would otherwise be because of excessive amounts of contaminants that are introduced into the storm drainage system by various non-stormwater discharges. Additionally, baseflows (during dry weather) are also common in storm drainage systems. In many cases, these baseflows have also been found to be contaminated and responsible for the majority of the annual pollutant emissions from urban storm drainage systems.

Provisions of the Clean Water Act (1987) require National Pollutant Discharge Elimination System (NPDES) permits for stormwater discharges. Section 402 (p)(3)(B)(ii) requires that permits for municipal separate storm sewers shall include a requirement to effectively prohibit problematic non-stormwater discharges into storm sewers. Emphasis will therefore be placed on the elimination of inappropriate connections to urban storm drains. This will require affected agencies to identify and locate any sources of non-stormwater discharges into storm drains so they may institute appropriate actions for their elimination.

Direct sources of non-stormwater discharges usually involve physical sanitary or industrial piping hookups to storm drainage systems. These non-stormwater discharges into storm drainage systems are for the most part, unauthorized and illicit. They will usually (but not always) result in continuous flows into the storm drainage system. They can originate from private homes, apartment buildings, commercial, industrial, or institutional establishments.

Indirect non-stormwater discharge sources in some cases may be authorized. They may be continuous or intermittent. Examples would include sources, conditions or activities that result in elevated levels of contaminants either on the ground surface or in the groundwater. Surface washoff during storms, washing down of surfaces (such as following small spills or during general maintenance clean-up), or subsurface infiltration, introduces the contaminants into the storm drainage systems.

Discharges from storm drain outfalls can be a combination of dry-weather base flows; stormwater runoff; snowmelt water; intermittent discharges of debris, wash-waters, and other waste materials into storm drains; and the relatively continuous discharges of sanitary and industrial cross-connected wastes. These discharges include stormwater that contains the washoff of pollutants from all land surfaces during rains, including washoff of pollutants from areas such as industrial material and waste storage areas, gas station service areas, parking lots, and other industrial and commercial areas, etc. Therefore, the quality of urban runoff can vary greatly with time (dry versus wet-weather, cold versus warm weather, etc.) and location.

The discharge of sanitary and industrial wastes into storm drainage can lead to serious water pollution problems. In many cases, urban receiving waters are badly polluted by stormwater alone, without additional pollutant loadings associated with sanitary or industrial non-stormwater discharges into the storm drainage system. The addition of sanitary wastes increases the concentrations of oxygen-demanding organic solids and nutrients, and increases the number of pathogenic microorganisms in the storm-induced discharge. Industrial wastes can be highly variable, but can substantially increase the concentrations of many filterable heavy metals in runoff, as an example. In many cases, annual discharge loadings from stormwater outfalls can be greatly affected by dry-weather discharges.

Recognition of Urban Runoff as an Important Source of Pollutants

Historically, concern with urban runoff has focused primarily on flooding. With urban development came an increase in land area made impervious to rain as a result of paving, building, soil compaction and the like. This increased the volume of runoff from any given storm event as well as the rate of flow. These factors often have had a decided effect on flooding and erosion rates. For this reason, quantity considerations with regard to urban runoff have been and continue to be a principal concern.

In recent years, however, concern over the role of urban runoff as a contributor to receiving water quality problems has increased. As point source discharges have been increasingly brought under control, the role of nonpoint sources of pollutants (including urban runoff) as potential contributors to water quality degradation has become more apparent. Areawide Water Quality Management Agencies, established as a result of Section 208 of the 1972 Federal Water Pollution Control Amendments, were among the first to call attention to water quality problems associated with non-point sources.

In 1973, the Council on Environmental Quality published a report entitled, "Total Urban Pollutant Loads: Sources and Abatement Strategies." The primary conclusion of this report was that much pollution was caused by urban runoff and that, unless this issue was addressed, the goals of the 1972 Federal Water Pollution Control Act Amendments would not be met (EPA 1983). Examples cited included an EPA study conducted in 1971 in Atlanta, Georgia, which determined that 64 percent of the BOD loading to local streams came from separate storm sewers, 19 percent from combined sewers, and 17 percent from treatment plants.

In spite of this, the Clean Water Act of 1977 (P.L. 95-217) deleted federal funding for the treatment of separate stormwater discharges. Reasons given centered on uncertainties associated with the local nature and extent of urban runoff water quality problems, the effectiveness of possible management and control measures, and their affordability in terms of benefits to be derived. Congress stated that there was simply not enough known about urban runoff loads, impacts, and controls to warrant making major investments in physical control systems (Congressional Quarterly Almanac 1976).

EPA Headquarters then reviewed the results of work on urban runoff by the technical community and various agencies and determined that additional (and more consistent) data were needed. The Nationwide Urban Runoff Program (NURP) was created to provide a better understanding of the nature of urban runoff.

The Nationwide Urban Runoff Program--

The Nationwide Urban Runoff Program (NURP) included 28 projects across the nation, conducted separately at the local level but centrally reviewed, coordinated and guided. The overall objective of the program was to provide credible information regarding urban runoff mechanisms, problems and controls on which to base decisions. The NURP was designed to simply provide a support function to local water quality planning efforts, the results of which would be of value to planning efforts elsewhere (EPA 1983). Data from the various NURP projects allowed many issues to be addressed at a national level. These included topics described in the program's overall objective such as "quantifying the characteristics of urban runoff, assessing the water quality effects on receiving water bodies attributable to urban runoff discharges, and examining the effectiveness of control practices in removing the pollutants found in urban runoff." Unfortunately, only the first and last objectives were really addressed, and produced mixed results (Pitt 1991).

A number of other issues emerged from the individual NURP projects. One of these issues involved illicit connections to storm drainage systems and was summarized as follows in the Final Report of the NURP executive summary: "A number of the NURP projects identified what appeared to be illicit connections of sanitary discharges to stormwater sewer systems, resulting in high bacterial counts and dangers to public health. The costs and complications of locating and eliminating such connections may pose a substantial problem in urban areas, but the opportunities for dramatic improvement in the quality of urban stormwater discharges certainly exist where this can be accomplished. Although not emphasized in the NURP effort, other than to assure that the selected monitoring sites were free from sanitary sewage contamination, this BMP (Best Management Practice) is clearly a desirable one to pursue" (EPA 1983).

The illicit discharges noted during NURP were especially surprising, because the monitored watersheds were carefully selected to minimize factors other than stormwater. Presumably, illicit discharge problems in typical watersheds would be much worse.

Role of Dry-weather Flows in Urban Stormwater Runoff Analyses

The EPA's NURP studies highlighted the significance of pollutants from illicit entries into urban storm sewerage (EPA 1983). Such entries may be evidenced by flow from storm sewer outfalls following substantial dry periods. Such flow, frequently referred to as "baseflow" or "dry-weather flow", could be the result of direct "illicit connections" as mentioned in the NURP final report (EPA 1983), or could result from indirect connections (such as leaky sanitary sewerage contributions through infiltration). Many of these dry-weather flows are continuous and would therefore also occur during rain induced runoff periods. Pollutant contributions from the dry-weather flows in some storm drains have been shown to be high enough to significantly degrade water quality because of their substantial contributions to the annual mass pollutant loadings to receiving waters.

Dry-weather flows and wet-weather flows have been monitored during several urban runoff studies. These studies have found that discharges observed at outfalls during dry weather were significantly different from wet-weather discharges. Data collected during the 1984 Toronto Area Watershed Management Strategy Study (TAWMSS) monitored and characterized both stormwater and baseflows (Pitt and McLean 1986). This project involved intensive monitoring in two test areas (one a mixed residential and commercial area, and another that was an industrial area) during both warm and cold weather and during both wet and dry weather. The annual mass discharges of many pollutants were found to be dominated by dry-weather processes.

During the mid-1980s, several individual municipalities and urban counties initiated studies to identify and correct illicit connections to their storm drain systems. This action was usually taken in response to receiving water quality problems or information noted during individual NURP projects. Data from these studies indicate the magnitude of the cross-connection problem in many urban areas. From 1984 to 1986, Washtenaw County, Michigan, dye-tested 160 businesses in an effort to locate direct illicit connections to the county stormwater sewerage. Of the businesses tested, 61 (38%) were found to have improper storm drain connections (Schmidt and Spencer 1986). An investigation of outfalls from the separate storm sewer system in Toronto, Canada revealed 59% with dry-weather flows. Of these, 84 (14% of the total outfalls) were identified as grossly polluted, based on the results of a battery of chemical tests (GLA 1983). In 1987, an inspection of the 90 urban stormwater outfalls draining into Inner Grays Harbor in Washington (Pelletier and Determan 1988) revealed 29 (32%) flowing during dry weather. A total of 19 outfalls (21%) were described as suspect, based on visual observation and/or anomalous pollutant levels as compared to those expected in typical urban stormwater runoff characterized by NURP.

The Huron River Pollution Abatement Program was the most thorough investigation of such improper connections. Beginning in 1987, 1067 businesses, homes and other buildings located in the Huron River watershed were dye tested. The following results were reported. Illicit connections were detected at 60% of the automobile related businesses inspected, including service stations, automobile dealerships, car washes, and auto body and repair shops. All plating shops inspected were found to have improper storm drain connections. Additionally, 67% of the manufacturers tested, 20% of the private service agencies, and 88% of the wholesale/retail establishments tested were found to have improper storm sewer connections. Of 319 homes dye tested, 19 were found to have direct sanitary connections to storm drains. The direct discharge of rug cleaning wastes into storm drains by carpet cleaners was also noted as a common problem. (Washtenaw County 1988).

A Sacramento, California, investigation of urban discharges (1985) identified commercial as well as domestic discharges of oil and other automobile related fluids as a common problem based on visual observations. Visual inspection of stormwater pipes discharging to the Rideau River (Ontario) found leakage from sanitary sewer joints or broken pipes to be a major source of storm drain contamination (Rideau River 1983).

Castro Valley Creek, Alameda County, California, Nationwide Urban Runoff Program Project--
In 1981, the two year San Francisco Bay Area National Urban Runoff Project was completed (Pitt and Shawley 1982). Information was collected from an urban station (Knox) on the Castro Valley Creek branch of the Castro Valley watershed. Land use in the 268 ha urban area consisted of single family dwellings (70%), commercial use (7%), open space and institutional land use (23%).

Table 1 shows median concentrations of constituents observed in the baseflow and stormwater runoff from this catchment. Obvious differences in water types were found. During baseflows, the water was quite hard and major components included calcium, sodium, chloride, sulfate, and magnesium. Total solids was high as a result of high concentrations of dissolved solids. During storm runoff conditions, the water became noticeably softer and suspended solids and chemical oxygen demand became much more important. In addition, almost all of the heavy metals were significantly greater in concentration during storm runoff, as compared to baseflow conditions. Mercury was an exception, occurring at higher levels in the baseflow.

Table 2 compares annual yields from baseflow and storm runoff. Significant portions of the major ions, alkalinity, hardness and total dissolved solids annual yields were associated with the baseflow. However, the runoff portion of the total annual yield accounted for practically all of the heavy metals, nutrients, suspended solids and organics. Baseflows accounted for approximately 88% of the flow duration and 10% of the total runoff during the monitoring period.

The rainy season in the San Francisco Bay area extends from November to April. Most of the pollutant yields associated with both baseflow and storm runoff occurred during these rainy winter months. Approximately 25% of the total annual baseflow yield occurred during February, while less than 10% occurred during each of the summer months. One third of the annual storm yield occurred in February, and less than 1% in each of the summer months.

Bellevue, Washington, Nationwide Urban Runoff Program Project--
During the Bellevue, Washington Urban Runoff Project (Pitt 1984; Pitt and Bissonnette 1984) baseflows as well as stormwater from two residential urban basins were monitored. The areas included in this study, Surrey Downs and Lake Hills, are about 5 km apart and each covered an area of about 40 ha. Both were fully developed, with predominantly single family residences. No septic tanks were present in either area and the storm drainage systems were thoroughly mapped and investigated to ensure no non-stormwater discharges to storm drainage systems or obvious illegal discharges.

Much runoff quality data was collected during this project. Samples were collected using automatic samplers on a time-sampling mode for baseflows and on a flow-weighted mode for stormwater. Table 3 summarizes the stormwater data. Average, minimum and maximum values for the water quality constituents, along with the flow and rain volumes, are shown for the study period.

TABLE 1. MEDIAN BASEFLOW AND STORMWATER CONTAMINANT CONCENTRATIONS OBSERVED IN CASTRO VALLEY (MG/L UNLESS NOTED)

	Baseflow	Stormwater
Total solids	1170	306
Total dissolved solids (TDS)	1060	117
Suspended solids (SS)	1	216
Volatile suspended solids (VSS)	1	46
Total alk., as $CaCO_3$	260	42
Non-carb. hardness, as $CaCO_3$	300	21
Total hardness, as $CaCO_3$	550	62
Calcium (diss)	95	15
Magnesium (diss)	70	6.4
Potassium (diss)	3.5	1.7
Sodium (diss)	150	14
Chloride(diss)	290	18
Sulfate (diss)	230	22
COD	32	80
Total N	2.6	2.9
Organic N	0.8	1.6
Total Kjeldahl N	1.1	1.8
Ammonia as N	0.05	0.06
Nitrites and Nitrates as N	1.4	1.1
Total P	0.32	0.39
Diss. Ortho-phosphates, as PO_4	0.71	0.46
Arsenic (µg/L)	2	5
Cadmium (µg/L)	0	1
Chromium (µg/L)	2	10
Copper (µg/L)	0	44
Iron (µg/L)	270	8000
Lead (µg/L)	8	300
Mercury (µg/L)	0.3	0.2
Nickel (µg/L)	0	0
Zinc (µg/L)	70	210

Source: Pitt and Shawley 1982

TABLE 2. CASTRO VALLEY URBAN BASEFLOW AND STORM RUNOFF ANNUAL YIELDS COMPARED

	Annual Urban Baseflow Total (lbs/acre/yr)	Annual Urban Storm Runoff Total (lbs/acre/yr)	Total Urban Runoff and Urban Baseflow (lbs/acre/yr)	Percentage of Total Urban Yield Due to Runoff Only (%)
Total Alk., as $CaCO_3$	45	70	120	60%
Non-carbonate hardness, as $CaCO_3$	50	30	80	40
Total hardness, as $CaCO_3$	95	100	200	50
Calcium, diss.	20	30	50	60
Magnesium, diss.	10	10	20	50
Potassium, diss.	0.6	3	4	75
Sodium, diss.	30	20	50	40
Chloride, diss.	50	25	75	30
Sulfate, diss.	35	30	70	40
Total Solids	200	600	800	75
Total Dissolved Solids (TDS)	190	200	400	50
Suspended Solids (SS)	1.4	300	300	100
Volatile Suspended Solids (VSS)	0.14	70	70	100
COD	6.5	150	160	90
Total Nitrogen	0.7	5	6	80
Organic Nitrogen	0.1	5	5	100
Total Kjeldahl Nitrogen	0.2	3.5	3.7	95
Ammonia, as N	0.05	0.2	0.3	70
Nitrites plus Nitrates, as N	0.5	3	3	100
Total Phosphorus	0.04	1	1	100
Dissolved Ortho-Phosphates as PO_4	0.1	2	2	100
Arsenic	0.0005	0.01	0.01	100
Cadium	0.00008	0.01	0.01	100
Chromium	0.00007	0.014	0.014	100
Copper	0.003	0.1	0.1	100
Iron	0.06	7	7	100
Lead	0.0065	0.6	0.6	100
Mercury	0.0002	0.001	0.001	100
Nickel	0	0.05	0.05	100
Zinc	0.014	0.5	0.5	100
Flow	0.8 inches	7.5 inches	8.3 inches	90

Source: Pitt and Shawley 1982

TABLE 3. STORMWATER RUNOFF QUALITY FOR BELLEVUE SITES
(TOTAL STORM FLOW-WEIGHTED COMPOSITES; mg/L, UNLESS OTHERWISE NOTED)

	Lake Hills (99 samples)			Surrey Downs (107 samples)		
Constituent:	min.	max	average	min	max	average
Runoff volume (ft^3)	1,210	223,000	39,650	1,260	401,000	36,100
Rain (in.)	0.04	1.58	0.40	0.04	4.38	0.49
Total solids	24	440	104	29	620	113
TKN	<0.5	5.9	1.0	<0.5	4.3	1.1
COD	13	120	42	15	150	34
Total phosphorus	0.015	3.6	0.27	0.002	1.2	0.24
Lead	<0.1	0.56	0.17	<0.1	0.82	0.17
Zinc	0.03	0.29	0.11	0.05	0.37	0.13
pH (pH units)	5.2	7.1	6.2	5.2	7.4	6.4
Specific conductance (µmhos/cm)	17	140	37	16	300	45
Turbidity (NTU)	6	150	22	4	67	16

Source: Pitt 1984

Baseflow samples were collected about once a month during the second year of the project. Table 4 summarizes the baseflow observations at the two sampling sites. The observed baseflow concentrations of COD, TKN, total phosphorus, lead, and zinc were about the same as those found in storm runoff. However, the baseflow total solids and specific conductance values were much greater than observed in the storm runoff.

The total solids during storm runoff events was mostly nonfilterable (suspended solids), while the total solids during baseflow conditions was mostly dissolved solids. The similarities in baseflow and storm runoff nutrient and heavy metal concentrations was surprising. In other areas (especially at the Castro Valley NURP site; Pitt and Shawley, 1982) the baseflow metal and nutrient concentrations were much less than the storm runoff concentrations. However, the Castro Valley baseflow dissolved solids, specific conductance, and major ion concentrations were all much greater than observed in the storm runoff. In Castro Valley, this implied that the baseflow was mostly associated with discharging groundwater that originated in non-urban areas above the study site. At the two Bellevue sites, however, the complete basins are urbanized and the groundwater that discharged into the storm drainage systems between rain events was much more contaminated than the rural groundwater discharges observed at Castro Valley.

An important amount of the total flows in both of the Bellevue test basins occurred between rains as baseflows. This was especially true during the dry months of the year (March to September). The winter months contributed most of the urban runoff flows. Average October, November, and December flows for the study period contributed about half of the total annual runoff flows observed. December through March contributed more than half of the baseflows. Generally, the baseflows were highest in those months also having high storm runoff flows. August was the driest month, with less than two percent of the annual urban runoff flow. The baseflow in the Surrey Downs basin accounted for about 25% of the total volume of urban flow, while baseflow in Lake Hills made up about 12% of the total. Baseflows alone accounted for approximately 87% of the flow duration in each area. Therefore, stormwater flows affected the total urban flow only about 13% of the time.

Table 5 summarizes the annual mass yields for baseflow and stormwater runoff in the study areas. Between 15 and 20 percent of the annual mass yields were contributed in both November and December while the summer months, May though August, each contributed only about 5 percent. A larger fraction of the total urban runoff in Surrey Downs occurred as baseflow between rain events. The runoff events in Lake Hills were more sharply defined, and the baseflows made up a much smaller fraction of the mass yields for urban runoff.

The estimated annual mass yields of the urban pollutants expressed in pounds per acre per year are similar to those reported in Castro Valley, California (Pitt and Shawley, 1982). The much smaller urban runoff pollutant concentrations observed in Bellevue when compared to Castro Valley is compensated for by the much larger amount of runoff that occurred.

The Bellevue, Washington, NURP project also summarized the reported incidents of intermittent discharges and dumpings of pollutants into the local storm drainage system. During a three year period of time, about 50 citizen contacts were made to the Bellevue Storm and Surface Water Utility District concerning water quality problems. About 25 percent of the complaints concerned oil being discharged into storm drain inlets. Another important category of complaints was for aesthetic problems, such as turbid or colored water in the creeks. Various industrial and commercial discharges into the storm drainage system were detected. Concrete wastes flushed from concrete trucks at urban job sites were a frequently occurring problem. Cleaning establishment discharges into creeks were also a common problem. Vehicle accidents also resulted in discharges of gasoline, diesel fuel, hydraulic fluids, and lawn care chemicals into the storm drain inlets.

Toronto, Ontario, Humber River Test Watershed Monitoring--

The 1984 Toronto Area Watershed Management Strategy Study (TAWMSS) monitored and characterized both stormwater and baseflows (Pitt and McLean 1986). The project involved intensive monitoring in two test areas. The Emery catchment area, located near the City of North York, covered approximately 154 ha with predominantly “medium” industrial land uses (processing goods for final consumption). The Thistledown catchment, located in the City of Etobicoke, covered approximately 39 ha with residential and commercial land uses.

TABLE 4. BELLEVUE BASEFLOW WATER QUALITY
(24-HR. TIME-COMPOSITES; mg/L, UNLESS OTHERWISE NOTED)

	Lake Hills (13 samples)			Surrey Downs (13 samples)		
Constituent:	min.	max	average	min	max	average
Total solids	108	326	210	130	226	193
COD	9.1	67	27	6.8	45	19
TKN	0.20	1.9	0.56	0.34	2.4	1.0
Total phosphorus	0.027	0.22	0.11	0.034	1.2	0.20
Lead	<0.1	0.1	<0.1	<0.1	0.1	<0.1
Zinc	0.03	0.14	0.073	0.026	0.47	0.10
Specific conductance (µmhos/cm)	138	430	270	146	300	240

Source: Pitt 1984

TABLE 5. ANNUAL BELLEVUE MASS YIELDS FOR BASEFLOW AND STORMWATER RUNOFF (kg/ha)

	Surrey Downs			Lake Hills		
Constituent:	Base Flow	Storm Runoff	Total	Base Flow	Storm Runoff	Total
Total solids	110	205	315	76	280	360
COD	11	90	100	9.9	110	120
Total Kjeldahl nitrogen	0.60	1.8	2.4	0.20	2.7	2.9
Total phosphorus	0.11	0.40	0.51	0.04	0.69	0.73
Lead	0.03	0.26	0.29	0.02	0.45	0.47
Zinc	0.06	0.24	0.30	0.027	0.31	0.34

Source: Pitt 1984

Table 6 shows median concentrations of some of the pollutants monitored. Baseflows from the residential catchment had surprisingly high concentrations of several pollutants including dissolved solids, pesticides, and fecal coliform bacteria, while the industrial area had dry-weather flows that had high concentrations of organic and metallic toxicants.

During cold weather, the increases in dissolved solids were quite apparent in baseflows and snowmelt for both study catchments. This increase was probably caused by high chlorides from road salt applications. In contrast, bacteria populations were noticeably lower in all outfall discharges during cold weather. Nutrient and heavy metal concentrations at the outfalls remained fairly constant during cold and warm weather.

Table 7 compares the estimated annual discharges from the residential and industrial catchments during the different runoff periods. Warm weather baseflows accounted for more than 70% of the flow duration and about 40% of the runoff volume during the monitoring period. The unit area annual yields for many of the heavy metals and nutrients were greater from the industrial catchment. The industrial catchment contributed most of the chromium to the local receiving water, and approximately equal amounts with the residential and commercial catchment for phosphorus, TOC, copper, and zinc. This table also shows the great importance of warm-weather baseflow discharges to the annual urban runoff pollutant yields. Cold-weather bacteria discharges were insignificant when compared to the warm weather bacteria discharges, but chloride (and dissolved solids) loadings were much more important during cold weather.

Annual yields of several constituents were dominated by cold-weather processes, irrespective of the land use monitored. These constituents included total solids, dissolved solids, chlorides, ammonia nitrogen, and phenolics. The only constituents for which total annual yields were dominated by warm weather processes, irrespective of land use, were bacteria and chromium. Lead and zinc were both dominated by either stormwater or snowmelt runoff, with lower yields of these heavy metals occurring during baseflows.

Either warm- or cold-weather baseflows were responsible for most of the yields for many constituents from the industrial catchment. These constituents included runoff volume, phosphorus, total Kjeldahl nitrogen, chemical oxygen demand and chromium. Important constituents that had high yields in the baseflow from the residential/commercial catchment included total solids, dissolved solids, chlorides, and fecal coliform and pseudomonas aeruginosa bacteria.

A few samples were analyzed for pesticides and PCB's. Industrial stormwater and baseflows typically contained much greater concentrations of these pollutants than the residential waters, however, dieldrin levels seemed to indicate a potential problem in the residential catchment.

Gartner Lee and Associates, Ltd. (GLA 1983) conducted an extensive survey of dry-weather flows in storm drainage systems in the Humber River watershed (Toronto) in an attempt to identify the most significant urban runoff pollutant sources. About 625 outfalls were sampled two times during dry-weather, with analyses conducted for many pollutants, including organics, solids, nutrients, metals, phenols, and bacteria. About 1/3 of the outfalls were discharging at rates greater than 1 L/sec. The dry-weather flows were found to contribute significant loadings of nutrients, phenols, and metals, compared to upstream conditions. About 10 percent of the outfalls were considered significant pollutant sources. Further investigations identified many industrial and sanitary sewage non-stormwater discharges into the storm drainage. An apartment building with the sanitary drains from eight units illegally connected to the storm drainage system was typical of the problems found. Other problem areas were found in industrial areas, including yard storage of animal hides and yard runoff from meat packing plants.

TABLE 6. MEDIAN CONCENTRATIONS OBSERVED (mg/L) FOR SEVERAL CONSTITUTENTS MONITORED IN TORONTO

	Warm Weather Baseflow		Warm Weather Stormwater	
Constituent	Residential	Industrial	Residential	Industrial
Total Solids	979	554	256	371
Total Dissolved Solids	973	454	230	208
Suspended Solids	<5	43	22	117
Total Phosphorus	0.09	0.73	0.28	0.75
Total Kjeldahl N	0.9	2.4	2.5	2.0
Phenolics (µg/L)	<1.5	2.0	1.2	5.1
COD	22	108	55	106
Fecal Coliforms (#/100mL)	33,000	7,000	40,000	49,000
Fecal Strep (#/100mL)	2,300	8,800	20,000	39,000
Chromium	<0.06	0.42	<0.06	0.32
Copper	0.02	0.045	0.03	0.06
Lead	<0.04	<0.04	<0.06	0.08
Zinc	0.04	0.18	0.06	0.19

	Cold Weather Baseflow		Cold Weather Melting Periods	
Constituent	Residential	Industrial	Residential	Industrial
Total Solids	2,230	1,080	1,580	1,340
Total Dissolved Solids	2,210	1,020	1,530	1,240
Suspended Solids	21	50	30	95
Total Phosphorus	0.18	0.34	0.23	0.50
Total Kjeldahl N	1.4	2.0	1.7	2.5
Phenolics (µg/L)	2.0	7.3	2.5	15.0
COD	48	68	40	94
Fecal Coliforms (#/100mL)	9,800	400	2,320	300
Fecal Strep (#/100mL)	1,400	2,400	1,900	2,500
Chromium	<0.01	0.24	<0.01	0.35
Copper	0.015	0.04	0.04	0.07
Lead	<0.06	<0.04	0.09	0.08
Zinc	0.065	0.15	0.12	0.31

Source: Pitt and McLean 1986

TABLE 7. ESTIMATED ANNUAL DISCHARGES FOR TORONTO

		Thistledown (Residential/Commercial)					Emery (Industrial)					approx indus./ resid total yield ratios	weighted indus. resid. total yield ratios(1)
		warm		cold			warm		cold				
Constituent	(units)	base flow	storm water	base flow	melt water	approx. total	base flow	storm water	base flow	melt water	approx. total		
Runoff volume	M^3/ha	1700	950	1100	1800	5600	2100	1500	660	830	5,100	0.9	0.3
Total solids	kg/ha	1700	240	2400	1700	6100	110	670	710	1500	4,000	0.7	0.2
Chlorides	kg/ha	480	33	1200	720	2400	160	26	310	700	1,200	0.5	0.2
Total phosphorus	g/ha	150	290	200	570	1200	1500	1300	220	540	3,600	3.0	1.0
Total Kjeldahl N	g/ha	1500	2800	1500	3500	9300	4900	3400	1300	2800	12,000	1.3	0.4
Phenolics	g/ha	<2.6	1.2	2.3	23	26	4.1	8.1	4.8	14	31	1.2	0.4
COD	kg/ha	38	51	52	130	270	220	170	45	91	530	2.0	0.7
Chromium	g/ha	<100	21	<10	15	36	860	600	160	290	1,900	50	18
Copper	g/ha	35	30	16	77	160	92	120	26	76	310	1.9	0.7
Lead	g/ha	<70	41	<70	170	210	<75	170	<25	150	320	1.5	0.5
Zinc	g/ha	70	74	70	270	480	370	430	100	350	1,200	2.5	0.8
Fecal Coliform Bact.	10 org/ha	560	480	110	62	1200	144	760	3	6	910	0.8	0.3

"Warm weather" is for the period from about March 15 through December 15, while "cold weather" is the period from about December 15 through March 15.

(1) If basin is 25% Industrial and 75% Residential and commerical.

Source: Pitt and McLean 1986.

Current Legislation

With additional data available, the Water Quality Act of 1987 contained provisions specifically addressing discharges from storm drainage systems. Section 402(p)(3)(B) provides that "permits for such discharges:

> (i) May be issued on a system or jurisdiction-wide basis
> (ii) Shall include a requirement to effectively prohibit non-stormwater discharges into the storm sewers: and
> (iii) Shall require controls to reduce the discharge of pollutants to the maximum extent practical 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."

In response to these provisions, the EPA issued a final rule to begin implementation of section 402(p) of the Clean Water Act on November 16, 1990. A screening approach which includes chemical testing of dry-weather flow (defined by a 72-hour antecedent dry period) from outfalls or storm sewers, was adopted. The parameters to be tested were a combination of several pollutants of concern and "tracers" that may be used to help identify contaminated outfalls and predict the source of illicit discharges.

Section 122.26 (d)(1)(iv)(D) of the rule applies specifically to this research effort. The EPA required an initial screening program to provide a means of detecting high levels of pollutants in dry weather flows which should serve as indicators of illicit connections to the storm sewers. Minimum requirements were "a narrative description ... of visual observations made during dry weather periods. If any flow is observed, two grab samples shall be collected during a 24-hour period with a minimum period of four hours between samples. For all such samples, a narrative description of the color, odor, turbidity, the presence of an oil sheen or surface scum as well as any other relevant observations regarding the potential presence of non-stormwater discharges or illegal dumping shall be provided. In addition, a narrative description of the results of a field analysis using suitable methods to estimate pH, total chlorine, total copper, total phenol, and detergents (or surfactants) shall be provided, along with a description of the flow rate. Where the field analysis does not involve analytical methods approved under 40 CFR part 136, the applicant shall provide a description of the method used including the name of the manufacturer of the test method along with the range and accuracy of the test."

General Approach to Identify Sources of Inappropriate Discharges

This report presents a methodology that can determine if a storm drain outfall (and drainage system) is affected by pronounced non-stormwater discharges to the storm drainage system. In many cases, the information to be collected following this methodology will also result in a description of the most likely sources of these discharges into the storm drainage.

An investigation of non-stormwater discharges into storm drainage needs to proceed along a hierarchy of procedures and locations; from those areas in a city with the greatest potential, to those with lesser potential; from using exploratory techniques to confirmatory procedures. The methodology presented in this report recognizes that limited resources are available to municipalities and makes maximum use of information typically available.

Many aspects of this methodology were derived from the experience of many municipalities that have previously investigated non-stormwater discharges into storm sewerage. This report contains references to many of these studies, and Appendix C includes brief summaries of several selected case studies. The case study information described identifies situations and techniques used by these agencies in implementing a program to identify the presence of non-stormwater discharges into storm drainage systems. When they eliminated the discharge, pertinent details of the implementation program is also described.

The purpose of the investigative procedures presented is to separate storm drain outfalls into three general categories (with a known level of confidence) to identify which outfalls (and drainage areas) need further analyses and investigations. These categories are outfalls affected by non-stormwater discharges from: (1) pathogenic or toxic pollutant sources, (2) nuisance and aquatic life threatening pollutant sources, and (3) unpolluted water sources. The pathogenic and toxic pollutant source category would be considered the most severe and could cause disease upon water contact or consumption and significant impacts on receiving water organisms. They may also cause significant water treatment problems for downstream consumers, especially if they contain soluble metal and organic toxicants. These pollutants may originate from sanitary, commercial, and industrial wastewater non-stormwater discharges. Other residential area sources (besides sanitary wastewater), such as inappropriate household toxicant disposal, automobile engine de-greasing, vehicle accident clean-up, and irrigation runoff from landscaped areas excessively treated with chemicals (fertilizers and pesticides) may also be considered in this most critical category.

Nuisance and aquatic life threatening pollutant sources can originate from residential areas and may include laundry wastes, landscaping irrigation runoff, automobile washing, construction site dewatering, and washing of ready-mix trucks. These pollutants can cause excessive algal growths, tastes and odors in downstream water supplies, offensive coarse solids and floatables, and highly colored, turbid or odorous waters.

Clean water discharged through stormwater outfalls can originate from natural springs feeding urban creeks that have been converted to storm drains, infiltrating groundwater, infiltrating domestic water from water line leaks, etc.

The recommended monitoring approach is separated into three initial phases:

- initial mapping effort,
- initial field surveys, and
- potential confirmatory analyses.

These three initial phases need to be followed by detailed storm drainage and site investigations to identify specific pollutant contributors and control options, as appropriate.

An important requirement of the methodology is that an initial field screening effort would require minimal effort, but would have little chance of missing a seriously contaminated outfall. This screening program would then be followed by a more in-depth analysis to more accurately determine the significance and source of the non-stormwater pollutant discharges.

If industrial and commercial land uses exist within a stormwater drainage area, additional activities are needed to identify the sources in sufficient detail to allow corrective actions. The control strategy must recognize that even with the removal of directly connected non-stormwater discharges to the storm drains, stormwater originating from industrial and commercial land uses will probably continue to convey unacceptable pollutant loads, as noted by Pitt and McLean (1986). The industrial and commercial area control strategy must be flexible enough to provide overall wet- and dry-weather flow control from a site, rather than simply altering piping to correct the obvious direct connections.

Any control strategy needs to take advantage of existing information. As an example, most communities have reasonable knowledge of their sanitary sewers through infiltration/inflow (I/I) and sewer system evaluation survey (SSES) studies. Municipalities also generally have arrangements with local industries through pretreatment and other regulatory programs. However, many industries that may potentially discharge contaminants into storm drains do not have discharges into the city's sanitary sewer systems, nor have their own process water discharges, and would therefore not have likely been historically regulated.

Figure 1 is a simplified flow chart for the methodology developed during this research. The initial phase of the investigative protocol includes the initial mapping and field surveys. These activities require minimal effort and result in little chance of missing a seriously contaminated outfall. The initial activities are followed by more detailed watershed surveys to locate and correct the sources of the contamination in the identified problem areas. After corrective action has been taken, repeated outfall field surveys are required to ensure that the outfalls remain uncontaminated. Receiving water monitoring should also be conducted to analyze water quality improvements. If expected improvements are not noted, then additional contaminant sources are likely present and additional outfall and watershed surveys are needed.

Development of Investigative Strategy

This project examined three categories of non-stormwater outfall discharges: pathogenic/toxicant, nuisance and aquatic life threatening, and clean water. The most important category is for outfalls contributing pathogens or toxicants. These are most likely originating from sanitary wastewater or industrial non-stormwater discharges to storm drainage systems. The outfall analyses should have a high probability of identifying all of the outfalls in this most critical category for detailed source identification.

Mapping Effort--

The first step of this procedure is an extensive mapping effort to identify the locations of all outfalls for sampling and to outline and characterize the drainage areas contributing to each outfall.

All outfalls need to be evaluated during the screening analysis. It is not sufficient to only map and examine the largest drainage areas, or largest outfalls, as small areas have been found to contribute significant non-stormwater discharges. For example, if commercial (especially automobile service related facilities) and manufacturing industrial areas are present in a drainage area, the probability for serious non-stormwater discharges is significantly increased. Therefore, this mapping effort is a very important part of the investigation as it will locate the outfalls for sampling and will describe the contributing watershed areas.

Outfall Screening Analyses--

The screening analyses at the outfalls include several visual measures (color, turbidity, oil sheens, floatables, coarse solids, etc.) along with measurements for chemical tracers (fluorides, potassium, ammonia, and surfactants). The visual measures have been found during many studies to be very good indicators of serious non-stormwater flow contamination at outfalls. The chemical tracers are needed to identify (and possibly quantify) the general source categories of non-stormwater flows.

Fluorides can be used to indicate if the water originated as treated domestic water (instead of infiltrating untreated groundwater). This may indicate sanitary sewage or other non-stormwater discharges to the drainage system. Surfactants can help in identifying sanitary sewage or wash water connections, in contrast to landscaped area irrigation runoff, rinse waters, or industrial waters. Potassium and ammonia can be very useful in separating the more important sanitary sewage sources from wash waters and other treated water sources. Some of these chemical tracer tests indicate similar sources, but the duplication is needed because of potential interferences and some uncertainty in the tracer concentrations associated with the source flows.

Appropriate analytical methods must be selected before the chemical analyses are made. This selection requires accurate estimates of the tracer concentration characteristics of the potential source flows. The desired contamination level to be detected and the variation of the chemical tracer concentrations expected affect the required detection limit and analytical precision needed.

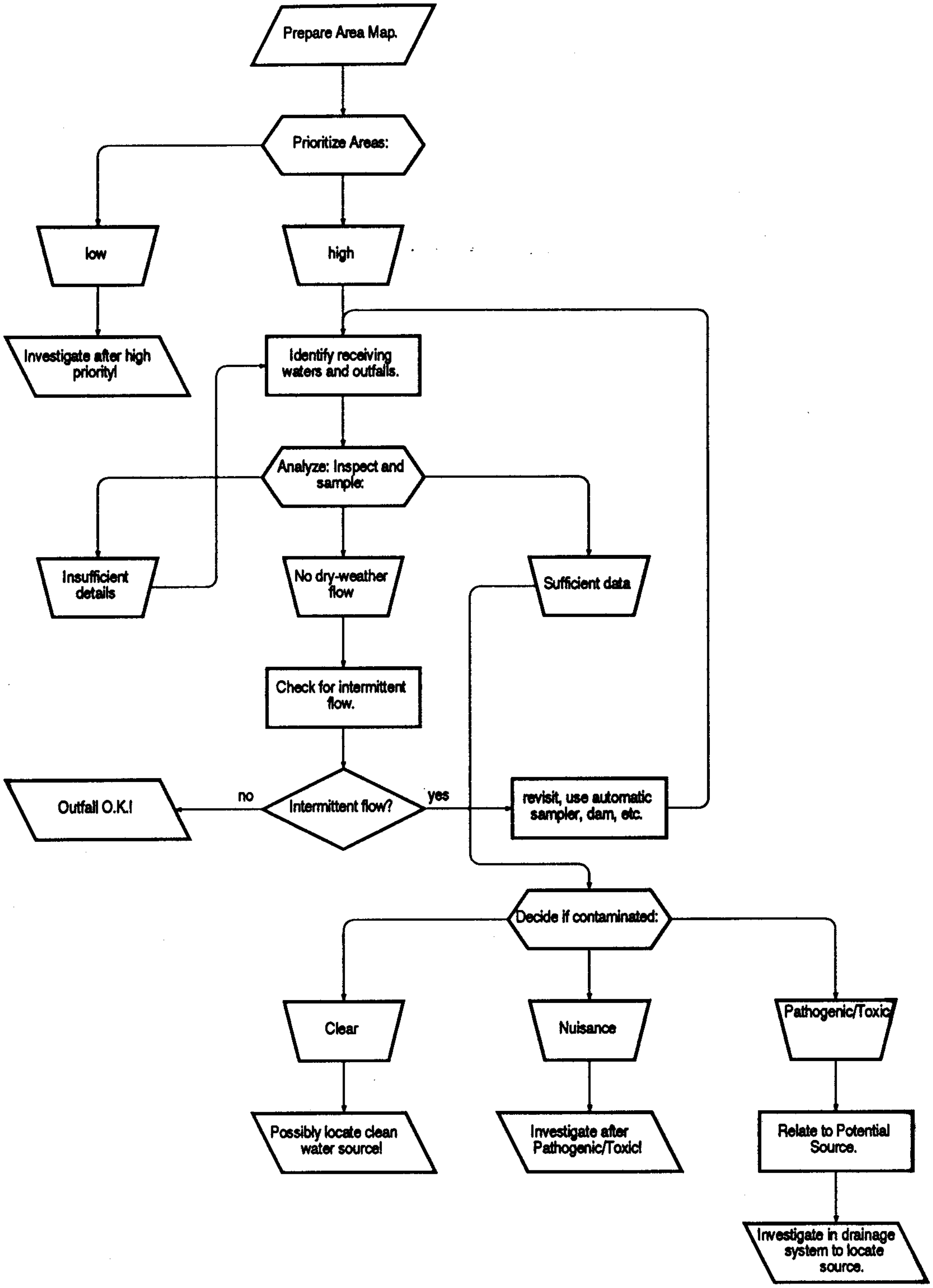

Figure 1. Flow chart for investigative procedures.

In addition, in order to estimate the source flow contributions affecting an outfall, the potential source flows must also be described with as much detail as possible. If the source flows cannot be described with narrow pollutant concentration ranges, for example, it is difficult to estimate the magnitude of source flow contributions, especially if they make up less than about 20 percent of the outfall flow. However, it is still possible to quantify the certainty that the different source flows are present at the outfall.

Confirmatory Analyses--

More sophisticated analyses are available to confirm and to make more accurate estimates of the potential sources. However, they most likely cannot be frequently employed for all outfall samples because of the high level of analytical skill and expensive equipment required. These analyses may include specific bacteria or biochemicals to examine sanitary sewage sources, for example. Metallic and organic toxicants could also be effectively used when examining problems at industrial and commercial areas.

Follow-up Sewerage and Site Investigations--

After an outfall has been identified as having significant non-stormwater flow sources, certain follow-up investigations are needed to locate the specific source locations and to correct the problem. The first step of these additional investigations would be to continue the same visual and chemical analyses at selected locations along the sewerage.

It may be efficient to divide the main trunk sewer into about ten reaches for these additional tests. Reaches of the sewerage affected by the unwanted sources could then be identified. Branch sewers contributing to the affected main sewer reaches could also be subdivided (into about three sections) for similar analyses. These subdivisions can be continued until relatively small areas of the watershed are isolated as contributors of important non-stormwater discharges. Establishments within these isolated areas would then be individually evaluated by inspecting all possible direct connections to the storm sewerage, inspecting all floor and yard drains, etc. Situations that would produce unusual wet-weather pollutant sources (such as material and equipment storage areas) also need to be identified for mitigation. When problems are found, the site owners need to be informed and required to make corrections.

Recommendations

This report should be used as part of a comprehensive stormwater management plan which addresses all sources of stormwater pollution. Correction of pollutant entries identified by use of only this report is unlikely to achieve a significant improvement in the quality of stormwater discharges or receiving waters. Similarly, if only wet-weather stormwater discharges are mitigated, inappropriate dry-weather discharges may prohibit receiving water beneficial uses from being obtained. An effective urban runoff management program must consider all sources of pollutants.

A municipality will need to plan their investigation of inappropriate entries to a storm drainage system to suit local conditions. The User's Guide (Pitt, *et al*. 1993) describes the issues in sufficient depth and provides examples to enable the design of a local investigation. Greater detail and the results of a comprehensive demonstration of these procedures are given in this report which supplements and incorporates much of the information contained in the User's Guide.

The full use of all of the applicable procedures described in this report is most likely necessary to successfully identify pollutant sources. Attempting to reduce costs, for example by only examining a certain class of outfalls, or using inappropriate testing procedures, will significantly reduce the utility of the testing program and result in inaccurate data. Also cursory data analyses is likely to result in inaccurate conclusions.

During investigations of non-stormwater entries to storm drainage systems, consideration should be given to any economic and practical advantages of designating the storm drainage system as a combined sewer system and applying end-of-pipe combined sewer overflow (CSO) control and treatment.

It is also recommended that the methodology (appropriately modified) described in this report be applied to other types of sewerage systems, such as combined and separate sanitary sewerage systems, to locate inappropriate entries, e.g. untreated or toxic industrial wastewaters/wastes or infiltration/inflow (I/I) in separate sanitary sewers.

It is recommended that this report be updated and refined by incorporating experience gained in its use. Incorporation of information from a wide variety of test locations (e.g., lake and large river receiving waters, tidal receiving waters, areas experiencing long dry periods, areas having short summers, areas having unusual groundwater characteristics, areas where the stormwater is pumped for discharge, etc.) will improve the testing and data analysis protocols described.

Organization of Report

This report contains several main sections and is supported by appendix material, as appropriate:

1. Introduction
2. Sources of non-stormwater discharges into separate storm drainage systems
3. Initial mapping effort to identify sources of non-stormwater discharges into storm drainage
4. Initial field surveys to identify sources of non-stormwater discharges into storm drainage
5. Selection of parameters for field surveys
6. Selection and evaluation of analytical methods
7. Data analyses to identify problem outfalls and flow components
8. Watershed surveys to confirm and locate inappropriate pollutant entries to the storm drainage system
9. Special considerations for industrial and commercial sources of inappropriate pollutant entries to the storm drainage system
10. Corrective techniques after inappropriate sources are identified
11. Birmingham, Alabama, demonstration study
12. References

Appendix A. Field equipment summary
Appendix B. Statistical plots to determine detection limit requirements
Appendix C. Case studies of non-stormwater discharges into separate storm sewer systems
Appendix D. Village Creek outfall and watershed data for Birmingham demonstration study area
Appendix E. Statistical analyses of data collected during the Birmingham demonstration study
Appendix F. Chemical mass balance model with Monte Carlo simulation
Appendix G. Analyses results for all outfall samples collected during Birmingham demonstration study
Glossary

The main information needed to design a local research project is included in Sections 3 through 8. The strategies are heavily based on information presented in Section 2, a discussion of the potential sources of non-stormwater discharges, including the experience of many municipal investigations of these problems, as presented in Appendix C. The selection of equipment (and indicator parameters) is greatly influenced by many characteristics of the local areas under investigation. Section 11 details the Birmingham demonstration study.

Section 2

Sources of Non-Stormwater Discharges into Separate Storm Drainage Systems

Potential Dry-Weather Discharge Sources

This report presents a methodology for the identification and location of non-stormwater entries into storm drainage systems. It is important to note that for any effective investigation of pollution within a stormwater system, all pollutant sources must be included. Prior research, as summarized in Section 1, has shown that dry-weather flows may contribute a larger annual discharge mass for many pollutants than stormwater. Significant pollutant sources may include dry-weather entries occurring during both warm and cold months and snowmelt runoff, in addition to conventional stormwater associated with rainfall. Consequently, much less pollution reduction benefit will occur if only stormwater is considered in a control plan for controlling storm drainage discharges. The investigations described in this report may also be used to identify illicit point source outfalls that do not carry stormwater. Obviously, these outfalls also need to be controlled. Table 8 summarizes the potential sources of contaminated entries into storm drainage systems, along with their likely flow characteristics. The following subsections summarize these sources.

Direct Connections to Storm Drains

Direct connections refer to physical connections of sanitary, commercial, or industrial piping carrying untreated or partially treated wastewaters to a separate storm drainage system. These connections are usually unauthorized. They may be intentional, or may be accidental due to mistaken identification of sanitary sewerlines. They represent the most common source of entries to storm drains by industry. Direct connections can result in continuous or intermittent dry-weather entries of contaminants into the storm drain. Some common situations are:

- Sanitary sewers that tie into a storm drain.
- Foundation drains or residential sump-pump discharges that are frequently connected to storm drains. While this practice may be quite appropriate in many cases, it can be a source of contamination when the local groundwater is contaminated, as for example by septic tank failures.
- Commercial laundries and car wash establishments that may route process wastewaters to storm drains rather than sanitary sewers.

Infiltration to Storm Drains

Continuous dry weather flows may be caused by groundwater infiltration into storm drains when the storm sewers are located below the local groundwater table. These continuous discharges generally are not a pollution threat to surface waters, since most ground waters which infiltrate into storm sewers are not contaminated, but these flows will have variable flow rates due to fluctuations in the level of the water table and percolation from rainfall events. Underground potable water main breaks are a potential clean source of releases to storm drains. While such occurrences are not a direct pollution source, they should obviously be corrected. However, when groundwater pollution does occur, such as from leaky underground storage tanks, storm drains may become a method of conveyance for these contaminants to the surface waters. Infiltration into storm drains most commonly occurs through leaking pipe joints and poor connections to catch basins, but can also be due to other causes, such as damaged pipes and subsidence. Storm drains, as well as natural drainage channels, can therefore intercept and convey subsurface groundwater and percolating waters.

TABLE 8. POTENTIAL INAPPROPRIATE ENTRIES INTO STORM DRAINAGE SYSTEMS

	Storm Drain Entry		Flow Characteristics		Contamination Category		
Potential Source:	Direct	Indirect	Continuous	Intermittent	Pathogenic/ Toxic	Nuisance	Clear
Residential Areas:							
Sanitary wastewater	**X**	x	**X**	x	**X**		
Septic tank effluent		**X**	**X**	x	**X**		
Household chemicals	x	**X**		**X**	**X**		
Laundry wastewater	**X**			**X**		**X**	
Excess landscaping watering		**X**		**X**	x	x	**X**
Leaking potable water pipes		**X**	**X**				**X**
Commercial Areas:							
Gasoline filling station	**X**	x		**X**	**X**		
Vehicle maintenance/repair	**X**	x		**X**	**X**		
Laundry wastewater	**X**		**X**	x	x	**X**	
Construction site de-watering		**X**	**X**	x		**X**	
Sanitary Wastewater	**X**	x	**X**		**X**		
Industrial Areas (see Section 9)**:**							
Leaking tanks and pipes	x	**X**	**X**	x	**X**		
Many process waters	**X**	x	**X**	x	**X**	x	x

Note: **X**: most likely condition
x: may occur
blank: not very likely

Groundwater may be contaminated, either in localized areas or on a relatively widespread basis. In cases where infiltration into the storm drains occurs, it can be a source of excessive contaminant levels in the storm drains. Potential sources of groundwater contamination include, but are not limited to:

- Failing or nearby septic tank systems.
- Exfiltration from sanitary sewers in poor repair.
- Leaking underground storage tanks and pipes.
- Landfill seepage.
- Hazardous waste disposal sites.
- Naturally occurring toxicants and pollutants due to surrounding geological or natural environment.

Leaks from underground storage tanks and pipes are a common source of soil and groundwater pollution and may lead to continuously contaminated dry-weather entries. These situations are usually found in commercial operations, such as gasoline service stations, or industries involving the piped transfer of process liquids over long distances and the storage of large quantities of fuel, e.g., petroleum refineries. Pipes that are plugged or collapsed as well, as leaking storage tanks, may cause pollution when they release contaminants underground which can infiltrate through the soil into stormwater pipes.

Residential and Commercial Sources

The most common potential non-stormwater entries, which have been identified by a review of documented case studies for commercial and residential areas, are:

- Sanitary wastewater sources:
    - raw sanitary wastewater from improper sewerage connections, exfiltration, or leakage
    - effluent from improperly operating, designed, or nearby septic tanks

- Automobile maintenance and operation sources:
    - car wash wastewaters
    - radiator flushing wastewater
    - engine de-greasing wastes
    - improper oil disposal
    - leaky underground storage tanks

- Relatively clean sources:
    - lawn runoff from over-watering
    - direct spraying of impervious surfaces
    - infiltrating groundwater
    - water routed from pre-existing springs or streams
    - infiltrating potable water from leaking water mains

- Other sources:
    - laundry wastewaters
    - non-contact cooling water
    - metal plating baths
    - dewatering of construction sites
    - washing of concrete ready-mix trucks
    - sump pump discharges
    - improper disposal of household toxic substances
    - spills from roadway and other accidents

From the above list, sanitary wastewater is the most significant source of bacteria, while automobile maintenance and plating baths are the most significant sources of toxicants. Waste discharges associated with the improper disposal of oil and household toxicants tend to be intermittent and low volume. These wastes may therefore not reach the stormwater outfalls unless carried by higher flows from another source, or by stormwater during rains.

Sewage Sources--
Sanitary sewage finds its way into separate storm sewers in a number of ways. Cross-connections may tie sanitary lines directly to storm drains, or seepage from leaking joints and cracked pipes in the sanitary collection system can infiltrate storm sewers. Surface malfunctions and insufficiently treated wastewater from septic tanks may contribute pollutants to separate storm sewers directly or by way of contaminated groundwater infiltration. Seepage of sewage or septic tank effluent (septage) into underground portions of buildings may be pumped into separate storm sewers by sump pumps (EPA 1989).

Table 9 summarizes many characteristics of domestic septage (EPA 1989). Alhajjar, *et al*. (1989) examined concentrations of major ions in septage for households using phosphate- and carbonate-built detergents (Table 10). Also included on these tables are the ranges of the constituent concentrations observed. A variety of organic chemicals, particularly solvents, are part of the formulation of many household products that become part of domestic wastewater. Kolega, *et al*. (1986) examined samples from the septic tank, leaching field and surrounding groundwater monitoring wells of condominium units and a business/residential complex in Monroe and Chester, CT. Their results are presented in Tables 11 and 12.

Raw sanitary sewage differs from the above described septage because it has not undergone any treatment. Tables 13 through 16 describe various characteristics of sanitary sewage. Table 13 shows typical constituent increases in sanitary sewage as compared to tap water. Tables 14 through 16 show concentrations of various pollutants in tub, shower, and washing machine wastewater. Ranges of the concentrations are also shown on these tables. A comprehensive characterization of municipal sewage from residential and commercial sources was carried out in Brussels, Belgium (Verbanck 1989). Though water consumption habits differ in the U.S. and Europe, this study provided additional parameter information not typically available from U.S. studies. Verbanck suggested that an appropriate tracer for sanitary sewage would be one which has physiological contributions as its main source. His work indicated that potassium fell into this category (coming directly from urine), while anthropogenic input explained only a minor part of the load for chloride, sodium, calcium and sulfate and was completely negligible for boron and silica. The occurrence of boron and silica was determined to be associated to a large extent with detergent use. Many detergents contain sodium perborate as a bleaching agent and sodium silicate as a corrosion inhibitor and building agent. Phosphate, sulfate, and bicarbonate are also common constituents of many detergent formulations, and occurrences will vary significantly with the choice of detergent (Alhajjar, *et al*. 1989).

Observed differences between weekend and weekday sanitary sewage pollutant concentrations suggested an industrial contribution of sulfate, sodium and chloride from the common industrial use of NaOH, HCl, and H_2SO_4. Initial concentrations of calcium, magnesium and bicarbonate in raw water supplies were found to be much more important than the additions due to water use. Verbanck found that ammonia accounts for 80% of total nitrogen in Brussels' sewer waters and would therefore be the most prevalent member of the nitrogen group for which to test. Verbanck's work also suggested that potassium levels might be useful in distinguishing between sanitary wastewaters and commercial wash waters. It would also identify sanitary wastes with more ease and reliability than tests involving fecal bacteria.

TABLE 9 NATIONWIDE RANGE OF SEPTAGE CHARACTERISTICS
(ALL VALUES IN MG/L, EXCEPT WHERE NOTED)

Parameter	Mean Concentration	Minimum Reported	Maximum Reported	Max. to Min. Ratio
TS	38,800	1,132	130,475	115
TVS	25,300	4,500	71,402	16
TSS	13,300	310	93,378	301
VSS	8,700	3,660	51,500	14
BOD$_5$	5,000	440	78,600	179
COD	42,900	1,500	703,000	469
TOC	9,900	1,316	96,000	73
TKN	680	66	1,900	29
NH$_3$-N	160	6	380	63
NO$_2$-N	----	0.1	1.3	13
NO$_3$-N	----	0.1	11	110
Total P	250	20	760	38
PO$_4$	----	10	170	17
Alkalinity	----	522	4,190	8
Grease	9,100	604	23,368	39
pH	6 to 9	1.5	12.6	8
LAS	160	110	200	2
Al	48	2.00	200	100
As	0.16	0.03	0.05	17
Cd	0.71	0.05	10.8	216
Cr	1.1	0.3	3.0	10
Cu	6.4	0.3	34.0	113
Fe	200	3.0	750	250
Hg	0.28	0.0002	4.0	20,000
Mn	5.0	0.5	32.0	64
Ni	0.9	0.2	28.0	140
Pb	8.4	1.5	31.0	20
Se	0.1	0.02	0.3	15
Zn	49.0	33.0	153	5

Source: EPA 1989

TABLE 10. SUMMARY CHARACTERISTICS OF SEPTIC SYSTEM EFFLUENTS FOR HOUSEHOLDS USING DIFFERENT DETERGENTS

Constituent (mg/L, unless otherwise noted)	PO_4 detergent				CO_3 detergent			
	Number of Samples	Mean	Range	Median	Number of Samples	Mean	Range	Median
Na	168	143	27-523	100	181	83	12-761	72
K	26	34	20-121	27	37	25	1.0-80	24
Ca	168	32	2.8-105	29	181	27	1.0-77	27
Mg	26	23	3.0-57	27	37	16	1.0-36	15
Cl	117	193	16-827	75	124	56	1.0-106	54
Alk (as CO_3)	124	412	128-800	396	142	401	188-908	359
EC (µmhos/cm)	170	1.5	0.5-3.5	1.4	187	1.1	0.5-2.2	1.0
pH	167	7.2	5.6-8.7	7.2	188	7.5	6.2-8.6	7.4
T (°C(	169	14	0.0-27	14	185	13	1.5-28	13

Source: Alhajjar, et al. 1989

TABLE 11. ORGANIC COMPOUNDS FOUND IN CONDOMINIUM SEPTIC TANK EFFLUENTS AND SURROUNDING GROUNDWATERS (MONROE, CT)

Constituent (mg/L)	Septic Tank Filtered Sample)	Leaching field (Unfiltered Sample)	Groundwater Monitoring Wells
Methylene chloride	1.5, 3.6	2.1	Not detected
1,1 dichloroethane	15, 56	1.8	2
t-1,3 dichloro-1-propene	44, 80	22	Not detected
Tetrahydrofuran	463	Not detected	Not detected
1,1,1-trichloroethane	52	15	10
Tetrachloroethylene	14	Not detected	Not detected
Toluene	120, 189	8	50
Trichloroethene	45	28	Not detected

Source: Kolega, et al. 1986.

TABLE 12. ORGANIC COMPOUNDS FOUND IN COMMERCIAL/RESIDENTIAL SEPTIC TANK EFFLUENTS AND SURROUNDING GROUNDWATERS (CHESTER, CT)

Constituent (mg/L)	Septic Tank (Filetered Sample)	Leaching Field (Unfiltered Sample)	Groundwater Monitoring Wells
February 19, 1985			
Methylene chloride	11	10	Not detected
Chloroform	9	2	Not detected
t-1, 3 dichloro-1-propane	63	13	Not detected
Benzene	1	2	Not detected
Toluene	290	4	Not detected
Trichloroethylene	16	Not detected	Not detected
Chlorobenzene	Not detected	6	Not detected
Ethylbenzene	Not detected	2	Not detected
March 21, 1985			
Methylene chloride	7	4	4
Chloroform	53	2	7, 9
Carbon tetrachloride	4	Not detected	Not detected
t-1, 3 dichloro-1-propene	29	39	Not detected
Chlorobenzene	1	4	Not detected
Dichloroethane	Not detected	Not detected	4
June 7, 1985			
Fluorotrichloromethane	205	234	120
Trans-1,2-dichloroethane	Not detected	Not detected	5
Trans-1,3-dichloropropene	170	220	3
Toluene	High quantity*	High quantity*	**
Chlorobenzene	<1	Not detected	Not detected
Ethyl benzene	<1	Not detected	Not detected

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* Recorded values over-scale

** Not reported. Toluene observed in water blank prior to sample analysis.

Source: Kolega, et al. 1986.

TABLE 13. CONTAMINANT INCREASES FOR SEWAGE, COMPARED TO TAP WATER (mg/L)

Reference:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	California 1954	U. S. 1958	Ohio 1964	U. S. 1964	Illinois 1967	1965 National Average Range	1989 Brussels Mean Increases
Total Dissolved Solids	100-300	120-450		150-500	262-364		
Calcium		7-109	1-43	10-50	17-53	6-16	28.6
Magnesium		1-109	1-111	5-20	7-37	4-10	(-6.9)
Ammonium	26- 48	4-45	9-27	2-20	10-37		42.4
Sodium		14-742	53-106		13-132	40-70	104.1
Phosphate	20-40	8-65	19-35	10-50	24-51	20-40	41.4
Silica		4-18		10-20	8-21	2-10	13.5
Chloride	20-50	22-1262	40-102	25-125	16-34	20-50	91
Nitrate				1-20	0-1	90-180	
Bicarbonate	60-100	12-392	25-130	18-60	34-118	50-100	159
Sulfate	15-30	10-191	15-52	10-40	8-75	15-30	63.6
Potassium	7-15					7-15	17.8
Carbonate						0-10	0
Baron	0.1-0.4					0.1-0.4	0.99
Iron						0.2-0.4	

Sources:
(1) State Water Pollution Control Board 1954 (California - 15 communities).
(2) Stone, Ralph, and Merrell 1958 (25 communities).
(3) Bunch and Ettinger 1964 (Ohio - 5 communities).
(4) Connell and Forbes 1964.
(5) Evans 1967 (Illinois - 4 communities - strictly residential).
(6) Tchobanoglons and Eliassen 1965.
(7) Verbanck, Vanderborght and Wollast 1969 (Brussels, Belgium).

TABLE 14. ORGANICS AND PHYSICAL PROPERTIES FOR TUB, SHOWER, AND WASHING MACHINE WASTEWATER (17 ANALYSES)

Characteristics	Units	Range	Average	Median
Suspended solids	mg/L	<100-128		<100
Total solids	mg/L	183-783	492	489
MBAS (detergent)	mg/L	0.19-96	43	36
TOC	mg/L	11-173	81	57
Urea	mg/L	<1-15.0		<1
Color	Subjective	Brown-Gray		
Conductivity	µmhos/cm	174-480	348	331
pH	pH units	6.9-8.4	7.6	7.7
Turbidity	SiO_2 equiv. mg/L	10-250	102	71

Source: Hypes, *et al*. 1975.

TABLE 15. MAJOR ION CONCENTRATIONS FOR TUB, SHOWER AND WASHING MACHINE WASTEWATER (17 analyses; all mg/L)

Characteristics	Range	Average	Median
Ammonia	<0.05-1.60		0.14
Calcium	23-31	27	29
Chloride	13-29	19	17
Chlorine			<0.05
Cyanide			<0.02
Fluoride	0.48-0.78	0.62	0.6
Nitrate/Nitrite	<0.05-1.1		<0.05
Phosphates	1.1-200.0	104	103
Potassium	2.5-11.0	6.0	5.5
Sodium	10-114	64	68
Sulfate	10-127	69	64

Source: Hypes, *et al*. 1975.

TABLE 16. METAL CONCENTRATIONS FOUND IN TUB, SHOWER AND WASHING MACHINE WASTEWATER (17 ANALYSES; ALL mg/L)

Characteristics	Range	Average	Median
Barium			<1
Boron			<1
Cadmium			<0.005
Chromium			<0.01
Copper	<0.1-0.4		0.1
Iron	0.2-0.8	0.4	0.3
Lead			<0.05
Magnesium	1.1-2.0	1.5	1.35
Manganese	<0.01-0.06		<0.01
Mercury			<0.001
Nickel			<0.1
Silver			<0.01
Zinc	0.30-0.84	0.54	0.5

Source: Hypes, *et al*. 1975.

Household and Automobile Maintenance--
Materials commonly used in residential areas for home maintenance and household automobile maintenance are often improperly disposed of either by direct disposal into storm sewers or disposal onto land with subsequent drainage into the storm sewer system. These materials include paints and thinners, toxic household chemicals, used oil, and radiator fluid.

Russell and Meiorin (1985) conducted a survey of household toxic material disposal practices and found direct disposal to a storm sewer, or street, in the following situations: 3% of households for paints and thinners; 11% of households for used motor oil; 83% of households that flushed their own automobile radiators for used radiator fluid, which was found to heavily contaminated with heavy metals. An additional, 14% of households that changed their own motor oil disposed of it by pouring it on the ground (EPA 1989). A survey of discount store shoppers in Oakland, California indicated that 11% of those changing their own oil poured it down storm sewers, while 36% poured it, or buried it, on their property or neighboring property (Cukor, *et al*. 1973).

The EPA estimated that 267 million gallons of used oil, including 135 million gallons from do-it-yourself automobile oil changes, are annually disposed improperly (EPA 1989). A 1979-80 survey of Providence, R.I., residents indicated that approximately 35% changed their own automotive lubricating oil. Used oil was disposed in the garbage can by 41% of these respondents, 30% dumped it in their backyard, 8% poured it down sewers or storm drains, 7% returned oil to a service station, 5% poured it on the road, and 3% took it to a town dump. The practice of pouring the waste oil on the road or into sewers accounted for 44 metric tons of petroleum hydrocarbons discharged into the city's combined storm and sanitary sewage treatment system annually, or 19% of the total hydrocarbons discharged annually into Narraganset Bay via the Providence River by this plant (Hoffman, *et al*. 1980). In 1976, direct oil spills into Narraganset Bay amounted to approximately 55 metric tons/year (Morgan 1978). Van Vleet and Quinn (1978) estimated that coastal communities release about 51,000 metric tons of petroleum hydrocarbons per year to coastal waters through their sewage treatment facilities. On a nationwide basis, approximately 17 percent of this value can be explained by the practice of do-it-yourselfers dumping their waste lubricating oil down sewers or onto roads.

A 1974 analysis of sediment samples from Colgate Creek in Baltimore harbor of Chesapeake Bay identified a number of benzene extractable hydrocarbons. Colgate Creek is exposed to continuous oil pollution, mainly from tank washings, accidental spills and storm sewer effluent discharges (Wegener 1973). Classes of hydrocarbons included alkanes, 1-ring cycloalkanes, 2-ring cycloalkanes, 3-ring cycloalkanes, alkylbenzenes, benzcycloparaffins, benzdicycloparaffins, naphthalenes, acenaphthenes, fluorenes, phenanthrenes, and cyclopentanaphenalenes (Walker and Colwell 1977).

Residential Irrigation Sources of Contaminants--
Over-watering of landscaped areas can contribute contaminants to storm drainage systems during dry weather. As an indicator of potential contaminant concentrations in this water, data is presented in Table 17 that was obtained from sheetflow samples from landscaped and undeveloped areas. These sheetflow samples are therefore affected by rain and not by domestic water. This, however, should not greatly affect the concentrations shown. Elevated concentrations of TDS, COD, phosphates, and nitrogen compounds are shown. Even though not analyzed in these studies, high concentrations of herbicides and insecticides are also expected to be associated with irrigation runoff.

Roadway and Other Accidental Sources of Contaminants--
A wide variety of materials are subject to spills during transport, transfer, use and storage. Thousands of incident reports are received by the U.S. Coast Guard's National Response Center (NRC) each year. Spilled substances are categorized as oil or CERCLA (Comprehensive Environmental Response Compensation and Liability Act) regulated materials. The term “oil” is used to represent 94 different materials, including various grades of crude oil, naphtha, coal tar, creosote, refined oils, gasoline, and jet fuels. Hazardous substances include 494 materials either regulated by, or containing substances regulated by CERCLA (EPA 1989).

TABLE 17. SHEETFLOW QUALITY FOR LANDSCAPED AREAS

Pollutants	Landscaped Areas	Undeveloped Areas
Total solids, mg/L	388 (4)	588 (4)
Suspended solids, mg/L	100 (4)	400 (1)
Total dissolved solids, mg/L	288 (4)	390 (1) 193 (4)
BOD_5, mg/L	3 (3)	---
COD, mg/L	70 (3) 26 (4)	72 (1) 54 (4)
Total Phosphorus, mg/L	0.42 (3) 0.56 (4)	0.40 (1) 0.68 (4)
Total Phosphate, mg/L	0.32 (3) 0.14 (4)	0.10 (1) 0.26 (4)
TKN, mg/L	1.32 (3) 3.6 (4)	2.9 (1) 1.8 (4)
Ammonia, mg/L	1.2 (3) 0.4 (4)	0.1 (1) <0.1 (4)
Phenols, µg/L	0.8 (4)	---
Aluminum, µg/L	1.5 (4)	11 (4)
Cadmium, µg/L	<3 (4)	<4 (4)
Chromium, µg/L	10 (3)	<60 (4)
Copper, µg/L	<20 (4) ----	31 (3) <20 (4)
Lead, µg/L	30 (2) 35 (3) <30 (4)	100 (1) 30 (2) <40 (4)
Zinc, µg/L	10 (3)	100 (4)

sources:

(1) Denver Regional Council of Governments 1983
(2) Pitt 1983 (Ottawa)
(3) Pitt and Bozeman 1982 (San Jose)

(4) Pitt and McLean 1986 (Toronto)

Spilled substances may drain into storm sewer systems on their own, be washed into storm sewer systems by subsequent rains, or may be flushed into the systems by well meaning, but ill advised, cleanup crews. Even where appropriate cleanup activities are initiated, a significant portion of a spill is usually not recoverable. No data is available to substantiate the number of unreported spills, but Merryman (1989) estimated that the NRC receives information on less than half of the reportable incidents occurring each year. For spills not reported to responsible authorities, little or no cleanup is probably attempted (EPA 1989)

Industrial Sources

There are several ways by which industries can produce dry-weather entries to storm sewers. Common examples include the discharge of cooling water, rinse water, other process wastewater, and sanitary wastewater. Industrial pollutant sources tend to be related to the raw materials used, final product, and the waste or byproducts created. Guidance on typical discharge characteristics and activities associated with common industries is given in Sections 3 and 9.

There is also a high potential for unauthorized connections within older industries. One reason for this is that at the time of an industry's development, sanitary sewers may not have been in existence, since early storm drains preceded the development of many sanitary sewer systems. Also, a lack of accurate maps of sanitary and storm drain lines may lead to confusion as to their proper identification. In addition, when the activities within an industry change or expand, there is a possibility for illicit or inadvertent connections, e.g., floor drains and other storm drain connections receiving industrial discharges which should be treated before disposal. Finally, industries processing large volumes of water may find sanitary sewer flow-carrying capacity inadequate, leading them to improperly remove the excess water through the storm drain system.

Continuous processes, e.g., industrial manufacturing, are important potential sources because any waste streams produced are likely to be constantly flowing. Detection of dry-weather discharges from these sources is therefore made easier, because the continuous and probably undiluted nature of these discharges is more noticeable, e.g., odors produced will be stronger and colors more intense, along with their tracer constituents being more concentrated and more readily detectable by sampling.

Industrial Area Wet Weather Discharges--

Although any of the situations identified above would introduce contaminants during wet as well as dry periods, there are some situations that would introduce excess contaminants into storm drains only during periods of stormwater runoff. These are more difficult to identify and locate, because to a large extent, it must be done by comparing the quality characteristics of the storm drain in question with some base line that reflects typical storm runoff. This report is therefore not recommending that the outfall monitoring activities described in Sections 4 to 7 be used to identify wet weather cross-contamination sources. These sources can be best identified by conducting on-site investigations of industrial and commercial establishments (see Sections 3, 8 and 9). Some typical situations that can introduce excess contaminant levels only during periods of normal runoff include the following:

- Contamination of outdoor areas subject to wash-off by normal rainfall. Loading dock areas, truck wash-down areas, and material handling areas are prime candidates. Parking lots and other outdoor areas in the immediate vicinity of an industrial process with poor control of fugitive air emissions, can be a significant source or surface contaminants subject to washoff by rainfall.
- Uncovered material stockpiles.
- Excessive fertilizer/pesticide applications to landscaped areas.

The most significant of these sources are probably associated with selected commercial and industrial activities, as discussed in Section 9. Conducting an inventory of the land uses in a drainage area, including the identification of specific critical activities, will be most useful in evaluating these potential indirect discharge problems.

Continuous Industrial Discharges--
Continuous discharges associated with industrial manufacturing processes are usually highly concentrated since they are not diluted by storm runoff or groundwater. Thus, the effects resulting from direct and uninterrupted flows will be more noticeable. For instance, odors produced will be much stronger and colors more intense, making it much easier to identify potential sources. Several sources of continual dry-weather flow exist in industry, including noncontact cooling water, rinse water, and process water.

Non-contact cooling water—
Industrial non-contact cooling water is water that decreases the temperature of a particular part or process without physical contact. "Non-contact" is achieved by allowing cooling waters to circulate around the part or process in a contained jacket or external channel. In order to discharge non-contact cooling waters into a storm drain, an industry must obtain a National Pollution Discharge Elimination System (NPDES) permit from the EPA, or designated state agency. These discharges will not cause pollution as long as cooling waters remain fully separated from the part or process they are cooling, are not above critical temperature limits, and do not contain additional chemicals (such as corrosion inhibitors or algicides). However, when cooling systems are not functioning properly, or when they must be blown down because of an excessive build-up of contaminants due to evaporation, they may become sources of contamination to the storm drainage system.

Industries use large amounts of non-contact cooling water for several purposes. Non-contact water is often used to cool raw materials, final products, and machinery (such as compressors or rectifiers). For example, the turbines and boilers used in coal steam electric power generation are cooled by using non-contact waters. These cooling waters are also frequently used for temperature control of chemical reaction vats or metal plating baths. The temperature of reactor vessels used in the production of plastics and synthetics is controlled by non-contact cooling waters. These cooling waters could become contaminated by leaks and spills from the primary process.

Rinse water—
Another common industrial source of continual dry-weather flow is industrial rinse water. Rinse water is water which cleans or reduces the temperature of an object through actual physical contact with the object. Discharges resulting from rinse waters are often allowed to enter floor drains which may be connected to storm sewers instead of to sanitary sewers. A high potential for continual dry-weather flow exists for those industries in which the raw materials, final products, or production machinery must be sanitized, or cooled, by using rinse waters.

Continual rinse waters may originate from industries that utilize regular washdown procedures. For instance, soft drink bottling plants use rinse waters for removal of waste drink, debris, and labels from returned bottles. Rinse waters can also be used for temperature reduction by dipping, washing, or spraying objects with cool water. For example, rinse water is sometimes sprayed over the final products of the metal plating industry for cooling.

Process water—
Industrial process water may also be discharged into floor drains. Process water is used in industry to perform a variety of functions, or as an actual product ingredient. Process waters which are likely to cause continual dry-weather flows are those used for filtration, dilution, soaking, and conveyance. As examples, large amounts of process water are used by breweries for the soaking and filtration of grain malts. In paper industries, large amounts of water are used for the conveyance of debarked and chipped wood.

Intermittent Industrial Sources--
The presence of regular, but intermittent, flows will usually be a good indication of contaminated entries to the storm drains, and can usually be distinguished from groundwater infiltration flows. This type of discharge may occur on a regular basis, or randomly, depending upon production schedules. However, as drainage areas increase in size, many intermittent flows will combine to create a continuous composite flow. Examples of possible situations or activities that can produce intermittent dry-weather flows are:

- Wash-up operations at the end of a work shift, or job activity.

- Wash-down following irregular accidents and spills.
- Disposal of process batches or rinse water baths.
- Over-irrigation of lawns.
- Vehicle maintenance, e.g., automobile washing, radiator flushing, and engine de-greasing.

Industries that operate on a seasonal basis, such as fruit canning and tourism can also be a source of longer duration intermittent discharges. Major intermittent industrial sources are described in the following paragraphs.

Rinse Waters—

Industrial rinse waters which are most likely to cause an intermittent flow are those used for clean-up at the end of a work shift, before product changeover, or after raw materials have been unloaded. One such case could be the flushing of a chemical delivery tank at an unloading dock.

Batch Dumps—

A batch dump is the intermittent disposal of process material which may be composed of a wide variety of substances, especially solvents, dyes, paints, or rinse water baths. A common example of batch dump waste comes from the pickling process used in steel mills. To remove dirt and grease, steel is immersed in dilute batches of sulfuric acid. This process produces a waste known as “pickling liquor” which contains mostly iron sulfate. Batch dump disposal occurs when the iron sulfate concentration has increased enough to inhibit the pickling process. At this point, the pickling liquor is replaced by a fresh batch of sulfuric acid. These wastes may periodically be discharged into the storm drain system.

Process Line Discharge—

Process line discharges occur when anything used in, or resulting from, a manufacturing process (including wastes, byproducts, chemicals, and fuels) is disposed. This type of waste is often seen in the food processing industry. For instance, cannery processes for vegetables often produce process line discharges. The process line wastes usually consist of solids from sorting, peeling, and coring operations, as well as can spillage from filling and sealing. These wastes may also be inappropriately discharged into the storm drain system.

Industrial Spills—

The previous situations are most likely to cause intermittent dry weather flows on a fairly regular basis. A primary cause of intermittent industrial dry-weather flows in a storm sewer is industrial spills, which are random. After a spill has taken place, the materials are often washed to floor drains which may be connected to storm sewers. Unless it is raining, this type of pollution can have very high concentrations of contaminants, since there is no dilution by stormwater.

Section 3
Mapping and Preliminary Watershed Evaluation

Purpose

An investigation of non-stormwater entries into a storm drainage system needs to proceed along a systematic path of action, which investigates areas from high to low potential for causing problems, and focuses in from general outfall screening to pin-pointing specific pollutant sources for correction. A mapping and evaluation methodology, as described in this section, is required to identify the areas to investigate and to provide a basis to prioritize the areas by their potential to contribute non-stormwater entries into the storm drainage system. The data collected in this phase is important as it forms the basis for the rest of the more detailed investigations, described in the subsequent sections of this report.

Mapping

To make this exercise as economical and productive as possible, full advantage should be taken of any existing and available information. Data gained from existing sources will need to be supplemented with information obtained by field investigations. The following summarizes the information required, likely data sources, and how to obtain the information.

Receiving Waters and Storm Sewer Outfalls

The receiving waters and stormwater drainage outfalls must be identified and accurately located on appropriate maps. However, records of all outfalls are unlikely to be found, and even for those that are, the locations of the outfalls may not be accurately shown. It is therefore important that the field survey described in Section 4 be used to supplement the data collected during this initial stage.

Possible sources of documented information include:

- City records, drainage maps and storm drain maps.
- Previous surveys e.g., sanitary sewer infiltration/inflow (I/I) and sewer system evaluation survey (SSES) studies.
- Topographic maps.
- Existing GIS (Geographic Information System) data.
- Pre-development stream locations.
- Drainage department personnel with knowledge of the area.
- Aerial surveys.

An important objective of these mapping activities is to identify the locations of all of the stormwater outfalls. Finding the outfalls is not trivial. In the case studies examined, repeated trips typically uncovered additional outfalls that were not be found during earlier excursions. In Toronto (GLA 1983), for example, most outfalls were located during the first field trip, but two more trips were needed before almost all of the outfalls were located. However, additional outfalls were periodically found that were not identified on the city storm drainage maps. It is very difficult for communities to maintain up-to-date mapping of drainage facilities.

The outfall locations must be identified for all outfalls, not just those that are greater than a certain diameter or serve a watershed greater than a specific area (see Section 4). There is currently no information to indicate a good relationship between the most significant sources of non-stormwater discharges and the largest drainage areas, or the largest diameter outfalls. There are relationships between significant sources and land uses, however, and that will be used in later aspects of this initial mapping effort.

Drainage Area for Each Outfall

The drainage area for each outfall must be determined and marked on the map. This will enable known potential pollutant source locations to be assigned to the correct outfall. Sources for this information are storm drain maps and topographical maps. These should be at least 1"=200' scale and have no greater than 5 ft contour intervals (depending on the steepness of the area).

Land Uses for Each Outfall Drainage Area

Local planning departments should have detailed zoning maps of the study area. These maps should designate residential, commercial, and industrial land uses in each outfall's drainage area. In addition, local revenue departments should have lists of business licenses for the entire municipality, but they may not be usefully organized. The public health department should know where septic tanks are used. Aerial photographs can provide useful information to identify and or confirm land use areas. Historical land uses, especially land fills and industrial areas, should also be noted.

An effective method to obtain this information may be to examine the municipality's zoning maps and to drive to the critical areas to conduct on-site inspections. The land uses of most interest are all industrial, most commercial, and some municipal activities. The activities in the commercial areas of most concern include vehicle related activities (sales, parts, service, or repair), laundry or dry cleaning (including hospitals and hotels), and restaurants. The municipal activities of most concern include land fills, bus barns, airports, and sanitary wastewater treatment facilities.

Table 18 can be used to identify the local industries in each drainage area most likely to contribute non-stormwater entries into the storm drainage system. The categories considered in this table include loading and unloading of dry bulk or liquid materials, outdoor storage or processing, water usage (cooling and process waters), dust or particulate generating processes, and illicit or inadvertent industrial connections. The likelihood of an industry producing dry-weather or wet-weather discharges in each of these categories was rated on the basis of high potential, moderate potential, low potential, and not applicable, if the activity is not likely at that land use. Section 9 discusses special considerations for the field screening activities in industrial areas.

The industrial categories listed in Table 18 were defined according to the 1987 Standard Industrial Classification Manual (SIC code). The industries were classified according to six main categories. The category for “Primary Industries” includes facilities involved in the production of food products and other basic goods. The category of “Material Manufacturing” includes those industries producing materials such as lumber, paper, glass, and leather. Similarly, the “Chemical Manufacturing” category includes those industries making products such as plastics, paints, detergents, fertilizers, pesticides, and other related substances. “Transportation and Construction” primarily concerns the discharge of contaminants from building or other types of outdoor development. The “Retail” category includes establishments engaged in the selling of merchandise or offering merchandise related services. Finally, all other industries which did not fit into any of the above classifications were placed into a “General” category. Those industries which are not specifically listed should have characteristics resembling the industries of the major groups with which they are classified by SIC code.

TABLE 18. SOURCES OF INDUSTRIAL NON-STORMWATER ENTRIES INTO STORM DRAINAGE SYSTEMS

		Industrial Categories Major Classifications SIC Group Numbers	Loading/Unloading		Outdoor Storage/ Processing	Water Usage		Particle Generating Process	Illicit/ Inadvertent Connections
			Dry Bulk	Liquids		Cooling	Process		
Primary Industries									
20		Food & Kindred Products							
	201	Meat Products	H	L	H	H	H	L	H
	202	Dairy Products Processing Industry	H	H	NA	H	H	NA	H
	203	Canned & Preserved Fruits & Vegetables	H	H	H	H	H	M	H
	204	Grain Mill Products	H	H	L	H	H	H	H
	205	Bakery Products	H	M	NA	NA	H	M	L
	206	Sugar & Confectionary Products	H	M	NA	L	M	H	L
	207	Fats & Oils	H	H	NA	M	H	NA	M
	208	Beverages	H	H	NA	H	H	M	L
21		Tobacco Manufactures	H	M	NA	NA	M	H	M
22		Textile Mill Products	H	L	NA	H	H	M	H
23		Apparel & Other Finished Products Made from Fabrics & Similar Materials	H	L	NA	NA	M	M	L
Material Manufacture									
24		Lumber & Food Products	H	L	H	NA	M	H	L
25		Furniture & Fixtures	H	M	NA	NA	L	M	L
26		Paper & Allied Products	H	H	H	H	H	H	H
27		Printing, Publishing, & Allied Industries	H	M	NA	NA	M	H	L
31		Leather & Leather Products	H	H	L	L	H	H	H
32		Stone, Clay, Glass, & Concrete Products	H	M	H	L	H	H	L
33		Primary Metal Industries	H	M	H	H	H	H	H
34		Fabricated Metal Products	H	H	L	H	H	H	H
37		Transporation Equipment	L	H	L	H	H	L	H

(continued)

TABLE 18. Continued

Industrial Categories Major Classifications SIC Group Numbers			Loading/Unloading Dry Bulk	Loading/Unloading Liquids	Outdoor Storage/ Processing	Water Usage Cooling	Water Usage Process	Particle Generating Process	Illicit/ Inadvertent Connections
Chemical Manufacture									
28	Chemicals & Allied Products								
	281	Industrial Inorganic Chemicals	H	H	NA	H	H	H	H
	282	Plastic Materials & Synthetics	H	H	L	H	M	L	H
	283	Drugs	L	L	NA	H	M	L	L
	284	Soap, Detergents, & Cleaning Preparations	H	H	NA	H	H	H	H
	285	Paints, Varnishes, Lacquers Enamels & Allied Products	H	H	NA	L	H	H	L
	286	Industrial Organic Chemicals	H	H	NA	H	H	H	M
	287	Agricultural Chemicals	L	L	NA	H	L	L	L
29	Petroleum Refining & Related Industries								
	291	Petroleum Refining	L	H	H	H	L	NA	H
	295	Paving & Roofing Materials	H	H	H	NA	M	M	L
30		Rubber & Misc. Plastic Products	H	H	NA	H	H	H	M
Transportation & Construction									
15		Building Construction	M	L	H	NA	L	H	L
16		Heavy Construction	M	L	H	NA	L	H	L
Retail									
52		Building Materials, Hardware Garden Supply, & Mobile Home Dealers	H	L	H	NA	L	NA	L
53		General Merchandise Stores	H	M	L	NA	L	NA	L
54		Food Stores	H	H	NA	NA	M	L	L
55		Automotive Dealers & Gasoline Service Stations	H	H	H	NA	M	L	M
56		Apparel & Accessory Stores	H	L	NA	NA	L	NA	L
57		Home Furniture, Furnishings and Equipment Stores	H	L	L	NA	L	NA	L
58		Eating & Drinking Places	H	M	NA	NA	M	NA	M
Other									
		Coal Steam Electric Power	H	L	H	H	L	H	L
		Nuclear Steam Electric Power	NA	L	NA	H	L	NA	NA

NOTE: H: High potential M Medium potential L Low potential NA: Not applicable

Investigators should take care to include any area where the land use has a potential to contribute pollutant sources to a storm drainage system. As stated above, these land uses may not be covered by Table 18. Some common examples of land use areas to be included are given below:

- Landfill areas can be a source of leachate and polluted runoff.
- Airports have a high potential for fuel spillage. Aircraft deicing agents, and other maintenance operations, produce wastewaters that may be discharged into the storm drainage system.
- Government facilities, such as military bases, may store or use polluting materials and have many vehicle maintenance facilities.
- Agricultural impacts are likely to be greater for wet-weather flows, but practices such as irrigation and drainage tiles may also produce dry-weather flows.

Finally, it is necessary to identify and locate existing permitted discharges to streams and storm drainage. The National Pollutant Discharge Elimination System (NPDES) permits, administered by most states or, if not, by the EPA Regional Offices, contain this information for the facilities currently having discharge permits. Only a small fraction of all industries have NPDES permits, as most have no direct wastewater discharges to waters of the United States. Pretreatment programs for municipal sewage treatment plants would also contain additional industrial information.

Other Relevant Information and Features

It is important that investigators be alert to any relevant features or information which may be specific to their drainage area. Examples of some items that need to be included are discussed in this subsection.

Information on pre-development streams and springs, which may have been routed into the storm drainage system, will aid in the identification of natural uncontaminated or contaminated dry-weather flows. Information regarding depth to the water table will be helpful. If the water table is well below the storm drains at all times, then groundwater infiltration may be less important as a potential source of dry-weather flow. However, the accumulation of percolating shallow groundwater will still occur in storm drainage fill material and be a potential source of some infiltration water. Groundwater conditions for the study area may be available from special studies conducted by the U.S. Geological Survey (USGS), the state water agency, or other sources. Utility construction and repair crews and earth moving companies should know of areas having shallow groundwater. Local I/I and SSES studies also include information concerning shallow groundwater. Well log data collected during drilling of water supply wells, and information from geotechnical investigations, may also be useful.

Areas serviced by sanitary sewerage and areas serviced by septic tanks should be determined in order to identify the areas most likely to have direct connections and infiltration sources, respectively. Local health, sewerage, utility, environmental, and public works departments may have information on the location of these areas.

Older residential areas with failing infrastructure (especially sanitary sewerage in poor condition), and high density residential areas with septic tanks, should be designated as areas with a high potential for pollutant entries into the storm drainage system.

Preliminary Watershed Evaluation

The above activities should produce maps with complete descriptions of the drainage areas, including outfall locations, NPDES permittees, critical land uses, drainage boundaries for each outfall, city limits, major streets, streams, etc. The investigators need to classify drainage areas for their potential for causing non-stormwater entries. This mapping information, together with the information to be obtained as described in Sections 4 through 6, and analyzed as described in Section 7, will form the basis to rank the drainage areas in order of priority for further detailed drainage area investigations (Sections 8 and 10).

The investigation of non-stormwater entries will have a cost associated with it, which will increase with the drainage system size and complexity, and with the number of sources being investigated. All pollutant sources, including both wet- and dry-weather pollutant entries, will need to be controlled to have an effective improvement in the quality of the stormwater system discharge. Pitt and McLean (1986) noted that even with the removal of directly connected non-stormwater entries, stormwater originating from industrial and commercial land uses has a high probability of having unacceptable pollutant loads. It would therefore be prudent, at an early stage in the investigation, to review the costs of the investigation and corrective action versus the cost for treatment of the stormwater system discharge. The classification of the storm drainage system as a combined sewer, and subsequent treatment of the flow, may prove to be a more economical and practical alternative. An appropriate time for such a review would be after the mapping and field screening activities to avoid complex, costly, and time consuming drainage system investigations into inappropriate non-stormwater entries, and instead direct resources to pollution control.

Section 4
Initial Field Surveys

Once the background data has been identified, as described in Section 3, the field investigation activities can begin. It is important to note that the field investigations do not require a massive amount of resources to be successful. The initial field surveys are to be used as a screening effort: to identify the outfalls needing more detailed investigations which would identify pollutant sources and control options. These initial surveys would include physical and limited chemical evaluations of outfall conditions and would be conducted to minimize "false negatives" (outfalls actually having important non-stormwater discharges, but falsely classified as not needing further investigation).

Different flow and pollutant characteristics of the potential discharge sources can be used to identify and quantify non-stormwater discharge problems. The initial surveys to obtain this key information should be repeated at all outfalls over several seasons. Many of the dry-weather discharges are intermittent and may not be noted during any one investigation. Various physical characteristics near the outfall can provide evidence that inappropriate discharges periodically occur. Repeated trips to the outfalls significantly increase the probability of identifying problem outfalls. It is also important to time outfall investigations during the times of day when possible activities may be contributing non-stormwater discharges.

It is difficult to develop a procedure that will separate the outfalls into clear "problem" and "no problem" categories. In some of the case studies investigated, correcting problems in watersheds above only the most critical outfalls resulted in insufficient receiving water quality improvements. It may be important to eventually correct all non-stormwater discharge problems throughout a city, not just the most severe problems. The first dry-weather outfall investigations should therefore only be considered as an initial effort that needs to be followed-up with repeated investigations at the outfalls. The purpose of these field surveys is to rank the outfalls in order of problem priorities. The watersheds associated with the highest priority problems should receive the initial clean-up efforts. Receiving water monitoring is also needed to document improvements after different stages of the control program. If the improvements are not adequate, then additional lower priority problems should be addressed.

Sampling Strategy

The importance of sampling all outfalls, regardless of size, should be stressed. Figure 2 shows the distribution of outfalls for the Birmingham, Alabama, area surveyed for the city's stormwater discharge permit application. The median equivalent diameter of the 566 outfalls was 36 inches. About 20% of the outfalls were greater than 60 inches in diameter and about 20% were less than 20 inches in diameter. Most of the largest outfalls were drainage ditches. There was an average of about 70 acres draining to each outfall, but the drainage areas ranged from much less than one acre to over 1500 acres. About 40% of the outfalls were affected by either commercial or industrial land uses and would therefore be considered as critical drainage areas for both dry-weather flows and stormwater runoff.

The Birmingham, Alabama, demonstration project that tested this protocol (as described in Section 11) was concentrated in a residential and commercial area having about 70 outfalls. The median outfall size of the outfalls in this study area was 16 in., and more than 75% of the outfalls were less than 36 in. in diameter, as shown in Figure 2. Examination of the outfalls during seven separate sampling occasions found that while some of the dry-weather flows occurred intermittently, most were continuous. About 25% of the outfalls were found to be consistently flowing during dry weather, with about two-thirds of the flows discharging from pipes that were less than 36 in. in diameter. About five percent of the outfalls exhibited dry-weather flows which were extremely toxic, or were raw, undiluted, sanitary wastewater. Each of these contaminated outfalls were 20 in., or less, in diameter. Some of the worst dry-weather flow discharge problems were associated with very small (4 in. diameter) pipes draining automobile service areas adjacent to the creek. It was found that small outfalls can contribute significant pollutant loads to receiving waters and should not be neglected if receiving water improvement is a serious goal.

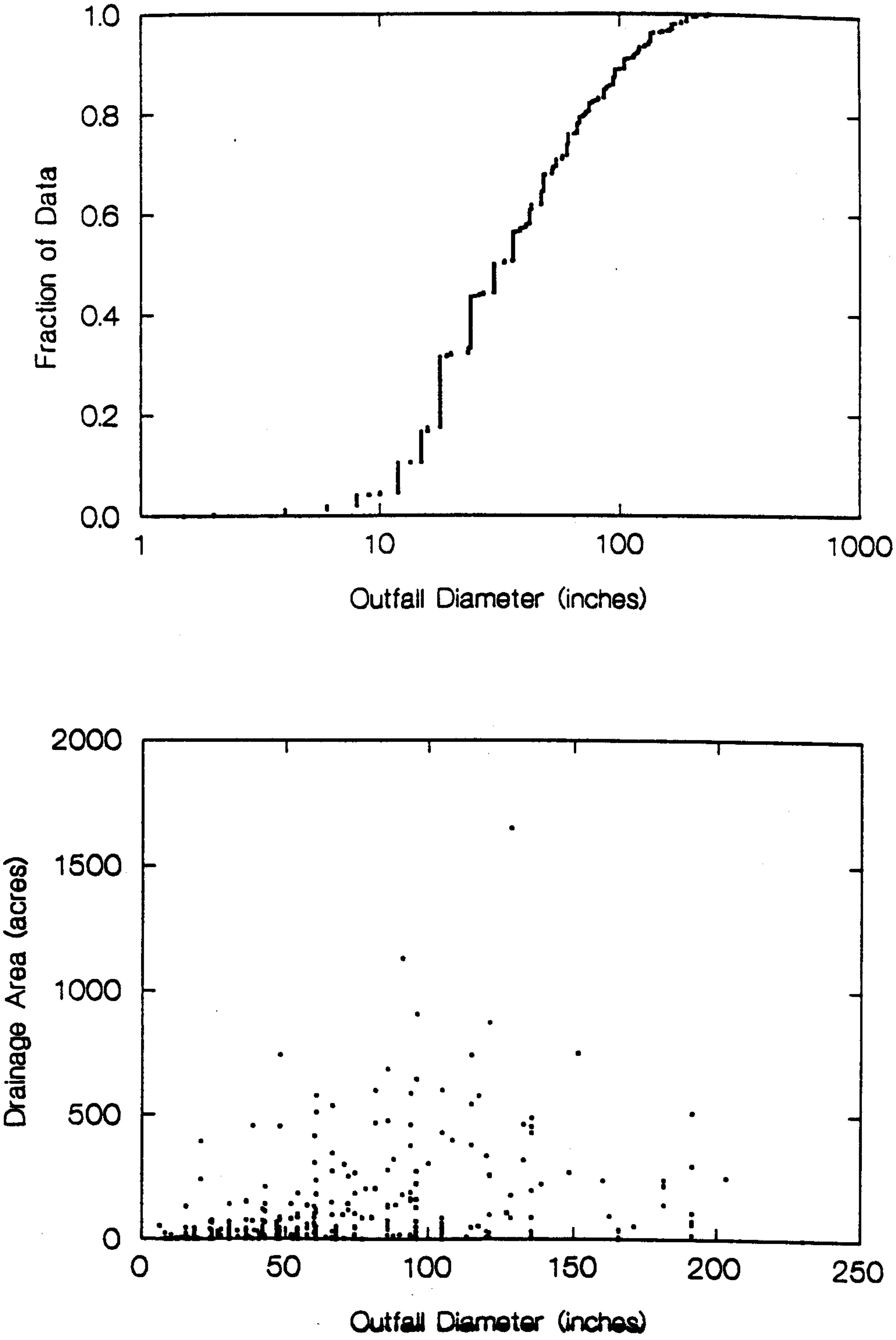


Figure 2. Outfall characteristics for Birmingham, AL, demonstration project.

Field Data Collection

Before the field data can be collected, preliminary mapping and land use evaluation work is needed. Section 3 described the preliminary work and the likely data sources for the information that is needed before the field investigations can begin. The most important preliminary information required is:

- outfall locations,
- outfall drainage areas,
- commercial and industrial activities in each drainage area, and
- locations of septic tanks in the individual drainage areas.

Outfall Locations

Frequently, city maps of known outfall locations are inadequate. Many outfalls are not located on city drainage maps because of infrequent or improper updating, or unauthorized installations. Because it is very difficult for communities to maintain up-to-date maps of drainage facilities, actual stream surveys are therefore needed to verify and update existing information. Illicit outfalls will not be shown on any maps and field surveys are therefore also needed to detect flagrant illegal discharges. Most newer developments do have accurate drainage and outfall maps, but the outfall locations may not be transferred to an overall city map. A few cities have Geographic Information Systems (GIS) in place and are including the storm drainage systems on appropriate data overlays. It is important to identify all outfalls as there is currently no information to indicate a good relationship between the most significant sources of non-stormwater discharges and the largest drainage areas, or the largest diameter outfalls.

Because of the likelihood of poor data concerning the outfall locations, it will probably be necessary to “walk” the creeks and actively look for outfalls. In most cases, it requires several trips (about three) to locate all outfalls. The initial outfall surveys should be conducted during times when riparian vegetation is minimal. Whenever an outfall is located, it needs to be marked (coded using spray paint).

If the receiving water is a small creek, it can be waded in a downstream direction. If the creek cannot be waded, a small boat or canoe can be used to look for outfalls above the water. Submerged outfalls are more difficult to find and require more careful examinations for storm drain man-holes along the shore. In a tidal area, surveys should be conducted during low tides which would expose more outfalls. In many cities, streets follow the banks of creeks or drainage canals that contain outfalls. It may be possible to carefully search the opposite bank from a moving automobile. It may also be cost-effective to use light aircraft (including helicopters) to search for outfalls from the air. Submerged outfalls would be much easier to identify from the air than from the water in cases where discharge plumes are visible.

Obviously, outfall flow characterizations should be conducted during these surveys, if possible. In all cases, at least two people are needed to look for outfalls, especially if wading a creek. Another person can drive a shuttle car to a convenient downstream location for crew rotation.

Field Survey

The main elements of the field sampling plan are the collection of necessary information and equipment, and preliminary screening of outfalls.

Maps --

Maps are the most important part of the field equipment. Adequate field maps can be prepared by enlarging standard USGS 7-1/2 minute quadrangle maps to appropriate scales. In addition, detailed street maps are also needed to locate specific street crossings and to identify locations of outfalls in the field.

Field Sampling and Analysis Equipment--
Table 19 lists the equipment that is needed for a field survey. In no case should personnel conduct the field surveys alone, wade streams without wearing waders, or be in boats without wearing life preservers. Heavy duty waders (heavy Cordura™ nylon) are preferred. Urban streams contain appreciable debris (broken bottles, etc.). In addition, urban streams are isolated wildlife areas which tend to concentrate certain wildlife species that live in close proximity to man (including cottonmouth, water moccasin, copperhead, and rattlesnakes), plus contain lush growths of poison ivy or oak. The self protection pepper spray may be especially handy in case of harassing dogs.

This equipment would supplement needed boating equipment, if boats are used. Some of this equipment (ice coolers and ice, along with extra bottles) would be kept in the vehicle. In most cases, the vehicle should be moved in about 1/2 mile increments. This length would typically contain up to ten outfalls, with relatively few flowing outfalls to sample. The collected samples would therefore be iced within about 1/2 hour of collection. It is possible that the vehicle driver could conduct critical analyses (chlorine, pH, and ammonia) while waiting. It is suggested that a three person crew rotate, with a new driver at each new shuttle location.

Arrange for Lab Testing and Other Support Equipment--
Before the field crew goes into the field to collect samples, the laboratory needs to be notified and ready to analyze the samples soon after they are available. As shown in Section 6, the laboratory testing procedures for the basic tracer parameters are all simple and can be conducted in an unsophisticated laboratory. It may be feasible for the field crew to conduct the sample analyses in the afternoon of the day when they are collected.

Preliminary Screening of Outfalls

Location of Outfalls--
Outfall locations need to be transferred to field maps and the daily activities planned. The number of outfalls that can be visited and sampled in a single day is highly dependent on outfall accessibility and mobility along the receiving water. The initial survey requires the longest time, after which repeated surveys require much less effort. In a small creek having shallow and slow water with numerous road crossings, about three miles of creek can be walked (with about 40 outfalls visited and ten outfall samples obtained) in a half-day of field activity with a crew of three people. Most other conditions would require additional labor for the same sampling effort. In all cases, careful planning, especially having an idea of where the outfalls are located, would greatly reduce the labor involved.

Scheduling Field Surveys--
It is important to schedule the field surveys during low water levels (during low tides or low flows) because outfalls will likely be submerged and concealed during high water conditions. It is also best not to conduct the field surveys during periods of high flow in the receiving waters because of safety concerns. The field surveys will also reveal more dry-weather discharges during anticipated periods of highest periods of flow from likely contaminating dry-weather flow sources (diurnal, or seasonally). As an example, morning periods usually experience the greatest sanitary wastewater flows. Scheduling sampling during these morning hours would be most successful in identifying sanitary wastewater contamination of the storm drainage system. Many inappropriate industrial entries to the storm drainage system also occur on a scheduled basis, e.g., cleaning up work areas between work shifts, or increased wastewater flows during periods of the year when a specific industry is especially busy. Again, investigating potentially affected storm drain outfalls during these critical periods would result in better data.

TABLE 19. FIELD EQUIPMENT LIST

Temperature and specific conductivity meter

Field notebook containing maps and non-stormwater flow evaluation field sheets

Waterproof marker/pen

Camera and film

Spray paint

Tape measures (both 3m and 30m)

Flashlight

Watch (with second hand)

Glass sample containers with waterproof labels (500 mL)

Plastic sample containers with waterproof labels (1 to 2 liter)

Ice boxes with ice (left in vehicle)

Backpack

Grab water sampler (dipper on long pole)

Hand operated vacuum pump sampler for shallow flows

Waders and walking stick

First aid kit and pocket knife

Self protection pepper spray

Two-way radios for communication between field crew and van driver

Hand held GPS (global positioning satellite) system receiver (only capable of locating positions within about 100 to 350 feet)

The field survey schedule will need to be flexible to avoid sampling during and immediately after a storm event to ensure only dry-weather flows are evaluated. In most urban areas, storm runoff flows will cease within 12 hours following the storm, but this will need to be reviewed with local experience. The time required for the runoff to flow through the upstream drainage system, if detention facilities are used, could extend beyond this 12 hour period.

Sampling Techniques--

After an outfall is located, it is labeled with paint and the form shown on Table 20 is completed in the field. The use of field sheets and laboratory record keeping is very important because of the large number of outfalls that will likely be surveyed in each municipality. Table 20 is a field sheet that can be used to record the observations and analytical results for the outfall survey. The top of the sheet includes basic outfall descriptive and weather information, a flow rate estimate, and an indication if industrial or commercial activities are known to occur in the area. The physical observation data section requires simple circling of the most appropriate value, or writing in another response. Samples should be obtained of floatable and staining materials for further laboratory microscopic analyses. If unusual vegetative conditions or damage to structures is found, then the extent of the damage should be described. In all cases, several photographs need to be taken of outfall conditions for each site visit. The analyses results are written on the form, along with a short descriptions of the equipment used.

Flows are estimated and visually characterized for each outfall visit. Field temperature (and possibly specific conductivity) measurements are made in the field, and dry-weather discharge water samples are collected for later (same day) laboratory analyses. A single water sample of 1 to 2 L is sufficient for almost all analyses that may be conducted on the sample. This sample can be collected in a polyethylene collapsible container. In addition, another 500 mL sample can be collected in a glass bottle (having a Teflon lined lid) if a toxicity screening procedure (like Microtox™) and selected organic tracers are to be analyzed. Specific sample volume requirements need to be determined in conjunction with the laboratory personnel. Excess samples should be placed in smaller polyethylene bottles and frozen for potential future analyses (such as heavy metals and major ions).

Sample Preservation--

Usually icing of samples after collection and same-day laboratory analyses is adequate. Ammonia, chlorine and pH are especially bothersome and special local tests may be needed to determine the tolerable delay before laboratory analyses. As noted previously, it is not efficient to generally analyze the samples in the field, especially after each sample is collected.

Field Tests--

The only test recommended for field analysis is temperature. If a multi-purpose temperature/specific conductivity meter is being used for the temperature analyses, then both can be easily determined in the field.

Record Keeping, Sample Preservation, and Analyses--

As noted above, the collected water samples need to be analyzed soon after collection. A central laboratory is much more effective than trying to analyze each sample in the field as it is collected. A later discussion in Section 6 presents the recommended laboratory procedures.

TABLE 20. SAMPLE EVALUATION SHEET

Outfall # __________ Photograph # ___________ Date:______________

Location:____

Weather: air temp.: ____ °C rain: Y N sunny cloudy

Outfall flow rate estimate: _____ L/sec

Known industrial or commercial uses in drainage area? Y N
describe:____

PHYSICAL OBSERVATIONS:

Odor: none sewage sulfur oil gas rancid-sour other:______

Color: clear yellow brown green red gray other:_________

Turbidity: clear cloudy opaque

Floatables: none oil sheen sewage other:________________ (collect sample)

Deposits/stains: none sediment oily describe:____________ (collect sample)

Vegetation conditions: normal excessive growth inhibited growth
extent: ____

Damage to outfall structures:
none / concrete cracking /concrete spalling/ peeling paint / metal corrosion
other:____
identify structure:____
extent:____

ANALYSES:			EQUIPMENT USED:
Specific conductivity:	_____	µS/cm	______________________
Temperature:	_____	°C	______________________
Fluoride:	_____	mg/L	______________________
Hardness:	_____	mg/L	______________________
Surfactants:	_____	mg/L	______________________
Florescence:	_____	% of scale	______________________
Potassium:	_____	mg/L	______________________
Ammonia:	_____	mg/L as N	______________________
pH:	_____		______________________

Data Analyses and Correction of Problems

Identification of Contaminated Outfalls--
Section 7 discusses several methods to identify the likely components in each flowing outfall. This information is then used to identify the most contaminated dry-weather flows.

Isolation and Correction of Contaminating Flow Sources--
After the problem outfalls are identified, drainage system surveys are used to find the sources of the contaminating flows. These procedures are discussed later in Section 8 of this report.

Evaluating Intermittent Flows

Irregular flows pose a special problem during the field surveys. Outfall dry-weather flows can be intermittent in nature, only flowing soon after rains and then remaining dry, or may flow when inappropriate water sources enter the storm drainage system. If associated with rains, outfall surveys should be postponed until sufficient time has lapsed since the last major rain. For most urban areas, storm runoff drainage ends after several (usually less than 6) hours after the rain stops. Extended, but decreasing flows, after rains could be associated with shallow groundwater infiltration into the drainage system. In this case, most outfall surveys should be further delayed. However, some pollutant sources may be associated with these flows, especially contaminated groundwaters (septic tank problems, leaky underground storage tanks, etc.). Therefore, it may be important to sample these flows, especially if these contaminant sources may occur.

Basic field indicators, such as the presence of oily deposits, coarse solids deposits, odors, etc. near the outfall in the absence of a flow, indicate the likelihood of intermittent dry-weather flows. Outfalls exhibiting these signs of non-continuous discharges should be visited several times to increase the probability of observing and sampling a dry-weather discharge. Analyzing pooled water immediately below the outfall or collected between visits in small, constructed dams within the storm drain can greatly assist in identifying non-continuous discharges. Similarly, coarse solids and/or floatables can be similarly captured through the erection of coarse screens and/or booms at the mouth of the outfall or in the receiving stream. It may be necessary to visit suspect outfalls frequently. However, it is virtually impossible to be able to capture a short-term intermittent flow (such as from the illegal dumping of wastes into the storm drainage system) from outfall visits.

Simple outfall area characteristics, noted above, are the most reliable indicator of a potential intermittent source at an outfall. In addition to using a dam, or other indicator device (such as a small screen to capture particulate debris), it may be desirable to use an automatic water sampler at especially important outfalls. Automatic samplers would be unreasonable and expensive to use at many outfalls in an area and test locations would need to be carefully selected. A sampler located in a close-by manhole and set to sample every fifteen minutes (with four samples placed in each bottle) can monitor for intermittent flows for a period of 24 hours. Automatic samplers can also be used to characterize variable quality flows. This information can be a highly valuable help in identifying possible discharge sources.

The presence of intermittent flows in outfalls labeled “dry” was investigated during the field study. Of special interest were the possibility of intermittent commercial flows which might occur on a regular basis. Such flows could be associated with shift changes or end of the day/end of the week wash-ups from commercial establishments. To explore the presence of such flows, small impoundments were created in outfall and discharge pipes located in the most commercial portion of the watershed. The impoundments were formed by placing a bead of latex caulk one half to one inch in height across the invert of the pipes. A total of 31 pipes were investigated during a dry period in August of 1992. Twenty-eight dry pipes were originally fitted with temporary dams shortly after noon. Pipes were inspected for flow at 6:30 p.m. and again shortly after noon the following day. One storm sewer outfall was found to have had flow, as evidenced by water in the impoundment, during the test period.

To further check the validity of the test method, dams were then placed in three additional direct discharge pipes known to have frequent intermittent flows during the day. Dams were put in place prior to facility operation in the morning and checked 6 hours later. All three dams showed evidence of flow. Impoundments in two pipes, which traditionally carried small, low velocity flows, were filled with water. In the third pipe, which traditionally carried high velocity, warm water flows, the caulk dam had been washed away by the flow. This simple method of investigation increases the likelihood of detecting intermittent flows which are relatively frequent, or periodic, in nature.

Section 5
Selection of Tracer Parameters

Introduction

The detection and identification of inappropriate entries requires the quantification of specific characteristics of the observed outfall baseflow. The characteristics of most interest should be relatively unique for each potential flow source. This will enable the presence of each flow source to be noted, based on the presence (or absence) of these unique characteristics. The selected characteristics are termed tracers, because they have been selected to enable the identification of the sources of these waters.

One approach presented in this report is based on the identification and quantification of clean baseflow and contaminated components. If the relative amounts of potential components are known, then the importance of the baseflow can be determined. As an example, if a baseflow is mostly uncontaminated groundwater, but contains 5% raw sanitary wastewater, it would be a likely important source of pathogenic bacteria. Typical raw sanitary wastewater parameters (such as BOD_5 or suspended solids) would be in low concentrations and the sanitary wastewater source would be difficult to detect. Fecal coliform bacteria measurements would not help much because they originate from many possible sources, besides sanitary wastewater. Expensive unique microorganism or biochemical measurements would probably be needed to detect the presence of the wastewater directly. A tracer may be identified that can be used to identify relatively low concentrations of important source flows in storm drain dry-weather baseflows.

The ideal tracer should have the following characteristics:

- Significant difference in concentrations between possible pollutant sources;
- Small variations in concentrations within each likely pollutant source category;
- A conservative behavior (i.e., no significant concentration change due to physical, chemical or biological processes); and,
- Ease of measurement with adequate detection limits, good sensitivity and repeatability.

In order to identify tracers meeting the above criteria, literature characterizing potential inappropriate entries into storm drainage systems was examined. Several case studies which identified procedures used by individual municipalities or regional agencies were also examined. Though most of the investigations resorted to expensive and time consuming smoke or dye testing to locate individual illicit pollutant entries, a few provided information regarding test parameters or tracers. These screening tests were proven useful in identifying drainage systems with problems before the smoke and dye tests were used. The case studies also revealed the types of illicit pollutant entries most commonly found in storm drainage systems.

This list of potential illicit sources (see Section 2) led to a search for information regarding the chemical and physical characteristics of these specific flows. This search yielded typical characteristics for sanitary wastewater, septic tank effluent, coin-operated laundries and car wash effluents, as well as potable water and “natural waters”. This information, along with specifics obtained from case studies, provided the basis for selecting parameters for further study. Specific analyses will be needed to identify the characteristics of local potential inappropriate entries and uncontaminated water sources, as described in Section 6.

Characterizations of Potential Dry-Weather Flows From Existing Literature

Table 21 summarizes available information characterizing potential flow sources. This information was used to identify parameters which occurred at different concentrations in natural and potable waters, as compared to sanitary, septage, car wash, and laundry wastewaters. Based on this very general information, several parameters looked promising when considered as part of a group of parameters to be used to characterize potential dry weather flow sources. Measurement of total dissolved solids (TDS) appeared to have good potential for distinguishing between potable water and sanitary wastewaters, though TDS in natural waters varies considerably. No information was available to indicate its usefulness in distinguishing between laundry, carwash and sanitary wastewaters. BOD, COD, and TOC measurements could perhaps accomplish the same thing, but available information indicated they would not be useful in distinguishing between commercial wash waters and sanitary flows. Values for TDS can be approximated by specific conductivity, which is considerably easier to measure than BOD, COD, or TOC (which are not very conservative anyways).

Although not conservative, ammonia and nitrate appeared to have potential for separating natural and potable waters from sanitary wastewaters, as did phosphate. Again, no information was available regarding levels of the compounds in laundry and carwash wastewaters. Alkalinity information was only available for potable water and sanitary wastewaters, but differences were noted between the two.

Total coliform bacteria counts might seem an obvious choice to identify sanitary wastewaters, but numerous researchers have noted problems in using coliforms for evaluation of water from storm drainage systems (Geldreich 1965; Geldreich, *et al*. 1968; Van Donsel, *et al*. 1969; Feachem 1975; Olivieri, *et al*. 1977; Matson, *et al*. 1978; Pitt and Bozeman 1982; Rideau River 1983; and Huron River 1988).

Candidate Parameters

Many different candidate parameters were evaluated before the suggested list was developed. It is recommended that the initial field screening effort include at least the following, in the absence of known commercial and industrial areas in the watershed:

- placement of outfall identification number;
- outfall discharge flow estimate;
- floatables, coarse solids, color, turbidity, oil sheen, and odor characteristics of water;
- other outfall area characteristics, such as stains, debris, damage to concrete, corrosion, unusual plant growth, or absence of plants;
- water temperature;
- specific conductivity;
- fluoride and/or hardness concentrations;
- ammonia and/or potassium concentrations;
- surfactant concentration and/or fluorescence; and
- chlorine concentration and pH.

If commercial or industrial activities occur in the drainage area, then it is important to add additional parameters (such as a toxicity screening procedure and specific metallic and organic toxicant analyses, and others, as noted in Section 9) to the above list.

TABLE 21. SUMMARY OF POTENTIAL FLOW SOURCE CHARACTERISTICS
(UNITS IN MG/L UNLESS NOTED)

Parameter	Natural[1]	Tap[2]	Sewage[3]	Septage[4]	Car Wash[5]	Laundry[6]
TDS	25-5000	47-63	250-850	291-2250		149-607
Conductivity (µmhos/cm)				500-2220		
BOD			110-400	34-547	<6-220	34-196
TOC	5	0.6-4.7	80-290		16-173	
COD			250-1000		61-1120	73-840
Total N			20-85	10-141		
Organic N			8-35	<0.5-72		
Ammonia	0-1	0.01-0.07	12-50	23-129		
Nitrites		0.2-0.4	0	<0.5-0.9		
Nitrate (NO_3	>0.1,<5	0.28-0.4	20-40			
Total P			4-15	2.8-39	0.25-24	
Organic P			1-5	<0.01-28		
Inorganic P			3-10			
Phosphate (PO_4)	>0.01,<0.1	0.02-0.04	5-15			
Total Alkalinity ($CaCO_3$)		18-36	50-200	128-908		
Bicarbonate (as $CaCO_3$)	5-500	18-36	50-100			
Carbonate (as $CaCO_3$)		0	0-10			
Grease			50-150		5.7-404	
Total Coliforms (org/mL)		0	10^6-10^9			
Chlorides	10-100	3.8-6	20-50	1-827		
Sulfate (SO_4)	5-200	9-12	15-50			
Calcium (Ca)	5-500	11-13	6-16	1-105		
Magnesium (Mg)	10-50	1-3	4-10	1-57		
Potassium (K)	>0.1,<5		7-15	1-121		
Sodium (Na)	10-100	1.6-3.6	40-70	12-761		
Aluminum (Al)	>0.01,<0.1	90-500ppb	0.1-0.2			
Boron (B)			0.1-0.4			
Fluoride (F)	>0.1,<5	0.9-1.1	0.2-0.4			
Manganese (Mn)			0.2-0.4			
Silica (SiO_2)	1-100	3-5	2-10			
pH		7.6-8.8		5.6-8.6	6.2-9	7.9-9.2
Total Hardness		32-40				
Manganese	>0.01,<0.1	<0.05				
Copper	>0.01,<0.1	<0.01			0-0.86	
Phenolics		<1ppb				
Zinc	>0.01,<0.1	10-130ppb			0-2.4	
Lead	>0.01,<0.1	<10ppb			0-4.2	
Detergents (as MBAS)		<0.01				12.6-101.3

[1] Kemmer & McCallien, 1979: NALCO

[2] Birmingham Water Works Board, 1992

[3] Metcalf & Eddy, 1991

[4] Alhajjar et al., 1989

[5] International Carwash Association

[6] International Coin Laundry Association

Most of the parameter characteristics listed above can be obtained at the outfall location using field procedures. It is much easier, more cost-effective, and much more accurate to collect samples in the field for later laboratory analyses. Analyzing multiple samples for the same parameter is much more efficient than trying to analyze a single sample for many parameters, especially under adverse field conditions.

The selection of the analysis procedures will depend on many conditions, most notably the expected concentrations in the uncontaminated baseflows and in the potential non-stormwater discharge flows, along with the needed probabilities of detection at the minimum contamination level. A description of the techniques developed as part of this study to help in the selection of the analytical procedures is given later in this section. Other factors affecting procedure selection include ease of use, analytical interferences, cost of equipment, training requirements, and time requirements to conduct the analyses.

Simple outfall estimates of discharge, and noting the presence of oil sheens, floatables, coarse solids, color, odors, etc. will probably be the most useful indicators of outfall problems. These observations will need to be repeated several times, especially if non-continuous discharges are likely. The presence of stains and structural damage will greatly assist in identifying significant non-continuous discharges, in addition to continuous discharges. In addition, the following optional characteristics may also be obtained at each outfall, depending on probable pollutant sources:

- hardness;
- toxicity screening; and
- specific metals.

Notably absent from the above list are fecal coliform bacteria, pH, and dissolved oxygen. These have been included in several previous non-stormwater discharge studies, but with limited value. These parameters have not been found to be extremely useful in identifying or categorizing non-stormwater sources. However, in areas having known industrial sources, pH may be an important parameter that would have to be added to this list. Specific analytical recommendations are given in Section 6.

Visual Inspection

Visual observations of outfall conditions have been noted in many case studies to be very useful in determining the significance of contaminated dry-weather baseflows. There was a good correlation between drains judged contaminated after physical inspection and those judged contaminated after chemical tests at Inner Grays Harbor (Pelletier and Determan 1988) and in Toronto (GLA 1983). Visual inspections also provided most of the information for prioritizing drains in Fort Worth (Falkenbury 1988). Correlations between corrections of improper drain connections and improvements in visual evaluations were also evident in Fort Worth. EPA stormwater permit application regulations require a narrative description of visual observations including color, odor, turbidity, the presence of an oil sheen or surface scum, along with a description of the flow rate.

Odor--

The odor of a discharge can vary widely and often directly reflects the source of contamination. Industrial dry-weather discharges will often cause the flow to smell like a particular spoiled product, oil, gasoline, specific chemical, or solvent. In particular, industries involved in the production of meats, dairy products, and the preservation of vegetables or fruits, are commonly found to discharge organic materials into storm drains. As these organic products or byproducts spoil and decay, the sulfur production creates this highly apparent and unpleasant smell. Significant sewage contributions to a dry-weather flow will cause pronounced and distinctive odors.

Color--

Color is another important indicator of inappropriate discharges, especially from industrial sources. During a field sampling program in Toronto (Pitt and McLean 1986), many periods of highly colored baseflows (red, brown, gray, etc.) were observed at an industrial outfall. Chemical analyses showed elevated concentrations of many pollutants. Specific sources of these flows could not be determined, except that the washing of work areas in cement and stone working plants could have been responsible for some of the cloudy dry-weather discharges, and metal plating wastes were probably responsible for many of the filterable metal discharges. Other potential dry-weather sources causing various colored contaminated waters from the industrial area could have included “non-contact” cooling water, process water (both slug or continuous discharges), equipment and work area cleaning water discharged to floor drains, spills during loading operations (and subsequent washing of the material into the storm drain).

Industrial dry-weather discharges may be of any color. Dark shades, such as brown, gray, or black, are most common. For instance, the color contributed by meat processing industries is usually a deep reddish-brown. Paper mill wastes are also brown. In contrast, textile wastes are varied. Other intense colors, such as plating-mill wastes, are often yellow. Section 9 further describes these characteristics for many different industries.

Turbidity--
Turbidity, or the clarity, of water is often affected by the degree of gross contamination. Dry-weather industrial flows with moderate turbidity can be cloudy and difficult to see through, while high turbidity flows will be opaque and practically impossible to see through. High turbidity is often a characteristic of undiluted dry-weather industrial discharges, such as those coming from some continual flow sources, or some intermittent spills. Sanitary sewage is also often cloudy in nature.

Floatable Material--
A contaminated flow may also contain floatables (floating solids or liquids). Evaluation of floatables often leads to the identity of the source of industrial or sanitary wastewater pollution, since these substances are usually direct products or byproducts of the manufacturing process, or distinctive of sewage discharges. Floatables of industrial origin may include substances such as animal fats, spoiled food products, oils, plant parts, solvents, sawdust, foams, packing materials, or fuel, as examples.

Deposits and Stains--
Deposits and stains (residue) refer to any type of coating which remains after a non-stormwater discharge has ceased. They will cover the area surrounding the outfall and are usually of a dark color. Deposits and stains often will contain fragments of floatable substances and, at times, take the form of a crystalline or amorphous powder. These situations are illustrated by the grayish-black deposits that contain fragments of animal flesh and hair which often are produced by leather tanneries, or the white crystalline powder which commonly coats sewer outfalls due to nitrogenous fertilizer wastes.

Vegetation--
Vegetation surrounding an outfall will also show the effects of intermittent or random non-stormwater discharges. Industrial pollutants will often cause a substantial alteration in the chemical composition and pH of the discharge water. This alteration will affect plant growth, even when the source of contamination is intermittent. For example, decaying organic materials coming from various food product wastes would cause an increase in plant life. In contrast, the discharge of chemical dyes and inorganic pigments from textile mills could noticeably decrease vegetation, as these dry-weather discharges often have a very acidic pH. In either case, even when the cause of industrial pollution is gone, the vegetation surrounding the outfall will continue to show the effects of the contamination.

In order to accurately judge if the vegetation surrounding an outfall is normal, the observer must take into account the current weather conditions, as well as the time of year in the area. Thus, flourishing or inhibited plant growth, as well as dead and decaying plant life, are all signs of pollution when the condition of the vegetation just beyond the outfall disagrees with the plant conditions near the outfall.

Structural Damage--
Structural damage is another readily visible indication of both continual and intermittent industrial dry-weather discharge contamination. Cracking, deterioration, and spauling of concrete or peeling of surface paint, occurring at an outfall are usually caused by severely contaminated discharges, usually of industrial origin. These contaminants are usually very acidic or basic in nature. For instance, primary metal industries have a strong potential for structural

damage because their batch dumps are highly acidic. However, confusion is possible due to the effects poor construction, hydraulic scour, and old age may have had on the condition of the outfall structure or sewerage system.

Chemical Parameters

Chemical tests are needed to supplement the above described physical inspection parameters. Chemical tests are needed to quantify the approximate components of a mixture at the outfall. In most cases, dry-weather discharges are made-up of many separate source flows (such as leaking domestic water, groundwaters, sanitary wastewater, and automobile washwaters). Statistical analyses of the chemical test results can be used to estimate the relative magnitudes of the various flow sources.

Based on water and wastewater characteristics discussed in Section 2, along with information obtained from case studies, the following parameters were chosen for study: specific conductivity, fluoride, hardness, detergents (as MBAS), fluorescence, potassium and ammonia. These parameters, and the reasons for choosing them, are discussed below. In addition to these, the following parameters were investigated due to their inclusion on the list of parameters for which municipalities must test to comply with the 1990 EPA Stormwater Regulations: pH, total chlorine, total copper and total phenol (monitoring of detergents was also required). The EPA's list applies to all types of land use areas. Some of these parameters may be useful in industrial areas, but of little use in commercial and residential areas.

Conductivity--

Conductivity can be used as an indicator of total dissolved solids. Conductivity measurements can be conducted relatively easily in the field, while total dissolved solids measurements must be made in a laboratory.

Specific conductance was judged to be a reliable and quick field indicator of general outfall contamination by Gartner Lee and Associates in Toronto (1983). Observed levels ranged from 25 to 100,000 µS/cm. Conductivity levels less than 1000 µS/cm indicated significant levels of rainwater in the drainage.

The reported range of conductivity in naturally occurring waters in the U.S. were from less than 50 µS/cm in Greenville, SC to greater than 1000 µS/cm in Los Angeles (Nalco 1979). Brussels tap water had conductivity values of about 620 µS/cm, while Brussels sewage had conductivity values of about 1,540 µS/cm (Verbanck, *et al*. 1990). The Langely Research Center, Hampton, VA, examined conductivity for tub, shower and washing machine wastewater (Hypes, *et al*. 1975):

Baseline tap water	180 µS/cm
Combined bath and laundry waters	414
Range for bath and laundry waters	174-480

Samples from 17 household septic systems in Wisconsin were collected over a two year period (Alhajjar, *et al*. 1989). The following list shows the conductivity values observed (no tap water data available):

8 households using PO_4 detergent:

Number of samples: 170
Mean: 1500 µS/cm
Range: 500-3500
Median: 1400

9 households using CO_3 detergent:

Number of samples: 187
Mean: 1100 µS/cm
Range: 500-2200
Median: 1000

The Allen Creek Drainage study reported that 92 percent of the known improper connections to storm sewers were corrected between 1984 and 1986 (Washtenaw Co. 1984). These were all from businesses, with very few known sanitary cross-connections. The following shows the average conductivity values observed during the year immediately before and after these corrections were made, along with the control value:

Conductivity: 1984: 910 µS/cm; 1986: 687; control: 620

These conductivity values apparently reflected the decreased discharges of non-stormwater discharges into the storm sewers.

The literature indicated that differences in conductivity between clean water and wastewater sources could be substantial enough to indicate the source of dry-weather flow in storm sewerage. Conductivity can be measured quickly, easily and cheaply. For these reasons, it was selected as a parameter for further study.

Total dissolved solids--
Total dissolved solids, or TDS, is another parameter to consider in a pollutant analysis for industrial areas. However, it is recommended that conductivity measurements, conducted in the field, be used as an indicator of total dissolved solids concentrations. If more precise total dissolved solids concentrations are needed, then laboratory measurements should then be conducted.

The TDS of uncontaminated baseflows should be between 100 to 200 mg/L (or ppm). The TDS of dry-weather industrial non-stormwater discharges may be greater than 2,000 mg/L. In fact, many undiluted industrial contaminants may have TDS concentrations of 10,000 mg/L, or greater.

Fluoride--
Fluoride measurements have often been used to distinguish treated waters from natural waters. Surface waters generally contain under 0.3 mg/L fluoride, while groundwaters usually contain higher levels (Viessman and Hammer 1985). In "natural waters", monitored fluoride concentrations range from 0.06 to 3 mg/L. More than 90 percent of waters sampled throughout the U.S. by the USGS had fluoride concentrations less than 1 mg/L (Davies and DeWiest 1966).

It is common practice for communities to add fluoride to municipal waters to improve dental health. Concentrations of total fluoride in fluoride-treated tap waters are usually in the range of 1.0 to 2.5 mg/L, while concentration above 5 mg/L are detrimental (Nalco 1979). As of 1970, over 88 million people in 7,458 communities received water with a fluoride concentration adjusted to the optimal level, or had an adequate natural fluoride content (Water Atlas of the U.S. 1973). In 1992, an American Water Works Association survey found that 43% of the public water supplies derived from groundwaters and 64% of the public water supplies derived from surface waters were fluoridated (AWWA 1992). The 1975 National Interim Primary Drinking Water Regulations, U.S. EPA, recommended fluoride limits for public drinking water supplies, as follows (Viessman and Hammer 1985):

Fluoride Ion Concentrations (mg/L)

water temp.*	Recommended Limits			Approval
(° F)	lower	optimum	upper	Limits
50.0-53.7	0.9	1.2	1.7	1.8
53.8-58.3	0.8	1.1	1.5	1.7
58.4-63.8	0.8	1.0	1.3	1.5
63.9-70.6	0.7	0.9	1.2	1.4
70.7-79.2	0.7	0.8	1.0	1.2
79.9-90.5	0.6	0.7	0.8	1.1

* Annual average of maximum daily air temperatures, based on temperature data obtained for a minimum of 5 years.

During the Allen Creek drainage study, the fluoride concentrations of dry-weather flows at outfalls reduced to undetectable concentrations (from previous fluoride concentrations of about 0.5 mg/L), after 92 percent of the known improper connections to storm drains were corrected (Washtenaw Co. 1988). As noted previously, very few of these improper connections were of sanitary wastewater to the storm drainage. Apparently, most of the non-stormwater discharges were treated tap water.

Fluoride measurements would be of limited use in distinguishing treated waters in areas of the country where natural waters contain fluoride near the optimal drinking water range. However, relatively few communities fall into this category, and most are in the southwest or high plains.

Fluoride should be a reliable indicator of water which has been treated for public consumption, in communities where fluoride is added to the water supply. Fluoride could therefore be used to differentiate between natural waters and tap water or sanitary wastewater. Several relatively simple procedures exist for measuring fluoride, and the Allen Creek study did not note matrix interference problems associated with wastewater samples.

Hardness--
Water hardness is caused by the divalent and trivalent metallic cations dissolved in water. In fresh water, these are primarily calcium and magnesium, although other metals such as iron, strontium and manganese may contribute to the extent that appreciable concentrations are present. Hardness is commonly reported as an equivalent concentration of calcium carbonate ($CaCO_3$). The hardness of waters varies considerably from place to place, with ground waters generally being harder (higher in concentration, as equivalent $CaCO_3$) than surface waters. Natural sources of hardness are limestones which are dissolved by percolating rainwater. In the U.S., drinking water supplies vary in hardness from near 1 mg/L as $CaCO_3$ to in excess of 180 mg/L (Sawyer and McCarty 1978). Information regarding the average hardness of tap water, as well as local ground water and surface waters, should be readily available wherever a public water supply system exists. Hypes (1975) found tub, shower and washing machine waters 25%-50% softer than the original tap water, because the addition of soap precipitates hardness-causing ions.

Hardness could be useful in distinguishing between natural waters, clean treated waters, and treated waters which have been subjected to domestic use.

Surfactants and florescence--
Detergents (surfactants) may enter water and wastewater through the discharge of aqueous wastes from household and industrial laundering and other cleaning operations. In the United States, anionic surfactants are commonly used in detergent formulations and account for approximately two-thirds of the total surfactants used.

The Langely Research Center experiment, in Hampton, Virginia, also examined surfactants (Hypes, *et al*. 1975). Average surfactant concentrations (expressed as methylene blue active substances, or MBAS), for tub, shower and washing machine wastewaters, were reported to be:

Baseline tap water:	0.3 mg/L as MBAS
Combined bath and laundry waters:	52 mg/L
Range for bath and laundry waters:	0.19-96 mg/L

Alhajjar, *et al*. (1989) measured septage system effluent, using the MBAS test. They did not find any detectable MBAS substances in the effluents. The surfactants were apparently totally degraded in the septic tanks.

During the Allen Creek drainage study, surfactants (as MBAS) decreased significantly after 92 percent of the improper non-stormwater discharges to storm sewers were corrected between 1984 and 1986 (Washtenaw Co. 1984; 1988):

1984: 0.187 mg/L as MBAS
1986: 0.03 mg/L
1986 control: 0.02 mg/L

These non-stormwater discharges were all from business, with very few sanitary wastewater cross-connections found.

Water florescence is also an indicator of detergent residue in waters. Most detergents contain fabric whiteners which cause substantial florescence. Florescence can be measured in the laboratory, or in the field using special field fluorometers. Ecoscience, of Moscoe, Pennsylvania, markets a septic leachate detector and service that uses an instrument that is a combination specific conductance meter and fluorometer. Background lake water characteristics are compared to sample characteristics of near-shore water that is pumped to the shipboard detector for analysis. Lakeside failing septic tanks can then be identified by unusual instrument responses for adjacent lake waters. The Madison septic tank studies found that MBAS material was apparently completely degraded in septic tanks. Ecoscience obviously has found that enough florescent indicators remain after discharge from septic tanks to be readily detectable. Therefore, if septic system failures are a potential non-stormwater source of contaminants to a storm drainage system, then florescence should be used as an indicator of detergents in the water, instead of MBAS measurements.

Potassium--
In natural waters, monitored potassium concentrations ranged from 0.4 to 15 mg/L, with 80 percent of the observations less than 5 mg/L (Davies and DeWiest 1985).

Increases of potassium concentrations in sanitary wastewater, over the base concentrations in tap waters, were observed to be about 7 to 15 mg/L during a 1954 California study (Evans 1967). During a 1989 Brussels study, the tapwater potassium concentration was about 2.8 mg/L, while the sanitary wastewater potassium concentration was about 17.8 mg/L (Verbanck, *et al*. 1990). Data from a Langely Research Center experiment, in Hampton, Virginia, examined potassium concentrations in tub, shower and washing machine wastewaters, reported as follows (Hypes, *et al*. 1975):

Baseline tap water: 1.3 mg/L
Combined bath and laundry waters: 5.6 mg/L
Range for bath and laundry waters: 2.5 to 11 mg/L

Early 1958-1959 potassium concentration observations found sanitary wastewater potassium concentrations of about 6 mg/L. Settled sewage samples had potassium concentrations of about 20 mg/L (Painter 1971). Samples from 17 household septic systems in Wisconsin, collected monthly over a two year period, found the following potassium concentrations (Alhajjor, *et al*. 1989):

8 households using PO_4 detergent:
Number of samples: 26
    Mean : 34 mg/L
    Range: 20-121 mg/L
    Median: 27 mg/L
9 households using CO_3 detergent:
    Number of samples: 37
    Mean: 25 mg/L
    Range: 1-80 mg/L
    Median: 24 mg/L

Potassium should be useful in distinguishing natural waters from waters which have been used domestically, or commercial wash waters.

Ammonia/Ammonium--

The presence or absence of ammonia (NH_3), or ammonium ion (NH_4^+), has been commonly used as a chemical indicator for prioritizing sanitary wastewater cross-connection drainage problems. Ammonia concentrations in “natural waters” can range from 0.2 to 20 mg/L. Eighty percent of these waters sampled had concentrations less than 5 mg/L (Davies and DeWiest 1966). In Brussels, ammonium concentrations averaged less than 1 mg/L in the tap water, while the ammonium concentrations in sewage averaged 42 mg/L (Verbanck, *et al*. 1990). The U.S. mean ammonia nitrogen concentrations in septage were reported to be 160 mg/L, while the minimum reported concentration was 6 mg/L and the maximum reported concentration was 380 mg/L (Lombardo and Assoc. undated). Increases of ammonium ion (the increased sanitary wastewater concentrations, compared to tap water concentrations) were:

Calif	U.S.	Ohio	U.S.	Ill.
1954	1958	1964	1964	1967
26-48	4-45	9-27	2-20	10-37 mg/L

(as reported by Evans 1968). A 1958-1959 study reported ammonia concentrations in sanitary wastewater that ranged from 4 to 35 mg/L, with a mean of 21 mg/L. Settled sewage ammonia concentrations ranged from 41 to 53 mg/L, with a mean 46 mg/L (Painter 1971). The Langley Research Center, Hampton, Virginia, examined wastewater from showers, tubs and washing machines. The ammonia levels in these wastewaters ranged from 0.09 mg/L to 1.6 mg/L (no tap water ammonia levels were reported, but can be assumed to be close to zero) (Hypes, *et al*. 1975).

Correlations between corrections of improper sanitary wastewater cross-connections into storm drainage and reduced numbers of sewer outfalls with ammonia present were noted in Fort Worth (Falkenbury 1988). During studies in Toronto, more “problem” storm sewer outfalls had high NH_3-N values (>1 mg/L) than any other single parameter, except TKN (GLA 1983). Ammonia nitrogen concentrations ranged from less than 0.1 mg/L to 360 mg/L for 239 outfalls that were sampled. During the Huron River study, ammonia levels were found to be greater at all “problem” storm drain outfalls than at controls locations (Washentaw Co. 1988). However, the Allen Creek Drainage study reported that with 92 percent of the improper non-stormwater discharges to storm sewers corrected, the ammonia concentrations did not change significantly (all were about 0.44 mg/L). Very few of the flow corrections were sanitary sewage wastewater cross-connections (Washentaw Co. 1984; 1988).

At Inner Grays Harbor, the range of ammonia and ammonium ion (as nitrogen) found in 29 storm drain outfalls having dry-weather discharges was 0.01 to 12 mg/L, with a mean concentration of 0.175 mg/L. An outfall with a confirmed sanitary cross-connection to the storm drainage had an ammonia concentration of 0.39 mg/L (Pelletier and Determan 1988). This information indicated that ammonia should be useful in identifying sanitary wastes and distinguishing them from laundry and carwash wastes.

pH--

During 1958-1959 studies, 43 sanitary sewage samples had pH values in the range of 6.7 to 7.5, with a mean 7.2. Seven settled sewage samples had a range of 7.6 to 8.2, with a mean of 7.8 (Painter 1971). Samples from 17 household septic systems in Wisconsin, collected monthly over a two year period, had the following pH values (Alhajjar, *et al*. 1989):

8 households using PO_4 detergent system:
  Number of samples: 167
  Mean: 7.2
  Range: 5.6-8.7
  Median: 7.2
9 households using CO_3 detergent systems:
  Number of samples: 188
  Mean: 7.5
  Range: 6.2-8.6

Median: 7.4

During the Inner Grays Harbor study, the observed pH dry-weather flow values from 27 of 29 stormwater outfalls ranged from 6.2 to 8.0. The extreme values were 4.6 and 10.1. The mean pH value observed was 7.2 (Pelletier and Determan 1988). Only five of 200 stormwater outfalls tested during dry-weather in Fort Worth had pH values either below 6 or above 9 (Falkenbury 1988). Of 239 stormwater outfalls sampled in Toronto, 84 were judged contaminated enough to justify intensive sampling. None of the 239 were reported to have unusually acidic or caustic discharges (GLA 1983).

Contaminants in industrial non-stormwater discharges to storm sewers tend to alter the pH of unaffected baseflows by making it either more basic or more acidic. The normal pH of most uncontaminated baseflows is usually quite close to neutral (pH of 7). However, the pH at an outfall near an industrial source may vary in the range from 3 to 12. Acids and alkalis released into storm sewers by chemically-oriented industries are frequently the cause of pH fluctuations.

Industries that commonly release acidic dry-weather discharges include textile mills, pharmaceutical manufacturers, metal fabricators, as well as companies producing resins, fertilizers, pesticides, or any other similar materials. A low pH range of 3 to 5 indicates an acidic discharge. Wastes containing sulfuric, hydrochloric, or nitric acids are the most common industrial sources of acidic discharges.

Alkaline wastes cause dry weather flows to become more basic (higher pH). Many industrial alkaline wastes contain chemicals such as cyanide, sodium sulfide, and sodium hydroxide. High concentrations of these contaminants are found in discharges from soap manufacturers, textile mills, metal plating industries, steel mills, and producers of rubber or plastic.

Based on this information, pH values were expected to be of very little use in identifying inappropriate discharges in commercial/residential land use areas. Most dry-weather flows anticipated in these areas would have similar pH values, with the possible exception of cleaning operations or repair shops having metal plating operations. Anomalous pH measurements could indicate discharges from industries on the fringes of commercial/residential zones or the illegal dumping of industrial wastes from waste haulers.

Temperature--

Temperature measurements may be useful in situations where the screening activities are conducted during cold months, or in areas having industrial activity. It may be possible to identify an outfall that is grossly contaminated with sanitary wastewater or cooling water during very cold weather. Both sanitary wastewater and cooling water could substantially increase outfall discharge temperatures. Elevated baseflow temperatures (compared to baseflows at other outfalls being screened) could be an indicator of substantial contamination by these warmer source flows.

Toxicity Screening Tests--

In addition to the parameters described above, relative toxicity can be an important outfall screening parameter. Short-term toxicity tests, such as the Microtox™ test (from Microbics) are valuable for quickly and cheaply assessing the relative toxicity of different storm drain baseflows, to a selected test organism. These tests can be used to directly identify outfalls that contain flows in the most serious (toxic) category and that require immediate investigation. These tests are also very useful in identifying likely sources of toxicants to the drainage system by utilizing a toxicity reduction evaluation (TRE) procedure in the drainage system. If an outfall contains a highly toxic flow, then specific metallic and organic toxicants can be analyzed to support source identification.

Total Chlorine--

EPA regulations require testing for total chlorine. Chlorine can be present in water as free available chlorine and as combined available chlorine (usually as chloramines). Both forms can exist in the same water and be determined together as total available chlorine. Chlorine was selected as an indicator by the EPA because chlorination of public drinking water supplies is widespread, and members of the EPA evaluation team felt that chlorine measurements would be useful in virtually every community for identifying water which had been through a treatment process.

Chlorine is not very stable in water, especially in the presence of organic compounds. Tests of clean potable water during the Birmingham demonstration project phase of this research found that total available chlorine only decreased by about 25 percent in 24-hours during an aerated bench-scale test. However, the chlorine demand of contaminated water can be very large, with chlorine concentrations decreasing to very small values after short periods of time. As an example, sheetflow samples from irrigated lawns had undetectable chlorine concentrations, even after very short (10 feet) flow paths and relatively high tap water chlorine concentrations (1.5 mg/L). Chlorine therefore cannot be used to reliably quantify flow sources because of its instability, but the presence of chlorine in baseflow waters (very unlikely) could indicate a significant and very close domestic water flow source, or industrial discharges, or illegal dumping.

Total Copper--
EPA regulations require testing for total copper. Copper was cited as the major toxic metal in urban runoff during NURP, with a median urban runoff value of 34 µg/L copper (EPA 1983). Measurement of copper levels may have merit in industrial areas, but is not expected to be of use in residential and commercial districts. Although levels of copper might be slightly elevated in wastewaters from domestic and commercial use which have come in contact with copper pipes, relatively expensive techniques would be necessary to quantify such small additions. Other suggested parameters should be able to identify water subjected to domestic use more easily and with less expense.

Total Phenol--
Phenols are industrial compounds used primarily in the production of synthetic polymers, pigments, and pesticides, and they occur naturally in fossil fuels (Viessman and Hammer 1985). Phenols are generally rather tedious and expensive to quantify. A new direct colorimetric comparator test is now available, but detection limits and precision have not been evaluated. Measurement of phenols in dry-weather flows from residential and commercial areas is not expected to provide useful illicit discharge information.

Fecal Coliform Bacteria as an Indicator of Inappropriate Discharges

During the Inner Grays Harbor study, a storm drain outfall with a confirmed domestic sewage connection was not reported to have exhibited an elevated fecal coliform level (Pelletier and Determan 1988). In the final report of the Nationwide Urban Runoff Project (NURP), it was noted that the seasonal differences noted in stormwater runoff quality did not correspond to differences in land use (EPA 1983). However, this comparison did not include dry-weather flows.

High fecal coliform bacteria populations were observed at storm sewer outfalls at all times in both industrial and residential/commercial areas during a study in Toronto (Pitt and McLean 1986). During the warm-weather storm sampling period, surface sheetflows were thought to be responsible for most of the observations of bacteria at the outfalls. However, during cold weather, very few detectable surface snowmelt sheetflow or snow pack fecal coliform observations were obtained, while the outfall observations were still quite high. High fecal coliform bacteria populations were also observed during dry-weather flow conditions at the storm sewer outfalls during both warm and cold weather. Leaking, or cross-connected, sanitary sewerage was therefore suspected at both study areas. Sump pump drainage contaminated with bacteria, or accumulated bacteria in the storm drainage sediments was not thought to be significant in these Toronto sampling areas. Contaminated sump pump water (from poorly operating septic tank systems in medium density residential areas) in the Milwaukee area, has been noted as a potentially significant source of bacteria to storm drainage systems (R. Bannerman, Wisconsin Department of Natural Resources, personal communication).

Bacteria Sources

The presence of bacteria in stormwater runoff, dry-weather flows and in urban receiving waters has caused much concern. Most of the attention has been given to fecal coliform populations and associated water quality standards. Research projects conducted in Toronto, Ontario (Pitt and McLean 1986) and in Madison, Wisconsin (Bannerman, personal communication, WI DNR) have investigated the abundance of common indicator bacteria, potential pathogenic bacteria, and bacterial types that may indicate the source of bacterial contamination. The monitoring efforts included sampling from residential, industrial and commercial areas.

As in many previous studies, fecal coliforms were found to commonly exceed water quality standards by large amounts. Fecal coliform populations were very large at all land uses investigated during warm weather (typical median outfall values were 10,000 to 30,000 organisms per 100 mL). Dry-weather baseflow fecal coliform populations were found to be statistically similar to the stormwater runoff populations. The cold weather fecal coliform populations were much lower, but still exceeded the water quality standards (typical median outfall values were 300 to 10,000 per 100 mL).

Samples were obtained from many potential source areas, in addition to the outfall, during the Toronto study (Pitt and McLean 1986). Source area fecal coliform populations were very similar for different land uses for the same types of areas, but different source areas within the watersheds varied significantly. Generally, roof runoff had the lowest fecal coliform populations, while roads and roadside ditches had the largest populations. Even though source area fecal coliform populations were very low during the winter, the outfall snowmelt and cold weather baseflow fecal coliform populations frequently were greater than 1000 organisms per 100 mL in areas "known" to have no sanitary sewage cross-connections.

The fecal coliform test is not specific for any one coliform type, or groups of types, but instead has an excellent positive correlation for coliform bacteria derived from the intestinal tract of warm blooded animals (Geldreich, *et al*. 1968). The fecal coliform test measures *Escherichia coli* as well as all other coliforms that can ferment lactose at 44.5 ^{o}C and are found in warm blooded fecal discharges. Geldreich (1976) found that the fecal coliform test represents over 96 percent of the coliforms derived from human feces and from 93 to 98 percent of those discharged in feces from other warm blooded animals, including livestock, poultry, cats, dogs, and rodents. Variations in specific fecal coliform bacteria biotypes are related to both fecal moisture content and diet. Moisture and diet may also affect the variety of bacteria biotypes found in the fecal coliform populations from different animal groups. In many urban runoff studies, all of the fecal coliforms were *E. coli* (Quresh and Dutka 1979). Fecal streptococci bacteria are all of the intestinal Streptococci bacteria from warm blooded animal feces (Geldreich and Kenner 1969). The types and concentrations of different bacteria biotypes varies for different animal sources. Quresh and Dutka (1979) found that pathogenic bacteria biotypes are present in urban runoff and are probably from several different sources.

Pseudomonas aeruginosa is reported to be the most abundant pathogenic bacteria organism in urban runoff and streams (Olivieri, *et al*. 1977b). This pathogen is associated with eye and ear infections and is resistant to antibiotics. They also stated that past studies have failed to show any relationships between *P. aeruginosa* concentrations in bathing waters and ear infections. However, Pseudomonas concentrations in urban runoff are at significantly greater concentrations (approximately 100 times) than the values associated with past bathing beach studies. Cabelli, *et al*. (1976) stated that *P. aeruginosa* is indigenous in approximately 15 percent of the human population. Swimmer's ear or other Pseudomonas infections may, therefore, be caused by trauma to the ear canals associated with swimming and diving, and not exposure to Pseudomonas in the bathing water.

Pseudomonas aeruginosa is expected to be the most common bacterial pathogen found in urban runoff, however, Salmonella has also been infrequently reported during urban runoff studies. Large outfall *Pseudomonas aeruginosa* populations were found during all warm weather study phases for these Madison and Toronto studies: median dry weather baseflow populations were about 2500 organisms per 100 mL and median stormwater runoff populations ranged from 2000 to 10,000 organisms per 100 mL. Cold weather observed populations were significantly less: median dry weather baseflow populations were about 50 to 100 organisms per 100 mL and median snowmelt populations were about 25 organisms per 100 mL.

The sources (nonhuman versus human) of bacteria in urban runoff is difficult to determine. Geldreich and Kenner (1969) caution against using the ratio of fecal coliform to fecal streptococci as an indicator, unless the waste stream is known to be "fresh". Unfortunately, urban runoff bacteria may have been lying on the ground for some time before rain washed it into the runoff waters. Delays may also be associated with some dry-weather bacteria sources. This aging process can modify the fecal coliform to fecal streptococci ratio to make the bacteria appear to be of human origin. In fact, samples collected in runoff source areas usually have the lowest FC/FS ratio in a catchment, followed by urban runoff, and finally the receiving water (Pitt 1983). This transition probably indicates an aging process and not a change in bacteria source. The best way to determine the possible source of bacteria may be to monitor for certain specific biotypes. The best biotypes to monitor may be *S. bovis, S. equinus* (only associated with nonhumans), and *S. faecalis* (the predominant human fecal streptococci).

Therefore, bacteria are usually poor indicators of the sources of dry-weather flows. Past use of fecal strep. to fecal coliform ratios to indicate human versus nonhuman bacteria sources in mixed and old wastewaters (such as most nonpoint waters) has not been successful. There may be some value in investigating specific bacteria types, such as fecal strep. biotypes, but much care needs to be taken in the analysis and interpretation of the results. A more certain indicator of human wastes may be the use of certain human-specific molecular markers, specifically the linear alkylbenzenes and fecal sterols, such as coprostanol and epicoprostanol (Eaganhouse, *et al*. 1988).

Coprostanol, and Other Organic Compounds, Utilized as Tracers of Sanitary Sewage Contamination

Neutral sterols are a class of compounds which include cholesterol and its main degradation products coprostanol, coprosterol and coprostanone. These compounds are formed in the colon by the action of microbial enzymes. Plants also produce a class of sterols called phytosterols and include campesterol, brassicasterol, stigmasterol, and b-sitosterol.

Coprostanol, a major fecal sterol in humans has been suggested as an indicator for sewage (Eaganhouse, *et al*. 1988). It has been quantified at the 75 ng level by gas chromatography/mass spectroscopy of Mercenaria mercenaria (bivalvia) taken from sewage-polluted water (Matusik, *et al*. 1988). Particulates and sediments collected from coastal areas in Spain and Cuba receiving municipal sewage loads were analyzed (Grimalt, *et al*. 1990) to determine the utility of coprostanol as a chemical marker of sewage contamination. Coprostanol can not by itself be attributed to fecal matter inputs. However, relative contributions of steroid components can be a useful indicator. When the relative concentrations of coprostanol and coprostanone are higher than their 5a epimers, or more realistically, other sterol components of background or natural occurrence, it can provide useful information. Sediment cores from Santa Monica Basin, CA and effluent from two local municipal wastewater discharges were also analyzed (Venkatesan and Kaplan 1990) for coprostanol to determine the degree of sewage addition to the sediment. Coprostanols were distributed throughout the basin sediments in association with fine particles. Some stations contained elevated levels, either due to their proximity to outfalls or because of preferential advection of fine-grained sediments. A noted decline of coprostanols relative to total sterols from outfalls seaward indicated dilution of sewage by biogenic sterols.

The range of concentrations of coprostanol found in sediments and mussels of Venice, Italy were reported by Sherwin (Sherwin, *et al*. 1993). Raw sewage is still discharged directly into the Venice lagoon. Coprostanol concentrations were determined in sediment and mussel samples from the lagoon using gas chromatography/mass spectroscopy. Samples were collected in interior canals and compared to open-bay concentrations. Sediment concentrations ranged from 0.2-41.0 mg/g (dry weight). Interior canal sediment samples averaged 16 mg/g compared to 2 mg/g found in open bay sediment samples. Total coprostanol concentrations in mussels ranged 80-620 ng/g (wet weight). No mussels were found in the four most polluted interior canal sites. Sediment samples collected from Humber River, ON, Canada and within the vicinity of the Humber sewage treatment plant were analyzed for organic compounds. Sediment organic matter samples were found to contain concentrations of coprostanol, a-tocopheryl acetate, linear-chain n-alkane hydrocarbons, and carbon and nitrogen isotopes (Coakley, *et al*. 1992). The potential for coprostanol to be used as an indicator for sewage is good when background levels, relationship to total sterol concentration, sediment advection, and possibly ionic strength of the body of water is known. Imperative is development of sensitive and selective analytical techniques which are capable of quantifying a range of sterols.

Other chemical compounds have been utilized for sewage tracer work. Saturated hydrocarbons with 16-18 carbons, saturated hydrocarbons with 16-21 carbons and coprostanol were chosen as markers for sewage in water, particulate, and sediment samples near the Cocoa, FL domestic wastewater treatment plant. The concentration of the markers was highest at points close to the outfall pipe and diminished with distance. However the concentration of C16-C21 compounds was high at a site 800 m from the outfall indicating that these compounds were unsuitable markers for locating areas exposed to sewage plume. The concentrations for the other markers were very low at this station (Holm, *et al*. 1990). Linear alkylbenzene sulphonates (LAS) from synthetic surfactants (Terzic and Ahel 1993) which do not degrade rapidly have been utilized as markers, as well as nonionic detergents (Zoller, *et al*. 1991). LAS was quickly dispersed from wastewater outfalls except in areas where wind was calm. In these areas LAS concentration increased in freshwater but was unaffected in saline water. After time, lower alkyl groups predominated, possibly as a result of degradation or settling of longer alkyl chain compounds with sediments.

Selection of Field Parameters

Table 22 is an assessment of the usefulness of the various field survey parameters in identifying different potential non-stormwater flow sources. Natural and domestic waters should be uncontaminated (except in the presence of contaminated groundwaters entering the drainage system, for example). Sanitary sewage, septage, and industrial waters can produce toxic or pathogenic conditions. The other source flows (wash and rinse waters and irrigation return flows) may cause nuisance conditions, or critically affect aquatic life.

The parameters marked with a plus sign can probably be used to identify the specific source flows by their presence. Negative signs indicate that the potential source flow probably does not contain the listed parameter, and may help confirm the presence of the source by its absence.

The list of recommended field parameters offers specific “fingerprints” that can be used to identify the flow sources. It is still necessary that local data be used to confirm these “absences and presences” and to obtain likely concentration ranges for the source flows. Knowing the concentration ranges will enable predictions of the mixture quantities to be made, as shown in the hypothetical investigative examples. Simple to complex data interpretation methods are given in Section 7 and a detailed demonstration study description, using these methods, is given in Section 11.

TABLE 22. FIELD SURVEY PARAMETERS AND ASSOCIATED NON-STORMWATER FLOW SOURCES

Parameter	Natural Water	Potable Water	Sanitary Sewage	Septage Water	Indus. Water	Wash Water	Rinse Water	Irrig. Water
Fluorides	-	+	+	+	+/-	+	+	+
Hardness change	-	+/-	+	+	+/-	+	+	-
Surfactants	-	-	+	-	-	+	+	-
Florescence	-	-	+	+	-	+	+	-
Potassium	-	-	+	+	-	-	-	-
Ammonia	-	-	+	+	-	-	-	-
Odor	-	-	+	+	+	+/-	-	-
Color	-	-	-	-	+	-	-	-
Clarity	-	-	+	+	+	+	+/-	-
Floatables	-	-	+	-	+	+/-	+/-	-
Deposits and stains	-	-	+	-	+	+/-	+/-	-
Vegetation change	-	-	+	+	+	+/-	-	+
Structural damage	-	-	-	-	+	-	-	-
Conductivity	-	-	+	+	+	+/-	+	+
Temperature change	-	-	+/-	-	+	+/-	+/-	-
pH	-	-	-	-	+	-	-	-

Note: - implies relatively low concentration
\+ implies relatively high concentration
+/- implies variable conditions

Tracer Characteristics of Local Source Flows

Table 23 is a summary of the tracer parameter measurements found in Birmingham, Alabama. This table is a summary of the "library" that describes the tracer conditions for each potential source category. The important information shown on this table includes the median and coefficient of variation (COV) values for each tracer parameter for each source category. The COV is the ratio of the standard deviation to the mean. A low COV value indicates a much smaller spread of data compared to a data set having a large COV value. It is apparent that some of the generalized relationships shown on Table 22 did not exist during the demonstration project. This stresses the need for obtaining local data describing likely source flows.

The fluorescence values shown on Table 23 are direct measurements from the Turner™ Model 111 fluorometer having general purpose filters and lamps and at the least sensitive setting (number 1 aperture). The toxicity screening test results are expressed as the toxicity response noted after 25 minutes of exposure. The Microtox™ unit measures the light output from phosfluorescent algae. The I_{25} values are therefore the percentage light output decreases observed after 25 minutes of exposure to the sample. If an outfall sample has a very high light attenuation value, it is typically subjected to additional organic and metallic toxicant tests. Fresh potable water has a relatively high response because of the chlorine levels present. Aged, or dechlorinated, potable water has much smaller toxicity responses.

Appropriate tracers are characterized by having significantly different concentrations in flow categories that need to be distinguished. In addition, effective tracers also need low COV values within each flow category. Table 22 showed the expected changes in concentrations per category and Table 23 indicates how these expectations compared with the results of an extensive local sampling effort. The study indicated that the COV values were quite low for each category, with the exception of chlorine, which had much greater COV values. Chlorine is therefore not recommended as a quantitative tracer to estimate the flow components. Similar data must be collected in each community where these procedures are to be used. Section 6 discusses how the number of samples needed per category can be estimated.

Recommended Parameters for Measurement

Observations made during the demonstration phase of this research (reported in Section 11) included color, odor, clarity, presence of floatables and deposits, and rate of flow, in addition to the chemical measurements shown on Table 24.

TABLE 23. TRACER CONCENTRATIONS FOUND IN BIRMINGHAM, ALABAMA, WATERS
(MEAN, STANDARD DEVIATION AND COEFFICIENT OF VARIATION, COV)

	Spring water	Treated potable water	Laundry wastewater	Sanitary wastewater	Septic tank effluent	Car wash water	Radiator flush water
Fluorescence	6.8	4.6	1020	250	430	1200	22,000
(% scale)	2.9	0.35	125	50	100	130	950
	0.43	0.08	0.12	0.20	0.23	0.11	0.04
Potassium	0.73	1.6	3.5	6.0	20	43	2800
(mg/L)	0.070	0.059	0.38	1.4	9.5	16	375
	0.10	0.04	0.11	0.23	0.47	0.37	0.13

Ammonia	0.009	0.028	0.82	10	90	0.24	0.03
(mg/L)	0.016	0.006	0.12	3.3	40	0.066	0.01
	1.7	0.23	0.14	0.34	0.44	0.28	0.3
Fluoride	0.031	0.97	33	0.77	0.99	12	150
(mg/L)	0.027	0.014	13	0.17	0.33	2.4	24
	0.87	0.02	0.38	0.23	0.33	0.20	0.16
Toxicity	<5	47	99.9	43	99.9	99.9	99.9
(% light decrease after	n/a	20	<1	26	<1	<1	<1
25 minutes, I_{25})	n/a	0.44	n/a	0.59	n/a	n/a	n/a
Surfactants	<0.5	<0.5	27	1.5	3.1	49	15
(mg/L as MBAS)	n/a	n/a	6.7	1.2	4.8	5.1	1.6
	n/a	n/a	0.25	0.82	1.5	0.11	0.11
Hardness	240	49	14	140	235	160	50
(mg/L)	7.8	1.4	8.0	15	150	9.2	1.5
	0.03	0.03	0.57	0.11	0.64	0.06	0.03
pH	7.0	6.9	9.1	7.1	6.8	6.7	7.0
(pH units)	0.05	0.29	0.35	0.13	0.34	0.22	0.39
	0.01	0.04	0.04	0.02	0.05	0.03	0.06
Color	<1	<1	47	38	59	220	3000
(color units)	n/a	n/a	12	21	25	78	44
	n/a	n/a	0.27	0.55	0.41	0.35	0.02
Chlorine	0.003	0.88	0.40	0.014	0.013	0.070	0.03
(mg/L)	0.005	0.60	0.10	0.020	0.013	0.080	0.016
	1.6	0.68	0.26	1.4	1.0	1.1	0.52
Specific conductivity	300	110	560	420	430	485	3300
(µS/cm)	12	1.1	120	55	311	29	700
	0.04	0.01	0.21	0.13	0.72	0.06	0.22
Number of samples	10	10	10	36	9	10	10

Table 24. Parameters Selected for Investigation

Parameters Initially Selected	Additional Parameters Selected by EPA
Physical Observations	pH
Detergents	Total Chlorine
Fluorescence	Total Copper
Potassium	Total Phenols
Ammonia	
Fluoride	
Conductivity	
Hardness	

Toxicity	

Section 6

Experimental Design And Selection/Evaluation Of Analytical Methods

Determining Number of Observations Needed for Tracer Data Library

It is very important to determine the number of observations needed for each tracer parameter for each source category in order to build a useful data library for analyzing the outfall data. The number of samples needed is a function of the tolerable error level in the data means and the concentration variations (usually expressed as the standard deviations). The following subsections briefly describe a method that can be used to estimate the sampling effort required to develop a useful library of source flow characteristic data.

Estimating Number of Samples Needed

One equation that can be used to calculate the number of analyses needed, based on the allowable error is (Cochran 1963):

$$\text{Number of samples} = 4(\text{standard deviation})^2/(\text{allowable error})^2$$

With a 95 percent level of confidence, this relationship determines the number of samples needed to obtain a value within the range of the sample mean, plus and minus the error. Figure 3 (Pitt 1979) shows the approximate sample size needed to obtain different allowable errors for different coefficient of variance (COV) values (COV = standard deviation/mean). This is a simplified equation that doesn't consider false negatives and assumes that the data is normally distributed. A later example shows how log-normally distributed data can be transformed for use with this equation. More comprehensive experimental design equations for environmental samples can be found in Gilbert (1990) and Berthoux (1994).

The above equation can also be used to predict the 95 percent confidence interval, based on the measured (or estimated) standard deviation and number of samples obtained (again ignoring false negatives):

$$\text{Error} = 2(\text{standard deviation})/(\text{number of samples})^{0.5}$$

where the confidence interval is the mean plus and minus the calculated error value.

Determining Sample Concentration Variations

Figure 4 can be used to estimate the COV value for a parameter by knowing the 10th and 90th percentile ratios (the "range ratio"), assuming a log-normal distribution. This is used to make initial estimates for COV that are needed to calculate the approximate number of samples that actually need to be sampled and analyzed. In many cases, the approximate range of likely concentrations can be estimated for a parameter of interest. The extreme values are not well known, but the approximate 10th and 90th percentile values can be estimated with better confidence. As an example, the likely 10th and 90th percentile values of fluoride in tap water can be estimated to be about 0.7 and 1.5 mg/L, respectively. The resulting range ratio is therefore 1.5/0.7 = 2.1 and the estimated COV value is about 0.25 from Figure 4.

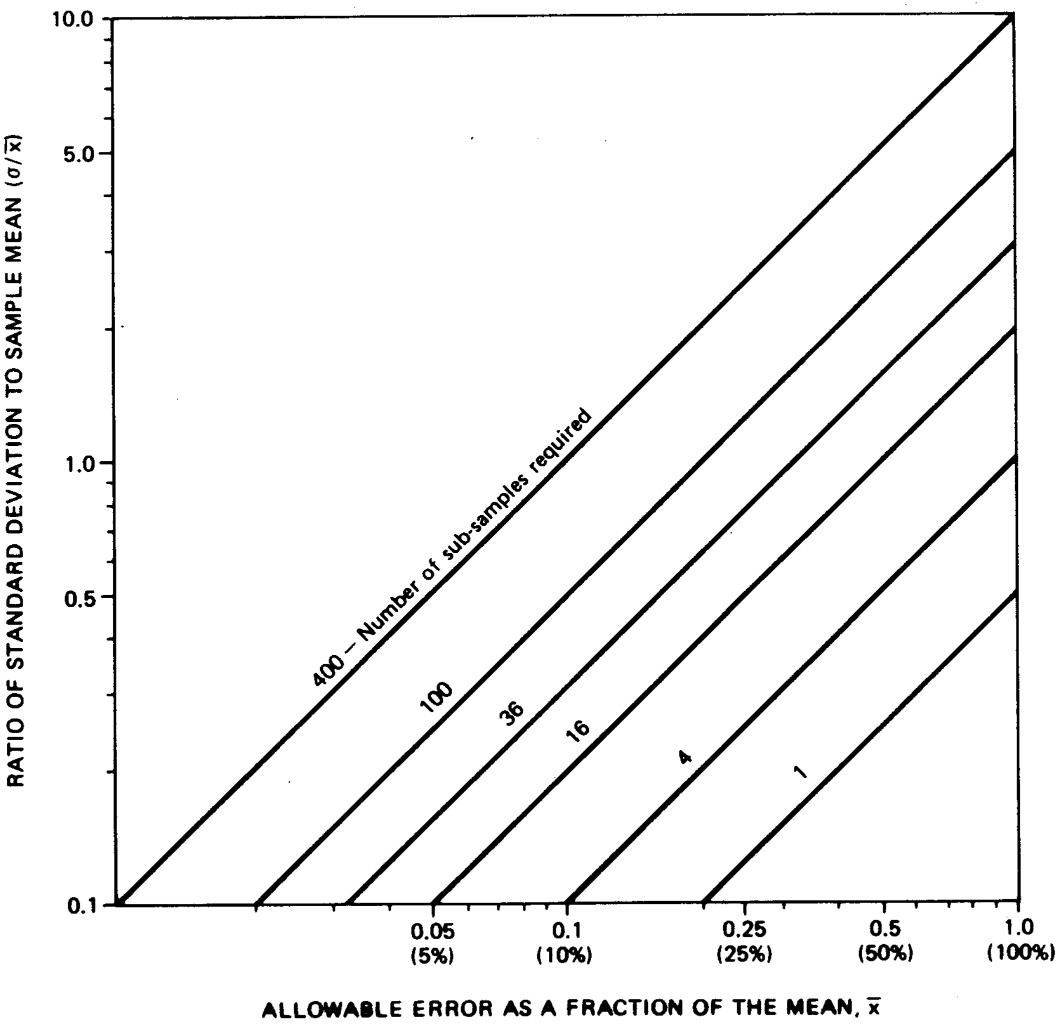


Figure 3. Required number of samples for allowable error and COV.

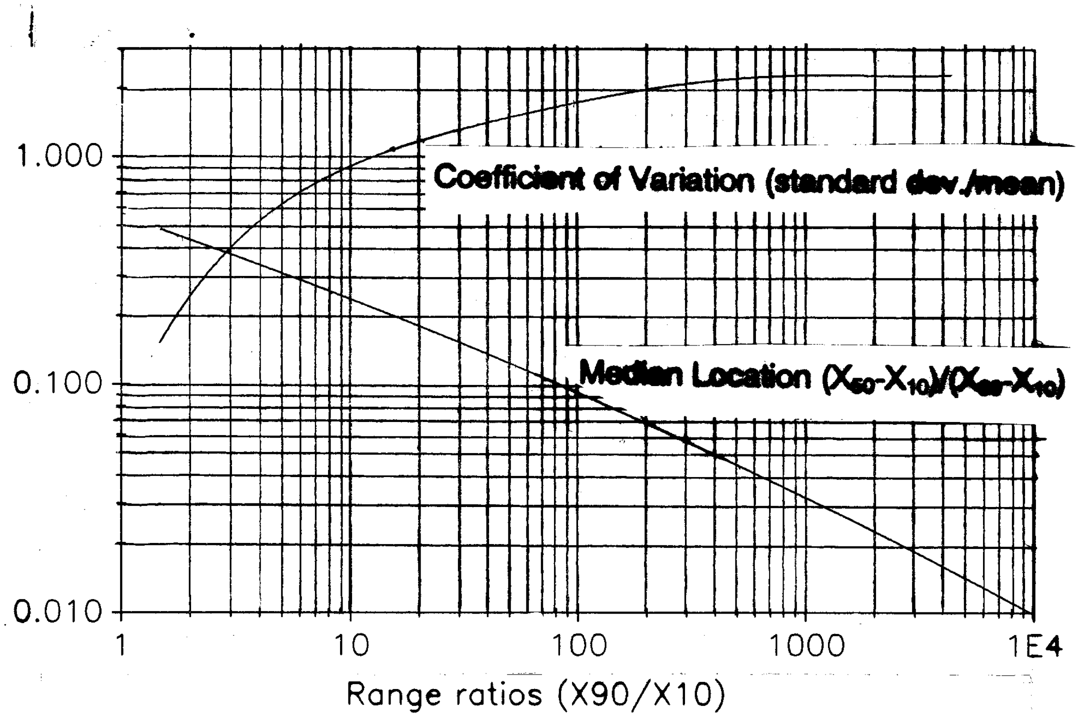


Figure 4. Relationship between data range ratios, coefficient of variation, and median values.

Also shown on Figure 4 is an indication of the location of the median value, compared to the 10 percentile value and the range ratio. As the range ratio decreases, the median becomes close to the midpoint between the 10th and 90th percentile values. Therefore, at low COV values, the differences between normal distributions and log-normal distributions diminish. As the COV values increase, the mean values are located much closer to the 10th percentile value. In log-normal distributions, no negative concentration values are allowed, but very large positive “outliers” can occur. In the above example, the median location is about 0.4 for a range ratio of 2.1. The following calculation shows how the median value can be estimated using this “median location” value:

median location = 0.4 = $(X_{50}-X_{10})/(X_{90}-X_{10})$

therefore $X_{50}-X_{10}= 0.4(X_{90}-X_{10})$.

$(X_{90}-X_{10}) = 1.5$ mg/L - 0.7 mg/L = 0.8 mg/L.

Therefore $X_{50}-X_{10} = 0.4\ (0.8) = 0.32$ mg/L

and then, $X_{50}-X_{10} = 0.32$.

With $X_{10} = 0.7$ mg/L, $X_{50} = 0.32$ mg/L + 0.7 mg/L = 1.0 mg/L.

For comparison, the average of the 10th and 90th percentile values is 1.1 mg/L. Because these two values are quite close, the fluoride distribution is likely close to being normally distributed and the simple equation shown previously can be used to estimate the required number of samples needed.

In order to more precisely determine this value, actual water samples must be collected and analyzed. Using Figure 3, the following sampling effort may be needed for different allowable error levels (using the estimated COV value of 0.25):

Allowable Error (% of mean)	Approximate Number of Samples Needed
5%	100
10	25
25	4
50	1
100	1

Obviously, the sampling effort increases dramatically as the desired allowable error decreases.

This preliminary procedure is helpful when estimating the sampling effort needed for all parameters of interest for all source areas. As an example, it may be desirable to obtain estimates of the mean with a 25% allowable error for each parameter and each source area. This procedure can be used to estimate the minimum number of analyses that may be needed to meet this goal. After the samples are analyzed, it may be necessary to perform additional analyses from additional samples for some of the source areas to meet the goal.

Example of Log_{10} Transformations for Experimental Design Calculations

For relatively large COV values, it may be necessary to transform the data from known log-normal distributions (checked using log-normal probability paper, for example) before calculating the actual error associated with the collected data. Log-normal probability distributions are commonly used to describe the concentration distributions of water quality data, including stormwater data (EPA 1983). The data ranging from the 10th to 90th percentile typically can be suitably described as a normal probability distribution, after $\log_{10}$ transformations of the data. However, values less than the 10th percentile value are usually less than predicted from the log-normal probability plot, while values greater than the 90th percentile value are usually greater than predicted from the log-normal probability plot. Non-transformed water quality data do not typically fit normal probability distributions very well, except for pH (which are log transformed, by definition).

Figure 5 presents a relationship between the COV value in real space (non-transformed), as determined from Figure 4, and the standard deviation of $\log_{10}$ transformed data. Knowing the $\log_{10}$ transformed standard deviation values enables certain statistical experimental design features to be determined. The most significant feature is determining the number of observations needed to enable the data to be described with a specific error level. It can also be used to calculate the error associated with any observation, based on the assumed population distribution characteristics and the number of observations.

As an example, consider a tracer having a COV of 0.23 and a median value of 0.14. The resulting $\log_{10}$ transformed standard deviation would be about 0.12. For ten samples, the resulting 95 percent confidence range of the median observation (0.14 mg/L) is:

$$\text{Error} = 2(0.12)/(10)^{0.5} = 0.076 \text{ in } \log_{10} \text{ space}$$

The confidence interval is therefore $\log_{10}(0.14)$ +/- 0.076, which is -0.778 to -0.930 in $\log_{10}$ space. This results in a conventional 95 percent confidence range of $10^{-0.930}$ (= 0.12) to $10^{-0.778}$ (= 0.17). The absolute value for the error in the estimate of the median value is therefore between 14% (100x(0.14-0.12)/0.14) and 21% (100x(0.17-0.14)/0.14) for ten samples. If the original untransformed data were used, the error associated with 10 samples is 15%, within the range of the estimate after log transformations. These results are close because of the low COV value (0.23). If the COV value is large, the need for log transformations increases.

The COV value in the above example (0.23) was close to the typical COV value for all of the source categories and tracer parameters found in the Birmingham test, as shown on Table 23 in Section 5. About 10 samples per source flow category should generally result in less than a 25% error for the mean values obtained.

As shown in a later subsection, narrow confidence intervals are needed for useful tracer parameters in order to estimate the relative mixes of the non-stormwater sources as measured at the outfall. Therefore, much care needs to be taken in order to estimate the characteristics of the potential non-stormwater flow sources, especially the COV values and means.

Understanding the mechanisms affecting the non-stormwater sources (such as time of day, season, area of town, type and magnitude of land use activities, etc.) and obtaining a relatively large data base library for the source flow tracer concentrations is very important and should be a significant portion of a dry-weather flow source identification project.

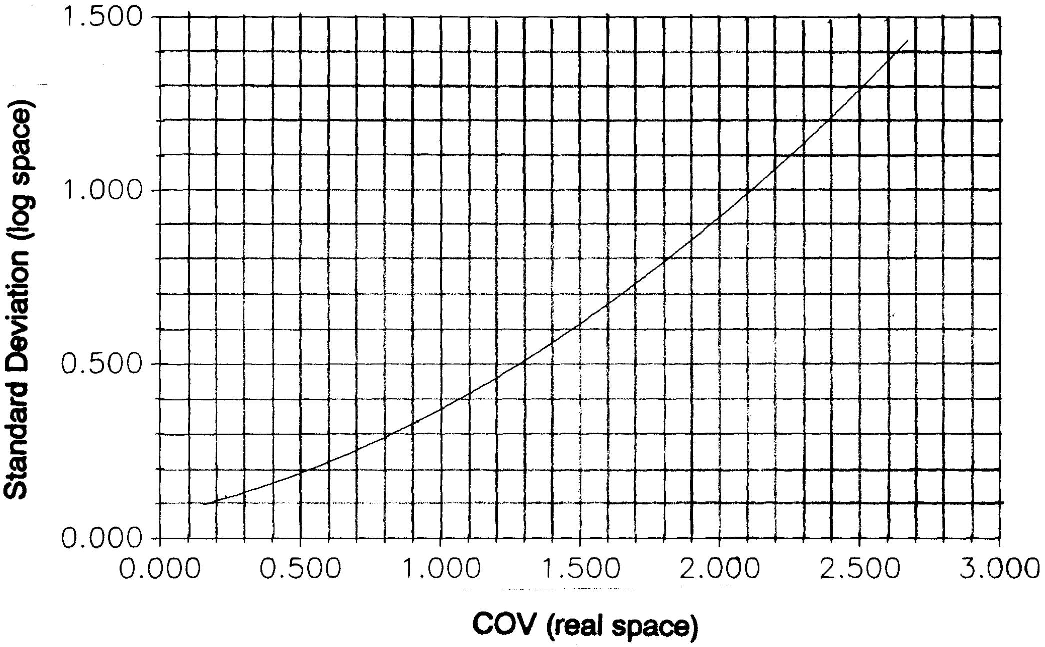


Figure 5. Relationship between standard deviations ($\log_{10}$ space) and coefficient of variation (real space).

Selection of Analytical Methods

The selection of the analytical procedure to be used is dependent on a number of factors, including (in order of importance):

- appropriate detection limits
- freedom from interferences
- good analytical precision (repeatability)
- low cost and good durability
- minimal operator training required

The following subsections discuss these requirements and present the recommended analytical procedures. Tracer characteristics in likely local source flows affect most of these requirements. Therefore, the suggested analytical procedures may not be the most cost-effective for all areas.

Detection Limit Requirements

In order to identify potential non-stormwater sources, it is necessary to have a basic knowledge about each potential source flow component. As shown above, a significant sampling and analysis effort is needed to develop a library of source area flow tracer concentrations. This subsection will show how the COV values and means of the tracer concentrations can be used to estimate the needed detection limits of the analytical procedures.

There are a number of different types of detection limits defined for laboratory use. Most instrument manufactures present a minimum readable value as the instrument detection limit (IDL) in their specifications for simple test kits. The usual definition of IDL, however, is a concentration that produces a signal to noise ratio of five. The method detection limit (MDL) is a more conservative value and is established for the complete preparation and analysis procedure. The practical quantification limit (PQL) is higher yet and is defined as a routinely achievable detection limit with a relatively good certainty that any reported value is reliable. *Standard Methods* (APHA, *et al.* 1989) estimates that the relationship between these detection limits is approximately: IDL:MDL:PQL = 1:4:20. Therefore, the detection limit shown in much of the manufacturer's literature is much less than what would be used by most analytical laboratories.

Because of the screening nature of the outfall field surveys, the instrument detection capabilities are appropriate for the methodology described in this report. The larger uncontrollable errors associated with obtaining representative outfall samples and in the variations of the tracer concentrations in the potential source flows would tend to diminish the significance of errors associated with reading concentration values from the instrument that are lower than the PQL.

A quick (and conservative) estimate of the needed detection limit can be made by only knowing the median concentration and the concentration variation of the tracer in the least contaminated component flow. Any amount of another component having a greater tracer concentration will increase the tracer concentration of the mixture. By ignoring this increase, minimum detection limits can be estimated based on the numerous probability calculations presented in Appendix B:

COV value:	Multiplier for detection limit:
<0.5 (low)	0.8
0.5 to 1.25 (medium)	0.23
>1.25 (high)	0.12

As an example, if the baseflow tracer has a low COV (<0.5), then the estimated required detection limit is about 0.8 times the median tracer concentration.

More than 80% of the library categories (source flows and tracers) examined in Birmingham, Alabama, during the demonstration of these procedures (shown on Table 23 in Section 5 and described in detail in Section 11) had low COV values. About 15% had medium COV values, and about 5% had high COV values. As an example, free available chlorine had medium or high COV values for almost all source categories. This is a major reason why chlorine should not be used quantitatively to identify source flow components in outfall samples. Chlorine is used in a similar manner as the aesthetic parameters (e.g. turbidity or odor). If high chlorine concentrations are found at the outfall (greater than about 0.5 mg/L), then a major treated potable water leak is likely associated with the dry-weather flow.

Table 25 lists the detection limit requirements for the tracer parameter concentrations found during the Birmingham, Alabama, demonstration project. The recommended analytical methods satisfy most of the required detection limits, except for ammonia and surfactants in spring water and surfactants in potable water. The spring water ammonia concentrations were about equal to the detection limit, but because the variation in the ammonia concentrations were so large, a much lower detection limit would be preferable.

Monte Carlo tests (using the microcomputer program PRISM, version 2.01, from Palisade Corporation, Newfield, NY) were used to examine the sensitivity of different concentration characteristics (10 to 90 percentile range) and mixtures on detection limits. These data can be compared to detection limits available for different analysis methods that can be used in the field (Appendix A).

Figures were prepared showing the required detection limits for different mixtures at different detection probabilities. If the median concentrations of two components of a mixture are close, and their concentration variabilities are large, it is very difficult to detect small portions of one component of the mixture with much significance, even if the equipment detection limit is very good. This situation would require the use of another tracer parameter to calculate the mixture sources.

Figures 6 through 9 are probability plots showing the required analytical detection limits for mixtures of two source area flows both having low COV values (similar to the majority of expected conditions). Appendix B contains similar plots for all possible combinations of COV values. Table 26 is an index of the 72 Appendix B figures for the different median concentration ratios and variabilities examined. In order to use these figures, an estimate of the median concentrations and variations associated with the mixture components must be made.

The Appendix B figures show four curves corresponding to four mixtures. PER100 is for a 100% solution of the flow having the higher tracer concentration, PER50 is for a solution having 50% each of two components, PER15 is for a solution of 15% of the component having the higher tracer concentration and 85% of the component having the lower tracer concentration, while PER0 is a solution only made of the component having the lower tracer concentration. Figure 6 is for two components that have mean concentrations differing by 1.33 times, Figure 7 is for a mixture where the component mean concentrations differ by five times, Figure 8 is for two components with mean concentrations differing by 20 times, and Figure 9 is for two components with mean concentrations differing by 75 times. Each figure shows the detection limits, relative to the lower base concentrations, for different probability of detection values. The detection limits required are reduced significantly as the means of the tracer components differ by greater amounts, especially for low probabilities of detection.

For example, if the two tracer mean concentrations vary by about five times (such as for treated potable water and sanitary wastewater potassium concentrations, as shown on Table 23) and a mixture of 15% sanitary wastewater and 85% potable water needs to be identified with a 90% probability of detection, the required detection limit would be about:

1.4 [factor from Figure 7] x 1.6 mg/L [potassium of treated water, from Table 23] = 2.2 mg/L.

TABLE 25. DETECTION LIMIT REQUIREMENTS

Tracer Parameter and units	Median Conc. of Least Contaminated Sources: median (COV)	Required Detection Limit	Available Detection Limit
Fluorescence % of full scale	Potable water: 4.6 (0.08) Spring water: 6.8 (0.43)	3.7 5.4	0.1
Potassium mg/L	Spring water: 0.73 (0.10) Potable water: 1.6 (0.04)	0.58 1.3	0.01
Ammonia mg/L	Spring water: 0.01 (1.7) Potable and radiator water: 0.03 (0.23)	0.001 0.024	0.01
Fluoride mg/L	Spring water: 0.031 (0.87) Sanitary wastewater: 0.77 (0.23)	0.01 0.62	0.01
Surfactants mg/L as MBAS	Spring and potable water: <1 Sanitary wastewater: 1.5 (0.82)	- 0.35	0.01
Hardness mg/L as $CaCO_3$	Laundry water: 14 (0.57) Potable and radiator water: 49 (0.03)	3.2 39	1
Color HACH™ color units	Spring and potable water: <1 Sanitary wastewater: 38 (0.55)	- 8.7	1
Specific conductivity µS/cm	Potable water: 110 (0.01) Spring water: 300 (0.04)	88 240	10

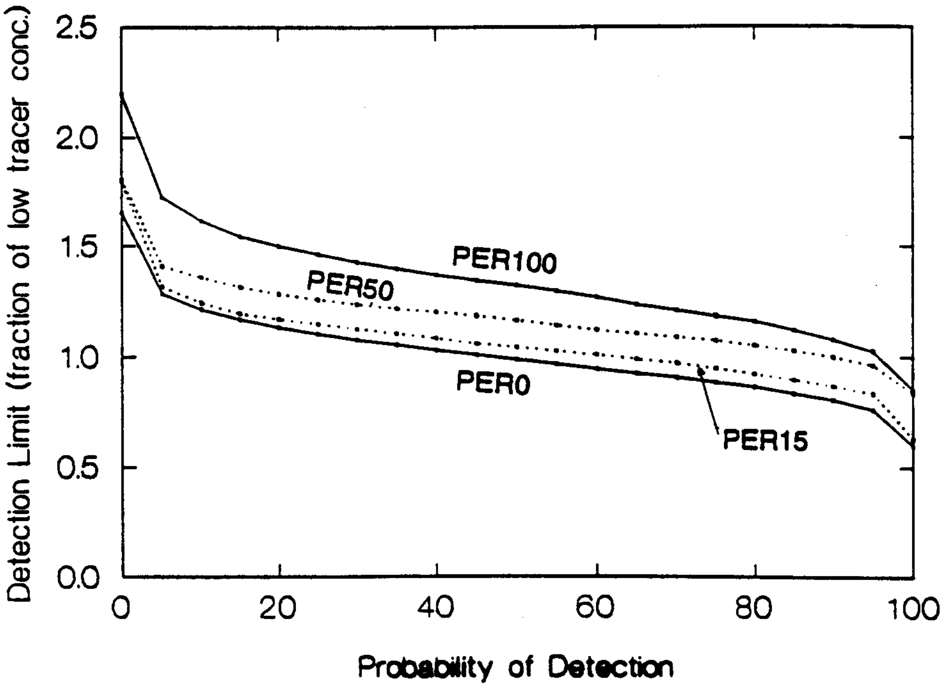


Figure 6. Required detection limits for low COV mixture components having means differing by 1.3 times.

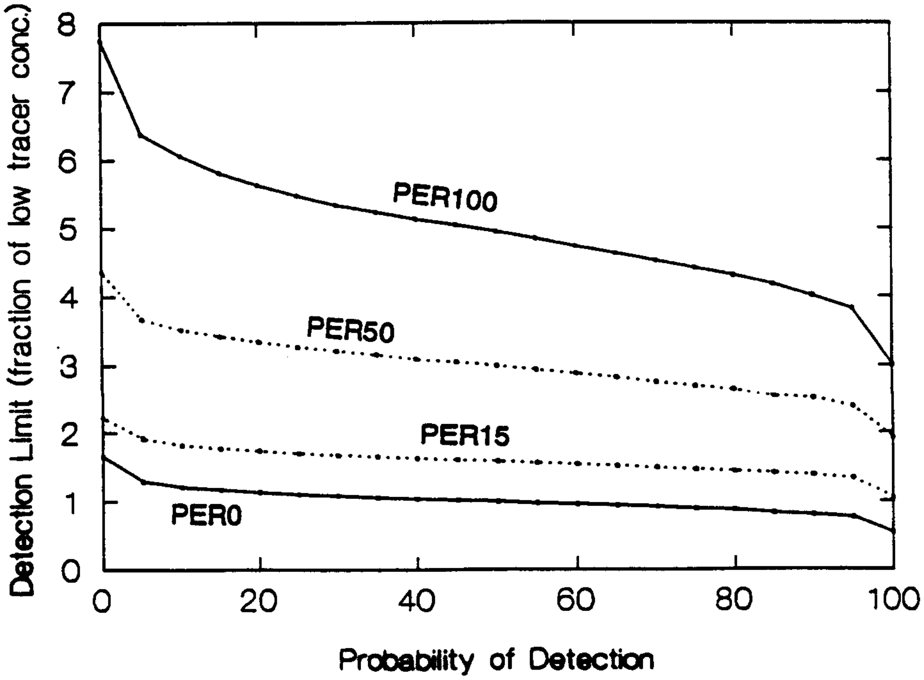


Figure 7. Required detection limits for low COV mixture components having means differing by 5 times.

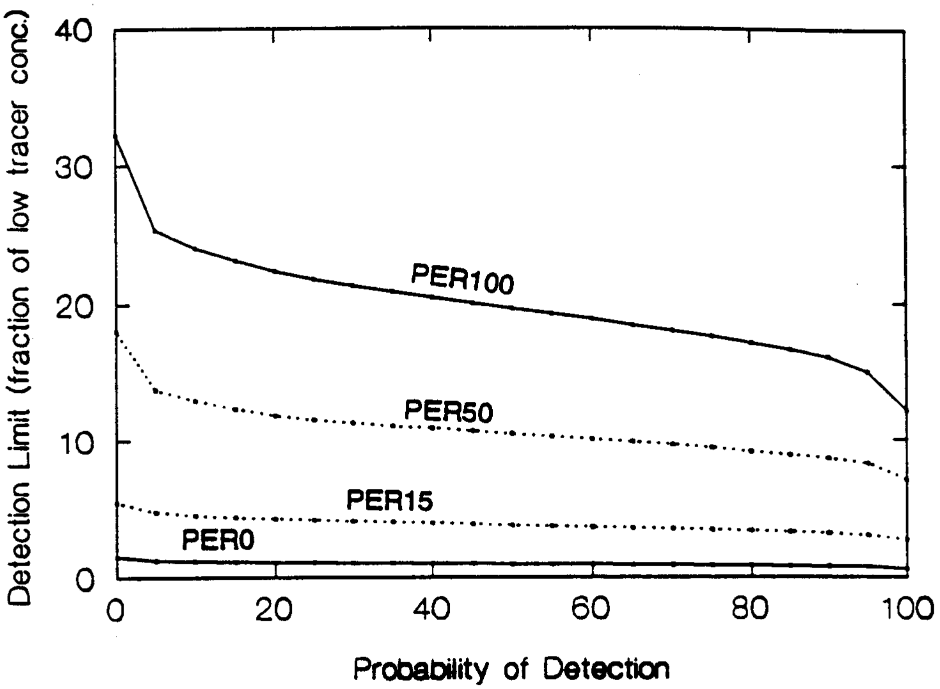


Figure 8. Required detection limits for low COV mixture components having means differing by 20 times.

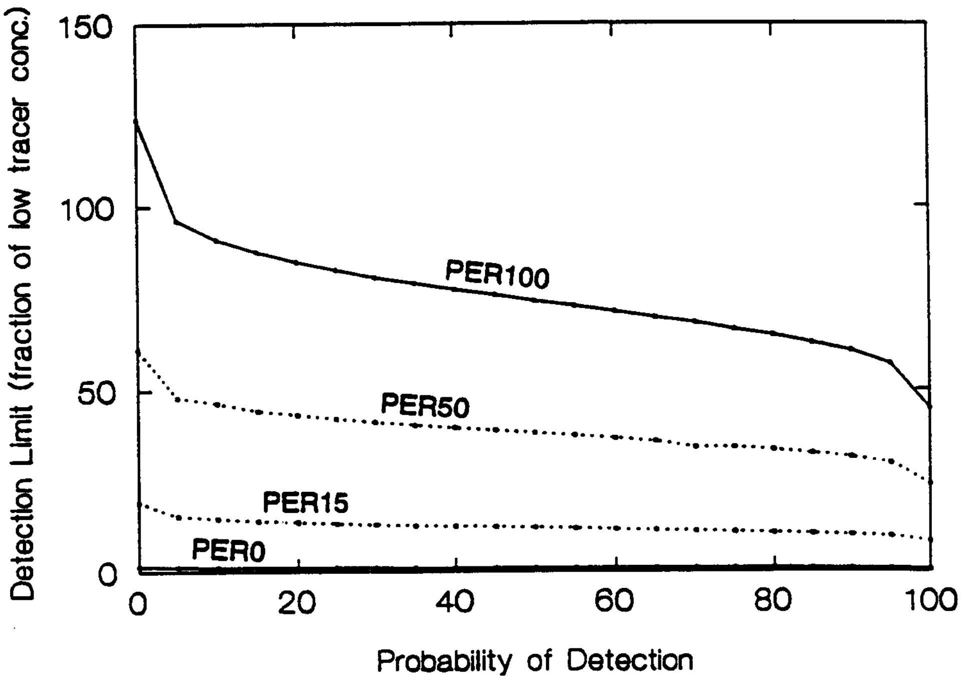


Figure 9. Required detection limits for low COV mixture components having means differing by 20 times.

TABLE 26. INDEX FOR PROBABILITY PLOTS (APPENDIX B FIGURE NUMBERS)

Contaminent/ Base concen. Ratio	Baseflow Tracer Variability - Contaminated Flow Tracer Variability L-L	L-M	L-H	M-L	M-M	M-H	H-L	H-M	H-H
1.33	1	2	3	4	5	6	7	8	9
2.14	10	11	12	13	14	15	16	17	18
2.86	19	20	21	22	23	24	25	26	27
5	28	29	30	31	32	33	34	35	36
7	37	38	39	40	41	42	43	44	45
20	46	47	48	49	50	51	52	53	54
35	55	56	57	58	59	60	61	62	63
75	64	65	66	67	68	69	70	71	72

The more conservative approach, stated previously, would result in a minimum detection limit of:

0.8 [factor for COV < 0.5] x 1.6 mg/L = 1.2 mg/L.

Even with the above analytical requirements satisfied, it may still be difficult to precisely estimate the degree of contamination, especially for low contamination levels and for high COVs. The tracer concentrations in the contaminating source flows must be much greater than the tracer concentrations in the cleaner baseflows when detecting small contaminating flow components. The list below shows (for 90% confidence levels and low COV values) the increasing tracer concentration requirements for the contaminating flows (compared to the cleaner baseflows) when trying to detect small amounts of contamination. The differences in tracer concentrations would be even greater for higher COV conditions.

Percent of Source Flow Contamination:	Required Concentration Ratios (for low COV values):
1%	50
5	10
10	7
25	3
35	1.5
50	1.2

As an example, the median tracer concentration in the contaminated flow must be about 10 times greater than the median tracer concentration in the cleaner baseflow to detect a five percent contamination level. If the tracer COV values are “medium” or “high”, then the required concentration differences are much greater (up to 250 times difference in concentrations may be required). Few tracers exhibit such a wide range in characteristics between flow categories.

Therefore, the differences in tracer concentrations must be quite large, and the concentration variations quite small, in order to have confident estimates of low levels of contamination. This is the main reason why the use of multiple tracers for different flow categories is important. Some tracers may not uniformly produce good estimates of contamination levels, but the use of redundant tracers for the same decision (such as ammonia and potassium to identify sanitary wastewater; fluorides and hardness to identify treated potable water; and surfactants and fluorescence to identify wash waters) and good estimates of local contaminant characteristics, will minimize these errors.

The actual minimum mixture level of contamination that would be detectable would also be dependent on the analytical precision, as discussed next.

Required Sample Analytical Precision

The repeatability of the analytical method is another important consideration in its selection. Precision, as defined in *Standard Methods* (APHA, *et al*. 1989), is a measure of the closeness with which multiple analyses of a given sample agree with each other. It is determined by repeated analyses of a stable standard, conducting replicate analyses on the samples, or by analyzing known standard additions to samples. Precision is expressed as the standard deviation of the multiple analysis results.

Figure 10 is a summary of the probability plots contained in Appendix B and indicates the needed analytical precision (repeatability) as a fraction of the median tracer concentration to resolve one percent contamination levels at a 90 percent confidence level. This figure was developed for COV values of the tracer parameters in the contaminating flows ranging from 0.16 to 1.67, and indicates the needed analytical precision (as a fraction of the baseflow tracer concentration) to resolve one percent contamination levels at a 90 percent confidence level. This figure was developed for contamination levels between zero and 15 percent. If the analytical precision is worse than these required values, then small contamination levels may not be detected. Therefore, even with adequate analytical detection limits, poor analytical precision may not allow adequate identification of low levels of contamination. In many cases, it is expected that a contamination level of just a few percent can cause significant toxic and pathogenic problems. Examples include gasoline spills, direct connections of raw sanitary wastewater, and metal plating bath wastewaters.

If the tracer concentrations of the flow components are close in value and the variation of the concentrations are high, then it will be very difficult to adequately separate flow components. In contrast, if the tracer concentrations of the flow components are widely different and have low variabilities, then much smaller levels of contamination could be detectable. As an example, if the median contaminant tracer concentrations differ by a factor of 10 in two flow components, but have high concentration variations (high COV values), a precision of between 0.015 to 0.03 of the lower baseflow median tracer concentration is needed, for each percent contamination that needs to be detected. If the median tracer concentration in the cleaner baseflow is 0.15 mg/L (with a corresponding tracer median concentration of 10 times this amount, or 1.5 mg/L, in the contaminating source flow), then the required analytical precision is about 0.015 X 0.15 = 0.002 mg/L to 0.03 X 0.15 = 0.005 mg/L per one percent contamination detection. If at least five percent contamination is needed to be detected, then the minimum precision would have to be 5 X 0.002 = 0.01 mg/L.

The conservative method noted previously can be used to estimate the detection limit requirements for the above example:

- low COV in the cleaner baseflow: 0.8 X 0.15 mg/L = 0.12 mg/L
- medium COV in the cleaner baseflow: 0.23 X 0.15 mg/L = 0.035 mg/L
- high COV in the cleaner baseflow: 0.12 X 0.15 mg/L = 0.018 mg/L.

The required analytical precision would therefore be about one-half of the lowest detection limit needed, and about 1/12 of the largest estimated required detection limit.

By examining the probability plots in Appendix B, it was possible to calculate the margin between the estimated detection limits (for zero percent contamination) and the concentrations associated with a ten percent chance that the concentrations would actually be greater than assumed. The ratios of the tracer concentrations in the contaminated flows to the tracer concentrations in the baseflows must increase as the desired contamination levels for detection decrease, as shown on Table 27 (for ten percent frequencies of errors). As an example, for low variations of the tracer in the baseflow, the median tracer concentration in the contaminated flow must be about 50 times greater than the median tracer concentration in the baseflow. If the range ratio of the tracer in the contaminated flow is 10 (a medium variation), then the contaminated flow concentration must be about 150 times the median tracer concentration in the baseflow. Therefore, the differences in tracer concentrations must be quite large, and the concentration variations quite small, in order to have confident estimates of lower levels of contamination. Again, redundant tracer parameters and data analysis methods minimize these problems.

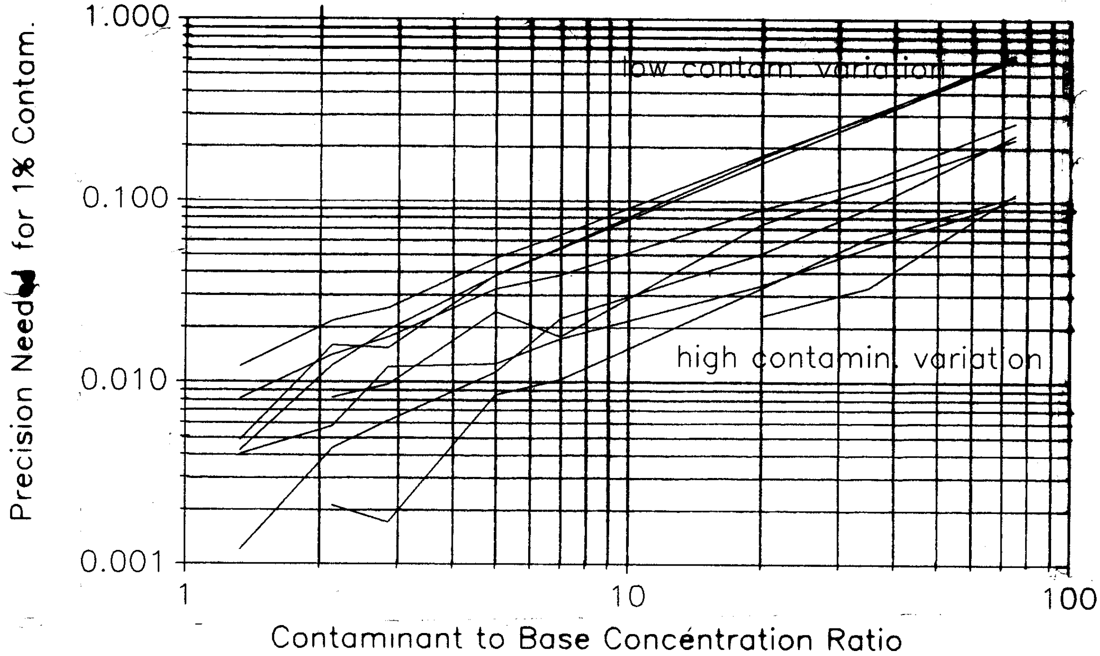


Figure 10. Analysis precision needed for detection of one percent contamination at ninety percent confidence.

TABLE 27. ALLOWABLE CONTAMINATION MIXTURES FOR DETECTION FOR VARIOUS TRACER VARIATION LEVELS

Required Tracer Concentration in Contaminated Flow, Compared to Baseflow (for Less Than a Ten Percent Frequency of Error):

Contamination Mixture to be Identified	Low Tracer Variation in Baseflow and Tracer Variation in Contaminated Flow: L	M	H	Medium and High Tracer Variation in Baseflow and Tracer Variation in Contaminated Flow L	M	H
1%	50*	150	300	1,000	>>1,000	>>1,000
5%	10	40	60	50	150	250
10%	7	15	35	25	70	150
25%	3	6	10	10	25	60
35%	1.5	4	7	7	20	50
50%	1.2	2	4	5	15	35

*Example: The tracer concentration in the “contaminated flow” component must be at least 50 times the tracer concentration in the “baseflow” component of the mixture. This would allow a mixture containing at least one percent of the contaminated flow to be identified, with less than a ten percent error frequency.

Evaluation of Analytical Methods

Analytical methods for the parameters used in this research were selected from a group of methods which had been initially identified with expense, portability and ease of use in mind. Interferences, detection limits, and accuracy (precision and bias) influenced the final selection. The following procedures were used in this selection process.

Initially, dry-weather flows were sampled at 12 locations from a grass swale drainage system serving a residential area containing septic tanks. Samples were obtained during an excessively dry summer period. Each of these 12 samples was analyzed using the entire group of representative methods which had been identified for each of the tracer parameters of interest. Analytical methods tested using these 12 samples are listed in Table 28.

In addition, four representative samples from this area were further examined using standard addition methods (known amounts of standards were added to each sample, and results were then compared to unaltered samples), to identify matrix interference problems. Analysis methods were also tested against a series of standard solutions to identify detection limits and repeatability. A discussion of analytical methods considered and selected follows.

Results of Comparison Tests of Analytical Procedures

Conductivity--

Conductivity is quickly and easily measured in the field using a dual dedicated (temperature/conductivity) meter. A YSI conductivity meter, model 33, was used. Both specific conductivity and temperature must be calibrated against standard specific conductivity solutions and a standard thermometer. Specific conductivity should also be corrected to standard values obtained at 25°C (APHA, *et al*. 1989):

$$K = (K_m C)/[1+0.0191(t-25)]$$

where K = specific conductivity at 25°C
K_m = measured specific conductivity at temperature $t\,^{o}C$
and C = cell constant

The cell constant is a correction factor determined by measuring a 0.01M KCl solution at 25°C, after three rinses, compared to 1413 µS/cm, the expected value. This equation results in about a 2% change in specific conductivity for every degree in temperature difference from 25°C. The SI specific conductivity unit of measurement is the µS/cm which is numerically equivalent to the U.S. Customary unit, µmhos/cm.

Fluoride--

An ion selective electrode (ISE) with millivolt meter and a spectrophotometric method (utilizing the SPADNS method without distillation) were tested. Fluorides are easily detected using a field spectrophotometer (HACH DR/2000) and evacuated reagent and sample vessels (AccuVac). The AccuVac procedure works well for samples with concentrations of less than 2.5 mg/L fluoride. Higher concentrations of fluoride require sample dilution because of non-linear responses. Standard addition tests showed error levels at or below 5%. Multiple measurements of fluoride standards resulted in a standard deviation of 0.02 mg/L (coefficient of variation 0.02). Resolution (the level of detail, or significant figures achievable) for this method was 0.01 mg/L.

Ion selective electrode membranes fouled quickly in wastewater and had to be changed often (after 5 to 10 samples). Again, error levels were at, or below, 5%. However, use of the spectrophotometer was chosen due to the inconvenience and cost of frequent membrane replacement with the ISE method.

TABLE 28. ANALYTICAL PROCEDURES INVESTIGATED

Parameter	Analysis Method
Conductivity & Temperature	YSI Conductivity Meter (Model 33)
Fluoride	HACH Ion Specific Electrode (ISE) HACH DR/2000 Spectrophotometer (AccuVac: SPADNS Method)
Hardness	HACH DR/2000 Spectrophotometer (Calmagite Method) HACH Field Titration Kit (EDTA Titration) Quant Test Strips
Detergents	HACH Detergent Test Kit (MBAS Colorimetric) Orion Surfactants Kit (ISE)
Fluorescence	Turner Filter Fluorometer (Model 111)
Potassium	HACH DR/2000 Spectrophotometer (Tetraphenylborate Method) HACH ISE Flame Atomic Absorption
Ammonia	HACH DR/20000 Spectrophotometer (Nessler Method - direct) HACH ISE Quant Test Strips Hanna Field Test Kit Chemet Field Test Kit
Color	HACH Color Kit
Toxicity	Microtox™ (Microbics, Inc.)
pH	Fisher Accument Model 610A Test Strips
Total Chlorine	HACH DR/2000 Spectrophotometer (AccuVac: DPD Method) HACH Titration Quant Test Strips
Total Copper	HACH DR/2000 Spectrophotometer (AccuVac: Bicinchonianate Method) Quant Test Strips Chemet Field Test Kit
Total Phenols	HACH Colorimetric Method

Hardness--

A digital titration kit, test strips, and a spectrophotometric method were tested. The HACH digital titration kit has a suitable range, was easy to use, and standard addition techniques revealed errors of less than 2.5%. A standard deviation of 0.02 mg/L (coefficient of variation 0.0002) as $CaCO_3$ was obtained, and the resolution of this method was 1 mg/L. The range for the spectrophotometric technique proved to be much too low for the samples being studied. Test strips identified hardness within a relatively wide range only, and were therefore not specific enough for this application. However, the hardness test paper can be used to estimate the titration end point. The HACH digital titration kit was selected for use.

Detergents--

A comparative colorimetric method and titration in combination with an ion selective electrode (ISE) were tested. Although sample dilution was sometimes necessary, the HACH comparative color detergent test kit proved much easier to use and was more sensitive than the ion selective surfactant electrode, which required prior knowledge of the expected sample range in order to select an appropriate concentration of titrant. The comparative colorimetric procedure must be carried out under a laboratory fume hood. Tests on standards revealed a standard deviation of 0.02 mg/L (coefficient of variation 0.03) MBAS using the comparative colorimetric method. The resolution of this method was 0.01 mg/L.

Fluorescence--

A Turner Filter Fluorometer (Model 111) was used to measure relative fluorescence. The repeatability was determined to be ± 2% of full scale (3.5 ppb as Rhodamine WT). General purpose filters (#546 primary filter and #590 secondary filter) and lamp (G4T4/1) were used to be most sensitive to detergent fluorescence, and dilutions of Intracid Rhodamine WT liquid (Compton and Knowles, Reading, PA) were tested as a reference. For the smallest aperture (slit 1x, the least sensitive position), the following equation relating % scale and ppb Rhodamine WT dye (standard 20% stock solution) was found:

$$\text{ppb Rhodamine WT} = 0.975 + 1.271\ (\text{percent scale reading})$$

Potassium--

Ion selective electrode, spectrophotometric, and flame atomic absorption methods were tested. During standard addition tests, the HACH tetraphenylborate spectrophotometric method yielded errors at or below 8% and was quite easy to use. A standard deviation of 0.13 mg/L K (coefficient of variation 0.03) was obtained. The resolution for this method was 0.01 mg/L. Flame atomic absorption resulted in smaller errors, but is a more costly technique. A specific-ion probe was also evaluated, but was not chosen because of rapid membrane fouling, long analysis times and inconsistent results. Error levels with standard additions were as high as 50% using the ion probe method.

Ammonia--

Ion specific electrode, spectrophotometric, and test strip methods were evaluated. Ammonia can be easily measured in the laboratory using a direct Nesslerization procedure and a spectrophotometer (HACH DR/2000). The standard deviation for this method was found to be 0.038 mg/L ammonia, and the resolution was 0.01 mg/L.

Errors and standard deviation were unacceptably high using a simpler salicylate spectrophotometric technique. The use of various indicator test papers for ammonia determination gave poor results and had insufficient resolution. As before, specific ion probe membranes fouled quickly in wastewater and gave inconsistent results. Typical problems encountered for other ammonia field test kit procedures, except for the direct Nesslerization procedure, were color interferences, long analysis times, inconsistent results, and poor performance when standard solutions were analyzed.

pH--
An accurately calibrated pH meter was used to measure pH on fresh samples in the laboratory. Measurements using pH test paper were found to be within one unit of the laboratory meter, but this difference was too large. The resolution and standard deviation of the Fisher Accumet Model 610A pH meter used was 0.01 pH unit.

Small "pen" pH meters most suitable for field use can easily be off by a 0.5 pH unit and are relatively hard to calibrate. They accordingly must be used with care.

Total Chlorine--
Titration (utilizing a digital titrator), a spectrophotometric method and test strip methods were evaluated. The DPD spectrophotometric method (HACH DR/2000 and AccuVac) proved to be the method of choice. The resolution was 0.01 mg/L using this method, and the standard deviation was found to be 0.02 mg/L (coefficient of variation was 0.05). Digital titration with phenylarsine oxide only provided 1 mg/L resolution, which is insufficient for this application. Test strips also had insufficient resolution.

Total Copper--
Test strip and spectrophotometric methods were tested. The bicinchoninate spectrophotometric method (HACH DR/2000 with AccuVac) provided a resolution of 0.01 mg/L copper, with a standard deviation of 0.009 mg/L (coefficient of variation 0.009). The resolution and detection limits provided by test strips were not sufficient.

Total Phenols--
A new direct colorimetric technique developed by HACH specifically for stormwater testing was used to measure total phenols. This technique is based on the 4-aminoantipyrine method and has a range of 0 to 5 mg/L phenol with a resolution of 0.1 mg/L. Repeatability was found to be within 0.2 mg/L.

Color--
Color was quantified using a simple colorimetric comparator with a resolution of 1 unit (HACH). The apparent color is measured in APHA Platinum Cobalt Units.

Toxicity--
The Microtox™ (Microbics, Inc.) screening test was evaluated for use as an indicator of relative baseflow toxicity. Microtox is relatively easy and inexpensive, as bioassays go, and it was hoped that this test might be an efficient indicator of general outfall contamination, identifying outfalls requiring further investigation, and eliminating the need for other tests.

The Microtox procedure utilizes a luminescent marine bacteria, *Photobacterium phosphoreum*. The living microorganisms emit light as a product of their metabolic processes. Any change in those processes, caused by exposure to a toxic test sample, causes a decrease in light output. Reduction of the light is proportional to the toxicity of the sample. Toxicity values reported in this research reflect the percent reduction in light emitted by the test organisms in a sample matrix, as compared to a control organism mixture, after 25 minutes of exposure (I25).

The Microtox Analyzer is a temperature-controlled photometer that brings test organisms and samples to standard temperatures, and measures the light output of the microorganisms under controlled test conditions. Test results demonstrate an average coefficient of variation of 0.16. Good repeatability (precision) and good sensitivity allows small changes in toxicity to be noted.

Toxicity screening tests have been found to be very useful as indicators of contamination of storm drains. The Microtox™ (from Microbics) toxicity screening test can be used for relative toxicity values. The 100 percent screening test was most commonly used. If the light output decrease after 25 minutes (the I_{25} value) was greater than 50 percent, then the standard Microtox test was used to determine the sample dilution required for a 50 percent light decrease (the EC50 value). If a sample results in a large toxic response, then specific toxicant analyses (organics and metals) could be performed to better identify the toxicant source. In general, the Microtox™ screening test was found to be an efficient method for toxicity analysis, particularly for identifying samples requiring further analyses. (A number of simple test kits were used for specific heavy metal analyses, but with very poor results. High-detection limits and interferences make these methods impractical, unless an outfall is grossly contaminated with a concentrated source, such as raw plating bath wastewater.)

Results of Dilution Studies

After suitable analytical methods were identified, mixtures of some potential contaminating flow sources and local spring waters were prepared and analyzed in order to determine functional limitations of procedures when trying to identify small levels of contamination. Mixtures of sanitary sewage, septage, and plating bath waters with spring water were prepared in the following percentages: 0, 0.1, 1, 5, 10, 25, 50, 75, 90, 99, 99.9, and 100. These wastewaters were chosen because they were readily available and were thought to represent extremes, in terms of pathogenicity and toxicity, of wastewaters likely to be encountered in dry-weather flow. One liter of each mixture was prepared.

Results from the sewage dilution study are presented in Table A-4 in Appendix A. The sewage sample used for this test was collected from influent to Jefferson County's Cahaba Wastewater Treatment Plant in Birmingham, Alabama. No chlorine, copper or phenols were detected in the sewage sample or spring water. Prior to measuring fluorescence, samples were filtered through a washed 0.45 µm glass fiber filter. This was necessary in order to achieve a stable reading on the fluorometer. With the exception of color, errors for all parameters, ((measured - expected)/expected) x 100), were less than, or equal to, 10% for dilutions containing 5% or more sewage. Errors observed in color measurements were high. The spring water had no color, and small additions of sewage (with a color of 30 units) resulted in color changes too small to be discerned by the human eye. The resolution of the manual color wheel used was 1 unit. Working with such relatively colorless samples, even half unit discrepancies between observed and expected values resulted in large errors. Expected values were calculated based on anticipated linearity. Toxicity and pH measurements will not be linear, and the dilution tests results confirmed the absence of linearity.

Table A-5 presents results from the septage dilution study. Septage, rather than septic tank discharge, was chosen for this portion of the study because it was much more easily accessible. The septage used was obtained from a residential septage tank cleaning truck. The septage was pre-filtered through a quarter-inch stainless steel sieve, followed by an eighth-inch sieve. Final filtration was through 1.5 feet of coarse sand supported by 3 inches of river rock on a quarter-inch sieve in order to simulate septic tank effluent after partially traveling through a leaching field. Before fluoride, fluorescence, detergent or hardness measurements were taken, samples were filtered through a washed 0.45 µm glass fiber filter in order to minimize color interference. With the exception of color and fluorescence, errors for all parameters were less than 8% for samples containing at least 5% septage. At 5% septage, the fluorescence value measured differed from the expected value by 12%. Color values exhibited errors of less than 8%, with the exception of samples containing 0.1% and 99% septage. Septage is much more highly colored than sewage, with a value of about 1000 color units at full strength. Therefore, even small additions of septage to spring water resulted in color additions which were discernible. Once again, toxicity and pH data confirmed their lack of linearity.

Results from the dilution study using metal plating bath wastes are presented in Table A-6. Plating bath wastewater was obtained from a local metal plating company, and samples were filtered through a washed 0.45 µm glass fiber filter before fluoride, fluorescence, detergent and hardness measurements were taken. With the exception of fluorescence, errors observed in all samples containing at least 5% plating wastes were below 8%. An error of 9% was noted between expected and observed fluorescence values for the 10% plating waste mixture. Toxicity and pH values were again observed to be non-linear on dilution.

These results indicate that, with the exception of color and fluorescence, measurements made using the analytical methods selected should be accurate to within 10%, even if inappropriate flows comprise as little as 5% of the total outfall flow. In addition, with the exception of toxicity and pH, the dilutions affected the measurements in a linear manner over the complete concentration ranges. Figures A-1 through A-10 are plots of the mixture fraction versus observed concentration for each of the 10 parameters measured. The spring water that was used as dilution water in the tests was obtained from three different springs. This explains the difference in the zero level concentrations obvious on some of the graphs.

Recommended Analytical Methodology

An important part of the development of these investigation procedures and the demonstration project was the laboratory and field testing of the alternative analytical methods, described previously. Dry-weather outfall samples were subjected to different tests which compared several analytical methods for each of the major tracer parameters of interest. Tests were conducted to enable comparison of the results of alternative tests with standard procedures and to identify which methods had suitable detection limits, based on real samples. In addition, representative samples were further examined using standard addition methods (known amounts of standards added to the sample and results compared to unaltered samples) in order to identify matrix interferences. Matrix interferences are generally caused by contaminants in the samples interfering with the analysis of interest. Many of the analysis methods were also tested against a series of standard solutions to identify analytical precision (repeatability), linearity, and detection limits.

Table 29 lists the analytical methods selected and the lower limit of detection determined for each of these methods. The lower limit of detection is defined in *Standard Methods* as the standard deviation multiplied by 3.29 (APHA 1989).

Most of the recommended analyses are conducted using small “field-type” instruments. However, despite their portability, the use of these instruments in the field can introduce many errors. Temperature and specific conductivity are the only analyses that are recommended for field analyses. For the other analyses, samples are collected at the site, iced, and taken back to the laboratory for analyses. The recommended analysis procedures can be easily conducted in a temporary laboratory; all that is needed is a work space and adequate ventilation. Access to power and water would be helpful, but all of the equipment can be operated with batteries. At each outfall, a 2 L sample of dry-weather discharge needs to be collected and stored in a polyethylene container. Another (500 mL) sample can also be collected in a glass container having a Teflon-lined lid for toxicity screening and selected toxicant analyses. All samples must be analyzed (or extracted) within accepted time limits. Table 30 is an example of the laboratory analyses reporting sheet for the above analyses.

TABLE 29. ANALYTICAL PROCEDURES SELECTED

Parameter	Analysis Method	Lower Limit of Detection
Conductivity & Temperature	YSI Conductivity Meter (Model 33)	17 µS/cm
Fluoride	HACH DR/2000 Spectrophotometer (AccuVac: SPADNS Method)	0.07 mg/L
Hardness	HACH Field Titration Kit (EDTA Titration)	0.07 mg/L
Detergents	HACH Detergent Test Kit (MBAS Colorimetric)	0.06 mg/L
Fluorescence	Turner Filter Fluorometer (Model 111)	3% of scale (4 ppb Rhodamine equiv.)
Potassium	HACH DR/2000 Spectrophotometer (Tetraphenylborate Method)	0.4 mg/L
Ammonia	HACH DR/2000 Spectrophotometer (Nessler Method - direct)	0.12 mg/L
Color	HACH Color Kit	3 color units
Toxicity	Microtox™ (Microbics, Inc.)	I_{25} = 0.15 (15% light attenuation after 25 minutes exposure)
pH	Fisher Accumet Model 610A	0.03 units
Total Chlorine	HACH DR/2000 Spectrophotometer (AccuVac: DPD Method)	0.07 mg/L
Total Copper	HACH DR/2000 Spectrophotometer (AccuVac: Bicinchonianate Method)	0.03 mg/L
Total Phenols	HACH Colorimetric Method	0.66 mg/L

NA: Not Applicable

TABLE 30. SAMPLE ANALYSES LAB SHEET

Sample number: __________

Date:___________________

Location:____

Outfall #:________________

Specific conductivity YSI™ SCT meter (field) _____________________________

Temperature YSI™ SCT meter (field) _____________________________

pH pH meter (lab) ____

Ammonia Direct Nesslerization (lab) ____________________________

Color HACH™ color kit (lab) ___________________________________

Fluoride HACH DR/2000™ spect. with AccuVacs™ (lab) _______________

Hardness HACH™ field titration kit (lab) ___________________________

Surfactants HACH™ detergent field kit (lab) ________________________

Fluorescence Turner™ fluorometer (lab) ___________________________

Potassium HACH DR/2000™ spect. (lab) __________________________

Turbidity HACH™ Nephelometer (lab) ______________________________

Chlorine HACH DR/2000™ spect. with AccuVacs™ (lab) ________________

Toxicity Microtox™ 100% sample screen (lab) _____________________

Section 7
Data Analysis to Identify Problem Outfalls and Flow Components

The purpose of the procedures presented in this report is to separate storm drain outfalls into general categories of causing problems (with a known level of confidence) and to identify which outfalls (and drainage areas) need control, or further analyses and investigations. The categories used in this report are outfalls affected by non-stormwater entries from: (1) pathogenic or toxic pollutant sources, (2) nuisance and aquatic life threatening pollutant sources, and (3) unpolluted water sources, as discussed in Section 2 of this report.

The pathogenic and toxic pollutant source category should be considered the most severe because it could cause disease upon water contact or consumption and cause significant impacts on receiving water organisms. They may also cause significant water treatment problems for downstream consumers, especially if they contain soluble metal and organic toxicants. These pollutants may originate from sanitary, commercial, and industrial wastewater non-stormwater entries. Other important residential area activities that may also be considered in this most critical category (in addition to sanitary wastewater) include inappropriate household toxicant disposal, automobile engine de-greasing, vehicle accident clean-up, and irrigation runoff from landscaped areas excessively treated with chemicals (fertilizers and pesticides).

Nuisance and aquatic life threatening pollutant sources can originate from residential areas and may include laundry wastewater, landscaped area irrigation runoff, automobile washing, construction site dewatering, and washing of ready-mix concrete trucks. These pollutants can cause excessive algal growths, tastes and odors in downstream water supplies, offensive coarse solids and floatables, and highly colored, turbid or odorous waters.

Relatively clean or unpolluted water discharged through stormwater outfalls can originate from natural springs feeding urban creeks that have been converted to storm drains, infiltrating groundwater, and infiltrating domestic water from water line leaks.

A method must be used to compare data from individual outfall dry-weather samples to the library of dry-weather flow source data to identify which outfalls belong in which general category of contamination listed above. This comparison should result, at the very least, in the identification of the outfalls that are considered as major pollutant sources for immediate remediation. The degree of detail which can be determined regarding any outfall will depend on the results of the local data collected to describe the likely source flows.

The procedures that can be used to identify outfall flow components may begin with simple yes/no checks. For example, if no surfactants are measured in an outfall sample, then sanitary wastewater is unlikely to be a contributor to the outfall flow. If no fluoride is measured, then fluoride treated potable water sources could be ruled out as contributors. The probability that remaining contenders are present alone or in a mixture may be determined using a combination of matrix algebra and the selecting of random values from within specified ranges using a Monte Carlo process and many iterations.

Most contaminated outfalls will require correction before the receiving water quality recovers to acceptable levels. However, ranking the outfalls allows the most serious outfalls to be recognized and enables corrective action to be initially concentrated in the most cost-effective manner. In some of the case studies investigated, correcting only problems at the most critical outfalls resulted in insufficient receiving water quality improvements. It may be important to eventually correct all non-stormwater discharge problems throughout a city, not just the most severe problems. The field screening program should therefore be considered as an initial effort that needs to be followed-up with more detailed watershed drainage surveys in most of the areas having observed dry-weather flows. The follow-up watershed surveys are to identify and correct inappropriate pollutant entries into storm drainage systems, as discussed in Section 8.

The identification of flow components of the dry-weather storm drain flow can be used to determine which outfalls have the greatest pollution potential. As an example, if an outfall contains sanitary wastewater, it could be a significant source of pathogenic microorganisms. Similarly, if an outfall contains plating bath water from a metal finisher, it could be a significant source of toxicants. These outfalls would be grouped into the most critical category of toxicants/pathogens. If an outfall contains washwaters from a commercial laundry or car wash, the wastewater could be a major source of nutrients and foaming material. These outfalls would be grouped into an intermediate category of nuisances. Finally, if an outfall only contains unpolluted groundwater or water from leaky potable water mains, the water would be non-polluting and the outfall would be grouped into the last category of clean water sources.

The seven methods of data analyses presented in the following discussions present a hierarchy of methods, ranging from relatively simple reviews of the outfall characteristics to more sophisticated methods requiring computer modeling for evaluation. It is suggested that as many of the procedures be used as possible in evaluating the data, as each method provides some unique insights of the problems. Most of these procedures were evaluated during the Birmingham demonstration project phase (Lalor 1994) which is reviewed in Section 11 of this report.

Indicators of Contamination

Indicators of contamination (negative indicators) are clearly apparent visual or physical parameters indicating obvious problems and are readily observable at the outfall during the field screening activities. These observations are very important during the field survey because they are the simplest method of identifying grossly contaminated dry-weather outfall flows. The direct examination of outfall characteristics for unusual conditions of flow, odor, color, turbidity, floatables, deposits/stains, vegetation conditions, and damage to drainage structures is therefore an important part of these investigations. Table 31 presents a summary of these indicators, along with narratives of the descriptors to be selected in the field.

This method does not allow quantifiable estimates of the flow components and it will very likely result in many incorrect negative determinations (missing outfalls that have important levels of contamination). These simple characteristics are most useful for identifying gross contamination. Only the most significant outfalls and drainage areas would therefore be recognized from this method. The other methods, requiring chemical determinations, can be used to quantify the flow contributions and to identify the less obviously contaminated outfalls.

Indications of intermittent flows (especially stains or damage to the structure of the outfall) could indicate serious illegal toxic pollutant entries into the storm drainage system that will be very difficult to detect and correct. Highly irregular dry-weather outfall flow rates or chemical characteristics could indicate industrial or commercial inappropriate entries into the storm drain system.

TABLE 31. INTERPRETATIONS OF PHYSICAL OBSERVATION PARAMETERS AND LIKELY ASSOCIATED FLOW SOURCES

Odor - Most strong odors, especially gasoline, oils, and solvents, are likely associated with high responses on the toxicity screening test. Typical obvious odors include: gasoline, oil, sanitary wastewater, industrial chemicals, decomposing organic wastes, etc.

sewage: smell associated with stale sanitary wastewater, especially in pools near outfall.
sulfur (“rotten eggs”): industries that discharge sulfide compounds or organics (meat packers, canneries, dairies, etc.).
oil and gas: petroleum refineries or many facilities associated with vehicle maintenance or petroleum product storage.
rancid-sour: food preparation facilities (restaurants, hotels, etc.).

Color - Important indicator of inappropriate industrial sources. Industrial dry-weather discharges may be of any color, but dark colors, such as brown, gray, or black, are most common.

yellow: chemical plants, textile and tanning plants.
brown: meat packers, printing plants, metal works, stone and concrete, fertilizers, and petroleum refining facilities.
green: chemical plants, textile facilities.
red: meat packers.
gray: dairies.

Turbidity - Often affected by the degree of gross contamination. Dry-weather industrial flows with moderate turbidity can be cloudy, while highly turbid flows can be opaque. High turbidity is often a characteristic of undiluted dry-weather industrial discharges.

cloudy: sanitary wastewater, concrete or stone operations, fertilizer facilities, automotive dealers.
opaque: food processors, lumber mills, metal operations, pigment plants.

Floatable Matter - A contaminated flow may contain floating solids or liquids directly related to industrial or sanitary wastewater pollution. Floatables of industrial origin may include animal fats, spoiled food, oils, solvents, sawdust, foams, packing materials, or fuel.

oil sheen: petroleum refineries or storage facilities and vehicle service facilities.
sewage: sanitary wastewater.

(continued)

TABLE 31 (continued).

Deposits and Stains - Refer to any type of coating near the outfall and are usually of a dark color. Deposits and stains often will contain fragments of floatable substances. These situations are illustrated by the grayish-black deposits that contain fragments of animal flesh and hair which often are produced by leather tanneries, or the white crystalline powder which commonly coats outfalls due to nitrogenous fertilizer wastes.

sediment: construction site erosion.
oily: petroleum refineries or storage facilities and vehicle service facilities.

Vegetation - Vegetation surrounding an outfall may show the effects of industrial pollutants. Decaying organic materials coming from various food product wastes would cause an increase in plant life, while the discharge of chemical dyes and inorganic pigments from textile mills could noticeably decrease vegetation. It is important not to confuse the adverse effects of high stormwater flows on vegetation with highly toxic dry-weather intermittent flows.

excessive growth: food product facilities.
inhibited growth: high stormwater flows, beverage facilities, printing plants, metal product facilities, drug manufacturing, petroleum facilities, vehicle service facilities and automobile dealers.

Damage to Outfall Structures - Another readily visible indication industrial contamination. Cracking, deterioration, and spalling of concrete or peeling of surface paint, occurring at an outfall are usually caused by severely contaminated discharges, usually of industrial origin. These contaminants are usually very acidic or basic in nature. Primary metal industries have a strong potential for causing outfall structural damage because their batch dumps are highly acidic. Poor construction, hydraulic scour, and old age may also adversely affect the condition of the outfall structure.

concrete cracking: industrial flows
concrete spalling: industrial flows
peeling paint: industrial flows
metal corrosion: industrial flows

Correlation tests were conducted to identify relationships between outfalls that were known to have severe contamination problems and the negative indicators during the Birmingham demonstration phase of this research project (Lalor 1994, and as summarized in Section 11). Review of the Pearson correlation results (to be presented in Section 11, Table 45) indicates that high turbidity (lack of clarity) and odors appeared to be the most useful physical indicators of contamination when contamination was defined by toxicity and the presence of detergents. Lack of clarity best indicated the presence of detergents with an 80% correlation. (As noted later, the detergent test was the most useful of the chemical tests for distinguishing between contaminated and uncontaminated flows.) Based on the Pearson correlation results, noticeable odor was the best indicator of toxicity, with a 77% correlation, although there is no theoretical connection between the two.

During the Birmingham demonstration project activities (Section 11), high turbidity was noted in 66 of 89 (or 74%) contaminated source flow samples (Table 44). This represented a 26% false negative rate (indication of no contamination when contamination actually exists), if one relied on turbidity alone as an indicator of contamination. Turbidity was noted in only 5% of the uncontaminated source flow samples. This represents the rate of false positives (indication of contamination when none actually exists) when relying on turbidity alone. Noticeable odor was indicated in 67% of flow samples from contaminated sources, but in none of the flow samples from uncontaminated sources. This translates to 37% false negatives, but no false positives. Typical obvious odors include gasoline, oil, sanitary wastewater, industrial chemicals or detergents, decomposing organic wastes, etc.

A 65% correlation was also found to exist between color and Microtox™ toxicity (Table 45) during the Birmingham demonstration project activities (Section 11). Color is an important indicator of inappropriate industrial sources, but it was also associated with some of the residential and commercial flow sources that were sampled during this research. Color was noted in 100% of the flow samples from contaminated sources, but it was also noted in 40% of the flow samples from uncontaminated sources (Table 44 of Section 11). This represents 60% false positives, but no false negatives. Finally, a 63% correlation between the presence of sediments (assessed as settleable solids in the collection jars of these source samples) and Microtox™ toxicity was also found. Sediments were noted in 34% of the samples from contaminated sources and in none of the samples from uncontaminated sources. The presence of sediments in the sanitary sewage samples collected could not be adequately determined. Samples entered the automatic sampler through a sampler inlet strainer which may have prevented the entry of some solids. Sediments in pipes could not be directly observed.

The Pearson correlation tests are based on analysis of pure samples taken directly from potential dry-weather flow sources. Analysis of diluted samples (as are possible from outfalls) would likely result in a much higher percentage of false negatives. False negatives are more of a concern than a reasonable number of false positives when working with a screening methodology, such as required by EPA. Screening methodologies are used to direct further, more detailed investigations. False positives would be discarded after further investigation. However, a false negative during a screening investigation results in the dismissal of a problem outfall for at least the near future. Missed contributors to stream contamination may result in unsatisfactory in-stream results following the application of costly corrective measures elsewhere.

This method, using physical characteristics to indicate contamination in outfall flows, does not allow quantifiable estimates of the flow components and, if used alone, will likely result in many incorrect determinations, especially false negatives. These simple characteristics are most useful for identifying gross contamination: only the most significantly contaminated outfalls and drainage areas would therefore be recognized from this method.

Detergents as Indicators of Contamination

Results from the Mann-Whitney U tests conducted during the Birmingham demonstration project (Lalor 1994, and as summarized in Section 11 and Appendix E) indicated that pure streams from any of the dry-weather flow sources investigated in this research could be correctly classified as clean or contaminated based only on the measured value of any one of the following parameters: detergents, color, or conductivity. Color and conductivity were present in samples from clean sources as well as contaminated sources, but their levels of occurrence were significantly different between the two groups. If pure streams from only one source were expected to make up outfall flows, the level of color or conductivity measured could be used to distinguish contaminated outfalls from clean outfalls. However, since multi-source flows occur, measured levels of color or conductivity could fall within acceptable levels because of dilution, even though a contaminating source was contributing to the flow. Detergents, on the other hand, can be used to distinguish between clean and contaminated outfalls simply by their presence or absence. "Presence" in this research translates to the lower limit of detection for the HACH detergent test kit, which is 3.29 times the standard deviation, or 0.06 mg/L of detergents. This reduces the probability of a false nondetection or a false detection to 5% (Standard Methods 1989). All samples analyzed from contaminated sources contained detergents in excess of this amount (with the exception of three septage samples collected from homes discharging only toilet flushing water). No clean source samples were found to contain detergents. Using 0.06 mg/L as the lower limit of detection, 85 of the 86 samples collected from contaminated sources in this investigation would be detected in mixtures with uncontaminated waters if they made up at least 10% of the mixture.

Simple Checklist for Major Flow Component Identification

Figure 11 is a simplification of the analysis strategy to separate the major non-stormwater discharge sources for areas having no industrial activity. The first indicator is the presence or absence of flow. If no dry-weather flow exists at an outfall, then indications of intermittent flows must be investigated. Specifically, stains, deposits, odors, unusual stream-side vegetation conditions, and outfall structural damage can all indicate intermittent non-stormwater flows. However, multiple visits to outfalls over long time periods are needed to confirm that only stormwater flows occur.

The following paragraphs summarize the rational used to distinguish between treated potable water and sanitary wastewater, the two most common dry-weather flow sources in storm drainage systems in residential and commercial areas.

Treated Potable Water

A number of tracer parameters may be useful for distinguishing treated potable water from natural waters:

- Major ions or other chemical/physical characteristics of the flow components can vary substantially depending upon whether the water supply sources are groundwater or surface water, and whether the sources are treated or not. Specific conductance may also serve as an indicator of the major water source.

- Fluoride can often be used to separate treated potable water from untreated water sources. This latter group may include local springs, groundwater, regional surface flows or non-potable industrial waters. If the treated water has no fluoride added, or if the natural water has fluoride concentrations close to potable water fluoride concentrations, then fluoride may not be an appropriate indicator. Water from treated water supplies (that test positive for fluorides, or other suitable tracer) can be relatively uncontaminated (domestic water line leakage or irrigation runoff), or it may be heavily contaminated. If the drainage area has industries that have their own water supplies (quite rare for most urban drainage areas), then further investigations are needed to check for industrial non-stormwater discharges (as described in Section 9). Toxicity screening methods would be very useful in areas known to have commercial or industrial activity, or to check for intermittent residential area discharges of toxicants.

Figure 11. Simplified Checklist to Identify Residential Area Non-Stormwater Flow Sources.

1) Flow? If yes, go to 2; if no, go to 3.

2) Fluorides (or different hardness)? If yes, probably treated water (may be contaminated), go to 4; if no, then untreated natural water (probably uncontaminated), or untreated industrial water (may be toxic), go to industrial checklist.

3) Check for intermittent dry-weather flow signs (may be contaminated). If yes, recheck outfall at later date; if no, then not likely a significant non-stormwater source.

4) Surfactants (or florescence, if septic systems in area)? If yes, may be sanitary wastewater, laundry water, or other wash water (may be pathogenic, or nuisance), go to 5; if no, then may be domestic water line leak, irrigation runoff, or rinse water (probably not a contaminated non-stormwater source, but may be a nuisance).

5) Elevated potassium (or ammonia)? If yes, then likely sanitary wastewater source (pathogenic); if no, likely wash water (probably not a contaminated non-stormwater source, but may be a nuisance).

- Hardness can also be used as an indicator if the potable water source and the baseflow are from different water sources. An example would be if the baseflow is from hard groundwater, and the potable water is from softer surface supplies.

- If the concentration of chlorine is high, then a major leak of disinfected potable water is likely close to the outfall. Because of the rapid loss of chlorine in water (especially if some organic contamination is present) it is not a good parameter for quantifying the amount of treated potable water observed at the outfall.

Water from potable water supplies (that test positive for fluorides, or other suitable tracers) can be relatively uncontaminated, e.g., domestic waterline leakage or irrigation runoff, or heavily contaminated, e.g., sanitary wastewater.

Sanitary Wastewaters

In areas containing no industrial or commercial sources, sanitary wastewater is probably the most important dry-weather source of storm drain flows. The following parameters can be used for quantifying the sanitary wastewater components of the treated domestic water portion:

- Surfactant (detergent) analyses may be useful in determining the presence of sanitary wastewaters, as noted previously. However, surfactants present in water originating from potable water sources could indicate sanitary wastewaters, laundry wastewaters, car washing wastewater, or any other waters containing surfactants. If surfactants are not present, then the potable water could be relatively uncontaminated (domestic water line leaks or irrigation runoff).

- The presence of fabric whiteners (as measured by fluorescence using a fluorometer in the laboratory or in the field) can also be used in distinguishing laundry and sanitary wastewaters.

- Sanitary wastewaters often exhibit predictable trends during the day in flow and quality. In order to maximize the ability to detect direct sanitary wastewater connections into the storm drainage system, it would be best to survey the outfalls during periods of highest sanitary wastewater flows (mid to late morning hours).

- The ratio of surfactants to ammonia or potassium concentrations may be an effective indicator of the presence of sanitary wastewaters or septic tank effluents. If the surfactant concentrations are high, but the ammonia and potassium concentrations are low, then the contaminated source may be laundry wastewaters. Conversely, if ammonia, potassium, and surfactant concentrations are all high, then sanitary wastewater is the likely source. Some researchers have reported low surfactants in septic tank effluents. Therefore, if surfactants are low, but potassium and ammonia are both high, septic tank effluent may be present. However, research during this study found high surfactant concentrations in septic tank effluent in the Birmingham, Alabama, area (section 11). This further stresses the need to obtain local characterization data for potential contaminating sources.

- Obviously, odor and other physical appearances such as turbidity, coarse and floating “tell-tale” solids, foaming, color, and temperature would also be very useful in distinguishing sanitary wastewater from washwater or laundry wastewater sources, as noted previously. However, these indicators may not be very obvious for small levels of sanitary wastewater contamination.

Flow Chart for Most Significant Flow Component Identification

A further refinement of the above checklist is the flow chart shown on Figure 12. This flow chart describes an analysis strategy which may be used to identify the major component of dry-weather flow samples in residential and commercial areas. This method does not attempt to distinguish among all potential sources of dry-weather flow identified earlier, but rather the following four major groups of flow are identified: (1) tap waters (tap water, irrigation water and rinse water), (2) natural waters (spring water and shallow ground water), (3) sanitary wastewaters (sanitary sewage and septic tank discharge), and (4) wash waters (commercial laundry waters, commercial car wash waters, radiator flushing wastes, and plating bath wastewaters). The use of this method would not only allow outfall flows to be categorized as contaminated or uncontaminated, but would allow outfalls carrying sanitary wastewaters to be identified. These outfalls could then receive highest priority for further investigation leading to source control. This flow chart was designed for use in residential and/or commercial areas only. Investigations in industrial or industrial/commercial land use areas must be approached in an entirely different manner (EPA 1993).

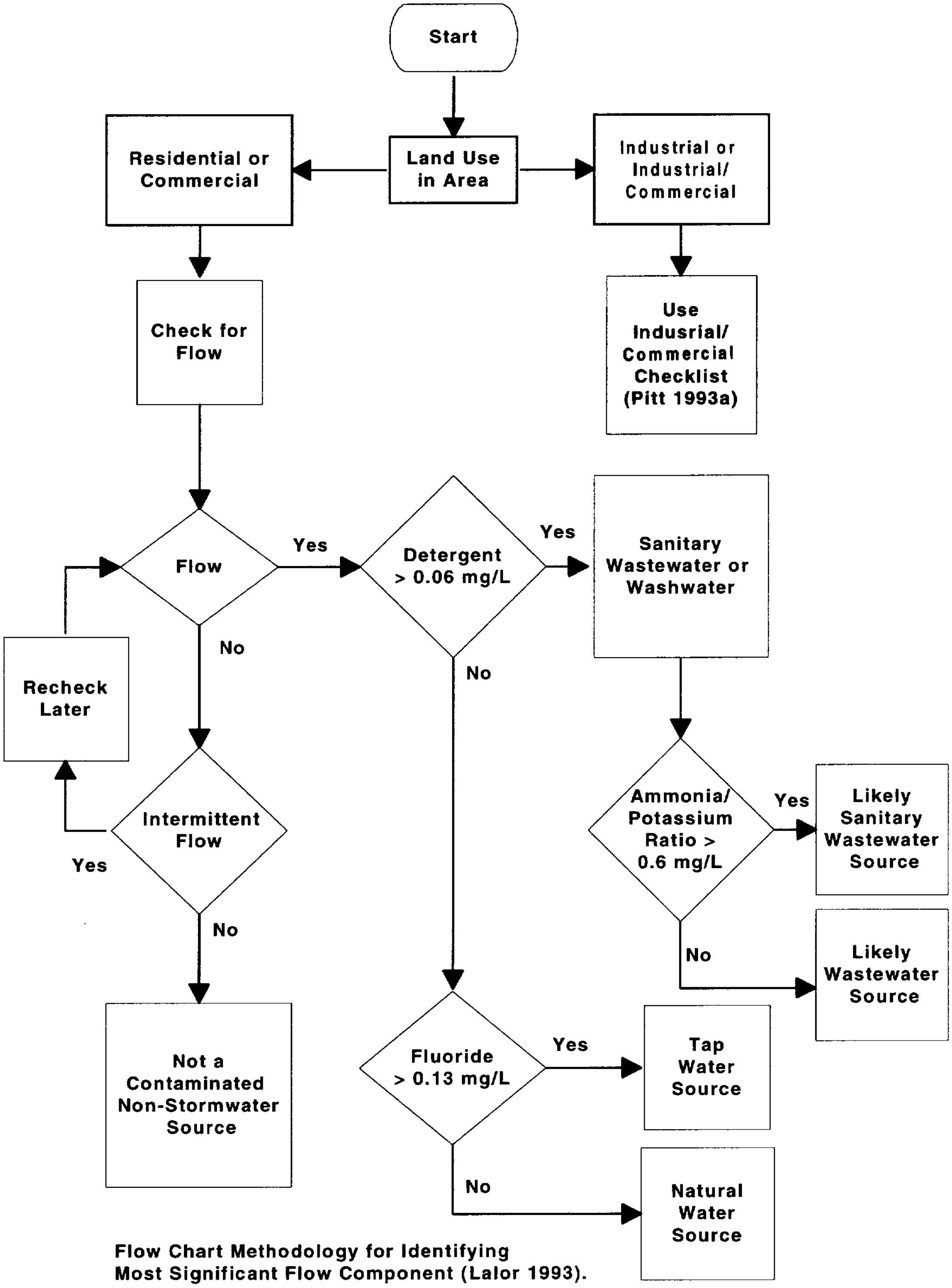
Flowchart Procedures

In residential and/or commercial areas, all outfalls should be located and examined. The first indicator is the presence or absence of dry-weather flow. If no dry-weather flow exists at an outfall, then indications of intermittent flows must be investigated. Specifically, stains, deposits, odors, unusual stream-side vegetation conditions, and damage to outfall structures can all indicate intermittent non-stormwater flows. However, frequent visits to outfalls over long time periods, or the use of other monitoring techniques, may be needed to confirm that only stormwater flows occur. If intermittent flow is not indicated, then the outfall probably does not have a contaminated non-stormwater source. The other points on the flow chart serve to indicate if a major contaminating source is present, or if the water is uncontaminated. Component contributions cannot be quantified using this method, and only the “most contaminated” type of source present will be identified. Sources are ranked from lowest to highest based on their contamination potential in the following way: (1) Natural water sources, (2) Tap water sources, (3) Wash water sources, (4) Sanitary wastewater sources.

If dry-weather flow exists at an outfall, then the flow should be sampled and tested for detergents. If detergents are not present, the flow is probably from a non-contaminated non-stormwater source. The lower limit of detection for the detergent test used in this research was 0.06 mg/L.

If detergents are not present, fluoride levels can be used to distinguish between flows with treated water sources and flows with natural sources in communities where water supplies are fluoridated and natural fluoride levels are low. In the absence of detergents, high fluoride levels would indicate a potable water line leak, irrigation water, or rinse water. Low fluoride levels would indicate waters originating from springs or shallow groundwater. Based on the flow source samples tested in this research (Table 32), fluoride levels above 0.13 mg/L would most likely indicate that a tap water source was contributing to the dry-weather flow in the Birmingham, Alabama, study area. This number was calculated from the mean plus 3 standard deviations for all natural water samples (spring waters and shallow ground waters) collected here. Fluoride values greater than 0.13 mg/L would be considered outliers for this source group. This number will vary from one geographic area to the next, based on the amount of fluoride naturally occurring in the water.

If detergents are present, the flow is probably from a contaminated non-stormwater source, as indicated on Table 32. The ratio of ammonia to potassium can be used to indicate whether or not the source is sanitary wastewater. Ammonia/potassium ratios greater than 0.60 would indicate likely sanitary wastewater contamination. The value of 0.60 is equal to the mean, plus 3 standard deviations, as calculated from car wash, laundry, plating bath, and radiator waste data as a group. Ammonia/potassium ratios were above 0.9 for all septage and sewage samples collected in Birmingham (values ranged from 0.97 to 15.37, averaging 2.55, with a median value of 1.72). Ammonia/potassium ratios for all other samples containing detergents were below 0.7. Values for these samples ranged from 0.00 to 0.65, averaging 0.11, with a median value of 0.01. One sample of radiator wastes had an ammonia/potassium ratio of 0.65.



Flow Chart Methodology for Identifying
Most Significant Flow Component (Lalor 1993).

Figure 12. Simple Flow Chart Method to Identify Significant Contaminating Sources

TABLE 32. SUMMARY OF DETERGENT, FLUORIDE, AMMONIA AND POTASSIUM DATA FOR SOURCE SAMPLES COLLECTED IN BIRMINGHAM, ALABAMA

Source	Sample #	Detergent (mg/L)	Fluoride (mg/L)	NH_3 (mg/L)	K (mg/L)	NH_3/K
Shallow Ground	1	0.00	0.08	NA	NA	-
	2	0.00	0.03	NA	NA	-
	3	0.00	0.14	NA	NA	-
	4	0.00	0.07	0.38	1.70	0.22
	5	0.00	0.05	0.89	2.15	0.41
	6	0.00	0.04	0.08	0.81	0.10
	7	0.00	0.05	0.05	0.91	0.05
	8	0.00	0.06	0.09	0.89	0.10
	9	0.00	0.04	0.13	1.01	0.13
	10	0.00	0.07	0.08	0.83	0.10
Spring	1	0.00	0.09	0.02	0.83	0.02
	2	0.00	0.01	0.00	0.76	0.00
	3	0.00	0.01	0.01	0.69	0.01
	4	0.00	0.03	0.05	0.72	0.07
	5	0.00	0.05	0.00	0.74	0.00
	6	0.00	0.00	0.00	0.73	0.00
	7	0.00	0.03	0.00	0.56	0.00
	8	0.00	0.03	0.00	0.72	0.00
	9	0.00	0.05	0.00	0.76	0.00
	10	0.00	0.01	0.01	0.77	0.01
Tap	1	0.00	0.98	0.02	1.48	0.01
	2	0.00	0.97	0.03	1.55	0.02
	3	0.00	1.00	0.04	1.46	0.03
	4	0.00	0.96	0.02	1.50	0.01
	5	0.00	0.95	0.03	1.66	0.02
	6	0.00	0.96	0.03	1.58	0.02
	7	0.00	0.96	0.02	1.57	0.01
	8	0.00	0.96	0.03	1.56	0.02
	9	0.00	0.97	0.03	1.60	0.02
	10	0.00	0.96	0.03	1.57	0.02
Irrigation	1	0.00	0.98	0.28	6046	0.04
	2	0.00	0.93	0.24	9.42	0.03
	3	0.00	0.65	0.55	3.21	0.17
	4	0.00	0.94	0.40	6.32	0.06
	5	0.00	0.97	0.41	5.44	0.08
	6	0.00	0.81	0.37	6.71	0.06
	7	0.00	0.93	0.31	6.49	0.05
	8	0.00	0.89	0.48	4.98	0.10
	9	0.00	0.91	0.35	5.79	0.06
	10	0.00	0.98	0.32	6.01	0.05

NA: Data not available

(Continued)

TABLE 32. CONTINUED

Source	Sample #	Detergent (mg/L)	Fluoride (mg/L)	NH_3 (mg/L)	K (mg/L)	NH_3/K
Laundry	1	37.0	15.89	0.94	3.47	0.27
	2	21.5	23.98	0.96	3.97	0.24
	3	17.0	54.48	0.62	3.37	0.18
	4	32.5	42.48	0.70	3.67	0.19
	5	35.0	48.98	0.84	3.57	0.24
	6	31.0	31.48	0.91	3.27	0.28
	7	20.0	22.48	0.78	3.77	0.21
	8	25.0	26.98	0.88	2.57	0.34
	9	24.0	35.98	0.69	3.67	0.19
	10	26.0	25.48	0.84	3.47	0.24
Carwash	1	50.4	16.50	0.28	22.00	0.01
	2	52.2	11.50	0.32	22.00	0.01
	3	52.5	12.50	0.20	78.40	0.00
	4	49.0	15.50	0.23	40.70	0.01
	5	56.7	12.50	0.19	47.70	0.00
	6	50.3	8.00	0.14	35.40	0.00
	7	38.0	10.20	0.23	48.20	0.00
	8	49.0	11.80	0.25	46.20	0.01
	9	43.5	12.30	0.19	16.70	0.01
	10	48.0	12.20	0.36	39.60	0.01
Radiator	1	17.4	136.50	16.90	3230.00	0.01
	2	13.8	177.00	32.40	2446.00	0.01
	3	14.7	172.50	21.00	3473.00	0.01
	4	14.2	133.30	18.10	2694.00	0.01
	5	15.1	129.80	22.30	2902.00	0.01
	6	18.3	121.50	12.20	2907.00	0.00
	7	13.5	183.00	8.90	2282.00	0.00
	8	13.5	124.50	90.10	2364.00	0.04
	9	14.6	170.10	23.80	2899.00	0.01
	10	15.3	145.00	17.50	2821.00	0.01
Plating	1	15.0	9.00	105.00	774.00	0.14
	2	1.80	1.68	74.20	552.00	0.13
	3	10.0	1.86	3.05	1730.00	0.00
	4	9.00	6.00	139.37	186.00	0.65
	5	11.4	5.52	29.33	220.00	0.13
	6	1.45	5.85	76.00	490.00	0.16
	7	1.60	6.00	58.60	356.00	0.16
	8	6.90	7.95	60.90	380.00	0.16
	9	3.90	4.20	101.00	1100.00	0.09
	10	7.00	3.20	9.05	4300.00	0.00

NA: Data not available

(continued)

TABLE 32. CONTINUED

Source	Sample #	Detergent (mg/L)	Fluoride (mg/L)	NH$_3$ (mg/L)	K (mg/L)	NH$_3$/K
Sewage	1	0.96	0.90	8.59	5.25	1.64
	2	3.80	0.72	7.25	4.79	1.51
	3	0.58	0.46	5.02	3.44	1.46
	4	0.54	0.58	5.22	3.09	1.69
	5	0.54	0.74	13.04	4.51	2.89
	6	0.99	0.87	14.23	5.88	2.42
	7	0.48	1.08	13.03	5.99	2.18
	8	3.60	0.77	9.67	5.70	1.70
	9	0.54	0.83	8.00	7.50	1.07
	10	0.95	0.93	8.81	7.20	1.22
	11	0.98	0.88	7.82	6.78	1.15
	12	0.96	0.88	7.32	7.56	0.97
	13	4.20	0.69	10.03	7.00	1.43
	14	4.40	0.64	9.18	6.73	1.36
	15	0.97	0.74	11.82	6.05	1.95
	16	0.99	0.60	11.04	4.03	2.74
	17	0.65	0.54	6.38	3.55	1.80
	18	0.64	0.43	6.00	4.94	1.21
	19	0.62	0.60	12.83	7.47	1.72
	20	0.65	1.04	19.49	7.13	2.73
	21	0.96	0.80	12.34	6.87	1.80
	22	0.98	0.97	10.67	6.88	1.55
	23	0.90	0.85	8.57	7.07	1.21
	24	0.94	0.83	9.25	7.55	1.23
	25	2.40	0.81	11.00	7.14	1.54
	26	1.60	0.66	9.99	6.75	1.48
	27	0.97	0.77	10.66	6.12	1.74
	28	0.96	0.67	8.29	5.06	1.64
	29	0.89	0.44	5.53	3.59	1.54
	30	0.76	0.43	5.84	3.57	1.64
	31	0.98	0.68	19.28	6.65	2.60
	32	0.95	1.04	15.74	5.68	2.77
	33	3.00	.94	10.99	6.69	1.64
	34	3.60	0.89	10.03	6.93	1.45
	35	4.00	0.85	7.43	7.11	1.05
	36	2.00	0.83	8.58	6.69	1.28
Septage	4	10.00	1.19	26.07	8.16	3.19
	5	5.00	0.70	135.75	8.83	15.37
	6	12.00	1.21	26.77	8.16	3.28
	7	0.50	0.92	89.60	20.85	4.30
	8	0.45	1.55	91.60	23.25	3.94
	9	0.57	1.26	86.10	22.25	3.87
	10	2.50	0.61	95.90	24.51	3.91
	11	1.00	0.42	107.80	18.66	5.78
	12	0.50	0.56	99.30	21.73	4.57
	13	0.45	0.87	113.20	31.81	3.56

Non-contaminated samples collected in Birmingham had ammonia/potassium ratios ranging from 0.00 to 0.41, with a mean value of 0.06 and a median value of 0.03. Using the mean values for non-contaminated samples (0.06) and sanitary wastewaters (2.55), flows comprised of mixtures containing at least 25% sanitary wastes with the remainder of the flow from uncontaminated sources would likely be identified as sanitary wastewaters using this method. Flows containing smaller percent contributions from sanitary wastewaters might be identified as having a wash water source, but would not be identified as uncontaminated.

In mixed flows made up of water from uncontaminated sources and water from one contaminating source, only the contaminating source would be identified. Wash water flows would always be correctly identified in Birmingham, because all uncontaminated sources, as well as all wash water sources, have ammonia/potassium ratios less than 0.9. Diluted sanitary wastewaters could be incorrectly identified as wash waters if the ammonia/potassium ratio were sufficiently reduced due to the presence of the uncontaminated water. The presence of flow from both categories of contaminated sources (wash waters and sanitary wastewaters) would result in the identification of only one of the contaminated flow components.

Flow-Weighted Mixing Calculations

This method was developed to quantify different major components that may be present in an outfall flow made up of multiple sources. Before any flow-weighted mixing calculations can be made, the characteristics of potential contaminating sources must be identified, as described in Sections 2, 5, and 6). Table 33 is a hypothetical example and summarizes example concentration means and COV values for various tracers. This method is an extension of the checklist method described previously and attempts to quantify the likely source flow components at the outfall during dry weather.

Analytical Equipment Selection to Support Analysis Methods

Two general groupings of flow sources can be recognized for each of these tracers. Table 34 describes these groups, along with their composite ranges, COV values, and medians. This information can also be used to determine the needed equipment to detect the tracer concentrations over the expected range of conditions, as described in Section 6. Required detection limits were determined based on the variations of the tracer concentrations in the lowest concentration component. Required precisions in the measurement techniques were also estimated for errors less than ten percent. Finally, minimum portions of the component having the higher concentration that could be resolved with less than ten percent errors were also estimated. These conservative tracer characteristics are summarized below:

Fluorides:

- detection limit: 0.05 mg/L
- precision: 0.01 mg/L
- minimum contamination detectable: 20 percent

Hardness:

- detection limit: 30 mg/L
- precision: 2 mg/L
- minimum contamination detectable: 10 percent

TABLE 33. ASSUMED SOURCE FLOW QUALITY (mg/L)

		Fluoride	**Hardness**	**Surfactants**	**Potassium**	**Ammonia**
Surface waters	range	0.1 to 0.2	30 to 50	0.30 to 0.4	0.5 to 1	0.2 to 3
	variation*	L (0.23)	L (0.20)	L (0.13)	L (0.23)	M/H (1.1)
	median	0.14	39	0.35	0.72	0.76
Groundwaters	range	0.2 to 0.4	200 to 300	<0.1	1 to 3	0.1 to 0.5
	variation	L (0.23)	L (0.14)	L	M (0.40)	M (0.63)
	median	0.29	250	0.05	1.7	0.22
Septage	range	1.0 to 1.5	30 to 50	<0.1	10 to 100	6 to 380
	variation	L (0.14)	L (0.20)	L	M (0.91)	H (1.5)
	median	1.3	39	0.05	21	47
Raw sewage	range	1.0 to 1.5	30 to 50	0.2 to 100	10 to 100	10 to 50
	variation	L (0.14)	L (0.20)	H+ (2.2)	M (0.91)	M- (0.63)
	median	1.3	39	4.6	21	22
Wash water	range	1.0 to 1.5	30 to 50	0.2 to 100	2.5 to 11	0.1 to 1
	variation	L (0.14)	L (0.20)	H+ (2.2)	M- (0.57)	M (0.91)
	median	1.3	39	4.6	5.3	0.31
Irrigation	range	1.0 to 1.5	30 to 50	0.3 to 0.4	0.5 to 1	0.1 to 1.5
	variation	L (0.14)	L (0.20)	L (0.13)	L (0.23)	M/H (1.1)
	median	1.3	39	0.35	0.72	0.38
Tap water (surface source)	range	1.0 to 1.5	30 to 50	0.3 to 0.4	0.5 to 1	0.1 to 0.5
	variation	L (0.14)	L (0.20)	L (0.13)	L (0.23)	M- (0.63)
	median	1.3	39	0.35	0.72	0.22

* Variation is described with variation category and COV (σ/x_{avg} not transformed):

range ration (x_{90}/x_{10})	COV (σ/x_{avg})	variation category
1.5	0.16	low
10	0.73	medium

100	1.67	high

TABLE 34. CHARACTERISTICS OF SOURCE GROUPINGS

Fluorides

	surface & groundwaters	all other categories
overall range:	0.1→0.4 mg/L	1→1.5 mg/L
COV:	0.54 (L/M)	0.14 (L)
median:	0.20 mg/L	1.3 mg/L

concentration ratio of medians: 6.5

Hardness

	groundwaters	all other categories
overall range:	200→300 mg/L	30→50 mg/L
COV:	0.14 (L)	0.20 (L)
median:	250 mg/L	39 mg/L

concentration ration of medians: 6.4

Surfactants

	raw sanitary wastewater & washwater	all other categories
overall range:	0.2→100 mg/L	0.04→0.4 mg/L
COV:	2.2 (H)	0.83 (M)
median:	4.6 mg/L	0.14 mg/L

concentration ratio of medians: 33

Potassium

	septic tank effluent & raw sanitary wastewater	all other categories
overall range:	10→100 mg/L	0.5→11 mg/L
COV:	0.91 (M)	1.2 (M/H)
median:	21 mg/L	2.3

concentration ratio of medians: 9.1

Ammonia

	septic tank effluent & raw sanitary wastewater	all other categories
overall range:	6→380 mg/L	0.1→3 mg/L
COV:	1.5 (H)	1.3 (M/H)
median:	47 mg/L	0.44 mg/L

concentration ratio of medians: 107

Surfactants:

- detection limit: 0.03 mg/L
- precision: 0.014 mg/L
- minimum contamination detectable: 50 percent

Potassium:

- detection limit: 0.3 mg/L
- precision: 0.07 mg/L
- minimum contamination detectable: 50 percent

Ammonia:

- detection limit: 0.05 mg/L
- precision: 0.09 mg/L
- minimum contamination detectable: 15 percent

The available equipment that can be used to measure these tracers, based on the detection limits, can be selected from the summaries presented in Appendix A. This appendix does not indicate analytical precision, so care must be taken to review that requirement. The following list summarizes the equipment that may be used for these analyses:

- Fluorides (50 µg/L detection limit)--Any of the indicated procedures, except possibly the comparative colorimetric method, may be suitable. Spectrophotometric and ion-selective probe methods should provide detection limits of less than 20 µg/L. Their precisions should also be less than the needed 10 µg/L value. Both of these methods require sample preparation and may take several minutes to 30 minutes to conduct.

- Hardness (30 mg/L detection limit)--Titrimetric, ion-selective probes, and indicator paper may all provide the necessary detection limit. The indicator paper would not provide the needed analytical precision and is probably subject to interferences, but would be the simplest and quickest method to use in the field, by far.

- Surfactants (30 µg/L detection limit)--Ion-selective probes and spectrophotometric methods should provide detection limits better than 3 µg/L and suitable precision. However, these methods could require up to 30 minutes for analyses.

- Potassium (300 µg/L detection limit)--Ion-selective probes and spectrophotometric methods should provide detection limits better than 70 µg/L and suitable precision. However, these methods could again require up to 30 minutes for analyses.

- Ammonia (50 µg/L detection limit)--Ion-selective probes and spectrophotometric methods should provide detection limits better than 10 µg/L and suitable precision.

For the above situation, ion-selective probes seem to provide the most consistent method for all of the required tracers. It may be possible to construct a probe rack with an electrode switch to simplify the analyses. With careful temperature measurements during the analyses, it may be possible to suitably compare the field ion-selective measurements with calibration curves prepared in the laboratory. Otherwise, probe standardizations would have to be conducted in the field. Unfortunately, the laboratory and field tests using ion-selective probes conducted during the Birmingham demonstration study were all disappointing, as noted in Section 6. Until ion-selective probes improve substantially, they are not recommended for field use, and should only be used in the laboratory by experienced technicians. Therefore, the titration and spectrophotometric procedures are recommended for these analyses.

Example Calculations

The following example shows the calculations necessary for this procedure. A hypothetical drainage area for a sampled outfall had no septic tanks or commercial or industrial land uses. The likely flow sources had source flow characteristics as described in Table 33. The required detection limits and precision for outfall characterizations must be determined, as previously described, for these source flow characteristics and desired study results. This outfall had the following tracer concentrations in a dry-weather sample:

Fluoride: 0.6 mg/L
Hardness: 200 mg/L as $CaCO_3$
Surfactants: 0.6 mg/L as MBAS
Potassium: 3 mg/L
Ammonia: 3 mg/L

The water had a slight septic odor, with some floatables of obvious sanitary wastewater origin. In addition, flow was observed at the outfall during all visits.

It is apparent that this outfall has a direct connection of raw sanitary wastewater. This method can determine the approximate mix of sanitary wastewater in the outfall flow and to identify the other flow components. Table 35 summarizes the example calculations used in this analysis. The following list indicates the approximate expected source components at this outfall from this analysis:

Sanitary wastewater: 5%
Wash wastewater: 5%
Groundwater: 70%
Remainder (most likely potable water, but may also contain irrigation water): 20%

This analysis did not consider the potential ranges in observed tracer concentrations and the resulting errors that may be associated with the above mixture portions. The following procedures are better suited for error analyses.

At a confidence level of 90 percent (based on the variabilities of the potential flow components and using Table 27 in Section 6), fluorides could detect contamination at the 20 percent level, hardness could detect contamination at the 10 percent level, surfactants and potassium could detect contamination at the 50 percent levels, and ammonia could detect contamination at the 15 percent level. Contamination is used here as the percentage of the component having the higher tracer concentration mixed with the component having the lower tracer concentration. Fluoride concentrations were used to separate treated and untreated water sources, hardness was used to separate groundwater and surface water sources, surfactant concentrations were used to separate sewage and wash water from other water sources, and potassium and ammonia concentrations were used to separate sewage from other water sources. The following list estimates the flow components, including the approximate confidence values:

Raw sewage: 5%, at less than 90% confidence
Wash water: 5%, at less than 90% confidence
Groundwater: 70%, at greater than 90% confidence
Irrigation water plus water supply: 20%, at about the 90% confidence level.

The number of samples obtained at the outfall and used to obtain the outfall tracer concentrations can also affect these estimates, as shown earlier.

A qualitative analysis can be used to describe the probability of contamination at the outfall, without estimating the degree of contamination, independent of the number of samples obtained. The observed fluoride outfall concentration was 0.6 mg/L, and the median concentration of the component having the lowest fluoride concentrations (non-treated water) was 0.2 mg/L. The variability of fluorides in the non-treated water component was estimated to be low to medium. For a factor of 3.0 (the observed outfall concentration divided by the median concentration of the non-treated water component) and using Table A-7 (probability values for different points on a log-probability scale), there is less than a one percent (for low variability conditions) to about a 15 percent (for medium variability conditions) probability that the non-treated water component alone could have caused the observed outfall concentration. Therefore it is very likely that the outfall flow contained at least some treated water. Similar analyses can be made for the other tracers to determine the probability of contamination of the outfall flow. The following list summarizes these results:

- Fluorides: less than 1 to 15% probability that raw water alone could have produced the observed outfall fluoride concentrations, without any treated water components.

- Hardness: much less than 1% probability that non-groundwater sources alone could have produced the observed outfall hardness concentrations, without any groundwater.

- Surfactants: about 5% probability that non-sewage or non-wash water sources alone could have produced the observed outfall surfactant concentrations.

- Potassium: about 40 to 45% probability that non-sewage sources alone could have produced the observed outfall potassium concentrations.

- Ammonia: about 2 to 15% probability that non-sewage sources alone could have produced the observed outfall ammonia concentrations, without any sewage contamination.

TABLE 35. MIXTURE CALCULATIONS TO IDENTIFY SOURCE FLOW COMPONENTS

Fluorides: 0.6 mg/L observed at outfall

x: treated water: 1.3 mg/L
y: raw water: 0.2 mg/L

$$x\ (1.3) + y\ (0.2) = \frac{0.6}{x+y}$$

x = 0.37 (treated water fraction = water supply, sewage, washwater, and irrigation water, with fluoride added)
y = 0.63 (raw water fraction = surface and/or groundwater)

Hardness: 200 mg/L as $CaCO_3$ observed at outfall

x: groundwater: 250 mg/L as $CaCO_3$
y: all others: 39 mg/L as $CaCO_3$

$$x\ (250) + y\ (39) = \frac{200}{x+y}$$

x = 0.76 (groundwater fraction)
y = 0.24 (all other fractions)

Therefore:

Groundwater & Surface water = 0.63
Groundwater alone = <u>0.76</u>
Surface water alone = - 0.13→0

$$\text{and groundwater} = \frac{0.63+0.76}{2} = 0.7$$

Surfactants: 0.6 mg/L as MBAS observed at outfall

x: raw sanitary wastewater& washwater: 4.6 mg/L as MBAS
y: all others: 0.14 mg/L as MBAS

$$x\ (4.6) + y\ (0.14) = \frac{0.6}{x+y}$$

x = 0.10 (raw wastewater & washwater)
y = 0.90 (all others)

(continued)

TABLE 35. (continued)

Potassium: 3 mg/L observed at outfall

x: raw sanitary wastewater: 21mg/L
y: all others: 2.3 mg/L

$$x\,(21) + y\,(2.3) = \frac{3}{x + y}$$

x = 0.04 (raw sanitary wastewater)
y = 0.96 (all others)

Ammonia: 3 mg/L observed at outfall

x: raw sanitary wastewater: 47 mg/L
y: all others: 0.44 mg/L

$$x\,(47) + y\,(0.44) = \frac{3}{x + y}$$

x = 0.06 (raw sanitary wastewater)
y = 0.94 (all others)

Therefore: Raw sanitary wastewater = $\frac{0.04 + 0.06}{2} = 0.05$

Washwater = 0.05

Even without the visual observations, it can be determined, at least to the 85 percent confidence level, that raw sewage was affecting the outfall non-stormwater flow. There was also a very large probability (greater than 99 percent significance level) that groundwater was also affecting the outfall flow. However, the specific portions of some of the different source components in this example could not be determined to a high level of significance. The groundwater and irrigation runoff plus water supply component portions were estimated at the 90 percent, or greater level of confidence. The more important sewage component would have to be present at least at a 15 percent level of contamination before the ammonia analyses could predict its contamination level with a 90 percent, or greater, confidence level. These results would certainly have been sufficient to target this outfall and drainage area for further investigations to locate the highly probable sewage source(s) discharging into the storm drainage system. The water utility should also be contacted concerning the high potential of treated water, possibly from leaky water mains, in the drainage area.

It is obvious from this example that more precisely defining the tracer characteristics of the potential non-stormwater flow components would have enabled much better estimates of the portions of each of these flow components affecting the outfall flow.

Matrix Algebra Solution of Simultaneous Equations

Other approaches can also be used to calculate the source components of mixed outfall flows. One approach is the use of matrix algebra to simultaneously solve a series of chemical mass balance equations. This method can be used to predict the most likely flow source, or sources, making up an outfall sample, and is discussed in the following paragraphs.

It is possible to estimate the outfall source flow components using a set of simultaneous equations. The number of unknowns should equal the number of equations available, resulting in a square matrix. If there are seven likely source categories, then there should be seven tracer parameters used. If there are only four possible sources, then only four tracer parameters should be used.

Further site specific statistical analyses may be needed to rank the usefulness of the tracers for distinguishing different flow sources. As an example, chlorine is generally not useful for these analyses because the concentration variability within many source categories is high (it is also not a conservative parameter). Chlorine may still be a useful parameter, but only to identify possible large potable water line leaks. Another parameter having problems for most situations is pH. The variation of pH between sources is very low (they are all very similar). However, pH may still be useful to identify industrial wastewater problems, but it cannot be used to quantify flow components. pH is also not linearly affected by mass balance mixtures (a solution of 50%/50% of two components would not result in a pH value that is the average of the two individual pH values). Toxicity is another parameter that was used during this research that was not found to be linearly additive. The following paragraphs describe this procedure, and contains an example.

This method estimates flow contributions from various sources using a “receptor model”, based on a set of chemical mass balance equations. Such models, which assess the contributions from various sources based on observations at sampling sites (the receptors), have been applied to the investigation of air pollutant sources for many years (Scheff and Wadden 1993; Daisey, Lioy and Kneip 1985; Gordon 1980; Cooper and Watson 1980; Friedlander 1973). The characteristic “signatures” of the different types of sources, as identified in the library of source flow data developed during this research, allowed the development of a set of mass balance equations. These equations described the measured concentrations in an outfall's flow as a linear combination of the contributions from the different potential sources. A major requirement for this method was the physical and chemical characterization of waters collected directly from potential sources of dry-weather flow. This allowed concentration patterns (fingerprints) for the parameters of interest to be established for each type of source. Theoretically, if these patterns are different for each source, the observed concentrations at the outfall would be a linear combination of the concentration patterns from the different component sources, each weighted by a source strength term (m_n). This source strength term would indicate the fraction of outfall flow originating from each likely source. By measuring a number of parameters equal to, or greater than, the number of potential source types, the source strength term could be obtained by solving a set of chemical mass balance equations of the type:

$$C_p = \sum_n m_n x_{pn}$$

where C_p is the concentration of parameter p in the outfall flow and x_{pn} is the concentration of parameter p in source type n.

As an example of this method, consider 8 possible flow sources and 8 parameters, as presented in Table 36. The number of parameters evaluated for each outfall must equal the number of probable dry-weather flow sources in the drainage area. Mathematical methods are available which provide for the solution of overspecified sets of equations (more equations than unknowns) but these are not addressed here.

The selection of parameters for measurement should reflect evaluated parameter usefulness. Evaluation of the Mann-Whitney U Test results (Lalor 1994 and as presented in Section 11 and Appendix E) suggested the following groupings of parameters, ranked by their usefulness for distinguishing between all the types of flow sources sampled. The first category of most useful parameters would include potassium and hardness, followed by a second category of useful parameters including fluorescence, conductivity, fluoride, ammonia, detergents, and color. Chlorine would be included in a third category of less useful parameters, and would only be used if more than 8 potential source categories were being considered (which is unlikely for any given outfall).

TABLE 36. SET OF CHEMICAL MASS BALANCE EQUATIONS

	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6	Source 7	Source 8	Outfall
Parameter 1:	(m1)(x11) +	(m2)(x12) +	(m3)(x13) +	(m4)(x14) +	(m5)(x15) +	(m6)(x16) +	(m7)(x17) +	(m8)(x18)	= C1
Parameter 2:	(m1)(x21) +	(m2)(x22) +	(m3)(x23) +	(m4)(x24) +	(m5)(x25) +	(m6)(x26) +	(m7)(x27) +	(m8)(x28)	= C2
Parameter 3:	(m1)(x31) +	(m2)(x32) +	(m3)(x33) +	(m4)(x34) +	(m5)(x35) +	(m6)(x36) +	(m7)(x37) +	(m8)(x38)	= C3
Parameter 4:	(m1)(x41) +	(m2)(x42) +	(m3)(x43) +	(m4)(x44) +	(m5)(x45) +	(m6)(x46) +	(m7)(x47) +	(m8)(x48)	= C4
Parameter 5:	(m1)(x51) +	(m2)(x52) +	(m3)(x53) +	(m4)(x54) +	(m5)(x55) +	(m6)(x56) +	(m7)(x57) +	(m8)(x58)	= C5
Parameter 6:	(m1)(x61) +	(m2)(x62) +	(m3)(x63) +	(m4)(x64) +	(m5)(x65) +	(m6)(x66) +	(m7)(x67) +	(m8)(x68)	= C6
Parameter 7:	(m1)(x71) +	(m2)(x72) +	(m3)(x73) +	(m4)(x74) +	(m5)(x75) +	(m6)(x76) +	(m7)(x77) +	(m8)(x78)	= C7
Parameter 8:	(m1)(x81) +	(m2)(x82) +	(m3)(x83) +	(m4)(x84) +	(m5)(x85) +	(m6)(x86) +	(m7)(x87) +	(m8)(x88)	= C8

Equations of the Form $C_p = \sum_n m_n x_{pn}$

where: C_p = the concentration of parameter p in the outfall flow

m_n = the fraction of flow from source type n

x_{pn} = the concentration of parameter p in source type n

If parameter variations within the sources are not accounted for, the equations would take the form presented in Table 37. Here, the x terms, representing parameter concentrations within the specified source, have been replaced with the mean concentrations noted in the source library (Table 38). After measured values are substituted into the equations for parameter concentrations in the outfall flow (C_p), this set of simultaneous equations can be solved using matrix algebra. The use of mean concentration values in the equation set was evaluated by entering the potential dry-weather flow source samples from Birmingham as unknowns (as if they were outfall samples) and solving for fractions of flow (the m terms in Table 37). This exercise resulted in 4 false negatives (6%) and 27 false positives (73%). The results of these simple preliminary tests indicated that there was too much variation of parameter concentrations within the various source types to allow them to be adequately characterized by simple use of the mean concentrations alone. The following procedure was therefore developed and tested that considers uncertainty of the source area concentration values (Lalor 1994).

Matrix Algebra Solution Considering Uncertainty

A stochastic version of this procedure, developed by Lalor (1994) enabled the variation within the library values for each source type to be considered. Instead of using a single value (i.e. mean value) to represent the parameter concentration (x_{pn}) for each likely type of source flow, a Monte Carlo simulation is used to randomly select values from a statistical distribution. Monte Carlo sampling is a traditional method of random sampling across an entire input variable distribution. Any value across the range of the distribution is possible, although the sampling is influenced by the relative probability assigned to each value. The more probable values will have a greater chance of being selected.

Based on samples collected from known sources in Birmingham, probability distributions were calculated, for each parameter, within each potential source flow (Table 38). Distributions considered in this procedure include normal, log-normal, and uniform. Local source flow quality monitoring is necessary to obtain this information, as discussed previously.

Monte Carlo simulation generates sets of concentration values based on the mean, coefficient of variation, and distribution of each parameter within each source. A set of equations in the form of Table 36 is established for each set of sampled concentration values generated by the Monte Carlo simulation. The fraction of flow from each potential source (represented by the m terms in Table 36) is calculated by solving each set of equations. These flow values are then stored. Multiple trials are used to calculate the most probable sources of contaminants for each outfall.

This procedure assumes a mass balance at the outfall, with the outfall concentrations affected by the magnitude of each contributing source. If the outfall flow is contaminated solely by sanitary wastewater and no other flows are present, then the outfall quality should obviously be very similar to sanitary wastewater quality as reflected in the library data. If the outfall is contaminated by a mixture of 25% sanitary wastewater and 75% infiltrating groundwater, then the outfall quality would be represented by a weighted fraction of the quality parameters of these individual flows. The values used to describe the individual potential source concentrations are randomly selected from a calculated distribution. The distribution description (mean, standard deviation, and distribution type) is based on actual local measurements of likely dry-weather flow source types, as presented in Table 38.

A computer program was developed (using TurboPascal, version 6) to perform the Monte Carlo trials, and prepare probability plots of the solutions (Lalor 1994). Appendix G contains the source code for this program and an example of its use. Each source concentration value (x_{pn}) is randomly selected from the calculated probability distribution by the Monte Carlo simulation based on the locally obtained source library data. The program is designed to evaluate a maximum of 12 potential sources per outfall. Three distribution options are available for each parameter within each type of source: normal, log- normal, and uniform. The uniform distribution option is assumed if the coefficient of variation is entered as 0 (all of the observations had identical concentrations). The parameter concentration (x_{pn}) is then always taken to be the mean value.

TABLE 37. CHEMICAL MASS BALANCE EQUATIONS WITH PARAMETER MEANS

Parameters	Spring Water 1	Ground Water 2	Tap Water 3	Irrigation Water 4	Sanitary Sewage 5	Septic Tank 6	Car Wash 7	Laundry Water 8	Unknown Sample
Potassium	(m1)(0.73)	+ (m2)(1.19)	+ (m3)(1.55)	+ (m4)(6.08)	+ (m5)(5.97)	+ (m6)(18.82)	+ (m7)(42.69)	+ (m8)(3.48)	= (1)(C_p)
Hardness	(m1)(240)	+ (m2)(27)	+ (m3)(49)	+ (m4)(40)	+ (m5)(143)	+ (m6)(57)	+ (m7)(157)	+ (m8)(36)	= (1)(C_p)
Fluorescence	(m1)(6.8)	+ (m2)(29.9)	+ (m3)(4.6)	+ (m4)(214)	+ (m5)(251)	+ (m6)(382)	+ (m7)(1190)	+ (m8)(1024)	= (1)(C_p)
Conductivity	(m1)(301)	+ (m2)(51)	+ (m3)(112)	+ (m4)(105)	+ (m5)(420)	+ (m6)(502)	+ (m7)(485)	+ (m8)(563)	= (1)(C_p)
Fluoride	(m1)(0.03)	+ (m2)(0.06)	+ (m3)(0.97)	+ (m4)(0.90)	+ (m5)(0.76)	+ (m6)(0.93)	+ (m7)(12.3)	+ (m8)(32.82)	= (1)(C_p)
Ammonia	(m1)(0.01)	+ (m2)(0.24)	+ (m3)(0.03)	+ (m4)(0.37)	+ (m5)(9.92)	+ (m6)(87.21)	+ (m7)(0.24)	+ (m8)(0.82)	= (1)(C_p)
Detergents	(m1)(0.00)	+ (m2)(0.00)	+ (m3)(0.00)	+ (m4)(0.00)	+ (m5)(1.50)	+ (m6)(3.27)	+ (m7)(49.00)	+ (m8)(26.90)	= (1)(C_p)
Color	(m1)(0.0)	+ (m2)(8.0)	+ (m3)(0.0)	+ (m4)(10.0)	+ (m5)(37.9)	+ (m6)(70.6)	+ (m7)(221.5)	+ (m8)(46.7)	= (1)(C_p)

Equations of the Form $C_p = \sum_n m_n x_{pn}$

where: C_p = the concentration of parameter p in the outfall flow
m_n = the fraction of flow from source type n
x_{pn} = the mean concentration of parameter p in source type n

TABLE 38. SUMMARY OF CHEMICAL CHARACTERISTICS OF SOURCE SAMPLES COLLECTED IN BIRMINGHAM, ALABAMA

Source	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L as CaCO$_3$)	Detergent (mg/L)	Fluorescence % scale	Potassium (mg/L)	Ammonia (mg/L)	Color (units)	Chlorine (mg/L)
Spring Water									
mean	301	0.03	240	0.00	6.80	0.73	0.01	0.0	0.00
COV	0.04	1.00	0.03	--	0.43	0.10	2.00	--	--
distribution	normal	normal	normal	uniform	normal	normal	L-norm	uniform	uniform
Shallow Ground Water									
mean	51.4	0.06	27.3	0.00	29.9	1.19	0.24	8.0	0.02
COV	0.84	0.50	0.39	--	1.55	0.44	1.26	1.42	1.62
distribution	normal	L-norm	normal	uniform	L-norm	normal	normal	L-norm	normal
Tap Water									
mean	112	0.97	49.3	0.00	4.63	1.55	0.03	0.0	0.88
COV	0.01	0.01	0.03	--	0.08	0.04	0.23	--	0.68
distribution	normal	normal	normal	uniform	normal	normal	normal	uniform	bi-modal
Landscaping Irrigation									
mean	105	0.90	40.2	0.00	214.4	6.08	0.37	10.0	0.03
COV	0.07	0.11	0.04	--	0.16	0.26	0.25	0.36	1.02
distribution	normal	normal	normal	uniform	normal	normal	normal	normal	normal
Sewage									
mean	420	0.76	143	1.50	251.0	5.97	9.92	37.9	.01
COV	0.13	0.23	0.11	0.82	0.20	0.23	0.34	0.55	2.00
distribution	normal	normal	normal	normal	normal	normal	L-norm	normal	L-norm
Septic Tank Discharge									
mean	502	0.93	56.8	3.27	382	18.82	87.21	70.6	0.07
COV	0.42	0.39	0.36	1.33	0.22	0.42	0.40	0.39	1.30
distribution	normal	normal	L-norm	L-norm	normal	normal	normal	normal	normal
Carwash									
mean	485	12.30	157	49.0	1190	42.69	0.24	221.5	0.07
COV	0.06	0.19	0.05	0.10	0.11	0.37	0.28	0.35	1.14
distribution	normal	normal	normal	normal	normal	normal	normal	normal	bi-modal
Laundry									
mean	563	32.82	36.2	26.9	1024	3.48	0.82	46.7	0.40
COV	0.21	0.38	0.08	0.25	0.12	0.11	0.14	0.27	0.26
distribution	normal	normal	normal	normal	normal	normal	normal	normal	normal
Radiator Waste									
mean	3280	149.32	5.60	15.0	22046	2801.80	26.32	2999	0.03
COV	0.21	0.16	1.88	0.11	0.04	0.13	0.89	0.01	0.52
distribution	normal	normal	normal	normal	normal	normal	normal	normal	normal
Plating Waste									
mean	10352	5.13	1430	6.81	293	1008.80	65.65	103.8	0.08
COV	0.45	0.47	0.32	0.68	0.70	1.24	0.66	0.91	1.20

distribution	normal	normal	normal	normal	normal	L-norm	normal	normal	L-norm

During program execution, 2000 random simulations are conducted for each outfall. The solutions are saved, sorted by source, and plotted by probability. The program output is in the form of plots, one for each potential source type selected for consideration. Each output plot shows the most likely fraction of flow (the 50th percentile value) contributed by one source type. The 10th and 90th percentile values are also noted in order to give an idea of the spread of solutions calculated. Appendix G contains an example showing the program input and output.

The most probable percent of flow being contributed to an outfall by each potential flow source is based on the 50th percentile value in the set of solutions for m which the program generates for each identified potential flow source. Each 50th percentile value represents the most likely fraction of flow from one particular source based on all calculated values of m for that source, but is independent of the numbers which happen to represent the 50th percentile values for other sources. As a result, the sum of the most likely fraction of flows from each source does not equal 1.00. The most likely flow contributions from each source can be normalized (divided by $\sum m_{50th}$). This allows contributions to be evaluated as percent of flow, while maintaining their relative level of importance.

Initial tests of the algorithm for solving the system of linear equations were carried out using the mean concentrations from each source group and allowing for no variation in concentration values. Therefore, coefficient of variation values were entered as 0, and mean concentration values for each parameter within each source type were used in solving the equation sets. When mean values for each potential source type were then entered as samples, the algorithm correctly predicted the source of the sample, indicating that the algorithm was working correctly.

Coefficients of variation and distributions types, from Table 38, were then added to the model. This allowed the Monte Carlo simulation to take place, choosing parameter concentrations to be used in solving the linear equation sets. Once again, mean values (Table 38) from each of the source types were entered as samples. Results are shown in Table 39. The correct source type was identified as the main contributor in each case. However, uncontaminated sources showed up as contributors in most of the tests and sewage was identified as contributing flow to the septage sample. This was not unexpected, given the high level of parameter variation noted in some source and parameter types. Negative fractions of flow were noted in some instances, as m was not constrained to be ≥ 0. Negative fractions of flow have no real meaning and result, in part, from concentration distributions which allow negative numbers to be selected as parameter concentrations. The distribution curve for some parameters, in some sources, extends beyond zero into the negative range. The program was revised to truncate concentration distributions at zero. This revision maintained the shape of the distribution curve but simply required the Monte Carlo program to sample again when a negative value was selected as a concentration.

In order to gain a better understanding of how the Monte Carlo program outputs should be interpreted, 103 of the samples collected directly from dry-weather flow sources were entered as “outfall” samples. Data from these runs are presented in Table 40, with most likely flow contributions from each source normalized to equal 100% of flow. The predictions resulted in no false negatives, but 11 false positives, an great improvement over the solutions achieved using only parameter concentration means to characterize flow sources. However, many extraneous contributions of flow were also predicted.

In this simple test, percent contributions below 16 never represented the actual flow source, but appear to be “background noise” generated by the variation allowed in the program. These results indicated that false positives could be minimized, without creating false negatives, if a threshold were established and all apparent percent contributions less than this threshold were ignored. The lower detection limits of the analytical methods used, and the dilution study results discussed earlier, indicated that a contaminating source would be difficult to detect in mixtures in which it made up less than 10% of the flow. This suggested using percent contributions of 10 as a lower threshold of detection for the program. Using this criterion, there were no false negatives (samples from a contaminated source identified as containing flow from only uncontaminated sources) and only 3 false positives (samples from an uncontaminated source identified as containing flow from a contaminated source) out of 103 samples.

TABLE 39. RESULTS FROM SOLUTION OF MASS BALANCE EQUATIONS USING MONTECARLO SIMULATON TO OBTAIN SOURCE PARAMETER CONCENTRATIONS

	Most Likely Fraction of Flow From Each Source							
Sample Source	Spring	Irrigation	Tap Water	Shallow Ground	Sewage	Septic Tank Discharge	Carwash	Laundry
100% Spring	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100% Irrigation	-0.02	1.01	0.05	0.07	0.01	0.00	0.00	0.00
100% Tap Water	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
100% Shallow Ground	0.01	0.05	0.13	0.40	0.04	0.00	0.00	0.00
100% Sewage	0.05	0.04	0.00	0.63	0.86	0.02	0.00	0.00
100% Septic Tank Discharge	-0.23	0.04	0.54	0.08	0.22	1.01	-0.02	-0.01
100% Carwash	-0.16	0.09	0.55	0.44	0.02	0.00	1.03	-0.02
100%Laundry	-0.08	-0.21	0.89	0.08	-0.09	0.00	0.02	1.02

Notes: Concentration means from each source type were used as samples

TABLE 40. RESULTS OBTAINED USING THE CHEMICAL MASS BALANCE PROGRAM TO ANALYZE SOURCE DATA (DATA NORMALIZED TO EQUAL 100% OF FLOW)

	Predicted Percent of Flow							
Sample	Spring	Shallow Ground	Tap	Irrigation	Sewage	Septic Tank Discharge	Laundry	Carwash
Spring								
1	90		6		4			
2	98	1						
3	99				1			
4	100							
5	99			1				
6	98	2						
7	99	1						
8	100							
9	99			1				
10	99			1				
Tap								
1			100					
2			100					
3			100					
4	5	9	78	8				
5	1		98	1				
6			100					
7			100					
8	1		99					
9			100					
10			100					
Irrigation								
1			45	54				1
2		6	41	52				1
3	7	20		64	7		2	
4		5	17	78				
5		6		91	2			
6		8		91	1			
7		3	8	89				
8	4			94	1		1	
9	3			97				
10		4	9	87				
Shallow Ground								
4		63		4	33			
5		76		4	20			
6	3	64			33			
7	36	32		32				
8	36	33		31				
9	20	49		31				

10	35	25		39				

(continued)

TABLE 40. (continued)

	Predicted Percent of Flow							
Sample	Spring	Shallow Ground	Tap	Irrigation	Sewage	Septic Tank Discharge	Laundry	Carwash
Sewage								
1	14	54		13	16	3		
2	45			17	30	4		4
3	37			17	44	1	1	
4	45			18	35	1	1	
5	30			16	47	6	1	
6	19			23	51	6	1	
7	18			31	43	6	2	
8	22			3	68	3	1	3
9	5	17	11	29	36	2		
10		8	26	16	49	1		
11	13		5	34	46	2		
12	9		2	39	49	1		
13		29	2	21	48			1
14		48			50			2
15		38	14		48			
16	1	58			39	1	1	
17	16	40			44			
18	12	11	46	1	29	1		
19	9		25	27	33	6		
20		33	6	36	25			
21		60			39	1		
22		66	1		32	1		
23		55	5	6	34			
24		42	18	3	37			
25		58	5		36	1		
26		50		1	49			
27		50		4	44	2		
28	11			16	72	1		
29	31			14	53	1		
30	12		9		79			
31		47			46	7		
32		64	4		30	2		
33		67	3		30			
34		46			52			2
35		31	16		51			2
36		60	5		35			

(continued)

TABLE 40. (Continued)

	Predicted Percent of Flow							
Sample	Spring	Shallow Ground	Tap	Irrigation	Sewage	Septic tank Discharge	Laundry	Carwash
Septic Discharge								
4		8			69	15		8
5	15	20			13	47	5	
6		10			66	16	1	7
7			41	5	29	25		
8			59	3	16	22		
9		22	42	1	17	18		
10			25	37		38		
11	21		3	29		46		
12	5	54		17		24		
13		30	38	12		19		
Carwash								
1		74	7				3	16
2	3	61			14		3	19
3			59	23		1		17
4			65			1	3	31
5			61			2		37
6	5	32						36
7		17	49	15		1		18
8	6		32	30		1		31
9	29				38		11	22
10	13			36			2	49
Laundry								
1	8				61		24	7
2	8	19		25	20		28	
3		30	48	2		2	18	
4		6	75			1	17	1
5		11	64			1	24	
6	12				12		71	5
7		24		12	29		35	
8			10		51		39	
9		36	39				25	
10	16				15		62	7

More specifically, Table 40 yields the following information. All tap water samples were correctly identified as containing only tap water. No other source types were identified as contributing ≥10% of the sample. Likewise, all spring water samples were correctly identified. Relatively small parameter variations within both these source types are responsible for the precision of these results. All samples from landscape irrigation runoff were correctly identified as coming from that source, but, tap water showed up as a contributor in three samples and shallow ground water in one.

Source predictions for the infiltrating shallow ground water samples were the least accurate of any uncontaminated sources. This result was linked to high parameter variations within the source type. The program identified infiltrating shallow ground water as contributing ≥10% in all samples, but landscape irrigation runoff, and spring water were predicted to make up ≥10% of some shallow groundwater samples. Also, all 3 false positives resulted from these samples. Sewage was identified as making up ≥10% of 3 samples of shallow ground water.

Car wash waters were correctly identified as major contributors in all 10 car wash samples and laundry water was correctly identified in all 10 laundry samples. However, spring water, shallow ground water, tap water, landscape irrigation runoff and sewage were also predicted to make up ≥10% of some samples.

Sewage was identified as a major contaminating source in all sewage samples and septic tank discharge was identified as a major contaminating source in all septic tank discharge samples. Sewage was also identified as a component in 6 of the 10 septic tank discharge samples. Spring water, shallow ground water, tap water and landscape irrigation runoff was also identified in some samples.

These results indicated that in spite of the theoretical results obtained using cluster analysis (see Section 11), the degree of variation which exists within many of the potential source types identified will reduce the effectiveness of a chemical mass balance solution at stormwater outfalls. The method was evaluated against actual outfall flows during the Birmingham demonstration project phase (Lalor 1994) and is summarized in Section 11.

Section 8
Watershed Surveys to Confirm and Locate Inappropriate Pollutant Entries to the Storm Drainage System

After initial outfall surveys have indicated the presence of contamination, further detailed analyses are needed to identify and locate the specific contaminant sources in the drainage area. For source identification and location, upstream survey techniques should be used in conjunction with an in-depth watershed evaluation. Information on watershed activities can be obtained from aerial photography and/or zoning maps, while upstream survey techniques will include the analysis of the dry-weather flow at several manhole sampling points along the storm drainage system to narrow the location of the contaminating source; tests for specific pollutants or ions associated with known activities within the outfall catchment area; and the measurement of water flow rate and temperature, visual and video camera inspections, and smoke and dye tests.

Detailed Outfall Analyses

Several confirmatory chemical analyses could be conducted at the outfall to verify the more significant sources of dry-weather flows. These analyses require highly trained personnel and specialized equipment that would not be available in most laboratories. It may not be feasible to analyze samples from each of the hundreds of outfalls several times a year for these materials, as would be required for the routine analyses discussed previously. These analyses may be very useful to check for false negatives and for more specific results on a random basis. These confirmatory analyses may include:

- trihalomethanes
- specific bacteria biotypes
- coprostanol, or other biochemicals

Trihalomethanes (THMs) are formed when chlorine reacts with certain natural organics (including tannins) present in most waters. The detection of these compounds in groundwaters has been used as a positive indication of treated city water leakage (Hargesheimer 1985). Chloroform and dichlorobromethane are the THMs most frequently used because of their very low detection limits and specific indicators of treated domestic water. Chlorine was found to rapidly “disappear” during sheetflow sampling of irrigation runoff water during the Birmingham demonstration tests, even with concentrations in the tap water source. In contrast, chlorine only very slowly disappeared during laboratory tests of aerated tap water samples. It is expected that the chlorine reacted with the organics in the lawn areas to form THMs, while the chlorine in the glass beakers in the laboratory could only dissipate through volatilization. Therefore, THM analyses are expected to be useful in identifying treated domestic water sources, if a cost-effective analysis procedure is available.

As noted previously in Section 5, specific bacteria biotypes and coprostanol may be useful to confirm sanitary sewage sources. However, the experience during the Birmingham demonstration project did not find that coprostanol was very helpful. The other methods described earlier in Section 7 for identifying sanitary sewage were much more cost-effective, accurate, and sensitive.

Using Tracer Parameters in the Drainage System

In order to identify the specific contaminant sources in the drainage system, further detailed watershed analyses are needed. These may include:

- drainage system surveys (tests for specific pollutants, visual inspections, video camera drainage pipe inspections, and smoke and dye tests),
- in-depth watershed evaluation (including aerial photographs), and
- industrial and commercial site studies (see Section 9)

Follow-up Drainage Area and On-Site Investigations.

Further drainage area investigations upstream of identified problem outfalls need to be conducted after the outfall studies have indicated dry-weather discharge problems. In order to be cost-effective, only a sub-sample of manholes located in a drainage area identified as having significant non-stormwater sources should be tested for the tracers. As an example, the main storm drain trunk sewer could be divided into tenths and the manholes closest to these subdivisions would be sampled. This would identify the upper limit of the drainage area above which the major sources are not located. A location may also be identified where the downstream manhole tracer mass yields (concentration times flow rate) are the same. This would mark the downstream limit of the contributing area for the tracers of concern. After the main trunk drainage reach is identified that contains the major non-stormwater sources, the branch storm drain lines can be similarly subdivided (but probably into fewer sections each, perhaps about three) and evaluated. Depending on the drainage area and complexity of the storm drainage system, this scheme could be suitably modified to enable the identification of relatively small areas responsible for the non-stormwater pollutant entries into the storm drainage system. These small areas would then be subject to more intensive on-site investigations that would include smoke tests, dye studies, and remote video inspections.

The above drainage system analysis procedure may find that the drainage system is contaminated by widespread sanitary wastewater entries, possibly due to sanitary and storm drainage systems in extremely poor condition. This condition may require that the drainage system undergo extensive and costly repairs. It may be more appropriate to consider the storm drainage system as a combined sewer and examine control alternatives that have been developed for combined sewer systems. This would also save further detailed drainage system analyses costs.

These drainage system surveys would be followed by industrial and commercial on-site investigations (such as dye and smoke studies) to locate specific sources of non-stormwater pollutant entries into the drainage system. Additionally, aerial photography can be very useful during later phases of non-stormwater discharge control projects. As an example, aerial photography can help identify areas having failing septic systems located in residential areas served by storm drainage systems. Aerial photography can also be used to identify continuous discharges to surface drainages, such as sump discharges, and to identify storage areas that may be contributing significant amounts of pollutants during rains. For example, the Tennessee Valley Authority (TVA), among other agencies, has extensively used aerial photography (stereo color infrared) to identify pollution sources, especially from failing septic tanks (Perchalski and Higgins 1988). The TVA's flights are made in early spring when investigating septic tank failures, to be able to identify unusual grass conditions, with minimal interference from trees. The flights are made at 6,000 feet, with resulting image scales of 1 inch to 1,000 feet. Their photography costs have been about $40 to $150 per square mile.

Section 9

Specific Considerations for Industrial and Commercial Sources of Inappropriate Pollutant Entries to the Storm Drainage System

Industrial Site Surveys

Additional pollutants associated with local commercial and industrial activities need to be monitored during the outfall screening activities, if these activities may be present in the watersheds of interest. This monitoring will assist in identifying the classes of commercial or industrial activities responsible for the contamination. The first step in this process is to identify which industrial and commercial activities exist in a watershed and what activities they be doing that may contribute non-stormwater discharges to the drainage system. The review of industrial user surveys or reports that are available needs to be done initially. It may be necessary to also send a questionnaire to industries in the watershed that are draining to the storm drainage system to identify the specific activities that may affect runoff quality and dry-weather discharges. Site inspections will still be required because questionnaires may not be returned or may give incorrect details (either deliberately or unknowingly).

Industrial areas are known to contribute excessive wet-weather stormwater discharges, along with contaminated dry-weather entries into the storm drainage system. Additional industrial site investigations are therefore needed to identify activities that most obviously contribute these contaminants to the storm drainage system. Figure 13 is an example industrial site survey form prepared by the Non-Point Source and Land Management Section of the Wisconsin Department of Natural Resources (R. Bannerman, personal communication). This form has been used to help identify industrial activities that contribute dry- and wet-weather non-stormwater entries into the storm drainage system.

This form only considers outside sources that would affect the storm drainage system by entering through inlets or through sheetflow runoff into drainage channels. This sheet does not include any information concerning indoor activities, or direct plumbing connections to the storm drainage system. However, the information included on this sheet can be very helpful in devising runoff control programs for industrial areas. This information most likely affects wet-weather discharges much more than dry-weather discharges. Obvious dry-weather leaching or spillage problems are also noted on the form.

Table 18 in Section 3 presents the types of activities in industrial areas that may contribute dry-weather discharges to storm drainage systems. This table can be used to rank the most likely industries that may produce non-stormwater discharges to a storm drainage system in an area. This table is used in conjunction with the industrial site survey form to catalog specific activities in the watershed that may need correction. After a listing of the candidate activities are known in the watersheds, additional tracer parameters may then be selected to add to the screening efforts.

Likely Dry-Weather Discharge Characteristics for Different Industries

Chemical and Physical Properties

Table 41 summarizes possible chemical and physical characteristics of non-stormwater discharges which could come from various industries. The properties considered are pH, total dissolved solids, odor, color, clarity, floatable materials, vegetation, and structural damage potential. The descriptions in each of these categories contain the most likely conditions for a non-stormwater discharge coming from a particular industry. It should be noted that a combination of just a few of these characteristics, or perhaps all of them, may occur at an outfall affected by a potential source. In addition, outfalls are likely to be affected by several sources simultaneously, further confusing the situation. Again, a complete watershed analysis describing the industrial and commercial facilities operating in each outfall watershed will be of great assistance in identifying which industries may be contributing harmful dry-weather discharges to the storm system.

City: ____________________________ Industry Name: ____
Site Number: ______________________________ Photo # _____________________________________
Street Address: ____________________________ Roll# ____
Type of industry: ____
Instructions: Fill in blanks or circle best answer in following (use back of sheet if necessary):

Material/waste Storage Areas

1. Type of material/waste: ____
2. Method of storage: pile tank dumpster other: ________________________________
3. Area occupied by material/waste (acres): ____
4. Type of surface under material/waste: paved unpaved
5. Material/waste is disturbed: often sometimes never unsure
6. Description of spills (material, quantity & frequency): ____
7. Nearest drainage (feet) and drainage type: ____
8. Control practice: berm tarp buffer none other: ______________________________
9. Tributary drainage area, including roofs (acres): ____
10. Does storage area drain to parking lot: yes no unsure

Heavy equipment storage

1. Type of equipment: ____
2. Area covered by equipment (acres): ____
3. Type of surface under equipment: paved unpaved
4. Nearest drainage (feet) and drainage type: ____
5. Control practice: berm tarp buffer none other: _____________________________
6. Tributary drainage area, including roofs (acres): ____
7. Does storage area drain to parking lot: yes no unsure

Air pollution

1. Description of settleable air pollutants (types & quantities): __________________________________
2. Description of particulate air pollutant controls: ____

Railroad yard

1. Size of yard (number of tracks): ____
2. General condition of yard: ____
3. Description of spills in yard (material, quantity & frequency): __________________________________
4. Type of surface in yard: paved unpaved
5. Nearest drainage (feet) and drainage type: ____
6. Type of control practice: berm buffer other: ______________________________________
7. Does yard drain to parking lot: yes no unsure
8. Tributary drainage area, including roofs (acres): ____

Loading Docks

1. Number of truck bays: ____
2. Type of surface: paved unpaved
3. Description of spills in yard (material, quantity & frequency): _________________________________
4. Nearest drainage (feet) and drainage type: ____
5. Type of control practice: berm buffer other: _____________________________________
6. Does loading area drain to parking lot: yes no unsure
7. Tributary drainage area, including roofs (acres): ____

Source: From Wisconsin Dept. of Natural Resources (R. Bannerman, Personal communication)

Figure 13. Industrial inventory field sheet (WI DNR).

TABLE 41. CHEMICAL AND PHYSICAL PROPERTIES OF INDUSTRIAL NON-STORMWATER DISCHARGES

Industrial Categories Major Classifications SIC Group Numbers	Odor	Color	Turbidity	Floatables	Debris and Stains	Structural Damage	Vegetation	pH	Total dissolved solids
Primary Industries									
20 Food and Kindred Products									
201 Meat Products	Spoiled Meats, Rotten Eggs and Flesh	Brown to Reddish-Brown	High	Animal Fats, Byproducts, Pieces o Processed Meats	Brown to Black	High	Flourish	Normal	High
202 Dairy Products	Spoiled Milk, Rancid Butter	Grey to White	High	Animal Fats, Spoiled Milk Products	Grey to Light Brown	High	Flourish	Acidic	High
203 Canned and Preserved Fruits and Vegetables	Decaying Products Compost Pile	Various	High	Vegetable Waxes, Seeds, Skins, Cores, Leaves	Brown	Low	Normal	Wide Range	High
204 Grain Mill Products	Slightly Sweet & Musty, Grainy	Brown to Reddish Brown	High	Grain Hulls and Skins, Straw &i Plant Fragments	Light Brown	Low	Normal	Normal	High
205 Bakery Products	Sweet and or Spoiled	Brown to Black	High	Cooking Oils, Lard, Flour, Sugar	Grey to Light Brown	Low	Normal	Normal	High
206 Sugar and Confectionary Products	NA	NA	Low	Low Potential	White Crystals	Low	Normal	Normal	High
207 Fats and Oils	Spoiled Meats, Lard or Grease	Brown to Black	High	Animal Fats, Lard	Grey to Light Brown	Low	Normal	Normal	High
208 Beverages	Flat Soda, Beer or Wine, Alcohol, Yeast	Various	Mod.	Grains 6 Hops, Broken Glass, Discarded Canning Items	Light Brown	High	Inhibited	Wide Range	High
21 Tobacco Manufactures	Dried Tobacco, Cigars, Cigarettes	Brown to Black	Low	Tobacco Stems& Leaves, Papers and Fillers	Brown	Low	Normal	Normal	Low
22 Textile Mill Products	Wet Burlap, Bleach, Soap, Detergents	Various	High	Fibers, Oils, Grease	Grey to Black	Low	Inhibited	Basic	High
23 Apparel and Other Finished Products	NA	Various	Low	Some Fabric Particles	NA	Low	Normal	Normal	Low

(continued)

TABLE 41. CHEMICAL AND PHYSICAL PROPERTIES OF INDUSTRIAL NON-STORMWATER DISCHARGES (continued)

Industrial Categories Major Classifications SIC Group Numbers	Odor	Color	Turbidity	Floatables	Debris and Stains	Structural Damage	Vegetation	pH	Total dissolved solids
Material Manufacture									
24 Lumber & Wood Products	NA	NA	Low	Some Sawdust	Light Brown	Low	Normal	Normal	Low
25 Furniture & Fixtures	Various	Various	Low	Some Sawdust, Solvents	Light Brown	Low	Normal	Normal	Low
26 Paper & Allied Products	Bleach, Various Chemicals	Various	Mod.	Sawdust, Pulp Paper, Waxes, Oils	Light Brown	Low	Normal	Wide Range	Low
27 Printing, Publishing, and Allied Industries	Ink, Solvents	Brown to Black	Mod.	Paper Dust, Solvents	Grey to Light Brown	Low	Inhibited	Normal	High
31 Leather & Leather Products	Leather, Bleach, Rotten Eggs or Flesh	Various	High	Animal Flesh & Hair, Oils, Grease	Grey to Black, Salt Crystals	High	Highly Inhibited	Wide Range	High
33 Primary Metal Industries	Various	Brown to Black	Mod.	Ore, Coke, Limestone, Millscale, Oils	Grey to Black	High	Inhibited	Acidic	High
34 Fabricated Metal Products	Detergents, Rotten Eggs	Brown to Black	High	Dirt, Grease, Oils, Sand, Clay Dust	Grey to Black	Low	Inhibited	Wide Range	High
32 Stone, Clay, Glass, and Concrete Products	Wet Clay, Mud, Detergents	Brown to Reddish-Brown	Mod.	Glass Particles Dust from Clay or Stone	Grey to Light Brown	Low	Normal	Basic	Low
Chemical Manufacture									
28 Chemicals & Allied Products									
2812 Alkalies and Chlorine	Strong Halogen or Chlorine, Pungent, Burning	Alkalies - NA Chlorine - Yellow to Green	Low	NA	Alkalies – White Carbonate Scale Chlorine - NA	High	Highly Inhibited	Basic	High
2816 Inorganic Pigments	NA	Various	High	Low Potential	Various	Low	Highly Inhibited	Wide Range	High
282 Plastic Materials and Synthetics	Pungent, Fishy	Various	High	Plastic Fragments, Pieces of Synthetic Products	Various	Low	Inhibited	Wide Range	High

(continued)

TABLE 41. CHEMICAL AND PHYSICAL PROPERTIES OF INDUSTRIAL NON-STORMWATER DISCHARGES (continued)

Industrial Categories Major Classifications SIC Group Numbers	Odor	Color	Turbidity	Floatables	Debris and Stains	Structural Damage	Vegetation	pH	Total dissolved solids
Chemical Manufacture (continued)									
283 Drugs	NA	Various	High	Gelatin Byproducts for Capsulating Drugs	Various	Low	Highly Inhibited	Normal	High
284 Soap, Detergents & Cleaning Preparations	Sweet or Flowery	Various	High	Oils, Grease	Grey to Black	Low	Inhibited	Basic	High
285 Paints, Varnishes, Lacquers, Enamels and Allied Products (SB - Solvent Base)	Latex - Ammonia SB - Dependent Upon Solvent (Paint Thinner, Mineral Spirits)	Various	High	Latex - NA SB - All Solvents	Grey to Black	Low	Inhibited	Latex-Basic SB - Normal	High
286 Indust. Organic Chemicals									
2861 Gum and Wood Chemicals	Pine Spirits	Brown to Black	High	Rosins and Pine Tars	Grey to Black	Low	Inhibited	Acidic	High
2865 Cyclic Crudes, & Cyclic Intermediates Dyes, & Organic Pigments	Sweet Organic Smell	NA	Low	Translucent Sheen	NA	Low	Highly Inhibited	Normal	Low
287 Agricultural Chemicals									
2873 Nitrogenous Fertilizers	NA	NA	Low	NA	White Crystalline Powder	High	Inhibited	Acidic	High
2874 Phosphatic Fertilizers	Pungent Sweet	Milky White	High	NA	White Emorphous Powder	High	Inhibited	Acidic	High
2875 Fertilizers, Mixing Only	Various	Brown to Black	High	Pelletized Fertilizers	Brown Emorphous Powder	Low	Normal	Normal	High
29 Petroleux Refining and Related Industries									
291 Petroleum Refining	Rotten Eggs, Kerosene, Gasoline	Brown to Black	High	Any Crude or Processed Fuel	Black Salt Crystals	Low	Inhibited	Wide Range	High
30 Rubber & Miscellaneous Plastic Products	Rotten Eggs, Chlorine, Peroxide	Brown to Black	Mod.	Shredded Rubber Pieces of Fabric or Metal	Grey to Black	Low	Inhibited	Wide Range	High

(continued)

TABLE 41. CHEMICAL AND PHYSICAL PROPERTIES OF INDUSTRIAL NON-STORMWATER DISCHARGES (continued)

Industrial Categories Major Classifications SIC Group Numbers	Odor	Color	Turbidity	Floatables	Debris and Stains	Structural Damage	Vegetation	pH	Total dissolved solids
Transportation & Construction									
15 Building Construction	Various	Brown to Black	High	Oils, Grease, Fuels	Grey to Black	Low	Normal	Normal	High
16 Heavy Construction	Various	Brown to Black	High	Oils, Grease, Fuels, Diluted Asphalt or Cement	Grey to Black	Low	Normal	Normal	High
Retail									
52 Building Materials, Hardware, Garden Supply, and Mobil Home Dealers	NA	Brown to Black	Low	Some Seeds, Plant Parts, Dirt, Sawdust, or Oil	Light Brown	Low	Normal	Normal	Low
53 Gen. Merchandise Stores	NA	NA	NA	NA	NA	Low	Normal	Normal	Low
54 Food Stores	Spoiled Produce, Rancid, Sour	Various	Low	Fragments of Food, Decaying Produce	Light Brown	Low	Flourish	Normal	Low
55 Automotive Dealers & Gasoline Service Stations	Oil or Gasoline	Brown to Black	Mod.	Oil or Gasoline	Brown	Low	Inhibited	Normal	Low
56 Apparel & Accessory Stores	NA	NA	Low	NA	NA	Low	Normal	Normal	Low
57 Home Furniture, Furnishings, & Equip. Stores	NA	NA	Low	NA	NA	Low	Normal	Normal	Low
58 Eating & Drinking Places	Spoiled Foods Oil & Grease	Brown to Black	Low	Spoiled or Leftover Foods	Brown	Low	Normal	Normal	Low
Coal Steam Electric Power	NA	Brown to Black	High	Coal Dust	Black Emorphous Powder	Low	Normal	Slightly Acidic	Low
Nuclear Steam Electric Power	NA	Light Brown	Low	Oils, Lubricants	Light Brown	Low	Normal	Normal	Low

Other Chemicals Indicative of Manufacturing Industrial Activities

Table 42 is a listing of various chemicals that may be associated with a variety of different industrial activities (from Klein 1962). It may be possible to examine non-stormwater outfall flow for specific chemicals, such as shown on this list, to identify which manufacturing industrial activities may be contributing the flows.

Example Problems for Locating an Industrial Source

Locating An Industrial Source

Hypothetical examples have been created to demonstrate how dry-weather discharges can be characterized so that their likely industrial sources can be identified. These examples show how observations of outfall conditions and simple chemical analyses, combined with a basic knowledge of wastewater characteristics of industrial and commercial operations located in the drainage area, can be used to identify the possible pollutant sources. The initial activities include pollutant analyses of outfalls being investigated. This requires the characterization on the non-stormwater flows, the identification of the likely industries responsible for the observed discharges, and finally, locating the possible specific sources in the watershed.

The industries which were identified as being located in a hypothetical stormwater drainage area (from the watershed analysis) included a vegetable cannery, general food store, fast food restaurant, cheese factory, used car dealer, cardboard box producer, and a wood treatment company. The methods used to determine the most likely industrial source of the dry-weather discharges are considered for three hypothetical situations of outfall contamination.

Case Example One

The hypothetical results of the pollutant analysis for the first situation found constant dry-weather flow at the outfall. The measurements indicated a normal pH (6) and low total dissolved solids concentrations (300 mg/L). Other outfall characteristics included a strong odor of bleach, no distinguishing color, moderate turbidity, sawdust floatables, a small amount of structural corrosion, and normal vegetation.

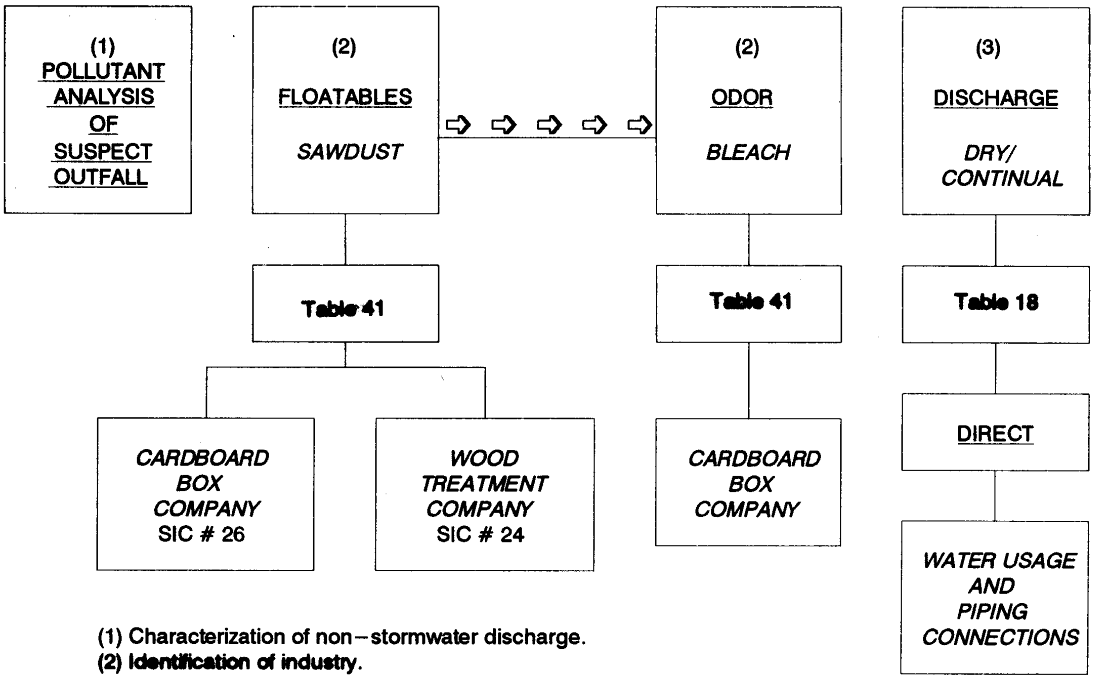
The significant characteristic in this situation is the sawdust floatables (see Figure 14). The industries which could produce sawdust and have dry-weather flow drainage to this pipe are the cardboard box company and the wood treatment company. According to SIC code, the cardboard box company would fall under the category of “Paper Products” (SIC# 26) while the wood treatment company would be under that of “Lumber and Wood” products (SIC# 24). Looking up these two industries by their corresponding SIC group numbers in Table 41 and comparing the listed properties, indicates that the paper industry has a strong potential for the odor of bleach. Wood products does not indicate any particular smell.

Based upon this data, the most likely industrial source of the industrial non-stormwater discharge would be the cardboard box company. Table 18 (Section 3) under SIC# 26 indicates that there is a high potential for direct connections in paper industries under the categories of water usage and illicit or inadvertent connections. At this point, further testing should be conducted at the cardboard box company to find if the constant source of contamination is coming from cooling waters, process waters, or direct piping connections (process waters are the most likely source, given the bleach and sawdust characteristics).

TABLE 42. SIGNIFICANT CHEMICALS IN INDUSTRIAL WASTEWATERS

Chemical:	Industry:
Acetic acid	Acetate rayon, pickle and beetroot manufacture
Alkalies	Cotton and straw kiering, cotton manufacture, mercerizing, wool scouring, laundries
Ammonia	Gas and coke manufacture, chemical manufacture
Arsenic	Sheep-dipping, fell mongering
Chlorine	Laundries, paper mills, textile bleaching
Chromium	Plating, chrome tanning, aluminum anodizing
Cadmium	Plating
Citric acid	Soft drinks and citrus fruit processing
Copper	Plating, pickling, rayon manufacture
Cyanides	Plating, metal cleaning, case-hardening, gas manufacture
Fats, oils	Wool scouring, laundries, textiles, oil refineries
Fluorides	Gas and coke manufacture, chemical manufacture, fertilizer plants, transistor manufacture, metal refining, ceramic plants, glass etching
Formalin	Manufacture of synthetic resins and penicillin
Hydrocarbons	Petrochemical and rubber factories
Hydrogen peroxide	Textile bleaching, rocket motor testing
Lead	Battery manufacture, lead mining, paint manufacture, gasoline manufacture
Mercaptans	Oil refining, pulp mills
Mineral acids	Chemical manufacture, mines, Fe and Cu pickling, brewing, textiles, photo-engraving, battery manufacture
Nickel	Plating
Nitro compounds	Explosives and chemical works
Organic acids	Distilleries and fermentation plants
Phenols	Gas and coke manufacture; synthetic resin manufacture; textiles; tanneries; tar, chemical, and dye manufacture; sheep-dipping
Silver	Plating, photography
Starch	Food, textile, wallpaper manufacture
Sugars	Dairies, foods, sugar refining, preserves, wood process
Sulfides	Textiles, tanneries, gas manufacture, rayon manufacture
Sulfites	Wood process, viscose manufacture, bleaching
Tannic acid	Tanning, sawmills
Tartaric acid	Dyeing; wine, leather, and chemical manufacture
Zinc	Galvanizing, plating, viscose manufacture, rubber process

Source: from Klein. *River Pollution, 2: Causes and Effects*. Butterworth & Co., 1962, presented in *The Water Encyclopedia*, D. Todd, Water Information Center, Port Washington, N.Y., 1979.



(1) Characterization of non–stormwater discharge.
(2) Identification of industry.
(3) Possible sources.

Figure 14. Flowsheet for industrial case example 1.

Case Example 2

The results of the pollutant analysis for the second situation found intermittent dry-weather discharges at the outfall. The test measurements indicated an acidic pH (3) and high total dissolved solids concentrations (approximately 6,000 mg/L). Other characteristics included a rancid-sour odor, grayish color, high turbidity, gray deposits containing white gelatin-like floatable material, structural damage in the form of spalling concrete, and an unusually large amount of plant life.

The rancid-sour smell and the presence of floatable substances at this outfall indicates that some type of food product is probably spoiling. This narrows the possible suspect industries to the fast food restaurant, cheese factory, vegetable cannery, and food store (see Figure 15). The corresponding SIC categories for each of these industries are “Eating and Drinking Places” (SIC# 58), “Dairy Products” (SIC# 202), “Canned and Preserved Fruits and Vegetables” (SIC# 203), and “Food Stores” (SIC# 54). Comparison of the properties listed in Table 41 for these SIC numbers indicates that elevated plant life is common to industrial wastes for the “Dairy Products” and “Food Stores” categories. However, the deciding factor is the acidic pH, which is only listed for “Dairy Products”. Thus, the white gelatin-like floatables are most likely spoiled cheese byproducts which are also the probable cause of the sour-rancid smell.

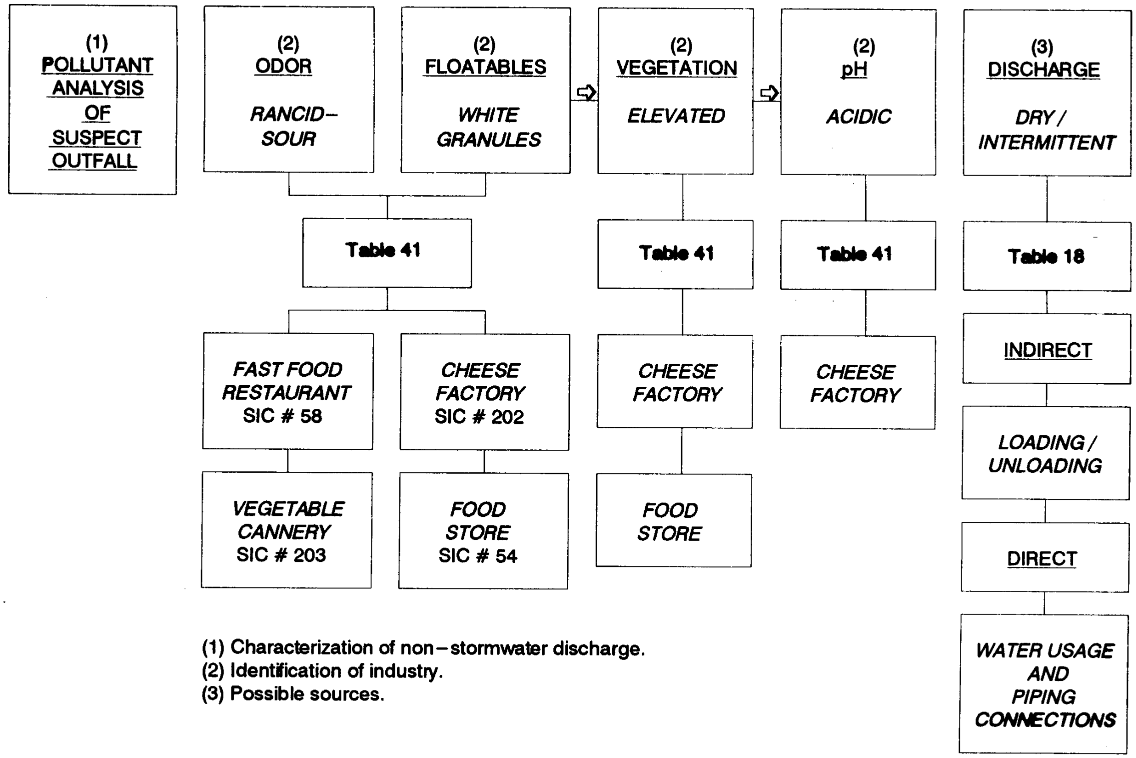
Since the dry-weather entry to the storm drainage system occurs intermittently, the flow could be caused by either a direct or indirect connection. To locate the ultimate source of this discharge coming from the cheese factory, both direct and indirect industrial situations are considered under the category of “Dairy Products” in Table 18 in Section 3. Thus, further examination of the loading dock procedures, water usage, and direct piping connections should be conducted since these categories all exhibit high potential for pollution in dairy production.

Case Example 3

The results of the test measurements for the final situation found a normal pH (6) and low total dissolved solids (about 500 mg/L). Signs of contaminated discharges were found at the outfall only during and immediately following rainfalls. Other outfall properties observed included an odor of oil, deep brown to black color, a floating oil film, no structural damage, and inhibited plant growth (see Figure 16).

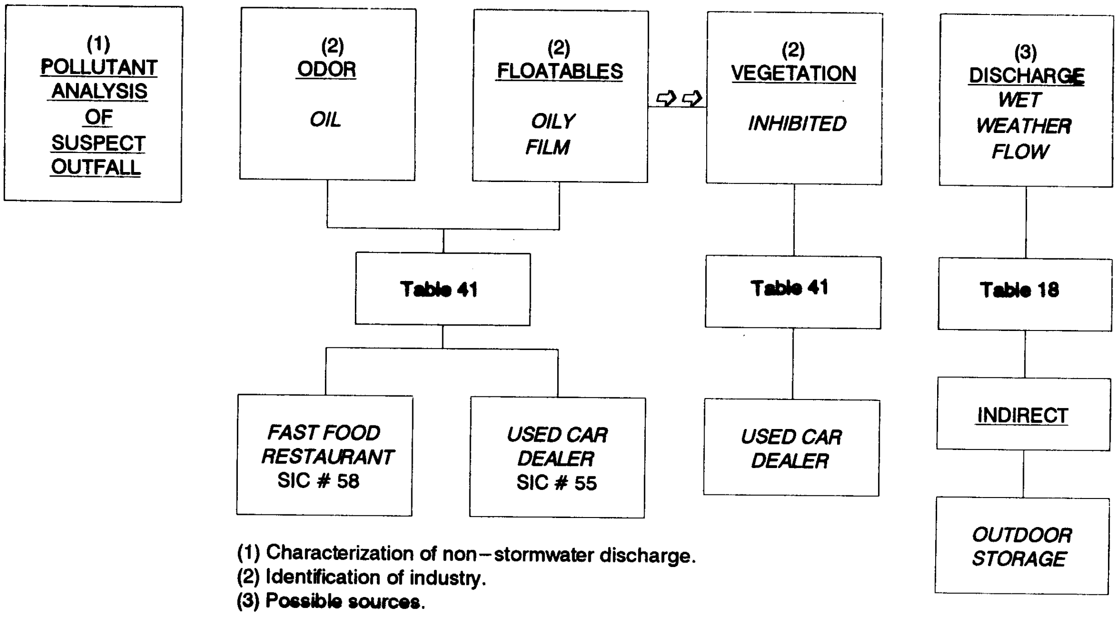
According to Table 41, the fast food restaurant and the used car dealer are the only two industrial sources in this area with high potential for causing oily discharges. Their respective SIC categories are “Eating and Drinking Places” (SIC# 58) and “Automotive Dealers” (SIC# 55). Comparison of the properties shown on Table 41 indicates inhibited vegetation only for the second category. Thus, the most likely source of the discharge is the used car dealer.

Furthermore, the source of contamination must likely be indirect, since the discharge occurs only during wet weather. Reference to Table 18 (Section 3), under the category of “Automotive Dealers”, indicates a high potential for contamination due to outdoor storage. This fact, plus the knowledge that most used cars are displayed outdoors, makes it fairly clear that surface runoff is probably carrying spilled automotive oil into the storm drain during rains.



(1) Characterization of non–stormwater discharge.
(2) Identification of industry.
(3) Possible sources.

Figure 15. Flowsheet for industrial case example 2.



(1) Characterization of non–stormwater discharge.
(2) Identification of industry.
(3) Possible sources.

Figure 16. Flowsheet for industrial case example 3.

Section 10
Corrective Techniques

In addition to identifying problems of unauthorized or inappropriate entries to stormwater systems, it is even more important to prevent problems from developing at all, and to provide an environment in which future problems will be avoided. Thus, a combined approach of identifying and correcting existing problems and avoiding future problems has considerable merit. In this section, the focus is on discussing ways in which future problems can be avoided. However it should be noted that this is not an in-depth review, but has been included to provide the reader with suggestions that could be incorporated into a pollution prevention program.

There are also situations in which the sanitary system is so connected to the stormwater system that good intentions, vigilance, and reasonable remedial actions will not be sufficient to solve the problems. In an extreme case, it may be that while it was thought that a community had a separate sanitary sewer system and a separate storm drainage system, in reality the storm drainage system is acting as a combined sewer system. When recognized for what it really is, the alternatives for the future become clearer: undertake the considerable investment and commitment to rebuild the system as a truly separate system, or recognize the system as a combined sewer system, and operate it as such, without the disillusionment that it is a problem-plagued storm drainage system which can be rehabilitated.

Less extreme than designating a polluted stormwater drainage system a combined sewer system, is the action of focusing on pollution prevention by:

- public education,
- an organized systematic program of disconnecting commercial and industrial non-stormwater entries into the storm drainage system,
- tackling the problem of widespread septic system failure,
- disconnecting direct sanitary sewerage connections,
- rehabilitating storm or sanitary sewers to abate contaminated water infiltration, and
- developing zoning and ordinances.

In this section, the above items will be discussed, together with a section on treatment of wide spread sanitary sewerage failure.

Public Education

One can argue that an ill informed and apathetic public has condoned the past actions of private citizens, commercial entities, industrial concerns, and public officials which led to some of the past and present problems with unauthorized entries to storm drainage systems. One also knows the power of an aroused, concerned public in altering behavior at all levels. Thus, public education has a role to play. It can be effective in altering the behavior of an individual who had assumed that the inlet on the curb was the place to discharge used crankcase oil. It can be effective when organized groups lobby for the return of a stream or a reservoir to a clean and attractive condition.

Public education carries with it the implicit assumption that an educated public will make the “right” decisions, the educated public will be concerned about the “right” problems, and it will encourage private and public organizations to develop solutions to the “right” problems. Fortunately, most of the problems, issues, and corrective measures are clear cut with respect to unauthorized entries to the stormwater system. Public education is a communication art associated with significant changes when successful, and imperceptible change when unsuccessful. As with all education, it does not end, but is a continuing process. The following paragraphs describe some of the ways in which public officials can help to educate the public. The “public” has been subdivided into categories which are representative of the problem areas with respect to unauthorized entries to storm drainage systems. The subcategories of the public are:

- industrial
- commercial
- residential
- governmental

Industrial decision makers can be educated by public officials through direct contact when they seek information, by education of the consultants from whom industry seeks advice, and by education of trade associations. Indirect educational opportunities are provided by speaking to meetings of professional organizations and by writing in professional newsletters and journals. Industrial decision makers are a small group which is likely to respond as they recognize that they have to address the problem of unauthorized entries to the stormwater system.

Commercial storm drainage system users are a larger group to educate. The educational process will have to focus on both proprietors and their employees. It will have to recognize the state of both groups, new businesses opening; existing businesses moving, expanding, and closing; and employees entering the work force and changing jobs. Education will have to be focused in the local community. The role of trade and professional associations will be less than was the case with industrial groups. News announcements in the local press will play a role as well as mailed news items. Individual contact between a public official and the proprietor of a commercial establishment will play a larger role. Follow up and repeated contact may be necessary to answer questions and cope with employee turnover. Public education can also benefit from failures. For example, certain violations of discharge practices may be so serious, or flagrant, that a citation or fine results. The local press, if informed, may find such an incident newsworthy. The general public, or other potential offenders, may benefit from this educational procedure.

An informed public willing to act on their convictions is the product sought from public education. The public educator focuses on large groups, as one-on-one contact is unlikely to be either time or cost effective. Long range educational goals may be tackled through school programs, while shorter range educational goals may focus on community groups. Public education will have to focus on broader environmental issues than inappropriate entries to storm drains. Subgroups in the community may play important roles in public education. For example, scouts may undertake community improvement projects including placing signs on curbside storm drains informing the public that the drain is for stormwater only, and not for discharge of wastes. Thus, public education must take advantage of opportunities presented by groups looking for community improvement projects, the opportunities that are available in working with the school system, and opportunities arising from the news media being supplied with newsworthy items.

The final group that public officials should address in public education is other public officials and governmental institutions. Some small governmental units may not know about precautions to be taken with discharges to storm drainage systems unless they are properly informed. Such subgroups may include road departments, sanitation workers, and workers at public institutions such as hospitals and prisons. A multilevel, multitarget public education program can help to avoid problems.

Commercial and Industrial Site Disconnections of Non-Stormwater Sources

Out of convenience and out of ignorance, commercial and industrial sites may impose an increasing load on the storm drainage system. This may be through direct discharges to the storm drainage system, or it may be through diffuse and indirect sources in which the site grounds are contaminated by spills and discharges which are then washed off by storm runoff to the storm drain during rainfall events or by wash water during wash-down operations. The problem is compounded by the vast array of sizes of commercial and industrial enterprises. A single person enterprise has little opportunity to build expertise on the subject of stormwater pollution, while a large industrial enterprise may have an environmental division. To the uninformed person, any curb opening may be thought to be part of a comprehensive sanitary wastewater treatment system and the proper entrance point for polluted water discharges or other debris.

Corrective measures for improper uses of storm drains have to be developed recognizing the differences in knowledge and sophistication of the client. Industrial users are few in number but are expected to have the most complex problems. If industrial users are aware, or made aware, of existing and or new federal, state, or local regulations to prevent pollution of stormwater drainage systems, they will usually comply with the regulation. If not, these regulations provide the authority and communication means to instigate corrective action.

Commercial groups are heterogeneous. An appropriate way of working with them to institute changes in their use of storm drainage systems, may be to work with one category of commercial groups at a time. For example, consider gasoline filling stations as a single category. It is possible to focus on correcting similar problems at many facilities that exist in this category. The flushing of radiators may be seasonally common. A typical practice is to let radiator flushing waters (including coolants) to drain to an inlet to the storm drainage system. Education followed by assurance that there will be strict enforcement of discharge regulations or ordinances may be effective. However, a group such as gasoline filling stations cannot be expected to have a long institutional memory as new operators take over and others drop out. Thus, vigilance and follow-up are important to insure that there is not a gradual diminution of appropriate practices.

For both small commercial and large industrial enterprises, willful and knowledgeable violation of the regulations limiting entries to storm drainage systems have to be dealt with firmly and promptly or the enforcement program runs the chance of becoming ineffective. Thus the governmental unit undertaking responsibility for improving the practices regarding entries to storm drainage systems must have an enforcement plan ready.

Failing Septic Tank Systems

Failing septic tank systems can have an impact on an otherwise well functioning storm drainage system. Before discussing corrective measures, it is important to identify the relationship that may develop between a septic tank system and a storm drainage system.

A septic tank system consists of two major components: a septic tank and a leaching field (a waste spreading or soil absorption system). In addition, of course, there is piping associated with the system. Domestic sanitary wastewaters are piped directly to the septic tank. The septic tank typically is made of concrete, is rectangular in shape, is usually divided into two compartments, and has a capacity of one to several thousand gallons. The septic tank serves as an anaerobic digestion and settling unit in which biological action converts the biodegradable liquid and solid waste particles into stable end products. Gravity separates a significant portion of both biodegradable and non-biodegradable particulate matter to the tank bottom or top (depending on whether the particles sink or rise, respectively). Some of the products of this partial treatment process are carbon dioxide, methane, hydrogen sulfide and other odor producing gases, digested and refractory or relatively non-biodegradable sludge, and floating scum. Because the septic tank remains full, it must discharge a volume of wastewater each time a volume of wastewater is discharged into it. This discharged water enters a leaching field where some additional treatment occurs and the final effluent is discharged to the groundwater.

A septic tank may be a low maintenance treatment unit, but it is not entirely maintenance free. As the septic tank continues to be loaded, the scum and sludge layers build up so that the remaining volume available for treatment is reduced. Thus, some of the partially digested or undigested solids, scum, and sludge may be carried from the septic tank to the leaching field where the soil void space may become clogged. As the soil voids become clogged, the ability of the leaching field to handle the liquid portion of the waste is reduced, and surface ponding of the wastewater may result. Of course, ponding could have been prevented by having the septic tank serviced; that is, by having the septic tank pumped. Pumping removes the sludge, scum, and other contents of the septic tank so that its storage and treatment capacity is restored. Pumping frequency varies depending on the size of the septic tank and its loading rate. Residential septic tanks may need to be pumped every two to five years. Commercial and institutional septic tanks may need more frequent pumping.

Failed septic tank systems have the potential to pollute stormwater because the leaching field will saturate the ground, and possibly form ponded water on the ground surface. The ponded water may run off and enter a storm drain inlet or drainage ditch, or infiltrate the ground in another area which is intercepted by a storm drain through infiltration. When it rains, any remaining ponded water may be washed off with the runoff to the storm drainage system. Depending on the severity of the septic tank failure, the ponded water can have the characteristics of partially treated sanitary wastewater or nearly untreated sanitary wastewater. Thus, septic tank failures can contaminate the stormwater drainage system during both wet and dry weather.

Septic tank systems may fail even with good maintenance practices. Such failure can result when the soil is simply not permeable enough for the leaching field, or when the soil absorbance capacity is exceeded through long use. A tight clay soil may have such low permeability that the leaching capacity is very limited. If a number of homes are built in close proximity, their septic tank leaching fields may collectively exceed the soil's capacity, leading to a stormwater pollution problem. Even properly operating septic tank systems are a potential pollutant source. Because the basic function of the leaching field is to discharge partially treated effluent to the groundwater, this septic tank effluent can infiltrate into nearby stormwater drainage systems.

Various corrective methods exist for failing septic tank systems that pollute stormwater. These methods include: improve maintenance, institute preventative measures to avoid problems, and abandon the septic tank system with connections made to a sanitary sewerage system. In some cases, improved maintenance may be the answer. Some persons will not do any maintenance to their septic tank system until it fails (they note ponded water in the leaching field area). Then they call for the septic tank to be pumped. In many cases, this is not sufficient to correct the problem: it may be too little action too late. The preventative action of having the septic tank pumped should have taken place prior to failure of the system. Education may provide part of the remedy. The septic tank user may respond to exhortations to have the septic tank pumped on a regular basis, before failure. Coercion through ordinances may be another answer. Ordinances may require that the septic tank be pumped at a specified frequency, with a public body monitoring the program to ensure that maintenance has been carried out.

It sometimes happens that soil conditions and population density rule out both voluntary or involuntary maintenance. In this case, it may be necessary to consider abandoning the septic tank system and installing a system consisting of sanitary sewers leading to a treatment plant. Another option consists of abandoning the septic tank treatment method in favor of small package treatment units that provide aerobic treatment of the domestic sanitary wastewater which is then discharged to a regional leaching field. This option may succeed where the septic tank system has failed, because wastes treated in an aerobic unit may not have the leaching field clogging potential of wastes treated in an anaerobic septic tank. However, experience has shown that these advantages are only obtained with proper control and maintenance. Aerobic systems are more sensitive than conventional septic tank systems to improper maintenance and may therefore not offer any real benefits.

Direct Sanitary Sewerage Connections

Due to indifference, ignorance, poor enforcement of ordinances, or other reasons, a stormwater drainage system may have sanitary wastewater sewerage direct connections. Obviously, the sanitary wastewater entering the storm drain will not receive any treatment and will pollute a large flow of stormwater, in addition to the receiving water. If the storm drain has a low dry-weather flow rate, the presence of sanitary wastewater may be obvious due to toilet paper, feces, and odors. In cases of high dry-weather flows, it may be more difficult to obviously detect raw sanitary wastewaters due to the low percentage of sanitary wastewater in the mixture. Even though the sanitary wastewater fraction may be low, the pathogenic microorganism counts may be exceedingly high.

The previously discussed field testing procedures (including detergents, ammonia, potassium, and fluorides) will assist in the detection and quantification of sanitary wastewater contamination in the storm drainage system. Flow monitoring may show the variations in the flow rate that are typical of domestic sanitary wastewater.

Dye testing can be effective in finding specific sanitary wastewater connections between a house and a storm drainage system. Dye, such as diluted rhodamine or fluorescein, is flushed down the toilet of a house and the storm drain is monitored to determine whether the dye appears. Care has to be exercised when using this method, as these dyes may stain fixtures that are being tested, and any spillage in the house causes stains that are very difficult to remove.

Monitoring of the storm drainage system with remote video cameras can show the locations of breaks in the storm drain where a domestic wastewater sewer was attached. Video cameras may also show discharges taking place at these locations, demonstrating that the lines are in active use.

Corrective measures involve undertaking a program of disconnecting the sanitary sewer connections to the storm drainage system and reconnecting them to a proper sanitary wastewater sewerage system. The storm drainage system then has to be repaired so that the holes left by the disconnected sanitary sewer entrances do not become a location for dirt and groundwater to enter.

Rehabilitating Storm or Sanitary Sewers to Abate Contaminated Water Infiltration

Infiltration of contaminated water into a stormwater drainage system can cause substantial pollution of the system. This could occur where a sanitary sewer overlies and crosses (or parallels) a storm drain, with sanitary wastewater exfiltrating from the sanitary sewer and infiltrating the storm drain. Other instances would be in areas of polluted groundwater, where the storm drainage is below the water table or intercepts infiltrating groundwater, or in areas having septic tank systems, as discussed previously.

It would be best to correct the sanitary sewer if only one drainage system can be corrected. This would have the dual advantage of preventing infiltration of high or percolating groundwaters and preventing pollution of stormwater with exfiltrating sanitary wastewater. Rehabilitation of the drainage systems by use of inserted liners, or otherwise patching leaking areas, are possible corrective measures. It is important that all drains with infiltration problems be corrected for this corrective action to be effective. This would also include repairing house lateral sanitary wastewater lines, as well as the main drainage runs. However, these corrective measures are more likely to be cost effective when only a relatively small part of the complete drainage systems require rehabilitation.

Zoning and Ordinances

Land use controls achieved by zoning have the potential to exacerbate problems or diminish them. For example, in an area with soils that are ill suited for septic tanks and leaching fields, the potential for future problems is increased if zoning allows small lots for single family residential development and allows septic tank systems. As the area develops, septic tank failures will become common, resulting in increased pollution of stormwater and groundwater. On the other hand, in areas having poor soils, zoning can require correspondingly larger lot sizes and larger leaching fields, resulting in fewer future problems. Ordinances may specify the results that have to be achieved by infiltration tests used to size leaching fields. Also, ordinances can require that a responsible public official be present when the infiltration test is run to decrease the likelihood of false or spurious results being reported. Certified septic tank installers, also checked by public official inspectors, should also be required to increase the likelihood of the system being installed correctly.

Zoning can also have a role to play in avoiding development of land that is subject to frequent flooding. In such land, flooding and high groundwater conditions can result in the sanitary sewerage system being gradually overloaded by infiltration so that cross flow to the storm drainage system can occur.

Ordinances can help to control problems by putting the force of law and public policy behind desirable practices. For example, ordinances can make mandatory practices such as septic tank maintenance that otherwise would be voluntary. By making the practice mandatory, desirable practices are performed on a regular schedule so that large problems have less opportunity to develop. Ordinances can also regulate the persons doing the pumping of septic tanks so that they discharge the septage to wastewater treatment plants where it can be properly treated rather than it being discharged improperly where the pollution problem is just transferred from one location to another.

Ordinances can also help prevent and or control pollution from many other sources by restrictions on: disposal of household toxic substances to storm drains, storage of chemicals by industry, disposal of industrial wash down water, etc.

Zoning and ordinances represent important means for governing bodies to anticipate problems, to avoid problems, and to manage problems, so that desirable ends are achieved and undesirable consequences are avoided. Enactment of zoning and ordinances occurs in the public arena where interested persons can participate and express their views and concerns. The public can become educated in this process, but zoning and ordinances have the desirable characteristic of being remembered and remaining enforceable long after an individual forgets, becomes disinterested, or becomes recalcitrant.

Another important step that municipalities can take is the development of policies and procedures for the management of spills from transportation (including both roadway and rail) and pipeline accidents. Spills should not be merely washed into the storm drainage system, but should be collected for proper treatment and disposal.

Widespread Sanitary Sewerage Failure

Connections (whether directly by piping or indirectly by exfiltration or infiltration) of sanitary sewers to the storm drainage system may be so widespread that the storm drainage system has to be recognized as a combined sewer system. This could also be the case when the prevalence of septic tank failures leads to widespread sanitary wastewater runoff to the storm drainage system. One usually thinks of a combined sewer system as having all of the sanitary sewer connections to the same sewers that carry stormwater, but the previous discussion suggests that there are degrees of a storm drainage system becoming a combined sewer system. Previously, the recommendations have been made that widespread failure of septic tank systems might necessitate the construction of a sanitary sewer to replace the septic tanks. Also recommended was a program of identifying and disconnecting sanitary sewers from the storm drainage system.

Prior to these actions taking place, the storm drainage system operates to some degree as a combined sewer system. It may be that the sanitary sewerage system is not capable of handling the load that would be imposed on it if a complete sewer separation program were undertaken. Or, in an extreme case, no sanitary sewer system may exist. By recognizing that a combined sewer system does in fact exist may help to focus attention on appropriate remedial measures. The resources may also not be available to undertake construction of a separate sanitary wastewater drainage system.

One should then focus on how to manage the combined sewer system that is in place. Management may require that end-of-pipe storage/treatment be investigated. Also, the combined sewer system may be tied into other combined sewers so that more centralized treatment and storage can be applied. While operation of a combined sewer system is not a desirable option, it may be preferable to having the stormwater and the large number of sanitary entries receive no treatment.

An early identification and decision to designate a storm drainage system a combined sewer system, will prevent abortive time and costs being spent on further investigations. These resources can then be more effectively used to treat the newly designated combined sewer system.

In essence, recognition of a system as being a combined sewer system provides a focus in the regulatory community so that it may be possible to operate the system so as to minimize the damage to the environment. Plans can then be developed to provide the resources to separate the system.

Section 11
Birmingham, Alabama, Verification Project

This section describes the demonstration project that was carried out in Birmingham, Alabama, to test the procedures presented in this report (Lalor 1994). Special attention was given to the collection of the library data and in evaluating the outfall data analysis procedures to identify the dry-weather sources.

Collection and Analysis of Background Data from Potential Dry-Weather Flow Sources

Potential sources of dry-weather flows identified within the commercial and residential land use area selected for study during this project included spring water, infiltrating shallow ground water, tap water, irrigation runoff from landscaped areas and a golf course, sewage, septic tank leachate, commercial laundry waters, commercial carwash waters, radiator wastes, and metal plating bath wastes. Obviously, some of these sources would contribute to pollution problems, and some would not. However, all have the potential for showing up in dry-weather flows in storm sewer systems. Therefore, a chemical understanding of each, with respect to the selected tracers, is needed to build a "library" to which outfall dry-weather flows can be compared.

Collection of Source Area Samples

To obtain the background information needed to construct such a library, samples were collected directly from the potential sources identified above. To the extent possible, specific sampling sites were located in the drainage area of the creek reach selected for the field investigation. Sample sets for each source category contained 10 to 12 samples, except where more samples were necessary to better represent large periodic variations (such as for sanitary sewage).

After collection, samples were iced and returned to the laboratory for analysis. All samples were analyzed using the test methods identified in Table 29 of Section 6. Physical characteristics were also noted for each category of samples. Table 43 contains a summary of the physical observations noted for each sample. Numbers in the numerator indicate the number of samples which displayed the characteristic in question. Denominators represent the total number of samples. All references to "sediments", in connection with these directly collected source samples, refer to settleable solids.

Tap Water Samples--

Tap water samples were collected along the length of the distribution system through the study area. Results are presented in Table 44. Chlorine values were inversely related to the distance of the sampling point from the water treatment plant. Values varied from a high of 1.5 mg/L near the plant, to a low of 0.03 mg/L near the end of the distribution branch. Samples 1 through 5 were taken from one branch of the distribution system, with sample site number 1 located nearest the treatment plant. Samples 6 through 10 were taken from another branch, with sample site number 6 located nearest the treatment plant. Ammonia and toxicity also had relatively high COV values for the tap water samples. In contrast, Fluoride concentrations were very consistent, in the narrow range of between 0.96 to 1.0 mg/L, irrespective of sampling location. Specific conductivity, hardness, detergents, fluorescence, potassium, pH, color, and phenols also had very small COV values. All tap water samples were also clear and free of odors, floatables, sheens and sediments.

TABLE 43. SUMMARY OF PHYSICAL CHARACTERISTICS OF SOURCE SAMPLES

Source	Color	Odor	Turbidity	Floatables/Sheens	Sediments
Spring Water	0/10	0\10	0\10	0\10	0\10
Shallow Ground	6/10	0\10	0\10	0\10	0\10
Tap Water	0\10	0\10	0\10	0\10	0\10
Landscape Irrigation	36/36	0\10	2\10	2\10	0\10
Sanitary Sewage	13\13	36\36	36\36	NA	NA
Septic Tank Discharge	10\10	8\13	0\13	0\13	0\13
Carwash Wastewater	10\10	3\10	10\10	3\10	6\10
Laundry Wastewater	10\10	5\10	10\10	3\10	0\10
Radiator Wastes	10\10	10\10	8\10	10\10	2\10
Plating Wastewaters	10\10	5\10	2\10	0\10	10\10

NA: Data not available

TABLE 44. TAP WATER SAMPLES

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25) (% reduc.)	Copper (mg/L)	Phenols (mg/L)
1	112	0.98	49	0	4.5	1.48	0.02	6.98	0	1.50	74.9	NA	NA
2	112	0.97	50	0	4.0	1.55	0.03	7.00	0	1.26	64.4	NA	NA
3	113	1.00	48	0	4.3	1.46	0.04	6.96	0	1.26	56.6	NA	NA
4	113	0.96	82	0	4.5	1.5	0.02	6.07	0	1.24	29.8	NA	NA
5	110	0.95	50	0	5.0	1.66	0.03	6.96	0	0.40	64.9	NA	NA
6	112	0.96	49	0	4.5	1.58	0.03	7.00	0	1.38	41.0	NA	NA
7	112	0.96	50	0	4.5	1.57	0.02	6.99	0	1.37	61.6	0.01	0.00
8	111	0.96	50	0	5.0	1.56	0.03	6.96	0	0.19	35.4	0.00	0.00
9	111	0.97	47	0	5.0	1.60	0.03	6.97	0	0.16	31.4	0.02	0.00
10	110	0.96	48	0	5.0	1.57	0.03	6.97	0	0.03	10.3	0.00	0.00
mean	111	.097	49	0	4.6	1.55	0.03	6.89	0	0.88	47.0	0.01	0.00
st. dev.	1.07	0.01	1.42	0	0.35	0.06	0.01	0.29	0.00	0.60	20.45	0.01	0.00
95%conf. limits (mean +/-)	0.67	0.01	0.88	0	0.22	0.04	0.00	0.18	0.00	0.37	12.6	0.01	0.00
median	112	0.96	49.5	0	4.5	1.57	0.03	6.97	0	1.25	48.8	0.01	0.00
COV	0.01	0.01	0.03	--	0.08	0.04	0.33	0.04	--	0.68	0.43	1.00	--
distribution	normal	normal	normal	uniform	normal	normal	normal	normal	uniform	bi-modal	normal	uniform	uniform

NA: Data not available

Spring Water Samples--
The field study area was pocked with springs prior to development, and some are still accessible at their source. All spring water samples were collected from these sources, and samples were collected during both rainy and dry seasons. Table E-1 (Appendix E) presents test results from the spring water samples. Hardness and conductivity were the most notable tracer parameters for the groundwater samples, being about 250 mg/L for hardness and about 300 µS/cm for conductivity. All other parameters were in very low concentrations, and the pH was very close to neutral. All spring water samples were clear and odor free, with no floatables, sediments or sheens.

Shallow Groundwater Samples--
Shallow groundwater was collected from flows above impervious layers exposed by road cuts and along river banks in the study area. Table E-2 presents test results from shallow ground water samples. Potassium and ammonia results for samples 1 through 3 were not available, as were pH results for samples 1 and 2. The chemical characteristics for shallow groundwater samples were significantly different from the spring water samples, especially in the lower hardness and conductivity values. Shallow groundwater samples had good clarity, were odor free, and were free of floatables, sediments and sheen. About half of the samples had some color noted.

Irrigation Water Samples--
Irrigation water samples were collected from sprinkler runoff over lawns and landscaped areas, as well as from a public golf course in the study area. Samples were collected using a hand-held vacuum pump which evacuated the sample bottle, drawing the sample through a Teflon™ tube. Results are presented in Table E-3. All chlorine concentrations were quite low (compared to most tap water samples) due to the rapid interaction of the chlorine with organics in the lawn areas. Fluorescence was also very high, compared to the tap water samples. All irrigation water samples had traces of color, and two of the samples were somewhat cloudy due to suspended soil particles. Grass or leaf fragments were observed floating on two samples. No sheens or odors were detected.

Sanitary Sewage Samples--
The characteristics of sanitary sewage were expected to change throughout the day, reflecting domestic activity and a time lag corresponding to the transit time of the wastewater in the sewers. A periodic pattern was observed for each parameter, as shown in Table E-4. Samples were collected from the sanitary sewage trunk line which runs through the study area. This line originates just above the study area, and carries wastes from commercial and residential areas only, with no known industrial discharges (based on maps and discussions with Jefferson County personnel). Fifteen-minute grab samples, compiled bi-hourly, were collected for 24-hour periods using an automatic sampler to identify the variation in sewage quality. Sampling took place on three different days during dry weather. Sanitary sewage samples were gray in color and cloudy. Conductivity, fluoride, detergents, fluorescence, potassium, ammonia, color, and toxicity are all distinguishable for these samples. A distinct and easily recognizable odor was apparent in all samples. No sheens were obvious on the water surfaces. A weighted, perforated (0.6 cm-openings) polypropylene intake was used with the sampler to help prevent clogging, so floatables, if present, were not collected.

Septage Samples--
Septage contributions to dry-weather flows may originate as septage field leachate, or seepage from failing septic systems. A Xitech groundwater sampler was used to collect some septage field leachate samples. Other samples were collected directly from septic tank effluent lines. Test results from these samples are presented in Table E-5. Septage samples number 1, 2 and 3 were collected from homes where only water from toilet flushings ("black water") entered the septic tank. These homes were located in a rural area outside of the project study area, but received tap water from the same water treatment plant. Other wastewaters from these homes were released directly onto adjacent portions of the homeowner's property. This situation would be highly unlikely in an urban area. The black water samples had greater concentrations of most tracer parameters, except for specific conductivity and color. All samples were also found to be extremely toxic, whereas the sanitary sewage samples shown on Table E-4 had only low to moderate toxicity. Color was apparent in all septage samples, but samples were clear, with no sheens or floatables. An indistinct, earthy odor was apparent in most samples.

Commercial Car Wash and Laundry Samples--
Wastewater was collected from the sumps of commercial carwashes and laundries. Tables E-6 and E-7 present test results from these samples. These two wash water sample groups were generally similar, except that hardness, potassium, and color were substantially greater for the commercial carwash samples than for the commercial laundry water samples. All carwash and laundry samples were highly toxic, colored and cloudy. Oil sheens were apparent on approximately one-third of the carwash samples, and solids often settled out in the sample jars. Some of the laundry samples had a distinguishable detergent odor, and floatables were noted in some samples.

Radiator Flushing Water--
Vehicle maintenance facilities provided radiator flushing wastes. Table E-8 presents data from radiator flushing water samples. Most radiator flushing wastes were intensely iridescent green, and most were cloudy. Oily or metallic odors were noted. The water had very high specific conductivity, very high fluorides, very high fluorescence and potassium and high color. All samples were also extremely toxic.

Metal Plating Bath Water--
Wastes from metal plating baths (pre-treated on site) were collected from three different facilities that had permits to discharge these wastes to the sanitary sewage system within the project study area. Processes at each site differed considerably, and the data collected and presented in Table E-9 reflect this variation. These samples all had very high conductivity, high fluorescence, very high hardness, high potassium, ammonia, copper, and color, and were extremely toxicity. All samples were colored and ranged from gray to green to gold. Sediments were apparent in all samples, and a slightly metallic or acidic odor was associated with half of the samples.

Data Analyses of Source Water Characteristics

Data from the above potential sources of dry-weather flow were also analyzed to: (1) determine which parameters contribute unique and significant information to the source characterizations, and (2) determine the degree to which individual source types could theoretically be separated and identified based on these source characterizations. The statistical analyses included exploratory and pattern recognition techniques including box plots, Pearson correlation matrices, Mann-Whitney U tests, and cluster analyses, as described below.

Box Plots of Source Water Characteristics--
Typical concentration patterns were established for each of the potential sources of dry-weather flow noted above. The extent to which these concentration patterns differed from one source to the next, and the variation observed in the patterns within a single source, would eventually determine the extent to which information from the outfall screening methodology could be used to identify the source or sources of dry-weather flow from a specific outfall.

An intuitive appreciation of this information can be gained from the box plots in Figure 17 for specific conductivity and Figures E-1 through E-12 for the other tracer parameters. The upper and lower boundaries of the “box” itself represent the 25th and 75th percentile values in the data set, and the horizontal line between the two represents the median. The ends of the upper and lower vertical lines, extending from the boxes, denote the 10th and 90th percentile values, while the circles represent the minimum and maximum values in each data set. Each of these figures visually summarize the concentrations at which one parameter occurs within each source category. Boxes that do not overlap (at the 25 and 75 percentile points) are generally significantly different at least at the 95% confidence level.

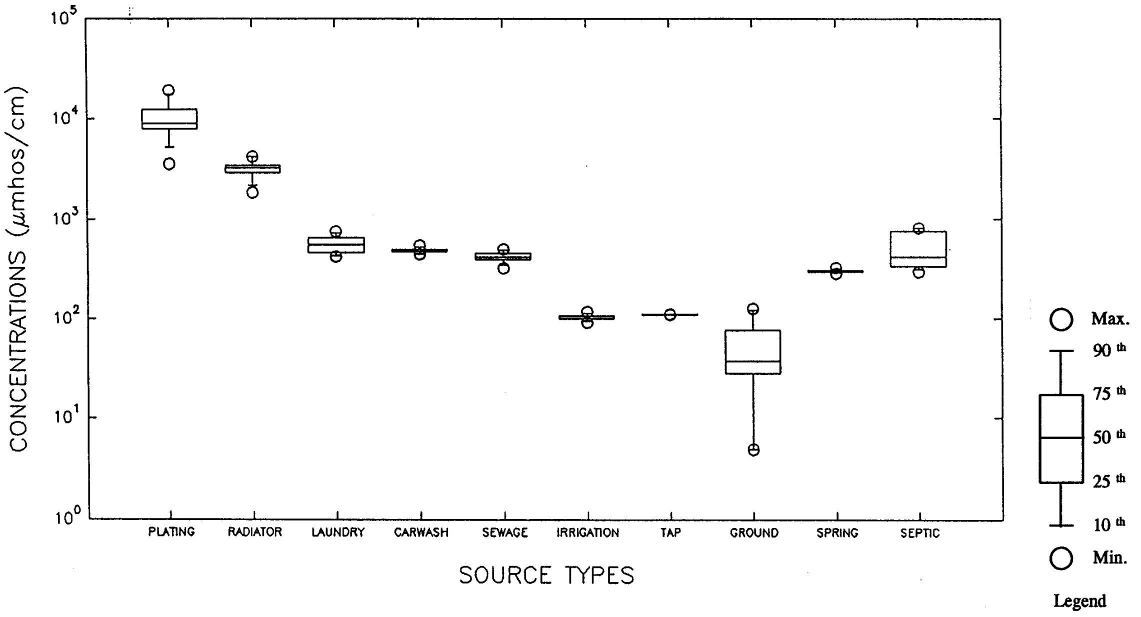


Figure 17. Conductivity comparisons for samples collected from potential dry-weather flow sources.

These figures graphically show significant groupings of sample types that may be distinguishable for different tracer parameters. The following lists shows these major groupings from these figures (in order of high to low concentrations):

Specific conductivity (Figure 17)
  - plating bath water
  - radiator flushing water
  - laundry, carwash, sewage, septic, and spring waters
  - irrigation and tap water
  - shallow ground water

Fluoride (Figure E-1)
  - radiator flushing water
  - laundry wash water
  - carwash water
  - plating bath water
  - sewage, irrigation, tap, and septic waters
  - groundwater and spring water

Hardness (Figure E-2)
  - plating bath water
  - spring water
  - carwash and sewage waters
  - irrigation, tap, and septic waters
  - radiator, laundry, and groundwaters

Detergents (Figure E-3)
  - carwash waters
  - laundry waters
  - radiator flush waters
  - plating, sewage, and septic waters
  - irrigation, tap, ground, and spring waters

Fluorescence (Figure E-4)
  - radiator flush water
  - laundry and carwash water
  - plating, sewage, irrigation, and septic waters
  - tap, ground, and spring waters

Potassium (Figure E-5)
  - radiator flush water
  - plating bath water
  - carwash water
  - septic water
  - laundry, sewage, and irrigation water
  - tap, ground, and spring water

Ammonia (Figure E-6)
  - plating and septic waters
  - radiator flush water
  - sewage water
  - laundry water
  - irrigation water

- carwash and groundwater
- tap water
- spring water

pH (Figure E-7)

- laundry water
- radiator, carwash, sewage, irrigation, tap, ground, spring, and septic waters
- plating bath waters

Color (Figure E-8)

- radiator flush water
- carwash water
- plating and septic waters
- laundry and sewage waters
- irrigation and ground waters
- tap and spring waters

Chlorine (Figure E-9)

- laundry and tap waters
- plating, radiator, carwash, sewage, irrigation, groundwater, and septic waters
- spring water

Toxicity (Figure E-10)

- plating, radiator, laundry, carwash, and septic waters
- sewage and tap waters
- irrigation, groundwater, and spring water

Copper (Figure E-11)

No data were available for radiator, laundry, carwash, irrigation, and spring waters

- plating and septic waters
- sewage, tap, and groundwater

Phenols (Figure E-12)

All measurements were less than the detection limits, and no data were available for radiator flushing waters.

The information collected thus far seemed to indicate that the background information collected from potential sources of dry-weather flow was sufficient to allow contaminated source types to be distinguished from non-contaminated source types. The results of the statistical tests presented in the next subsection confirmed this, and indicated that additional source flow information could be derived by more detailed analyses of the outfall data.

Correlation Analyses of Source Water Characteristics--

A Pearson correlation matrix analysis was conducted to investigate linear relationships between parameters. This information could be used to eliminate redundancy in testing. Pearson's correlation is a statistical technique for analyzing the association (or correlation) between variables (in this case measured parameters). This technique is designed to determine if a relationship exists, the strength of the relationship, and the direction of the relationship. Two different parameters are associated if the distributions of y change for the various conditions of x. Pearsons's correlation coefficient (Pearson's *r*) ranges from -1.00 to +1.00, with 0 indicating no association and +1.00 and -1.00 indicating perfect positive and perfect negative correlations, respectively. Values between these extremes describe relationships in terms of how closely they approach the extremes. For example, coefficients approaching 0.00 can be described as “weak” and those approaching +1.00 or -1.00 as “strong”.

A Pearson correlation matrix for all test parameters, from all likely sources combined, is presented in Table 45. A strong positive relationship (*r* value of >0.9) was found to exist between fluorescence and detergents. This was not unexpected. Fluorescence was originally included as a means of distinguishing between septic tank discharge and sewage, based on research by Alhajjar (1989) who found that detergents were not found in septic tank discharges. However, samples of septic tank discharges analyzed during this research were all found to contain detergents, when the septic tanks received the full spectrum of wastewaters generated in the household. Results of the Pearson correlation test indicated that testing for both fluorescence and detergents, for the most part, provided redundant information. However, elevated levels of fluorescence were noted in all samples of irrigation runoff from landscaped areas, while detergents were not detected. This information could aide in distinguishing this source from other relatively clean water sources. However, because fluorescence is also much easier to measure in the laboratory (and in the field) than detergents, it may be the more effective tracer parameter to use. Rather strong correlations (*r* values between 0.8 and 0.9) were also found to exist between hardness and conductivity, as well as between turbidity and detergents, and between turbidity and fluorescence.

Mann-Whitney U-Tests of Source Water Characteristics--
Data collected was also subjected to the Mann-Whitney *U* test (sometimes called the two-sample Wilcoxon rank test) in an effort to determine which test parameters exhibit significantly different values from one source to another. The Mann-Whitney *U* test is a non-parametric test and, as such, does not require the assumption of normally distributed data. It is particularly useful when working with small sample sets, especially when the distribution characteristics may not be well understood.

Working with one parameter at a time, individual measurements from two sample sets are pooled and ranked from highest to lowest. The ranks for each of the two sample sets are then totaled and compared. If the two sample sets represent populations not significantly different from each other, then the total ranks for the two sample groups will be similar in value. On the other hand, if the two sample sets represent populations that do differ for the variable of interest, these totals will be very different. The significance of the difference was tested at the 95% confidence level. Minitab statistical software was used to perform the calculations and compute the significance levels (p-values). The tables in Appendix E contain the p-values resulting from these comparisons. Values greater than 0.05 indicate that the differences between the compared data sets were not significant at the 95% confidence level.

Results from the Mann-Whitney U test can be evaluated in two ways. First and most basically, results can be used to indicate which parameters are best able to distinguish between clean flows (spring water, shallow ground water, tap water, landscape irrigation runoff) and contaminated dry-weather flow sources (sewage, septic tank discharges, wash waters, plating wastes, radiator flushing wastes). This is reflected by the percentage of contaminated sources which differ significantly from clean sources, with respect to the parameter of interest. Figure 18 summarizes this information. Secondly, the test results can be used to indicate which parameters are most useful for distinguishing between each of the individual sources of dry-weather flows. Figure 19 summarizes the results of the Mann-Whitney U test from this perspective.

If simply categorizing flows as contaminated or uncontaminated is the objective, it is apparent from Figure 18 that conductivity, detergent (as MBAS) and color tests would provide the most useful basic information in that 100% of the comparisons between individual contaminated and clean sources revealed significant differences at the 95% confidence level. Pairings of clean and contaminated source data for potassium, fluorescence, ammonia and toxicity revealed significant differences 96% of the time, followed by hardness at 92% and fluoride at 88%.

TABLE 45. PEARSON CORRELATION MATRIX

	Conductivity	Fluoride	Hardness	Detergent	Fluorescence	Potassium	Ammonia	pH	Color
Conductivity	1.000								
Fluoride	0.064	1.000							
Hardness	0.821	0.042	1.000						
Detergent	-0.031	0.688	-0.066	1.000					
Fluorescence	-0.017	0.779	-0.076	0.932	1.000				
Potassium	0.766	-0.027	0.443	-0.033	-0.053	1.000			
Ammonia	0.461	-0.068	0.548	-0.166	-0.034	0.138	1.000		
pH	-0.583	0.287	-0.452	0.076	0.096	-0.291	-0.397	1.000	
Color	0.171	0.416	0.134	0.771	0.704	0.208	0.042	-0.166	1.000
Chlorine	-0.023	0.241	-0.089	0.005	0.083	0.025	0.028	0.200	-0.084
Toxicity	0.457	0.605	0.428	0.614	0.690	0.305	0.523	-0.189	0.654
Copper	0.493	-0.015	0.504	-0.105	-0.009	0.135	0.703	-0.616	0.096
Phenols	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Odor	0.159	0.422	0.140	0.626	0.714	-0.009	0.429	-0.364	0.602
Turbidity	0.088	0.718	-0.096	0.800	0.827	0.157	-0.200	0.149	0.525
Floatables	-0.148	0.303	-0.160	0.407	0.389	-0.101	-0.183	0.150	0.371
Sediments	0.700	0.215	0.737	0.365	0.342	0.471	0.376	-0.495	0.594

BDL: Below Detection Limits for all samples

(continued)

TABLE 45. (continued)

	Chlorine	Toxicity	Copper	Phenols	Odor	Turbidity	Floatables	Sediments
Conductivity								
Fluoride								
Hardness								
Detergent								
Fluorescence								
Potassium								
Ammonia								
pH								
Color								
Chlorine	1.000							
Toxicity	0.273	1.000						
Copper	-0.010	0.418	1.000					
Phenols	BDL	BDL	BDL	BDL				
Odor	0.007	0.769	0.441	BDL	1.000			
Turbidity	0.117	0.498	-0.158	BDL	0.434	1.000		
Floatables	-0.044	0.134	-0.144	BDL	0.121	0.304	1.000	
Sediments	-0.072	0.629	0.366	BDL	0.434	0.256	0.040	1.000

BDL: Below Detection Limits for all samples

Note: Prepared using SYSTAT™ software version 5.0

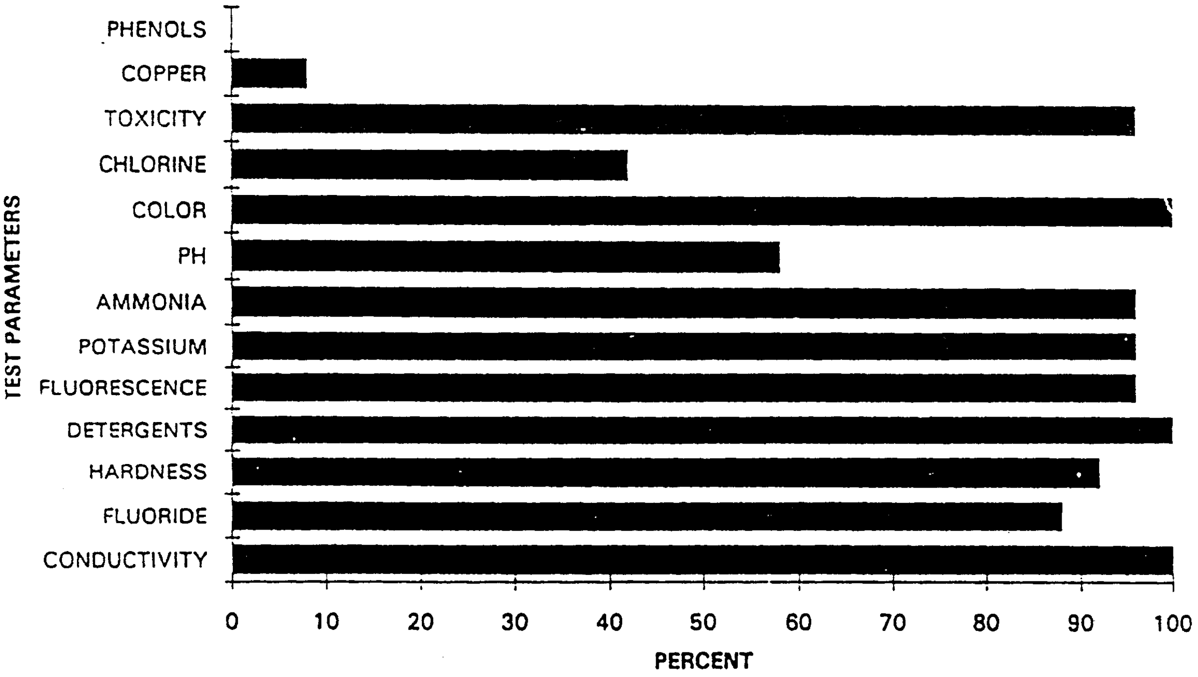


Figure 18. Significant differences when contaminated sources are compared to uncontaminated sources.

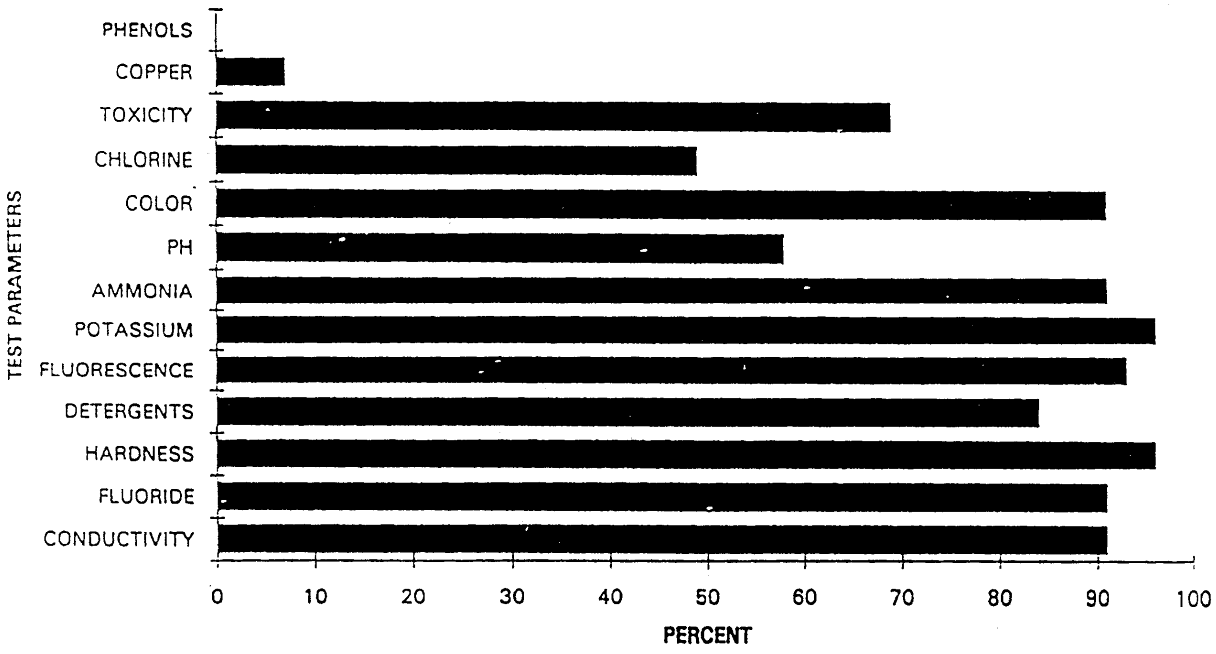


Figure 19. Significant differences when all sources are compared to uncontaminated sources.

Results from the Mann-Whitney U test indicate that pure streams from any of the dry-weather flow sources investigated in this research could be correctly classified as clean or contaminated based only on the measured value of any one of the following parameters: detergents, color, or conductivity. Color and conductivity were present in samples from clean sources as well as contaminated sources, but their levels of occurrence were significantly different between the two groups. If pure streams from only one source were expected to make up outfall flows, the level of color or conductivity measured could be used to distinguish contaminated outfalls from clean outfalls. However, since this is not always the case, measured levels in outfalls with multiple dry-weather flow sources could fall within acceptable levels, even though a contaminated source was contributing to the flow. Detergents, on the other hand, can be used to distinguish between clean and contaminated outfalls simply by their presence or absence. All contaminated source samples analyzed contained detergents, with the exception of the three septage samples collected from homes discharging only toilet flushing water to their septic system. This situation is highly unlikely in an urban area. No clean source samples were found to contain detergents. The detergent test used had a range of 0.00 to 1 mg/L, with a resolution of 0.01 mg/L and a standard deviation of about 0.02 mg/L. At this level, 99.2% of the samples collected from contaminated sources in this investigation would be detected in outfall flow mixtures, if they made up at least 6.5% of the flow. One septic tank leachate sample was responsible for the 0.08% exception. This source would not have been detected if it made up less than 20% of a mixed outfall flow with clean waters. The three rural septage samples collected from homes discharging only water from toilet flushings to their septic systems were not included in the Mann-Whitney tests because of the unusual nature of the wastewater.

Parameters which are best able to distinguish between all individual sources of dry-weather flows will be most useful when more detailed investigations are needed when identifying individual flow sources. Figure 19 shows that potassium and hardness levels were found to be significantly different in 96% of the comparisons between all flow source categories. Fluorescence followed at 93%. Conductivity, fluoride, ammonia and color measurements were significantly different in 91% of the comparisons, and detergents were different in 84%. A lower value for detergents was to be expected when analyzing Mann-Whitney results from this perspective since none of the samples from uncontaminated flow sources contained any detergents. These sources would therefore not be significantly differently from each other with respect to detergents, hence lowering the total percentage of comparisons which were significantly different.

Based on these analyses, pH would appear to be of little use in either case, but it is a quick and inexpensive procedure, and could reveal unexpected industrial sources not previously identified in the watershed, including illegal dumping. Chlorine measurements also appear to contribute little useful information to this study, and the analysis of copper and phenol even less.

Cluster Analyses of Source Water Characteristics--

While the Mann-Whitney U tests were performed with one parameter at a time, a cluster analysis was used to detect natural groupings in the data when all valid parameters were considered concurrently. Cluster analysis achieved this, by evaluating the differences in data between, and within, the dry-weather source categories. This information was needed to help determine the number and type of source categories which could be clearly defined and distinguished from one another, based on the test results from direct sampling of potential dry-weather flow sources. The cluster analysis was carried out using SYSTAT™ software (SYSTAT Inc., Evanston, IL).

Cluster analysis is a multivariate procedure for detecting natural groupings in data. It is used to classify a set of objects or cases into subgroups, although neither the number nor members of the subgroups are known. The SYSTAT™ cluster module distributes individual samples (cases) into groups such that between-group variation is as large as possible relative to within-group variation. The SYSTAT™ Cluster function provides two broad classes of clustering: Join and Kmeans. "Join" includes hierarchical, tree, or linkage methods. "Kmeans" uses a splitting method, which is not necessarily hierarchical.

Joining methods are often called hierarchical because they partition a set of objects into a group of nested sets. For example, hierarchical clustering splits four clusters into five by breaking apart one of the clusters. Non-hierarchical methods may rearrange all the objects from four clusters before producing a solution for five clusters. Output from hierarchical clustering analyses can be represented as a tree or dendrogram. This display shows the linkages between each object, or group of objects, as a joining of branches in a tree. Kmeans clustering splits a set of objects into a pre-selected number of groups; reassigning members to each group in order to maximize between-cluster variation relative to within-cluster variation.

Each individual sample from every source was entered in SYSTAT™ as a separate case. All data, with the exception of copper and phenol levels, were entered for each individual sample. Copper and phenol values were omitted based on the results of the Mann-Whitney U Tests which showed them to be of little or no use in distinguishing among dry-weather flow sources. Many of the clustering variables (test parameters) were on entirely different measurement scales and had wildly different concentration ranges, so variables were standardized in order to keep the influence of the individual variables comparable. Standardizing puts measurements on a common scale. Using SYSTAT™, this was accomplished by determining the distance (in terms of standard deviations) of each value from the mean ((Value - Mean)/Standard Deviation).

The complete data set was subjected to "Join" clustering. "Join" computes Euclidean distance (root mean squared distance) between objects for its clustering metric. This is an acceptable method for data from continuous or ratio scales (Fisher and Van Ness 1971). As noted previously, data were standardized to put the parameter measurements on a common scale. This is important when Euclidean distances are used. Single linkage clustering (Hartigan 1975) was used to compute the distance between one cluster and another. This linkage method takes the distance between two clusters as the distance between the two closest members of those clusters.

SYSTAT™ displays the output from "Join" as a tree. The tree is printed with a unique ordering, such that every branch is lined up so that the most-similar objects are closest to each other. If a perfect seriation (one-dimensional ordering) exists in the data, the tree reproduces it. The seriation algorithm for ordering trees is given in Gruvaeus and Wainer (1972). Seriation is considered advantageous for single linkage clusterings.

Figures 20 and 21 summarize the results of the cluster analysis. In Figure 20, 100% of the radiator waste samples clustered together, as did all car wash samples, all laundry samples and all plating wastes. Samples within each of these groups were much more similar to each other than they were to members of any other group. All other sample sources clustered together in a group referred to here as "residential waters". The reason for this is a problem of scale. The commercial sample sources were so dissimilar that distances were measured on a 10,000 unit scale. At this level, details of the much smaller differences between residential water sources were lost. Figure 21 examines the "residential waters" group alone.

In Figure 21, septic tank leachates are the most dissimilar group of samples. These septic tank samples split into two groups, based on the presence or absence of detergents. As noted earlier, three septage samples (15% of the total number) were collected from rural homes outside the project field study area where only water from toilet flushings entered the septic tank. Virtually no detergents were measured in these three samples. Therefore, these samples were separated from the 85% of the septage samples in which detergents were measured.

All shallow ground water samples clustered together, as did all spring water samples, all sewage samples and all irrigation water samples. Tap water samples split into two groups, based on chlorine content. The samples included in the 60% grouping were the samples with chlorine values greater than 1.2 mg/L. Samples included in the 40% grouping had chlorine values less than 0.5 mg/L.

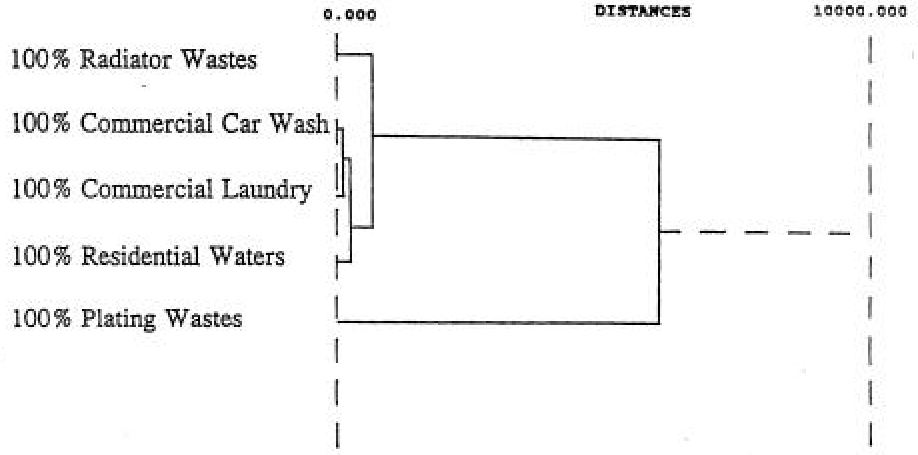


Figure 20. Cluster analysis for all potential dry-weather flow sources.

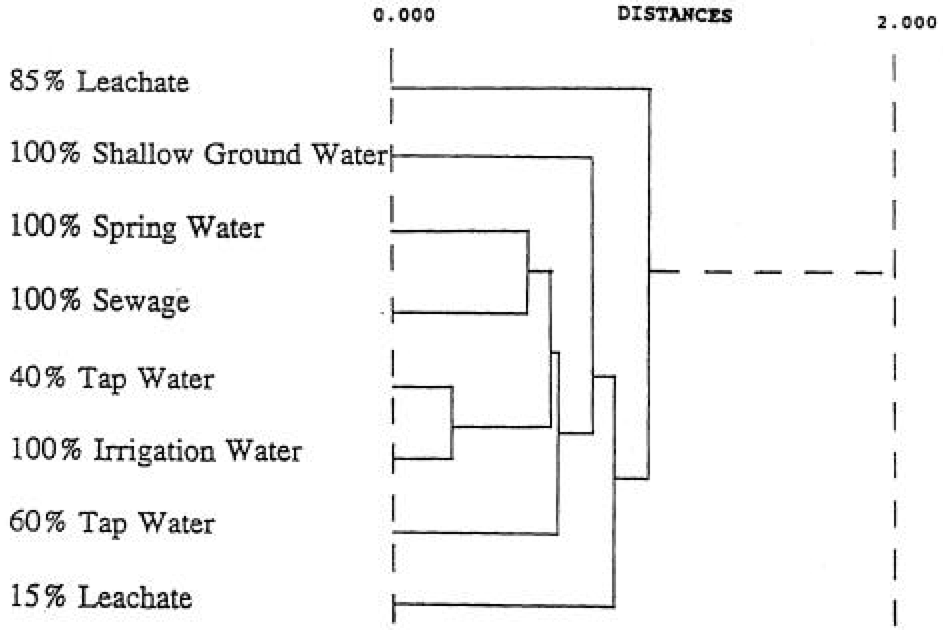


Figure 21. Cluster analysis for residential area dry-weather flow sources only.

These results indicate that the parameters being measured should be sufficient to distinguish among all of the potential commercial/residential sources of dry-weather flows identified.

Testing of Procedures Using Outfall Samples to Distinguish Flow Sources

A field investigation was carried out to confirm the usefulness of the proposed sampling and analysis schemes. A three-mile section of Village Creek in Birmingham, Alabama, was selected for the investigation. The drainage area for this section of the creek contains about 4500 acres. Figure 22 is a map of this area. Appendix D also contains additional drainage area land use and outfall information. Residential land use comprises approximately 88% of the total area, commercial land use approximately 8%, and industrial land use less than 1%. Approximately 4% of the area is classified as undeveloped, but includes a park and public golf course. The majority of the drainage area is serviced by sanitary sewers, but some septic tanks are also used. This information was developed from zoning maps, aerial photographs of the area, and topographic maps with one-foot contour intervals obtained from the City of Birmingham's Engineering Department. Septic tank information was obtained from the Jefferson County Department of Public Health.

Field Surveys

Maps locating city storm sewer outfalls were not originally available during this demonstration project. Stormwater outfalls, as well as direct discharges to the creek, were located by walking along the creek itself. A total of 88 outfalls and discharges were located and numbered, described as follows: 64 storm drains, 17 direct discharges from creek-side businesses, 1 “both”, and 6 “other”. Preliminary surveys were carried out during late fall when foliage was less likely to obscure the outfalls. Even so, seven outfalls were initially missed. Outfall diameters were recorded and ranged from 2 inches to 12 feet, excluding open ditches. Dry-weather flow (defined by a 72-hour antecedent dry period) was noted at 14 outfalls or discharges during the preliminary survey. All sites were visited at least 8 times during the field investigation period (September 1990 to March 1993). Appendix F contains all outfall data obtained during these site visits. Table 46 summarizes physical information collected for each outfall and discharge location.

Estimates of individual drainage areas for each storm sewer outfall were determined from topographic maps with one foot-contour intervals. It is understood that there are errors associated with assuming that storm drainage pipes always follow the topography, but in the absence of storm sewer maps, this method represents a logical approach to the problem. Corresponding land use and zoning maps, confirmed by site visits, were used to establish land use in each outfall drainage areas. Pipes and ditches, installed for purposes other than storm drainage (separate point source outfalls), were labeled as direct discharges, and no drainage area was assigned.

Outfall Data Collection

Data used to compile the history of dry-weather flow for each outfall was accumulated during the dry-weather site visits. Visits were conducted during different months of the year, including both rainy and dry seasons in Birmingham. Table 46 indicates the flow histories at the outfall locations. Outfalls and discharge locations described as “dry” were never observed to have dry-weather flow, and those described as “flowing” were found to be flowing during every visit, but not necessarily at the same flow rate. Outfalls and discharges labeled “intermittent” were observed to have flow during at least one site visit. A total of 65 stormwater outfalls were located. Of these, 48 (74%) were always dry, 6 (9%) had flow intermittently, and 11 (17%) were always flowing. Eighteen direct unpermitted discharges to the creek from nearby industries and commercial areas were located; 10 (56%) were dry, 6 (33%) had intermittent flow, and 2 (11%) were always flowing. (Outfall number 65 was counted in both categories, because it carries stormwater and pre-treated industrial wastewater from an NPDES permitted aircraft maintenance facility.) The 6 outfalls placed in the category of “other” included a lake spillway, old direct discharge pipes which were obviously abandoned, a submerged sewer overflow cap, and a PVC pipe placed underneath a stormwater outfall to intercept water leaking through a damaged joint.

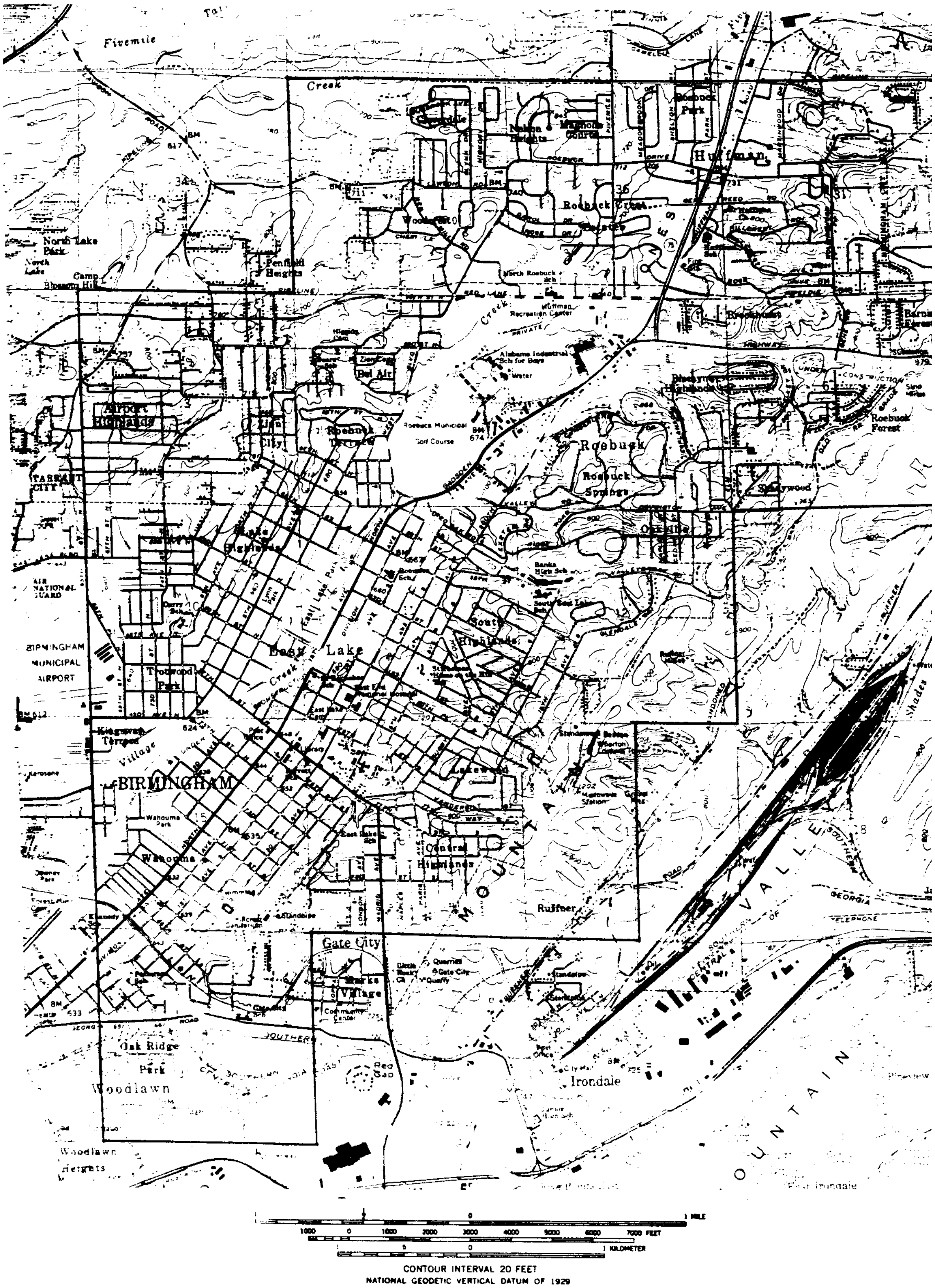


Figure 22. Site of field investigation along Village Creek, Birmingham, AL (Irondale, AL, USGS Quadrangle map).

TABLE 46. DESCRIPTION OF VILLAGE CREEK OUTFALLS

Outfall Number	Pipe Size and Type	Drainage Area/ Direct Discharge	Land Use	Record of Dry-Weather Flow
1	6'x6' conc	295	R	D
2	30" conc	6.8	R	D
3a	18" conc	1.5	R	D
3b	18" conc	1.7	R	D
3c	18" conc	2.3	R	D
3d	18" conc	2.5	R	D
3e	36" conc	5.4	R	D
4a	24" conc	1.9	R	D
4b	24" conc	2.5	R	D
5	6" steel	DD	R	D
6	16" conc	1.2	R	D
7a	6'x10' con	123.8	R/U	D
7b	36" con	4.8	R/U	D
7c	12" conc	2.1	R/U	D
8	16" conc	9.3	R/U	D
9	open ditch	5.2	R/U	D
10a	16" conc	1.5	R	D
10b	18"x38" con	2.3	R	D
10c	gutter	0.8	R/U	D
10z	ditch	5.22	R	D
DB	dry branch	896.6	R/C	D
11	2" steel	DD	U	D
12	6" pvc	DD	R	D
13	3'x8' open ditch	50.3	R/C	D
14	3" pvc	DD	U	F
14z	open ditch	50.8	R/U	I
15	10" conc.	5.2	U	D
16	3" pvc	DD	U	I
16z	12" conc	56.6	R	D
16zz	10" conc	1.2	R	D
17	18" clay	1.4	R	D
18a	18" clay	4.0	R	D
18b	2' conc	3.9	R/C	D
19a	4" iron	DD	C	D
19b	4" iron	DD	C	D
20	3'x4' stone	52.5	R/C	F
21	6"iron	DD	C	I
22	4" iron	DD	C	I
23	4" iron	DD	C	D
24	2" pvc	DD	C	I
25	4" pvc	DD	C	D
26	48" conc	65.0	R/C	F
27	24" conc	1.4	R	D
28	18" conc	0.8	C	I
29	conc	none		D
29z	5'x12' stone	306.2	R/C	F

(continued)

TABLE 46. (continued)

Outfall Number	Pipe Size and Type	Drainage Area/ Direct Discharge	Land Use	Record of Dry-Weather Flow
30	12" conc	1.8	C	D
31a	16" conc	DD		I
31b	16" conc	DD		D
32	12" conc	3.1	R	D
33	48" brick	144.8	R	D
34	16" clay	1.3	R	D
35	16" clay	2.1	R/U	D
36	6" steel	DD		D
37	submerged overflow cap	DD		D
38	36" alum	6.9	U	F
39	12" steel	DD		I
40	open ditch	380.6	R/C/U	I
40z	15" clay	3.6	R/U	I
41	15" clay	1.1	C	D
42	36" conc	7.7	R/C	F
43	24" conc	2.2	R/C	D
44	spillway			D
45	4'x6' conc	4.7	R/C	I
46	6" pvc	none		D
47	18" conc	3.8	R/C	D
48	36" conc	4.3	R	F
49	6" stone	none		D
50	9" iron	DD		D
51	ditch	1.2	C	D
52	35" conc	42.6	R/C	F
53	6'x6'	397.8	R/C	F
54	12" clay	1.6	R	D
55	30" conc	7.1	R/C	D
56	20" steel	DD		D
57	18" conc	3.7	R	D
58	24" conc	3.9	R	D
59	24" conc	1.3	R	D
60	48" conc	31.6	R/C	F
60a	48" conc	90	R/C	I
61a	16" clay	1.6	R	D
61b	16" clay	2.1	R	D
61c	16" clay	1.8	R	D
61d	18" conc	3.1	R	D
62	open ditch	53.8	R/C	D
63	48" conc	3.9	R/C	D
64	open ditch	394.9	R/C/N	F
65	open ditch	577.7 and DD	R/C/N	F

Legend -

R: Residential Land Use
C: Commercial Land Use
N: Industrial Land Use

U: Undeveloped Land or Parks
I: Intermittent Flow (dry-weather flow observed at least once)
D: Dry Outfall (no dry-weather flow observed)
F: Flowing (dry-weather flow observed consistently)

During the field investigation, samples were collected from all flowing outfalls as well as direct discharges, iced and returned to the lab for analysis. A field sheet (Table 47) was completed for each sample collected. This sheet is similar to Table 20 in Section 4, but was expanded for the additional parameters that were evaluated during this demonstration project. Physical observations, along with conductivity and temperature measurements, were made in the field. All other analyses were carried out in the laboratory. Complete analysis results from all outfall samples collected over the course of this research are located in Appendix F.

Watershed Surveys to Identify Flow Sources for Test Outfalls

A total of ten outfalls and direct discharges, representing a variety of parameter characteristics, were selected for source confirmation. Results from four of the outfall analysis methods, summarized in Section 7, were then compared to the actual source or sources of flow which had been identified in the field. Most of these outfall sources were identified at the end of the field investigation. However, some were identified during the course of the investigation in conjunction with observations of anomalous flow characteristics.

A variety of techniques were utilized to determine the actual source, or sources, of dry weather flow for a particular outfall. Open ditches and large pipes could be walked to their source. Other dry-weather flows were followed from manhole to manhole up the storm drainage system until a flow source was located. Samples were taken periodically from manholes along the way to identify changes in flow characteristics which would indicate the entrance of another flow. Most direct discharge pipes identified could be easily traced to the commercial establishment from which they issued.

A single outfall sample, taken at the time the actual source or sources of flow for each outfall was identified, was used for evaluating the various outfall analysis methods. Data from the 10 selected outfalls are presented in Tables 48 and 49. Table 48 contains the results of laboratory analyses of each outfall sample. Table 49 lists physical observations made on site.

- Outfall 14 (spring water/uncontaminated)--

Outfall 14 appeared to be a direct discharge located on a public golf course. The outfall, a 3" PVC pipe, exhibited flow consistently during the study period. Discussions with golf course personnel and a review of course irrigation plans revealed that the pipe was connected to a pressure release valve which was part of an irrigation system covering a small portion of the property. The source of water for this irrigation system was a spring located on the property. Therefore, it was concluded that the source of dry-weather flow from Outfall 14 was spring water. The outfall was designated uncontaminated.

- Outfall 20 (spring water and rinse water/uncontaminated)--

Outfall 20 also exhibited consistent dry-weather flow during the study period. This 3-foot x 4-foot stone outfall receives drainage from approximately 53 acres of residential and commercial property. Tracking the flow up the drainage system from the outfall, the uppermost point with flow was located. Flow at this point was originating from runoff around a wholesale/retail food manufacturing facility. The manager of the facility was consulted and indicated that high pressure potable water was used to rinse product loading areas, parking lots and delivery vans several times a day. A grass-lined ditch surrounded the facility on two sides and served to intercept and store runoff until it gradually percolated into the ground or drained into a culvert connected to the storm drainage system.

Analysis of this water showed it to be unlike the water collected at the outfall, indicating the presence of other flows between the outfall and the uppermost point of flow. Flow was sampled from manholes between these two points in order to locate the section or sections of the drainage system where additional flows were entering. Samples were analyzed, and the results are presented in Table 50. Results indicated that additional flow was entering the system between the outfall and the first manhole upgradient.

TABLE 47. FIELD SHEET USED DURING VILLAGE CREEK DEMONSTRATION PROJECT

NON-STORMWATER FLOW EVALUATION FIELD SHEET

Outfall # __________Photograph # ___________Date: ____________ Time: ____________

Location: ____

Air temp.: __________ sunny cloudy days since last rain: _______________

Outfall flow estimate: ____________________

Describe known industrial of commercial activities in drainage area: ____________________

____

____

OBSERVATIONS:

Odor: none sewage sulfur oil gas rancid-sour other:

Color: clear yellow brown green red gray other: _______________

Clarity: clear cloudy opaque

Floatables: none oil sheen other: ________________________________

Deposits/Stains: none sediment oily other: ______________________________

Vegetation conditions: normal excessive growth inhibited growth

Structural damage: none concrete cracking concrete spauling peeling paint metal corrosion

other: ____

ANALYSES:

Conductivity________________________________	Fluoride ____________________________________
Temperature _______________________________	Ammonia ___________________________________
pH ____	Potassium ___________________________________
Hardness __________________________________	Chlorine _____________________________________
Color _____________________________________	Total Copper _________________________________
Fluorescence ______________________________	Total Phenols ________________________________
Detergents _________________________________	Toxicity _____________________________________

NOTES: ____

____

____

____

TABLE 48. PARAMETER CHARACTERISTICS FOR SELECTED OUTFALLS

Outfall Number	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L)	Detergent (mg/L)	Fluorescence (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (mg/L)	Chlorine (mg/L)	Toxicity (% reduc.)	Copper (mg/L)	Phenols (mg/L)
14	327	0.04	240	0	9	0.69	0	7.01	0	0	0	0	0
20	188	0.61	127	0	13	1.98	0.03	7.11	0	0.02	2.4	0	0
21	480	2.8	85	20	491	5.08	0.11	7.04	120	0.09	100	0.04	0.04
26	358	0.07	239	0	8	0.72	0.01	7.68	0	0	0	0	0
28	340	0.74	203	0.23	200	5.96	2.89	7.31	30	0.05	5.9	0	0
31	165	1.13	34	18	235	2.96	0.24	8.34	25	0.19	79	0	0
40z	275	0.33	101	0.5	127	4.67	14.1	6.83	20	0	88.7	0	0
42	361	0.07	228	0	6	0.81	0	7.72	0	0	0	0	0
48	482	0.53	162	5	245	5.65	10.46	7.33	32	0	13.7	0	0
60a	197	0.86	52	0	128	3.84	0.29	7.48	0	0.01	0	0	0

TABLE 49. PHYSICAL CHARACTERISTICS FOR SELECTED OUTFALLS

Outfall	Odor	Color	Turbidity	Floatables	Sediments\Stains	Vegetation Conditions	Structural Damage
14	none	none	none	none	none	normal	none
20	fried food	none	none	none	none	normal	none
21	oily	gray	opaque	oil sheen	oily	inhibited growth	none
26	none	none	none	none	none	normal	none
28	rancid-sour	none	none	yellow particles	yellow slime	normal	none
31	none	none	none	strings	none	normal	none
40z	none	none	none	none	none	normal	none
42	none	none	none	none	none	normal	none
48	none	none	none	none	none	normal	none
60a	none	none	none	none	none	normal	none

TABLE 50. ANALYSIS OF SAMPLES COLLECTED DURING SOURCE CONFIRMATION

Outfall	Sample Source	Conductivity	Fluoride	Hardness	Detergent	Fluores.	Potassium	Ammonia	pH	Color	Chlorine	Copper	Phenols
20	Ditch	112	0.96	80	0	15	2.69	0.05	7.09	0	0.01	0	0
	Manhole 3	115	0.95	79	0	16	2.68	0.05	7.10	0	0	0	0
	Manhole 2	115	0.95	77	0	15	2.69	0.06	7.12	0	0	0	0
	Flow 2	300	0.03	236	0	11	0.71	0	6.97	0	0.01	0	0
	Flow 1	303	0.04	235	0	10	0.73	0	6.97	0	0	0	0
	Manhole 1	190	0.62	127	0	12	1.99	0.02	7.09	0	0	0	0
	Outfall	188	0.61	127	0	13	1.98	0.03	7.11	0	0.02	0	0
					0					0		0	0
26	Spring	350	0.06	237	0	9	0.72	0.00	7.70	0	0	0	0
	Manhole 2	355	0.07	237	0	8	NA	NA	7.69	0	0.01	0	0
	Manhole 1	355	0.06	240	0	8	NA	NA	7.70	0	0	0	0
	Outfall	358	0.07	239	0	8	0.72	0.01	7.68	0	0	0	0
28	Manhole	332	0.81	199	0.25	210	6.01	2.94	7.24	35	0.10	0	0
	Outfall	340	0.74	203	0.23	200	5.96	2.89	7.31	30	0.05	0	0
40z	Sheetflow	269	0.34	100	0.55	133	4.66	14.2	6.80	23	0	0	0
	Outfall	275	0.33	101	0.5	127	4.67	14.1	6.83	20	0	0	0
42	Spring	358	0.05	225	0	8	0.79	0	7.70	0	0	0	0
	Manhole	359	0.05	231	0	8	NA	NA	7.70	0	0	0	0
	Outfall	361	0.07	228	0	6	0.81	0	7.72	0	0	0	0
48	Sewage	555	0.98	122	0.96	305	7.49	19.23	7.13	60	0	0	0
	Outfall	482	0.53	162	0.5	245	5.65	10.46	7.33	32	0	0	0
60a	Sheetflow	189	0.86	50	0	130	3.83	0.30	7.44	0	0	0	0
	Outfall	197	0.86	52	0	128	3.84	0.29	7.48	0	0.01	0	0

The drainage system was large enough to permit entry, and research personnel entered at the outfall and walked through the system. Two sites of additional dry-weather flow entry were located. The two entry sites were in close proximity to each other, and flow was entering through cracks or unintended holes in the drainage system. Samples of flow from both sites were collected, using a hand-held vacuum pump, and they were returned to the laboratory for analysis ("Flow 1" and "Flow 2" on Table 50). Analyses indicated that this water was spring water.

The prevalence of springs in the study area was mentioned earlier, and seepage of spring water from the creek bank had been noted in the area of this outfall. Flow estimates made at the outfall and just upgradient from the spring water entry sites indicated that approximately one third of the outfall flow was originating from the spring water on that particular day. In summary, investigation of outfall 20 indicated that approximately one third of the dry-weather flow issuing from the outfall was spring water and approximately two thirds was rinse water (from a tap water source).

This outfall could conceivably have been classified as contaminated or non-contaminated. There was the potential for food residue from the loading facility and the delivery vehicles as well as street dirt from the delivery vehicles and parking lot. In an effort to correctly characterize this outfall, samples were tested for some standard representatives of important categories of pollutants, namely solids, oxygen-consuming constituents, nutrients, and heavy metals. Biochemical oxygen demand was consistently found to be below 1 mg/L, total suspended solids below 10 mg/L, total phosphorous below 0.15 mg/L, and lead below detection limits (0.01 mg/L). These numbers were exceptionally low as compared to typical urban runoff, as characterized during the Nationwide Urban Runoff Program (EPA 1983). Based on this information, the outfall was characterized as uncontaminated.

- Outfall 21 (vehicle and engine wash area/contaminated)--

Outfall 21 was a direct discharge pipe, easily traced to a used auto sales facility. The pipe was connected to a floor drain in an area where used cars were washed and prepared for sale. The manager of the facility would not discuss the nature of the discharges to the floor drain. An employee later indicated that car and engine wash waters were most common, although fluids drained from vehicles, as well as cleaning and painting solvents, were also washed down the floor drain on occasion. The facility was in operation approximately nine hours a day, and wastewaters entered the floor drain intermittently during that period. The outfall was designated contaminated.

- Outfall 26 (spring water/uncontaminated)--

Outfall 26 was a 48-inch concrete pipe draining approximately 65 acres, of which 93% were commercial and 7% were residential. Flow was traced from manhole to manhole upgradient until the uppermost source of flow was discovered. A spring was found feeding a small marshy area which drained into a culvert leading into the storm drainage system. Water samples were taken from the spring and at two points between the spring and the outfall. The results of laboratory analysis are presented in Table 50. All samples were very similar and flow estimates were constant throughout the system. It was concluded that no other flows were contributing to the dry-weather flow from Outfall 26, and the outfall was designated uncontaminated.

- Outfall 28 (restaurant wash area/contaminated)--

Outfall 28, an 18-inch concrete pipe draining less than an acre of commercial property, was observed to have dry weather flow only twice during the study period, with the source of flow confirmed the second time flow was observed. Flow was traced up the drainage system until a manhole was observed to have no flow. Backtracking revealed a restaurant facility where a washdown of food storage and preparation areas was underway. A floor drain collecting wastewater at the rear of the facility was apparently directly connected to the storm sewer system. Floatables observed at the outfall were identifiable in the wastewater. Management would not allow a sample to be taken on site, but the analysis results from the first manhole below the restaurant (presented in Table 50) were comparable to values measured at the outfall. The outfall was designated contaminated.

- Outfall 31 (laundry/contaminated)--

Outfall 31 was a direct discharge pipe traced to a small motel laundry which was visible from the creek bank. The effluent from a single commercial washing machine was directed into the pipe. This information was confirmed by hotel management, but a sample could not be collected. The single washing machine serviced linen for the entire motel and operated almost continuously during the day. This was reflected in the intermittent but regular flow observed at the outfall. The outfall was designated contaminated.

- Outfall 40z (septage/contaminated)--

Outfall 40z was a 15-inch clay pipe intended to carry stormwater from an approximately 4-acre residential and undeveloped area. Dry-weather flow was observed only one time during the study period, and the source of flow was identified at that time. The outfall was observed to be flowing following an extremely wet period. Flow was followed up the pipe, from manhole to manhole, to its source. Water was observed to be flowing out of a property owner's front yard, into the storm gutter and curb inlet. Discussions with the home owner confirmed the fact that the home was serviced by a septic tank, and surface flow from the area of the tank and leaching field took place routinely during extremely wet periods. The first manhole upgrade from the curb inlet was observed to be dry. Flow into the curb inlet was estimated to be approximately equal to outfall flow and laboratory analyses of the two flows were comparable (Table 50). The outfall was designated contaminated.

- Outfall 42 (spring water/uncontaminated)--

Outfall 42 was observed to have dry-weather flow consistently during the study period. The outfall is a 36-inch concrete pipe which drains approximately 8 acres of residential and commercial area. Once again, the pipe was traced back to a marshy area fed by a spring, draining into a culvert connected to the concrete storm drain. Analysis results of water samples taken from the marshy area, the outfall and one manhole in between are presented in Table 50. Flow estimates were comparable, as were analysis results. The outfall was designated uncontaminated.

- Outfall 48 (spring water and sanitary sewage/contaminated)--

Outfall 48 was a 36-inch concrete pipe draining approximately 14 acres of residential area. The outfall flowed consistently, but a change in the quality and quantity of flow was noted approximately halfway through the study period (See Appendix F.), and the source of flow was identified at that time. The majority of the drainage area for this outfall lay across a major highway from Village Creek. Dye was added at the first manhole identified upgrade of the highway to confirm the connection to outfall 48. Moving up the storm drainage system, a creek, once again apparently fed primarily by spring water, was found to be channeled through the storm system. Upgrade from the creek inlet, a discharge was found to be entering through a curb inlet. The source of this discharge was found to be a leaking sanitary sewer line. Further upgrade yet another creek was entering the storm system. Flow from the creeks explained the continuous dry-weather flow noted at the outfall, and the leaking sanitary sewer line was apparently responsible for the change in quality and quantity of flow which had been noted. Flow from the creeks was estimated to be approximately equal to flow from the sanitary sewer. A sample was collected from the sanitary sewer, and analysis results are reported in Table 50. In summary, investigation of outfall 48 indicated that approximately one half of the dry-weather flow issuing from the outfall was from a natural water source, and half was sanitary sewage. The outfall was designated contaminated.

- Outfall 60a (irrigation water/uncontaminated)--

Outfall 60a, a 48-inch concrete pipe draining approximately 90 acres of primarily residential property, was observed to have dry-weather flow on only one occasion during the study period, and the source of flow was investigated at that time. Flow was followed upgrade from manhole to manhole and eventually the source was found to be runoff from an automatic irrigation system in a newly landscaped yard. Flow into the nearest curb inlet was estimated to be approximately the same as the flow at the outfall. The next manhole upgrade from the curb inlet was observed to be dry. A sample was collected, using a hand-held vacuum pump, as the flow entered the curb inlet. Analysis results are presented in Table 50 and are comparable to results from the outfall sample. The outfall was designated uncontaminated.

Comparison of Data Analysis Methods to Predict Source Flows

Predictions of outfall problem ranking and sources of flow were compared to the actual sources of flow at the ten outfalls described above. Four of the outfall analysis methods described in Section 7 were used for this comparison:

physical indicators of contamination, detergents as indicators of contamination, flowchart for identification of the most significant flow portion, and matrix algebra solutions of simultaneous equations. The following subsections discuss the results of these comparisons for each of the analysis methods.

Physical Indicators of Contamination--

As noted in Section 7, the direct examination of outfalls for unusual condition of flow, odor, color, turbidity, floatables, deposits/stains, vegetation conditions and damage to drainage structures (negative indicators), is the simplest method of identifying grossly contaminated dry-weather outfall flows. Table 51 summarizes the results of applying this method of investigation to the ten selected outfalls. The actual flow quality column reflects the designation of "contaminated" or "uncontaminated" assigned to each outfall based on the source of flow that was verified in the field. Predicted flow quality is based solely on the presence or absence of negative indicators at the outfall.

Negative indicators would have led to further investigation of outfalls 20, 21, 28, and 31. Commercial sources contributed all or part of the flow to each of these outfalls. Outfalls 21, 28, and 31 were designated contaminated at the time of source confirmation in the field. However, outfall 20 was designated uncontaminated. Odor and/or the presence of floatables were noted at all four of the outfalls in question. A lack of negative indicators would have suggested there was no need for further investigation of outfalls 40z or 48. However, outfall 40z was contaminated with septic tank leachate, and outfall 48 was contaminated with sanitary sewage. Therefore, the presence of negative indicators alone failed to identify 2 of the 5 contaminated outfalls. Based on the 10 selected outfalls tested, this represents a high false negative rate (of 20%).

Uncontaminated outfalls 14, 26, 42 and 60a had no negative indicators. However, the presence of a negative indicator (odor) at outfall 20 incorrectly identified that outfall as contaminated. This represents a false positive rate of 10%.

Detergents as Indicators of Contamination--

The second method tested was a simple contaminated/uncontaminated categorization based on the presence, or absence, of detergents alone. As discussed previously in Section 7, analysis of only detergents correctly identified the samples collected directly from potential dry-weather flow sources as contaminated or uncontaminated. Table 52 shows the results of applying this method of investigation to the ten selected outfalls.

Dry-weather flows from all contaminated outfalls (21, 28, 31, 40, and 48) were found to contain detergents. None of the uncontaminated outfalIs were found to contain detergents on the days that sources were verified in the field. Use of this technique therefore resulted in a 100% correct categorization of the ten outfalls selected for testing as contaminated or uncontaminated (no false negatives or positives were identified).

Flow Chart for Most Significant Flow Component Identification--

Data from each of the 10 selected outfall samples were analyzed using the flow chart presented in Figure 12 in Section 7. Conclusions from this analysis are presented in Table 53. This method was not able to distinguish among each of the potential sources of dry-weather flow identified earlier; rather, the following four groups of flow were distinguishable: (1) uncontaminated domestic waters (tap water, irrigation or rinse water); (2) natural groundwaters (spring water or infiltrating shallow groundwater); (3) sanitary wastewaters; and, (4) wash waters.

TABLE 51. ANALYSIS OF OUTFALLS BASED ON PHYSICAL INDICATORS OF CONTAMINATION

Outfall Number	Negative Indicators	Predicted Flow Quality	Actual Flow Quality	Confirmed Flow Source
14	none	uncontaminated	uncontaminated	Spring Water
20	odor	contaminated	uncontaminated	Rinse Water and Spring Water
21	odor, color, turbidity, floatables, sediment, vegetation	contaminated	contaminated	Wash Water (Automotive)
26	none	uncontaminated	uncontaminated	Spring Water
28	odor, floatables, sediments	contaminated	contaminated	Wash Water (Restaurant)
31	floatables	contaminated	contaminated	Laundry (Motel)
40z	none	uncontaminated	contaminated	Shallow Ground Water and Septic Tank Leachate
42	none	uncontaminated	uncontaminated	Spring Water
48	none	uncontaminated	contaminated	Spring Water and Sewage
60a	none	uncontaminated	uncontaminated	Landscaping Irrigation Water

TABLE 52. ANALYSIS OF OUTFALLS BASED ON DETERGENTS AS INDICATORS OF CONTAMINATION

Outfall Number	Predicted Flow Quality	Actual Flow Quality
14	uncontaminated	uncontaminated
20	uncontaminated	uncontaminated
21	contaminated	contaminated
26	uncontaminated	uncontaminated
28	contaminated	contaminated
31	contaminated	contaminated
40z	contaminated	contaminated
42	uncontaminated	uncontaminated
48	contaminated	contaminated
60a	uncontaminated	uncontaminated

TABLE 53. RESULTS OF USING FLOW CHART FOR MAJOR FLOW COMPONENT IDENTIFICATION

Outfall Number	Predicted Flow Quality	Actual Flow Quality	Predicted Flow Source	Confirmed Flow Source
14	uncontaminated	uncontaminated	Natural Waters	Spring Water
20	uncontaminated	uncontaminated	Potable Waters	Rinse Water and Spring Water
21	contaminated	contaminated	Wash Waters	Wash Water (Automotive)
26	uncontaminated	uncontaminated	Natural Waters	Spring Water
28	contaminated	contaminated	Wash Waters	Wash Water (Restaurant)
31	contaminated	contaminated	Wash Waters	Laundry (Motel)
40z	contaminated	contaminated	Sanitary Wastewaters	Shallow Ground Water and Septic Tank Leachate
42	uncontaminated	uncontaminated	Natural Waters	Spring Water
48	contaminated	contaminated	Sanitary Wastewaters	Spring Water and Sewage
60a	uncontaminated	uncontaminated	Potable Waters	Landscaping Irrigation Water

Flow from outfall 14 contained no detergents and low levels of fluoride, leading to the correct identification of a natural water source. Flow from outfall 20 contained no detergents, but had high fluoride levels, correctly identifying a potable water source. Flow from outfall 21 contained detergents, and had an ammonia/potassium ratio of 0.02 (less than 0.9). This correctly indicated a wash water source. Flow from outfall 26 contained no detergents, and low levels of fluoride, again correctly predicting a natural water source. Flow from outfall 28 contained detergents, and had an ammonia/potassium ratio of 0.5 (less than 0.9). A wash water source was correctly predicted. Flow from outfall 31 contained detergents, and had an ammonia/potassium ratio of 0.08 (less than 0.9). A wash water source was correctly predicted. Flow from outfall 40z contained detergents, and had an ammonia/potassium ratio of 3.0 (greater than 0.9). A sanitary wastewater source was correctly predicted. Flow from outfall 42 contained no detergents, and low fluoride levels; a natural water source was correctly predicted. Flow from outfall 48 contained detergents, and had an ammonia/potassium ratio of 1.85 (greater than 0.9), correctly predicting a sanitary wastewater source. Flow from outfall 60a contained no detergents, and had a high fluoride level. An uncontaminated potable water source was correctly predicted.

Use of this method resulted in the correct categorization of each outfall with respect to contamination. No false negatives or false positives were reported. Furthermore, for all outfalls, the most serious (with respect to potential contamination) type of flow to the outfall was correctly predicted. Source types were ranked from lowest to highest, with respect to contaminating potential as follows: natural water sources, tap water sources, wash water sources, and sanitary wastewater sources.

Chemical Mass Balance at Outfalls--
Results from the chemical mass balance algorithm are shown in Table 54. The following 8 parameters were used in this analysis: specific conductivity, fluoride, hardness, detergents, fluorescence, potassium, ammonia, and color. The choice of parameters was based on results of the Mann-Whitney U tests and linear dilution tests described in Section 6. The eight potential flow sources considered for each outfall were: spring water, tap water, infiltrating shallow groundwater, landscape irrigation runoff water, sewage, septic tank discharge, carwash water, and laundry water. Table 54 shows the most likely percent of the total outfall flow coming from each source. This table also compares these predictions to the confirmed sources of flow for each outfall. All sources predicted to contribute to an outfall's flow are listed. Predicted contributions, and confirmed sources, are listed from highest to lowest order of percent contribution to flow. Contributions in parentheses indicate numbers which would be attributed to "background noise", as they make up less than 10% of the source flow, as discussed in Section 7.

Outfalls 28 and 31 carried dry-weather flow from sources not specifically sampled and evaluated during the source characterization portion of this research. Consequently, a perfect fit was not possible. Outfall 28 carried wash water, but it was from the washing of loading and storage areas of a fast food restaurant. Outfall 31 carried laundry wash water, but the source was the washing machine of a small motel which used a household laundry detergent, rather than one of the commercial varieties used by the laundries which were sampled.

No false negatives resulted from the use of this method. However, the false positive rate would have been 40%, if the 10% threshold value was not used. Additionally, many extraneous sources of flow were predicted for most of the outfalls, thus negating the potential advantage this method had to offer: the ability to accurately predict all specific types of sources contributing to a dry-weather flow.

Summary of Field Demonstration Tests

The use of negative physical indicators of contamination alone, such as color, odor, lack of clarity, and the presence of floatables or deposits, resulted in a high false negative rate of 20%, and a false positive rate of 10%. Examination of outfalls for negative indicators of contamination identified only the most grossly contaminated outfalls affected by commercial activities. Outfalls carrying sanitary wastewaters in mixtures with uncontaminated waters (one of the most serious concerns) were frequently missed using this method.

TABLE 54. ANALYSIS OF OUTFALLS BASED ON RESULTS OF THE CHEMICAL MASS BALANCE PROGRAM

Outfall Number	Predicted Flow Source	Confirmed Flow Source
14	88% Spring (7% Sewage) (5% Tap)	100% Spring
20	60% Tap 32% Spring (8% Irrigation)	67% Tap 33% Spring
21	55% Sewage 35% Ground (8% Car Wash) (2% Laundry)	100% Washwater (Automotive)
26	74% Spring Water 18% Tap Water (8%Sewage)	100% Spring Water
28	46% Ground Water 21% Irrigation Water 18% Sewage 10% Spring Water (5%Tap Water)	100% Wash Water (Restaurant)
31	55% Sewage 25% Spring Water 18% Laundry (1% Carwash Water)	100% Laundry (Motel)
40z	27% Sewage 23% Tap Water 19% Ground Water 12% Spring Water 11% Septic Tank Discharge (8% Irrigation Water)	Shallow Ground Water and Septic Tank Discharge
42	63% Spring Water 28% Tap Water (9% Sewage)	100% Spring Water
48	79% Sewage 15% Spring Water (5% Carwash Water) (1% Septage)	50% Sewage 50% Spring Water

60a	56% Tap Water 37% Irrigation Water (7% Sewage)	100% Irrigation Water

Testing dry-weather flows in residential and commercial areas for only the parameters identified by EPA as minimum requirements, (pH, chlorine, copper, phenols and detergents), can be used to accurately categorize outfall as contaminated or uncontaminated. This determination in fact can be based simply on the presence or absence of detergents (lower limit of detection 0.06 mg/L as MBAS). During this research effort in Birmingham, Alabama, all flows from contaminated outfalls contained detergents, while all flows from uncontaminated outfalls did not. No false positives or false negatives resulted from the use of this method. No further prioritization of outfalls was possible using only the parameters identified by EPA. However, in residential and commercial areas, pH, total chlorine, total copper, and total phenols could be useful in identifying industrial discharges not previously known to exist within the drainage area (EPA, 1993).

Testing for fluoride, ammonia, and potassium, in addition to detergents, allowed for further prioritization of outfalls, by identifying the outfalls most likely to be contaminated by sanitary wastewaters, wash waters, or relatively clean tap water sources. Using the flow chart method, the most serious contaminating source can usually be identified for each outfall, whether or not the flow is a mixture originating from several sources. In flows issuing from a single source, the sole flow component can be identified. In multiple source flows, which include at least one contaminating source, a contaminated source can be identified as long as it comprises at least 10% of the flow. In mixed flows, contaminating sanitary wastewaters may be incorrectly identified as wash water when they contribute less than about 25% of the flow, depending on the ratio of ammonia to potassium in both the sanitary wastewater and the other flow sources. The use of the flow chart in this research resulted in no false negatives, no false positives, and further, the correct identification of the most contaminated source contributing to each outfall analyzed.

The use of chemical mass balance equations as a means of identifying all sources contributing to flow at a given outfall is appealing in theory. However, this research indicated that the amount of variation present within potential sources of dry-weather flow, as well as the likelihood of unexpected, and thus uncharacterized flows, especially in commercial areas, made this method less effective than desired. Possible additional modifications to the chemical mass balance program, such as allowing for the inclusion of more sources than unknowns (over-specification), variable weighting, and the linking of variables with relatively high correlation coefficients, could improve its effectiveness (Wilson 1958). However, these modifications would not compensate for the lack of information for certain specific (and previously unknown) source flows which will be encountered in some watersheds. The amount of time and effort required to adequately identify and characterize potential sources also decreases the economic advantage of this method over wide-scale dye testing or video camera surveying.

Defining a threshold level, based on analysis of many samples from known sources, and disregarding flow contributions below this level, reduced the false positive rate to zero while maintaining a false negatives rate of zero. However, the most contaminated contributor to flow was still incorrectly identified much of the time, making this method less useful for prioritizing outfalls than the simpler flow chart approach.

In summary, the following screening methodology is suggested for residential and commercial areas:

Characteristics of Local Source Waters--

- It is extremely important to determine the local characteristics of potential source waters. As a minimum, tracer parameters to be tested should include: fluoride, detergent (or fluorescence), ammonia, and potassium.

Outfall Surveys--

- All stormwater outfalls and direct discharge pipes should be located and evaluated.
- All dry-weather flows should be sampled, regardless of the size of the pipe or characteristics of the drainage area.

- Physical characteristics of any flow and unusual characteristics surrounding the outfall must be noted to identify gross contamination and evidence of intermittent flows.

Outfall Sample Analyses and Interpretation—

- The flow chart method should be the primary method used to identify the contaminating flow sources and for prioritizing the level of contamination of the outfall flows.
- Outfall samples should be primarily tested for detergents (or fluorescence).
- If desired, outfall samples testing negative for detergents could be tested for fluoride, to identify flows from relatively clean tap water sources.
- Samples testing positive for detergents should be tested for ammonia and potassium. A high ammonia-to-potassium ratio indicates those outfalls most likely carrying flows from sanitary wastewater sources. These outfalls should receive the highest priority for source correction measures.

Section 12
Emerging Technologies for the Detection and Elimination of Illicit Discharges

Introduction

This section describes several newly emerging technologies that may be useful for the identification of inappropriate ("illicit") discharges to storm drainage systems. This section also describes a series of tests where the original methods described previously in this report, along with selected new procedures, were examined using almost 700 stormwater samples collected from telecommunication manholes from throughout the U.S. About ten percent of the samples were estimated to be contaminated with sanitary sewage using these methods, similar to what is expected for most stormwater systems. The original methods are still recommended as the most useful procedure for identifying contamination of storm drainage systems, with the possible addition of specific tests for *E. coli* and enterococci and UV absorbance at 228 nm. Most of the newly emerging methods that have been published require exotic equipment and unusual expertise and are therefore not very available, especially at low cost and with fast turn-around times for the analyses. These emerging methods may therefore be more useful for special research projects than for routine screening of storm drainage systems.

Use of Bacteria as an Indicator of Sanitary Sewage Contamination

As previously mentioned in Section 5, bacteria has historically been used as an indicator of sanitary sewage contamination of stormwaters and receiving waters. This method has been beset with many analytical and interpretation problems. The following discussion is derived from: R. Pitt. *Stormwater Quality Management*, CRC Press, in preparation, and presents some historical background information concerning the likely sources of bacteria in urban areas that are not derived from sanitary sewage.

Several historical investigations have studied potential sources of bacteria and selected pathogens that are found in urban runoff. Some of these studies have examined surface sheet flows during rain induced and snowmelt induced runoff that would not likely be contaminated by human fecal matter. More commonly, many studies have examined runoff sampled at outfalls where the runoff may have been contaminated by inappropriate discharges to the storm drainage. The following discussion summarizes some of the observations from these studies.

Tests in Toronto examined sources of urban stormwater bacteria (Pitt and McLean 1986), as shown in Table 55. High bacteria populations were found in sidewalk, road, and some bare ground sheetflow samples (collected from locations where dogs would most likely be "walked"). Some of the Toronto sheetflow contributions were not sufficient to explain the concentrations of some constituents observed in runoff at the outfall. Most of the fecal coliform populations observed in sheetflows were significantly lower than those observed at the outfall, especially during snowmelt. It is expected that some sanitary sewage was entering the storm drainage system. Runoff from paved parking areas, streets, and landscaped areas generally had the highest observed bacteria densities, while runoff from roofs and freeways had low densities.

Table 55. Source Area Bacteria Sheetflow Quality Summary (means)

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/ Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets	Land-scaped	Un-developed	Freeway Paved Lane and Shoulders
Fecal Coliforms (#/100 mL)												
Residential:	85 (3) <2 (4) 1400 (5)	250,000 (5)	100 (5)		600 (5)			11,000 (5)	920 (4) 6,900 (5)	3300 (5)	5400 (3) 49 (4)	1500 (9)
Commercial	9 (4)	2900 (3) 350 (4) 210 (1) 480 (7) 23,000 (8)										
Industrial:	1600 (5)	8660 (8)	9200 (5)	18,000 (5)	66,000 (5)	300,000 (5)		55,000 (5)	100,000 (5)			
Fecal Strep (#/100 mL)												
Residential:	170 (3) 920 (4) 2200 (5)	190,000 (5)	<100 (5)		1900 (5)		1800 (5)		>2400 (4) 7300 (5)	43,000 (5)	16,500 (3) 920 (4)	2200 (9)
Commercial:	17 (3)	11,900 (3) >2400 (4) 770 (1) 1120 (7) 62,000 (8)										
Industrial:	690 (5)	7300 (5)	2070 (5)	8100 (5)	36,000 (5)	21,000 (5)		3600 (5)	45,000 (5)			
Pseudo, Aerug (#/100 mL)												
Residential:	30,000 (5) 50 (5)	1900 (5)	100 (5)		600 (5)		600 (5)		570 (5)	2100 (5)		
Industrial:		5800 (5)	5850 (5)	14,000 (5)	14,300 (5)	100 (5)		3600 (5)	6200 (5)			

References:
(1) Bannerman, *et al*. 1983 (Milwaukee, WI) (NURP)
(3) Pitt 1983 (Ottawa)

(4) Pitt and Bozeman 1982 (San Jose)
(5) Pitt and McLean 1986 (Toronto)
(7) STORET Site #590866-2954309 (Shop-Save-Durham, NH) (NURP)
(8) STORET Site #596296-2954843 (Huntington-Long Island, NY) (NURP)
(9) Kobriger, *et al.* 1981 and Gupta, *et al*. 1977

The Regional Municipality of Ottawa-Carleton (1972) studied the importance of rooftop, street surface, and field runoff in contributing bacteria contaminants to surface waters in the Ottawa area. Gore and Storrie/Proctor and Redfern (1981c) also investigated various urban bacteria sources affecting the Rideau River in Ottawa. They examined dry weather continuous coliform sources, the resuspension of contaminated river bottom sediments, exfiltration from sanitary sewers, and bird feces. These sources were all considered in an attempt to explain the relatively high dry weather coliform bacteria concentrations found in the river. They concluded, however, that stormwater runoff is the most probable source for the wet weather and continuing dry weather bacteria Rideau River concentrations. However, the slow travel time of the river water usually does not allow the river to recover completely from one rainstorm before another begins.

The Regional Municipality of Ottawa-Carleton (1972) summarized the early Ottawa activities in correcting stormwater and sanitary sewage cross-connections. Since that time, many combined sewer overflows have also been eliminated from the Rideau River. Loijens (1981) stated that as a result of sewer separation activities, only one overflow currently remained active (Clegg Street). During river surveys in 1978 and 1979 in the vicinity of this outfall, increased bacteria levels were not found. Gore and Storrie/Proctor and Redfern (1981c) stated that there was no evidence that combined sewer overflows were causing the elevated fecal coliform bacteria levels in the river. Environment Canada, (1980) however, stated that high, dry weather bacteria density levels, especially when considering the fecal coliform to fecal strep. ratio, constitutes presumptive evidence of low volume sporadic inputs of sanitary sewage from diverse sources into the downstream Rideau River sectors. The case study presented later examines some of these issues.

Street surfaces have been identified as potential major sources of urban runoff bacteria in many locations. Pitt and Bozeman (1982) found that parking lots, street surfaces, and sidewalks were the major contributors of indicator bacteria in the Coyote Creek watershed in California. Gupta, *et al*. (1981) found high concentrations of fecal coliforms at a highway runoff site in Milwaukee. This site was entirely impervious and located on an elevated bridge deck. The only likely sources of fecal coliforms at this site were bird droppings and possibly feces debris falling from livestock trucks or other vehicles.

Several studies have found that the bacteria in stormwater runoff in residential and light commercial areas were from predominantly nonhuman origins (Qureshi and Dutka 1979). They found that there may be an initial flush of animal feces when runoff first develops. However, the most important bacteria source for runoff is the feces bacteria that have been distributed generally in the soils and on the surfaces of the drainage area. Geldreich and Kenner (1969) stated that the fecal coliforms in stormwater are from dogs, cats, and rodents in city areas, and from farm animals and wildlife in rural areas. The most important source, however, may be feces bacteria that are distributed in the soil and not the fresh feces washing off the impervious surfaces.

Some studies have investigated vegetation sources of coliform bacteria. For example, Geldreich (1965) found that the washoff of bacteria from vegetation does not contribute significant bacteria to the runoff. They also found that most of the bacteria on vegetation is of insect origin. Geldreich, *et al*. (1980) found that recreation activities in water bodies also increase the fecal coliform and fecal strep. concentrations. These organisms of intestinal origin will concentrate in areas near the shore or in areas of stratification. Fennell, *et al*. (1974) found that open dumps containing domestic refuse can be a reservoir of Salmonella bacteria that can be spread to nearby water bodies by foraging animals and birds.

When a drainage basin has much of its surface paved, the urban runoff bacteria concentrations can be expected to peak near the beginning of the rainfall event and then decrease as the event continues. Initial high levels of bacteria may be associated with direct flushing of feces and small feces particles from paved surfaces. These feces are from dogs defecating on parking lots and street areas and from birds roosting on rooftops. When a drainage area has a lot of landscaped areas or open land, relatively high bacteria concentrations in the urban runoff may occur throughout the rain event.

Bacteria Survival in Stormwater

The survival of urban runoff bacteria in receiving waters is an important issue. Very little direct consumption or contact of urban runoff usually occurs. However, when the runoff is discharged into a larger receiving water, consumption or contact may occur shortly after the rain event has ended. The Rideau River Stormwater Management Study (Ottawa, Ontario) examined the die-off of fecal coliform bacteria in the Rideau River (Droste and Gupgupoglu 1982; Environment Canada 1980; Gore and Storrie/Proctor and Redfern 1981b and 1981c). They found that the 90 percent die-off for Rideau River fecal coliforms was about two days. Because of the long travel time on the Rideau River and short interevent times of rains in the area, the effects of bacteria discharges from stormwater from one storm can affect the river concentrations during the next storm. The persistence of fecal coliforms and the slow river velocities cause downstream beach bacteria concentrations to seldom, if ever, regain true low background bacteria concentration levels. Environment Canada (1980) reported significant increase in coliform concentrations in recently excreted moist feces.

Seidler (1979) stated that the sources of Salmonella bacteria can determine their survival. This is probably true for most types of bacteria because the different bacteria sources usually determine the specific bacteria biotypes found in the feces. Different bacteria types can have quite different die-off rates.

Factors affecting urban runoff bacteria survival in stormwater have been found to be quite variable and site specific. Geldreich, *et al*. (1968) found that no significant differences in survival of urban runoff bacteria could be related to the chemical constituents present. Water temperature, however, did have a strong influence on urban runoff bacteria survival. Geldreich, *et al*. (1980) found in a Kentucky study that when copper sulfate was applied as an algicide in a reservoir, sharp declines in fecal coliform densities occurred. The standard plate count densities, however, sharply increased. They found that the survival of urban runoff bacteria was longer near the bottom of the reservoir than in shallower waters. They also found that reduced dissolved oxygen concentrations near the sediments was not detrimental to bacteria survival. Faust and Goff (1978) found that high clay concentrations in the Rhode River in the Chesapeake Bay area extended the survival of fecal coliform bacteria.

Many studies reported the effects of temperature on urban runoff bacteria die-off. Geldreich, *et al*. (1968), in a series of lab tests, found that stormwater bacteria persisted at higher concentrations under winter water temperature conditions (10^{o}C) than they did for summer water temperature conditions (20^{o}C). There were some differences in survival for the various specific types of stormwater bacteria, but this trend seemed typical. Van Donzel, *et al*. (1967) found that fecal strep. did not survive as long as fecal coliform bacteria during the summer months, while in the autumn there was little difference in their survival times. In the winter and spring, the fecal strep. survived much longer than the fecal coliforms. Seidler (1979) found that Salmonella survived for longer periods of time in colder water temperatures. McSwain (1977) reported that coliform bacteria were able to multiply in bottom sediments at a rate regulated by stream temperature. They reported another study that found significant enteric bacteria concentration increases at temperatures above 16^{o}C, but that little or no growth occurred below 10^{o}C. The conditions affecting bacteria survival in water appear to be site and bacteria specific. Many of the differences are probably associated with the specific bacteria biotype present and with the water temperature. Chemical constituent concentrations do not appear to be a factor, except when they are present at very low concentrations.

Table 56 summarizes reported 90 day die-off rates for different stormwater bacteria types. Fecal coliform die-off values varied from less than one day to about 13 days, but can be considered quite fast. Fecal strep. die-off values, however, were longer than the fecal coliform die-off rates. Some of the Streptococcus bacteria types had long survival rates, while others had short survival rates. The forms likely to be associated with agricultural activities (*S. bovis* and *S. equinus*) all are shown to have much shorter survival times than more common urban Streptococcus types (*S. faecalis*).

Table 56. Survival of Stormwater Bacteria

Bacteria type	Location and conditions	Days survival before 90% dieoff	Reference
Fecal Coliforms	Rideau River – summer	2	Droste and Gupgupogula 1982
	Cincinnati – stormwater at 10^{o}C	10	Geldreich, *et al*. 1968
	Cincinnati – stormwater at 20^{o}C	2	Geldreich, *et al*. 1968
	Oakland, CA – bird feces into urban lake	Rapid	Pitt and Bozeman 1979
	Stormwater – summer	3	Van Donsel, *et al*. 1967
	Stormwater – autumn	13	Van Donsel, *et al*. 1967
Fecal Strep.	Oakland, CA – bird feces into urban lake	>30	Pitt and Bozeman 1979
	Stormwater – summer	3	Van Donsel, *et al*. 1967
	Stormwater – autumn	20	Van Donsel, *et al*. 1967
Streptococcus faecalis	Cincinnati – stormwater	>14	Geldreich, *et al*. 1968
S. faecalis var*. liquifaciens*	Cincinnati – stormwater at 10^{o}C	>14	Geldreich, *et al*. 1968
	Cincinnati – stormwater at 20^{o}C	6	Geldreich, *et al*. 1968
S. bovis	Cincinnati – stormwater at 10^{o}C	<1	Geldreich, *et al*. 1968
	Cincinnati – stormwater at 20^{o}C	1	Geldreich, *et al*. 1968
S. equinus	Cincinnati – stormwater	<1	Geldreich and Kenner 1969
Salmonella	Rural Oregon Creek	>6	Seidler 1979
S. typhirmrium	Cincinnati – stormwater at 10^{o}C	7	Geldreich, *et al*. 1968
	Cincinnati – stormwater at 20^{o}C	2	Geldreich, *et al*. 1968
Shigella flexneri	Baltimore – stormwater	>8	Field, *et al.* 1976
Enterbactor aerogenes	Cincinnati – stormwater at 10^{o}C	5	Geldreich, *et al*. 1968
	Cincinnati – stormwater at 20^{o}C	4	Geldreich, *et al*. 1968

Survival of Bacteria in Soil

Because of the importance of soil bacteria as a source of urban area bacteria, their survival in the soil after deposition is important. If an area has long interevent times between rain events, soil bacteria survival would have to be quite long in order for the soil to be a significant urban runoff bacteria source. However, in areas having frequent rains, soil bacteria survival is less important (assuming that it is greater than the interevent period). Many site conditions have been reported to influence soil bacteria survival. Van Donsel, *et al*. (1967) found that sunlight, temperatures, rainfall, soil moisture, pH, organic matter, and the presence of other microorganisms all affect the survival of total coliforms, fecal coliforms, and fecal strep. soil bacteria. They also reported that feces bacteria deposited on dry soils are relatively immobilized and subject to the specific site conditions. After-growth of soil bacteria (increasing populations without new deposition) may account for some of the seasonal variations in runoff bacteria counts. If the soil has not been recently contaminated, the runoff would have an immediate supply of microorganisms from the soil. Contamination of the receiving waters would be out of proportion to the true sanitary history of the area. They also stated that non-fecal coliforms reappeared after fecal organisms declined. They were also present in much higher concentrations after fecal bacteria die-off than before the soil was contaminated.

Both after-growth and decline of bacteria in soils have been reported. Soil coliforms exhibit after-growth following rainstorms and exhibit rapid declines during freezing weather. If very warm weather follows a rain, a very large increase in soil coliform bacteria was noted, while the increase was much less if cool weather followed a rain. They also found declining bacteria soil populations if the soil was dry. Alternate freezing and thawing at exposed winter sites caused significant morality of soil coliform bacteria. Evans and Owens (1972) reported that *E.Coli* and Enterococci showed 90 percent reductions after about two or three months in soils. Van Donzel, *et al*. (1967) reported prolonged persistence of other bacteria types. Various strains of Salmonella were found to exist for long periods of time (nine months for *S typhimurium*). It is not uncommon for soil bacteria to survive for up to 200 days after inoculation.

Fecal Coliform to Fecal Strep. Bacteria Ratios

Geldreich (1965) found that the ratio of fecal coliform to fecal strep. bacteria concentrations may be indicative of the probable fecal source. In fresh human fecal material and domestic wastes, he found that the fecal coliform densities were more than four times the fecal strep. densities. However, this ratio for livestock, poultry, dogs, cats, and rodents was found to be less than 0.6. These ratios must be applied carefully, because of the effects of travel time and various chemical changes (especially pH) on the die-off rates of the component bacteria. As a generality, he stated that fecal coliform to fecal strep. ratios greater than four indicate that the bacteria pollution is from domestic wastes, which are composed mostly of human fecal material, laundry wastes, and food refuse. If the ratio is less than 0.6, the bacteria is probably from livestock or poultry in agricultural areas or from stormwater runoff in urban areas. He found that agricultural and stormwater runoff can be differentiated by studying the types of fecal strep. bacteria found in the water samples. Geldreich and Kenner (1969) further stressed the importance of carefully using this ratio. They stressed that samples must be taken at the wastewater outfalls. At these locations, domestic waste, meat packing wastes, stormwater discharges, and feedlot drainage contain large numbers of fecal organisms recently discharged from warm blooded animals. Once these organisms are diffused into the receiving stream, however, water temperature, organic nutrients, toxic metals, and adverse pH values may alter the relationship between the indicator organisms. This ratio should only be applied within 24 hours following the discharge of the bacteria.

Feachem (1975) examined how these ratios could be used with bacteria observations taken over a period of time. Because the fecal coliform and fecal strep. bacteria die-off rates are not the same, the ratio gradually changes with time. He found that bacteria is predominantly from human sources if the FC/FS ratios are initially high (greater than four) and then decrease with time. Non-human bacteria sources would result in initially low fecal coliform to fecal strep. ratios (less than 0.7) which then rise with time.

Table 57 summarizes the observed fecal coliform to fecal strep. bacteria population ratios in the Rideau River study area. These ratios are separated into source area sheetflow samples, Rideau River water samples and water samples collected at the swimming beaches. The source area sheetflow samples contain the most recent contamination, while the river segment and beach samples contain “older” bacteria. The initial source area samples all have ratios of less than 0.7. However, the river averages range from 0.5 to 1.2 and the beach samples (which may be “older” than the river samples) range from 1.7 to 2.8. These ratios are seen to start with values less than 0.7 and increase with time. Based on Feachem’s (1975) work, this would indicate that the major bacteria sources in the Rideau River are from non-human sources. This substantiates the previous conclusions as presented in the Phase 1 Rideau River Stormwater Management Report. Periodic high bacteria ratios in the river and at the beaches could be caused by the greater die-off ratio of fecal strep. as compared to fecal coliform. The observed periodic high Rideau River FC/FS ratios (which can be greater than four) may therefore be from old, non-human fecal discharges and not from fresh human fecal discharges.

Table 57. Fecal Coliform to Fecal Strep. Bacteria Population Ratios in Study Area (Pitt 1983)

Source Areas	FC/FS ratio
Rooftop runoff	0.5
Vacant land sheetflow	0.3
Parking lot sheetflow	0.2
Gutter flows	0.2
Average of source area values	0.3
Rideau River Segment	
A	1.2
B	0.6
C	0.5
D	0.5
E	1.0
Average of river segment values	0.7

River Swimming Beaches	
Strathcona	2.8
Brantwood	2.3
Brighton	2.1
Mooney's Bay	1.7
Average of swimming beach values	2.2

River and Lake Sediment Bacteria

Matson, *et al*. (1978) studied the effects of river and lake sediments as a source of bacteria to the water column in Connecticut. They found that resuspended sediments in shallow waters can elevate the water column bacteria concentrations significantly. They stated that the physical resuspension of shallow water sediments is increased by elevated river discharges, wind induced turbulence, dredging, motorboats, swimming, walking, and wading and normal activities of aquatic microorganisms. The magnitude of sediment resuspension varies with the intensity of the mechanisms involved, and the water depth to the sediment. They stated that during stable river flows, the water bacteria populations are relatively constant, but during periods of high flows, sediment organisms can be scoured from the benthic surfaces and mixed into the water column. After peak discharges, water borne microorganisms resettle downstream, which increases those sediment bacteria populations. Geldreich, *et al*. (1980) also studied bacteria interactions between sediment and water. They found that the sediment-water interface of a water body is an attractive habitat for a variety of different bacteria involved in different biochemical processes. Shallow bottom sediments attract a variable bacteria population because of the physical and chemical requirements that can be satisfied there, in contrast to the more limited conditions available in the water or buried in the sediments.

Davis (1979) stated that bacteria contamination of waterways during and following storm events is a function of the stream sediment bacteria concentrations, the concentrations of bacteria in soils adjacent to the stream (and source areas in an urban watershed), and the stream velocities. Davis further stated that stream sediments can contain greater densities of coliform bacteria on a number per unit weight or volume basis than the water body itself; the concentrations of bacteria in the top two inches of mud can be 100 to 1,000 times greater than the concentrations of the bacteria in the water. He reported fecal coliform sediment concentrations up to 100 organisms per gram of sediment and that the suspended sediments can be a major source of bacteria contamination. Geldreich, *et al*. (1980) stated that sediment bacteria concentrations can be as high as 3,000 to 15,000 organisms per square meter of particulate surface. Pitt and Bozeman (1979), in a study of an urban lake in Oakland, California, found fecal coliform sediment concentrations that ranged from one to 35,000 organisms per gram and averaged about 1,000. McSwain (1977) found that in a rural study in North Carolina, total and fecal coliform concentration increases were more related to bottom sediment disturbances than to stream bank flushing.

Soil Bacteria Sources

Van Donsel, *et al*. (1967) stated that soil bacteria pollution may occur from direct defecation by livestock, pets, and wild animals, by malfunctioning or overflowing septic tank systems or by flooding of sewerage systems. Much of the total coliform indicator bacteria organisms in urban areas, however, are not from these sources. Geldreich, *et al*. (1968) found that in a Cincinnati urban runoff study, direct fecal contamination accounted for less than 10 percent of the total coliform bacteria present in the stormwater. The remaining coliforms (which were non-fecal in origin) were assumed to be contributed from soil erosion. Therefore, soil can contain large numbers of both non-fecal and fecal coliform bacteria. Because rain water contains very small bacteria concentrations, urban runoff becomes contaminated with bacteria when the rain water contacts contaminated surfaces. In wilderness areas, runoff has very little fecal coliform bacteria, while runoff from agricultural areas or urban areas can have varying amounts of fecal coliform bacteria. Seidler (1979) found that the movement of fecal coliform bacteria in saturated soils were extremely rapid. Soil can add appreciable fecal and non-fecal coliform bacteria to rain runoff. Casserly and Davis (1979) found that coliform types in urban soils were the same as they found in urban runoff, indicating a strong interaction between polluted soils and contaminated urban runoff. Davis (1979) found that irrigated soils, with high humic content, can yield greater amounts of bacteria. Evans and Owens (1972) found that the concentrations of *E. Coli* and Enterococci in stormwater runoff were affected by the soil bacteria concentrations.

Evans and Owens (1973) reported that bacteria was more likely to erode than the particulate matter in the soil. Davis (1979) found that the leaching action of rain on soil bacteria was quite erratic. The most important factors affecting bacteria concentrations in runoff were found to be the concentrations of the bacteria in soils. They reported total coliform concentrations in soils ranging from 200 to more than 500,000 total coliform organisms per gram. Fecal coliform soil concentrations ranged from less than 20 to about 300 organisms per gram and fecal strep. soil concentrations ranged from less than 20 to about 1,000 organisms per gram.

Wildlife Sources of Bacteria

Effects of Birds on Water Bacteria Concentrations

Several studies have been conducted which examined the effects of large migratory or permanent waterfowl populations on the bacteria quality of water bodies. A study at the Montezuma Bird Refuge in New York (Have 1973) found inconsistent relationships between the bird populations and the total coliform, fecal coliform, and fecal strep. counts. Peak populations of 70,000 geese and 100,000 ducks frequent this 1,000 acre refuge. In fact, they found that the concentrations of the non-pathogenic bacteria in the two major streams flowing into the refuge were greater than in the water flowing out of the refuge. The specific conductance of the inflowing water was also greater than the outflowing water. The effluent did have higher concentrations of phosphorous and nitrogen. They concluded that the settling effect of the quite waters in the refuge may help explain the improvement in the quality of water leaving the refuge.

Brierley, *et al*. (1975) studied the Rio Grande Refuge in New Mexico. This refuge supports bird populations of more than 10,000 Sandhill cranes, 2,000 Canada geese, more than 8,000 snow geese, and more than 25,000 ducks from October to early March along ten miles of river channel. The water flowing into this bird refuge area along the Rio Grande River has high concentrations of suspended sediments and bacteria. The bacteria concentrations seem to correlate directly with the high sediment concentrations. The presence of the large number of birds apparently does not affect the concentrations of the bacteria that were investigated (total heterotrophic bacteria, fecal and total coliforms, and Enterococci). Most of the birds use a single large pond at the end of their winter habitat. The draining of this pond at the end of their season did not seem to significantly change the bacteria population of the receiving channel water. The bird habitat pond, in fact, had decreased concentrations or bacteria during and following the period of maximum use. They concluded that the bacteria originated in upstream areas before it reached the refuge.

In a study at Lake Wingra in Wisconsin (Geldreich 1980), intermittent high fecal coliform counts during the late summer and early fall were found to be due to a combination of wastes from mallard ducks and the local weather. They reported that fecal coliforms in the sand due to duck defecation multiplied during the first week after deposition and then die-off occurred. Bacteria in these near-lake sands were transported into the water primarily by stormwater runoff erosion and by the foot traffic of bathers when going into the water.

Oplinger (1977) studied the effects of waterfowl populations on the water quality of a small creek park in Pennsylvania. They felt that increasing waterfowl populations and the declining water quality were related and threatened the health and welfare of both the waterfowl and the human watershed users.

Figley and Vandraff (1974), in a study of suburban parks in New York state, noted that mallard ducks are especially attracted to suburban lagoon developments. They felt that urban concentrations of semi-wild ducks may be detrimental, by serving as the focal points for outbreaks of infectious avian diseases and as a reservoir of diseases that could be transmitted to migrating wildfowl.

A study by Fennell, *et al*. (1974) examined the effects of about 500 roosting gulls on a one million cubic meter storage reservoir. Salmonella were usually found in the reservoir waters but never in the incoming water. They also found close correlations between the number of gulls and the degree of bacteria contamination. The sources of Salmonella appeared to be household and other refuse from dumps where the gulls were foraging. When the gulls left, after bird scaring fireworks were used, the Salmonella and other bacteria concentrations almost immediately decreased. The bacteria concentrations remained at low levels for a period of five weeks until the fireworks were stopped; the birds were allowed to return, and the bacteria concentrations in the reservoir immediately increased.

It is evident that birds can have varying effects on the bacteria concentrations in waterbodies. Large refuges do not seem to be severely affected by the wildlife populations. In fact, the ponding of waters in refuges appears to improve the water quality through sedimentation. Waterfowl frequenting smaller bodies of water, especially creeks and small lagoons, appear to have the potential for substantially increasing the water bacteria concentrations.

Gore and Storrie/Proctor and Redfern, (1981a) summarized the results of studies made to determine the effects of birds roosting on bridges over the Rideau River on river bacteria concentrations. They found that the birds on the bridges could have a statistically significant impact on fecal coliform concentrations, especially during the low summer flows. Measured concentration increases of fecal coliform bacteria downstream from the Queensway Bridge was found to be about 300 fecal coliform organisma/100 mL.

Other Wildlife Bacteria Contributions

Certain biotypes are specific to certain forms of wildlife. The presence or absence of certain bacteria types in environmental samples can be a very important factor in identifying the bacteria sources (feces from which animals). As an example, *Streptococcus bovis* and *S. equinus* have not been found in human feces by several investigators. (These types, however, are the predominant fecal strep. type found in livestock feces.) Their absence in a sample indicates the probable absence of livestock feces contamination, however, their absence may only indicate die-off and not absence of fecal contamination. Geldreich and Kenner (1969) stated that the absence of fecal strep. bacteria indicates the absence of warm blooded animal fecal pollution. The presence of *Streptococcus faecalis* indicates human fecal contamination. *S. faecalis* far outnumbers *S. inulinaceus* in sewage and in sewage polluted waters, even though *S. inulinaceus* is in great abundance in fresh feces (Bartley and Slanetz 1960). *S. faecalis* var. *liquefaciens* is ubiquitous as it is present in almost all samples tested (Geldreich and Kenner 1969; Bartley and Slanetz 1960). *S. mitis* and *S. salivarious* are considered sensitive indicators of human pollution when they are found (Seidler 1979). *S. bovis* and *S. equinus* are nearly ideal non-human mammal fecal indicators (Seidler 1979). They have rapid die-off rates (much faster than fecal coliform die-offs) and are the most sensitive bacteria in the fecal strep. category. Their presence indicates recent livestock pollution (Feacham 1975; Geldreich 1976; Bartley and Slanetz 1960; Geldreich and Kenner 1969).

Drake, *et al*. (1961) found a wide variation in the coliform content of some wild and domestic animal feces. Coliform bacteria were present in small numbers or were absent for some feces, such as from rabbits, shrews, deer, elk, some squirrels, and many birds. They also found that coliform bacteria were not found in some carnivores (shrews) but were present in large number in the carnivores (coyotes and bears). They also found no significant differences in the fecal coliform content of different animals of the same species that were collected in different areas. However, feces from different species of animals collected in the same area could have large differences in their fecal coliform concentrations. They also noted that some mammals (coyote, bear, some gophers, and some squirrels) had coliform concentrations in the feces that were similar to human coliform concentrations. Animals with soft or moist feces (man and many domestic animals such as cows, dogs, and pigs) had very high numbers of coliform bacteria (many thousands to millions of coliform bacteria per gram). The feces of other animals, especially those with hard or dry feces, may contain few or no coliform bacteria.

Geldreich (1976) summarized a study that showed the variations in fecal strep. bacteria concentrations in human feces from different locations. Feces collected from humans living in Cincinnati had concentrations more than five times greater than samples collected from healthy people in Nagpur, India (13 million and 2 million fecal strep. organisms per gram, respectively). He also reported that fecal strep. densities in farm animal, cat, dog, mice, and chipmunk feces samples were in the order of millions of organisms per gram. Rabbit feces fecal strep. concentrations, however, may be several orders of magnitude lower than those found in other animals. The Ottawa waterbird feces samples were reported to have the largest total coliform, fecal coliform, and fecal strep. concentrations when compared to all other samples reported (except for the fecal strep. dog feces concentrations). Gull feces generally have the highest fecal coliform concentrations in their feces, followed by Ottawa pigeons, ducks, dogs, sheep, and humans. Other urban bird feces (pigeons, sparrows, robins, starlings, and blackbirds) were all reported to have much lower fecal coliform concentrations that were unusually high.

Feces Discharges from Wildlife

Table 58 summarizes reported discharges of feces from different mammals and birds. These discharges are expressed in grams per animal per day and vary quite widely, depending on the study. Animals can deposit substantial quantities of feces in an urban area, depending upon the animal's population. Geldreich (1976) stated that major contributions of bacteria in urban communities are from fecal discharges from cats, dogs, and rodents. These feces are deposited on soil, asphalt, and cement. He stated that the one-half million dogs in New York City deposit about 150,000 pounds of feces on the streets, sidewalks, and park areas per day. Significant populations of rodents may also contribute large amounts of fecal material in urban areas. Fortunately, very little of this fecal bacteria enters receiving waters. Faust (1976), in an agricultural watershed in the Rhode River near Chesapeake Bay, found that only about one percent of the fecal coliform bacteria deposited by cattle in the watershed was washed into the receiving waters. Sometimes the yields (application rates) were higher, with high values around 5 percent and on one occasion reaching 25 percent. They concluded that fecal coliform discharges can be substantial from a watershed that has the equivalent of about one cow per two hectares. Evans and Owens (1973), from a study in Scotland, stated that most of the bacteria in the runoff water came from the soil. They found that the soil bacteria washoff yield was only about one-tenth of one percent of the estimated total soil bacteria population. They felt that the maximum annual discharge of bacteria from the contaminated soil would only be about 0.15 percent of the total soil bacteria population.

Table 58. Estimated Feces Discharges

Animal	Discharge[1] (grams/animal/day)	Reference
Mammals		
Humans	150	Geldreich 1976
Farm animals		
pig	680	Howe 1969
sheep	1,100	Howe 1969
cow	7,000	Howe 1969
horse	7,000	Howe 1969
Domestic pets		
cat	70	Howe 1969
dog	140	Howe 1969
	23 to 100	Marron and Senn 1974
Possible urban wildlife		
rabbit	550	Howe 1969
rat	35	Howe 1969
mouse	10	Howe 1969
Birds		
Farm birds		
chicken	55	Howe 1969
	180	Geldreich 1976
turkey	160	Howe 1969
	450	Geldreich 1976
Possible urban birds		
pigeon	25 to 50	Gore & Storrie/Proctor & Redfern 1981a
gulls	10 to 25	Gould and Fletcher 1978
duck	70	Howe 1969
	340	Geldreich 1976
goose	160	Howe 1969

[1] estimated application factors (fraction reaching urban receiving waters): 0.01 for land animals and 0.5 for waterfowl

Case Study: Investigation of Urban Runoff Pathogen Sources in Ottawa, Ontario

The City of Ottawa, Ontario, sponsored several studies in the early 1980s investigating the sources of the high bacteria concentrations found in the Rideau River, and possible control procedures. The following discussion (from Pitt 1983) summarizes their findings, especially relating to the relative magnitude of urban bacteria sources.

Table 59 summarizes the bacteria concentrations observed for the different samples collected in the Ottawa urban area. Except for rooftop runoff, the catchment subarea sheetflow concentrations all approach the concentrations of the urban runoff. The urban runoff bacteria concentrations are slightly greater than the river concentrations below Mooney's Bay. The catchment area sheetflow fecal strep. concentrations, again except for rooftop runoff, are all substantially greater than the river concentrations.

Table 59. Typical Bacterial Population Densities in the Ottawa Area (Pitt 1983)

	Total Coliforms	Fecal Coliforms	Fecal Strep.
Water Samples (organisms/100 mL)			
Rideau River			
Below Mooney’s Bay	7,000	1,000	500
Above Mooney’s Bay	500	50	50
Urban runoff	na	10,000	na
Snowmelt	3,000	<2	2
Catchbasin sump water	na	50	300
Gutter flows	na	4,000	20,000
Parking area sheetflow	na	3,000	10,000
Vacant land and park sheetflow	na	6,000	20,000
Rooftop runoff	na	100	200
Sediment Samples (organisms/gram solids)			
Rideau river sediments (urban area)	na	20,000	na
Sewerage sediments	na	8,000	20,000
Catchbasin sump water	400	20	100
Street dirt	na	400	2,000

Estimated Unit Area Bacteria Yields

Five to eleven storms were completely monitored for fecal coliform concentrations at four test catchments from 1978 to 1981. Table 60 summarizes these observations for the 34 monitored storms. The resultant calculated catchment bacteria runoff yields expressed in millions of organisms per hectare per day are shown in Table 61. Approximately 1.5 x 10^8 fecal coliforms per hectare per year and about 3.7 x 10^8 fecal strep. organisms per hectare per year are the estimated bacteria yields for the Ottawa six month runoff season.

Table 60. Catchment Runoff Fecal Coliform Bacteria Observations in Ottawa area (Pitt 1983)

	Alta Vista	Chesterton	Leonard	St. Lauraent	Overall
Geometric mean* (#/100 mL)	14,100	12,300	21,700	4,580	10,200
Min. (#/100 mL)	5,900	720	11,500	540	540
Max. (#/100 mL)	38,000	96,600	64,100	31,400	96,600
Number of storms monitored	11	7	5	11	34
Study period	1980 and 1981	1978, 1979, and 1981	1980 and 1981	1980 and 1981	1978 through 1981

* geometric mean of flow-weighted averaged concentrations for monitored storms

Table 61. Estimated Ottawa Catchment Bacteria Runoff Yields (10^6 organisms/ha/day) (Pitt 1983)

Catchment	Fecal Coliforms Mean (range)	Fecal Strep. Mean (range)
Alta Vista	0.5 (0.3 to 1.1)	1.3 (0.8 to 3)
Chestron	0.6 (0.4 to 1.5)	1.5 (1 to 4)
Leonard	1.4 (0.7 to 3)	3.5 (2 to 8)
St. Laurent	0.6 (0.3 to 1.4)	1.5 (0.8 to 4)
Average	0.8×10^6 FC org/ha/day	2×10^6 FS org/ha/day

In order to determine the importance of each of the catchment subareas in contributing urban runoff pollutants, a small sampling effort was conducted to collect sheetflow samples during two rain events. Table 62 summarizes the results of these analyses. The rooftop bacteria samples had substantially lower fecal coliform and fecal strep. bacteria concentrations than samples collected from vacant land and park sheetflows, parking lot sheetflows and street gutter flows. The rooftop samples, however, did have important bacteria concentrations, especially when compared to Rideau River bacteria concentrations above Mooney's Bay.

Table 62. Catchment Subarea Sheetflow Bacteria in Ottawa (August and September, 1981, observations) (Pitt 1983)

		Rooftop runoff	Vacant land and park sheetflow	Parking lot sheetflow	Gutter flow
Fecal coliforms	Geometric mean (#/100 mL)	85	5,600	2,900	3,500
	Min (#/100 mL)	10	360	200	500
	Max (#/100 mL)	400	79,000	19,000	10,000
	Number of observations	4	7	6	7
Fecal Strep.	Geometric mean (#/100 mL)	170	16,500	11,900	22,600
	Min (#/100 mL)	20	12,000	1,600	1,800
	Max (#/100 mL)	3,600	57,000	40,000	1,200,000
	Number of observations	4	7	6	7

The urban runoff fecal coliform unit area yield is more than a factor of ten greater than the snowmelt yield, and about a factor of ten greater than the sewerage and catchbasin sump yields. Therefore, snowmelt and sewerage accumulations probably do not appreciably affect the total annual yields, but they may significantly affect individual snowmelt and storm event concentrations and yields. The street surface particulate fecal coliform and fecal strep. accumulations are as much as one to two orders of magnitude greater than the total urban runoff bacteria discharges. Bacteria urban runoff yields do not appear to be source-limited in that substantial quantities of bacteria reside on the street surfaces that are not washed off by rain. A large quantity of bacteria is associated with particulates that are trapped in the street textures and may be subject to significant die-off during periods of dry weather. The many other sources of bacteria in the urban area would further increase this overabundance of bacteria sources for urban runoff.

These observed subarea bacteria concentrations were much greater than those observed in a similar sampling program in San Jose, California, (Pitt and Bozeman 1982). In San Jose, the observed fecal coliform gutter and parking lot sheetflow sample concentrations were much greater than elsewhere in the San Jose study areas, and were from several hundred to about 1000 organisms/100mL. Rooftop runoff and landscaped area runoff fecal coliform concentrations were less than ten and less than 50 organisms/100 mL., respectively. The San Jose sheetflow fecal strep. concentrations were closer to the observed Ottawa concentrations. An earlier Ottawa study reported by the

Regional Municipality of Ottawa - Careleton (1972) measured rooftop runoff bacteria concentrations. The runoff from a roof at an experimental farm that was frequented by many birds had coliform concentrations greater than 10,000 organisms/100 mL. Street surface and parking lot runoff showed total coliform concentrations in the hundreds of thousand of organisms/100 mL.

The differences in bacteria yields from street surfaces when comparing large rains with small rains very large. The bacteria yields from the street surfaces decrease much more for the larger rains because of the high bacteria concentrations observed in non-street surface sheetflows. Even if all of the street surface bacteria was removed from the streets, a maximum reduction of about 60 to 70 percent in outfall bacteria yields would be achieved, and only for the runoff from residential areas and for the smallest rains. For the largest rains, and if all of the fecal coliform bacteria was removed from the streets, only about 10 to 25 percent bacteria reductions would be observed at the outfall. If sidewalks and driveways were cleaned, a greater fraction of the bacteria could be controlled. If the shopping center parking lots, along with the streets, were cleaned, then much of the bacteria in these areas could also be controlled and for almost all storms.

Mammal and Bird Populations and Bacteria Discharges in the Ottawa Urban Area

Table 63 summarizes the expected populations of mammals and birds in the lower Rideau River watershed. There are other domestic and wild animals in this watershed (such as other birds and rodents) but their population estimates are not available. It is estimated that about 16,000 dogs and the same number of cats live in this watershed, corresponding to approximately one dog or cat for every other house. The waterbird estimates are based upon actual population counts made along the river.

Table 63. Estimated Bird and Pet Populations in the Lower Rideau River Watershed (below Hogs Back) (Pitt 1983)

Animal	Population Density (animals/ha)	Total estimated animal population in the Lower Rideau River Watershed (4000 ha)
Dogs[1]	4	16,000
Cats[1]	4	16,000
Robins[2]	7	28,000
Pigeons (land)[1]	1	4,000
Pigeons (on bridges)[3]		600
Ducks (on river)[3]		100
Gulls (on river)[3]		150
Swans (on river)[3]		15
Other birds on river (sparrows and blackbirds)[3]		10

[1] estimated from Colt, *et al.* 1977

[2] estimated from Howard 1974

[3] Regional Municipality of Ottawa-Carleton 1980

The estimated total annual bacteria discharges from the mammals and birds in this watershed, based upon population estimates, fecal discharges, application factors, and bacteria concentrations in the feces is 2 X 10^{11} fecal coliforms per ha per year. This estimate is about two to three orders of magnitude greater than what is expected in the annual urban runoff bacteria yield. This large difference is likely associated with bacteria die-and sedimentation.

The major source of fecal coliforms in the Rideau River is expected to be pigeons (when using the high Ottawa pigeon fecal coliform values), followed by dogs and ducks. The other sources shown would all contribute less than a total of five percent. Dogs are expected to contribute almost half of the river total coliform organisms, while pigeons on the bridges and ducks on the river make up most of the remainder. Dogs are expected to contribute almost all of the river fecal strep. bacteria, with ducks on the river contributing to less than five percent. Pitt and Bozeman (1979) found that lake birds can contribute a significant amount of fecal strep. bacteria to a lake refuge in the middle of an urban area in Oakland, CA. However, urban runoff components contribute much more bacteria during wet weather conditions.

It is interesting to compare these calculated estimates of fecal coliform contributions with those reported elsewhere. Faust and Goff (1977) reported 10^9 to 10^{10} fecal coliforms discharged per hectare per year in the Chesapeake Bay area from cultivated lands, forests, and pastures. These values are about ten to 100 times the estimated urban area yields for the lower Rideau River watershed.

Summary of Ottawa Case Study

The limited assimilative capacity of the river and how the bacteria quality decreases as the river flows through Ottawa was previously described. The substantial bacteria density increases during wet weather indicate an urban runoff problem and the probable lengthy duration of adverse river conditions. The number of observations showing bacteria densities greater than the standards indicates that Strathcona, Brantwood, and Brighton Beaches exceed the fecal coliform criteria of 100 organisma/100 mL most of the time. Mooney’s Bay Beach exceeds this criteria about ten percent of the time. A limited field program was conducted during this study that found the Rideau River bottom sediments to have substantial bacteria population densities.

An important phase in designing an urban runoff control program is to determine the sources of the problem pollutants in the watershed. An understanding of where they accumulate in the catchment is needed before appropriate controls may be selected. As an example, bacteria may accumulate almost everywhere in an urban area (on rooftops from birds, and on streets, parking lots, landscaped areas, and vacant land from dogs and other urban animals). Original sources therefore affect a variety of potential control areas. The Rideau River Stormwater Management Plan report identified urban runoff as the major source of the problem bacteria discharges. This special study summarized here included a limited field program which roughly identified the specific locations in the urban area where the bacteria originated. Feces from warm blooded animals are the only sources of fecal bacteria, while soils can contain some non-fecal bacteria. The ratio of fecal coliforms to fecal strep. bacteria population densities can be used to differentiate between human and non-human sources if the samples are obtained very close to the time of discharge. Otherwise, the different survival times of the fecal strep. biotypes can radically change this ratio with time. The periodic high ratios of these two bacteria indicator groups in the Rideau River may be explained by relatively old non-human discharges. If water bodies were small (creeks and small reservoirs), a relatively small number of birds (less than 100) were found to significantly increase various fecal bacteria biotypes in the water. However, if the water bodies were large (large bird refuges and large rivers), then large numbers of birds (as many as 100,000) did not significantly increase the bacteria population densities in the water. The water flowing from the bird refuges typically had better water quality than the inflowing water, possibly due to sedimentation in the refuge marshes. Dog feces are expected to contribute much of the fecal coliforms in urban runoff, while pigeons (on bridges) and ducks on the Rideau River may contribute most of the bacteria to the River. Polluted river sediments may also play an important role in contaminating river water.

Based on monitoring from the Rideau River Stormwater Management Study and other runoff bacteria studies, it is concluded that many potentially pathogenic bacteria biotypes can be present in the local urban runoff. Most of these pathogenic biotypes can cause health problems when ingested. Because of the low probability of ingestion of urban runoff, many of the potential human diseases associated with these biotypes are not likely to occur. The required infective doses of many of these biotypes and their relatively low concentrations in stormwater would require very large amounts of urban runoff to be ingested. As an example, Salmonella, when observed in Ottawa urban runoff and receiving waters, has been found in very low concentrations requiring the consumption of more than 20 liters of urban runoff for infections. Shigella, however, may be present in urban runoff and receiving waters and when ingested in low numbers can cause dysentery.

The pathogenic organisms of most importance in urban runoff are usually associated with skin infections and body contact. Body contact with urban runoff is not likely. However, the Rideau River retains many of the pathogenic biotypes originating from urban runoff for a long period of time after rains. The most important biotype causing skin infections is *Pseudomonas aeruginosa*. This biotype has been frequently detected in urban runoff at many locations in concentrations that may cause potential infections. However, there is little information relating increased infection hazards with increased *Pseudomonas* concentrations. *Staphylococci aureus* may also cause skin problems with body contact, but there is little information concerning the concentrations of this biotype in urban runoff. Various pathogenic yeasts and viruses may also be found in urban runoff, but their concentrations and infective pathways are not well enough known to establish criteria for urban runoff pollution. Therefore, the local bacteria concentration objectives based on fecal coliform concentrations may be unreasonable when actual potential health effects are considered.

Further studies also need to be made concerning populations of pathogenic bacteria (specifically *Pseudomonas aeruginosa, Staphylococci aureus* and Shigella) in the Rideau River. Population densities of these pathogens may be related to River location, storm type, and possibly indicator (fecal coliform) bacteria densities. If adverse levels of these pathogens can be predicted, or easily and quickly measured, then they should be used as the basis for beach closures in the River.

Emerging Tools for Identifying Sources of Discharges

Coprostanol and Other Fecal Sterol Compounds Utilized as Tracers of Contamination by Sanitary Sewage.

A more likely indicator of human wastes than fecal coliforms and other “indicator” bacteria may be the use of certain molecular markers, specifically the fecal sterols, such as coprostanol and epicoprostanol (Eaganhouse, *et al*. 1988). However, these compounds are also discharged by other carnivores in a drainage (especially dogs). A number of research projects have used these compounds to investigate the presence of sanitary sewage contamination. The most successful application may be associated with sediment analyses instead of water analyses. As an example, water analyses of coprostanol are difficult due to the typically very low concentrations found, although the concentrations in many sediments are quite high and much easier to quantify. Unfortunately, the long persistence of these compounds in the environment easily confuses recent contamination with historical or intermittent contamination.

Particulates and sediments collected from coastal areas in Spain and Cuba receiving municipal sewage loads were analyzed by Grimalt, *et al*. (1990) to determine the utility of coprostanol as a chemical marker of sewage contamination. Coprostanol can not by itself be attributed to fecal matter inputs. However, relative contributions of steroid components can be a useful indicator. When the relative concentrations of coprostanol and coprostanone are higher than their 5α epimers, or more realistically, other sterol components of background or natural occurrence, it can provide useful information.

Sediment cores from Santa Monica Basin, CA, and effluent from two local municipal wastewater discharges were analyzed by Venkatesan and Kaplan (1990) for coprostanol to determine the degree of sewage addition to sediment. Coprostanols were distributed throughout the basin sediments in association with fine particles. Some stations contained elevated levels, either due to their proximity to outfalls or because of preferential advection of fine-grained sediments. A noted decline of coprostanols relative to total sterols from outfalls seaward indicated dilution of sewage by biogenic sterols.

Other chemical compounds have been utilized for sewage tracer work. Saturated hydrocarbons with 16-18 carbons, and saturated hydrocarbons with 16-21 carbons, in addition to coprostanol, were chosen as markers for sewage in water, particulate, and sediment samples near the Cocoa, FL, domestic wastewater treatment plant (Holm, *et al.* 1990). The concentration of the markers was highest at points close to the outfall pipe and diminished with distance. However the concentration of C16-C21 compounds was high at a site 800 m from the outfall indicating that these compounds were unsuitable markers for locating areas exposed to the sewage plume. The concentrations for the other markers were very low at this station.

The range of concentrations of coprostanol found in sediments and mussels of Venice, Italy, were reported by Sherwin, *et al*. (1993). Raw sewage is still discharged directly into the Venice lagoon. Coprostanol concentrations were determined in sediment and mussel samples from the lagoon using gas chromatography/mass spectroscopy. Samples were collected in interior canals and compared to open-bay concentrations. Sediment concentrations ranged from 0.2-41.0 µg/g (dry weight). Interior canal sediment samples averaged 16 µg/g compared to 2 µg/g found in open bay sediment samples. Total coprostanol concentrations in mussels ranged from 80 to 620 ng/g (wet weight). No mussels were found in the four most polluted interior canal sites.

Nichols, *et al*. (1996) also examined coprostanol in stormwater and the sea-surface microlayer to distinguish human versus nonhuman sources of contamination. Other steroid compounds in sewage effluent were investigated by Routledge, *et al*. (1998) and Desbrow, *et al*. (1998) who both examined estrogenic chemicals. The most common found were 17β-Estradiol and estrone which were detected at concentrations in the tens of nanograms per liter range. These were identified as estrogenic through a toxicity identification and evaluation approach, where sequential separations and analyses identified the sample fractions causing estrogenic activity using a yeast-based estrogen screen. GC/MS was then used to identify the specific compounds.

Estimating Potential Sanitary Sewage Discharges into Storm Drainage and Receiving Waters using Detergent Tracer Compounds. As described above, detergent measurements (using methylene blue active substance, MBAS, test methods) were the most successful individual tracer to indicate contaminated water in storm sewerage dry-weather flows. Unfortunately, the MBAS method uses hazardous chloroform for an extraction step. Different detergent components, especially linear alkylbenzene sulphonates (LAS) and linear alkylbenzenes (LAB), have also been tried to indicate sewage dispersal patterns in receiving waters. Boron, a major historical ingredient of laundry chemicals, can also potentially be used. Boron has the great advantage of being relatively easy to analyze using portable field test kits, while LAS requires chromatographic equipment. LAS can be measured using HPLC with fluorescent detection, after solid phase extraction, to very low levels. Fujita, *et al*. (1998) developed an efficient enzyme-linked immunosorbent assay (ELISA) for detecting LAS at levels from 20 to 500 mg/L.

LAS from synthetic surfactants (Terzic and Ahel 1993) which degrade rapidly, as well as nonionic detergents (Terzic and Ahel 1993) which do not degrade rapidly, have been utilized as sanitary sewage markers. LAS was quickly dispersed from wastewater outfalls except in areas where wind was calm. In these areas LAS concentrations increased in freshwater but were unaffected in saline water. After time, the lower alkyl groups were mostly found, possibly as a result of degradation or settling of longer alkyl chain compounds with sediments. Chung, *et al*. (1995) also describe the distribution and fate of LAS in an urban stream in Korea. They examined different LAS compounds having carbon ratios of C12 and C13 compared to C10 and C11, plus ratios of phosphates to MBAS and the internal to external isomer ratio (I/E) as part of their research. Gonález-Mazo, *et al*. (1998) examined LAS in the Bay of Cádiz off the southwest of Spain. They found that LAS degrades rapidly (Fujita, *et al*., 1998, found that complete biodegradation of LAS requires several days), and is also strongly sorbed to particulates. In areas close to shore and near the untreated wastewater discharges, there as significant vertical stratification of LAS: the top 3 to 5 mm of water had LAS concentrations about 100 times greater than found at 0.5 m.

Zeng and Vista (1997) and Zeng, *et al*. (1997) describe a study off of San Diego where LAB was measured, along with polycyclic aromatic hydrocarbons (PAHs) and aliphatic hydrocarbons (AHs) to indicate the relative pollutant contributions of wastewater from sanitary sewage, nonpoint sources, and hydrocarbon combustion sources. They developed and tested several indicator ratios (alkyl homologue distributions and parent compound distributions) and examined the ratio of various PAHs (such as phenanthrene to anthracene, methylphenanthrene to phenanthrene, fluoranthene to pyrene, and benzo(a)anthracene to chrysene) as tools for distinguishing these sources. They concluded that LABs are useful tracers of domestic waste inputs to the environment due to their limited sources. They also describe the use of the internal to external isomer ratio (I/E) to indicate the amount of biodegradation that may have occurred to the LABs. They observed concentrations of total LABs in sewage effluent of about 3 mg/L, although previous researchers have seen concentrations of about 150 mg/L in sewage effluent from the same area.

The fluorescent properties of detergents have also been used as a tracer by investigating the fluorescent whitening agents (FWAs), as described by Poiger, *et al*. (1996) and Kramer, *et al*. (1996). HPLC with fluorescence detection was used in these studies to quantify very low concentrations of FWAs. The two most frequently used FWAs in household detergents (DSBP and DAS 1) were found at 7 to 21 mg/L in primary sewage effluent and at 3 to 9 mg/L in secondary effluent. Raw sewage contains about 10 to 20 mg/L FWAs. The removal mechanisms in sewage treatment processes is by adsorption to activated sludge. The type of FWAs varies from laundry applications to textile finishing and paper production, making it possible to identify sewage sources. The FWAs were found in river water at 0.04 to 0.6 mg/L. The FWAs are not easily biodegradable but they are readily photodegraded. Photodegradation rates have been reported to be about 7% for DSBP and 71% for DAS 1 in river water exposed to natural sunlight, after one hour exposure. Subsequent photodegradation is quite slow.

Other Compounds Found in Sanitary Sewage that may be used for Identifying Contamination by Sewage. Halling-Sørensen, *et al*. (1998) detected numerous pharmaceutical substances in sewage effluents and in receiving waters. Their work addressed human health concerns of these low level compounds that can enter downstream drinking water supplies. However, the information can also be possibly used to help identify sewage contamination. Most of the research has focused on clofibric acid, a chemical used in cholesterol lowering drugs. It has been found in concentrations ranging from 10 to 165 ng/L in Berlin drinking water sampler. Other drugs commonly found include aspirin, caffeine, and ibuprofen. Current FDA guidance mandates that the maximum concentration of a substance or its active metabolites at the point of entry into the aquatic environment be less than 1 mg/L (Hun 1998).

Caffeine has been used as an indicator of sewage contamination by several investigators (Shuman and Strand 1996). The King County, WA, Water Quality Assessment Project is examining the impacts of CSOs on the Duwamish River and Elliott Bay. They are using both caffeine (representing dissolved CSO constituents) and coprostanol (representing particulate bound CSO constituents), in conjunction with heavy metals and conventional analyses, to help determine the contribution of CSOs to the river. The caffeine is unique to sewage, while coprostanol is from both humans and carnivorous animals and is therefore also in stormwater. They sampled upstream of all CSOs, but with some stormwater influences, 100 m upstream of the primary CSO discharge (but downstream of other CSOs), within the primary CSO discharge line, and 100 m downriver of the CSO discharge location. The relationship between caffeine and coprostanol was fairly consistent for the four sites (coprostanol was about 0.5 to 1.5 mg/L higher than caffeine). Similar patterns were found between the three metals, chromium was always the lowest and zinc was the highest. King Co. is also using clean transported mussels placed in the Duwamish River to measure the bioconcentration potential of metal and organic toxicants and the effects of the CSOs on mussel growth rates (after 6 week exposure periods). Paired reference locations are available near the areas of deployment, but outside the areas of immediate CSO influence. *US Water News* (1998) also described a study in Boston Harbor that found caffeine at levels of about 7 mg/L in the harbor water. The caffeine content of regular coffee is about 700 mg/L, in contrast.

DNA Profiling to Measure Impacts on Receiving Water Organisms and to Identify Sources of Microorganisms in Stormwater. This rapidly emerging technique seems to have great promise in addressing a number of nonpoint source water pollution issues. Kratch (1997) summarized several investigations on cataloging the DNA of *E. coli* to identify their source in water. This rapidly emerging technique seems to have great promise in addressing a number of nonpoint source water pollution issues. The procedure, developed at the Virginia Polytechnic Institute and State University, has been used in Chesapeake Bay. In one example, it was possible to identify a large wild animal population as the source of fecal coliform contamination of a shellfish bed, instead of suspected failing septic tanks. DNA patterns in fecal coliforms vary among animals and birds, and it is relatively easy to distinguish between human and non-human sources of the bacteria. However, some wild animals have DNA patterns that are not easily distinguishable. Some researchers question the value of *E. coli* DNA fingerprinting believing that there is little direct relationship between *E. coli* and human pathogens. However, this method should be useful to identify the presence of sewage contamination in stormwater or in a receiving water.

One application of the technique, as described by Krane, *et al*. (1999) of Wright State University, used randomly amplified polymorphic DNA polymerase chain reaction (RAPD-PCR) generated profiles of naturally occurring crayfish. They found that changes in the underlying genetic diversity of these populations were significantly correlated with the extent to which they have been exposed to anthropogenic stressors. They concluded that this rapid and relatively simple technique can be used to develop a sensitive means of directly assessing the impact of stressors upon ecosystems. These Wright State University researchers have also used the RAPD-PCR techniques on populations of snails, pill bugs, violets, spiders, earthworms, herring, and some benthic macroinvertebrates, finding relatively few obstacles in its use for different organisms. As noted above, other researchers have used DNA profiling techniques to identify sources of *E. coli* bacteria found in coastal waterways. It is possible that these techniques can be expanded to enable rapid detection of many different types of pathogens in receiving waters, and the most likely sources of these pathogens.

Stable Isotope Methods for Identifying Sources of Water. Stable isotopes had been recommended as an efficient method to identify illicit connections to storm sewerage. A demonstration was conducted in Detroit as part of the Rouge River project to identify sources of dry weather flows in storm sewerage (Sangal, *et al*. 1996). Naturally occurring stable isotopes of oxygen and hydrogen can be used to identify waters originating from different geographical sources (especially along a north-south gradient). Ma and Spalding (1996) discuss this approach by using stable isotopes to investigate recharge of groundwaters by surface waters. During water vapor transport from equatorial source regions to higher latitudes, depletion of heavy isotopes occurs with rain. Deviation from a standard relationship between deuterium and ^{18}O for a specific area indicates that the water has undergone additional evaporation. The ratio is also affected by seasonal changes. As discussed by Ma and Spalding (1996), the Platte River water is normally derived in part from snowmelt from the Rocky Mountains, while the groundwater in parts of Nebraska is mainly contributed from the Gulf air stream. The origins of these waters are sufficiently different and allow good measurements of the recharge rate of the surface water to the groundwater. In Detroit, Sangal, *et al*. (1996) used differences in origin between the domestic water supply, local surface waters, and the local groundwater to identify potential sanitary sewage contributions to the separate storm sewerage. Rieley, *et al*. (1997) used stable isotopes of carbon in marine organisms to distinguish the primary source of carbon being consumed (sewage sludge vs. natural carbon sources) in two deep sea sewage sludge disposal areas.

Stable isotope analyses would not be able to distinguish between sanitary sewage, industrial discharges, washwaters, and domestic water, as they all have the same origin, nor would it be possible to distinguish sewage from local groundwaters if the domestic water supply was from the same local aquifer. This method works best for situations where the water supply is from a distant source and where separation of waters into separate flow components is not needed. It may be an excellent tool to study the effects of deep well injection of stormwater on deep aquifers having distant recharge sources (such as in the Phoenix area). Few laboratories can analyze for these stable isotopes, requiring shipping and a long wait for the analytical results. Sangal, *et al*. (1995) used Geochron Laboratories, in Cambridge, Massachusetts.

Dating of sediments using ^{137}Cs was described by Ma and Spalding (1996). Arsenic contaminated sediments in the Hylebos Waterway in Tacoma, WA, could have originated from numerous sources, including a pesticide manufacturing facility, a rock-wool plant, steel slags, powdered metal plant, shipbuilding facilities, marinas and arsenic boat paints, and the Tacoma Smelter. Dating the sediments, combined with knowing the history of potential discharges and conducting optical and electron microscopic studies of the sediments, was found to be a powerful tool to differentiate between the different metal sources to the sediments.

Summary of Emerging Techniques

In almost all cases, a suite of analyses is most suitable for effective identification of inappropriate discharges. A recent example was reported by Standley, *et al*. (2000), where fecal steroids (including coprostanol), caffeine, consumer product fragrance materials, and petroleum and combustion byproducts were used to identify wastewater treatment plant effluent, agricultural and feedlot runoff, urban runoff, and wildlife sources. They studied numerous individual sources of these wastes from throughout the US. A research grade mass sperctrophotometer was used for the majority of the analyses in order to achieve the needed sensitivities, although much variability was found when using the methods in actual receiving waters affected by wastewater effluent. This sophisticated suite of analyses did yield much useful information, but the analyses are difficult to conduct and costly and may be suitable for special situations, but not for routine survey work.

Another recent series of tests examined several of these potential emerging tracer parameters, in conjunction with the previously identified parameters, during a project characterizing stormwater that had collected in telecommunication manholes, funded by Tecordia (previously Bellcore), AT&T, and eight regional telephone companies throughout the country (Pitt and Clark 1999). Numerous conventional constituents, plus major ions, and toxicants were measured, along with candidate tracers to indicate sewage contamination of this water. Boron, caffeine, coprostanol, *E. coli*, enterococci, fluorescence (using specific wavelengths for detergents), and a simpler test for detergents were evaluated, along with the use of fluoride, ammonia, potassium, and obvious odors and color. About 700 water samples were evaluated for all of these parameters, with the exception of bacteria and boron (about 250 samples), and only infrequent samples were analyzed for fluorescence. Coprostanol was found in about 25 percent of the water samples (and in about 75% of the 350 sediment samples analyzed). Caffeine was only found in very few samples, while elevated *E. coli* and enterococci (using IDEXX tests) were observed in about 10% of the samples. Strong sewage odors in water and sediment samples were also detected in about 10% of the samples. Detergents and fluoride (at >0.3 mg/L) were found in about 40% of the samples and are expected to have been contaminated with industrial activities (lubricants and cleansers) and not sewerage. Overall, about 10% of the samples were therefore expected to have been contaminated with sanitary sewage, about the same rate previously estimated for stormwater systems.

Additional related laboratory tests, funded by the University of New Orleans and the EPA (Barbe', *et al*. 2000), were conducted using many sewage and laundry detergent samples and found that the boron test was a poor indicator of sewage, possibly due to changes in formulations in modern laundry detergents. Laboratory tests did find that fluorescence was an excellent indicator of sewage, especially when using specialized “detergent whitener” filter sets, but was not very repeatable. We also examined several UV absorbance wavelengths as sewage indicators and found excellent correlations with 228 nm, a wavelength having very little background absorbance in local spring waters, but with a strong response factor with increasing strengths of sewage.

Table 64 summarizes the different measurement parameters discussed above. We recommend that our originally developed and tested protocol, as reported by Pitt, *et al*. (1993), still be used as the most efficient routine indicator of sewage contamination of stormwater drainage systems, with the possible addition of specific *E. coli* and enterococci measurements and UV absorbance at 228 nm. The numerous exotic tests requiring specialized instrumentation and expertise do not appear to warrant their expense and long analytical turn-around times, except in specialized research situations, or when special confirmation is economically justified (such as when examining sewer replacement or major repair options).

Table 64. Comparison of Measurement Parameters used for Identifying Inappropriate Discharges into Storm Drainage

Parameter Group	Comments	Recommendation
Fecal coliform bacteria and/or use of fecal coliform to fecal strep. ratio	Commonly used to indicate presence of sanitary sewage.	Not very useful as many other sources of fecal coliforms are present, and ratio not accurate for old or mixed wastes.
Physical observations (odor, color, turbidity, floatables, deposits, stains, vegetation changes, damage to outfalls)	Commonly used to indicate presence of sanitary and industrial wastewater.	Recommended due to easy public understanding and easy to evaluate, but only indicative of gross contamination, with excessive false negatives (and some false positives). Use in conjunction with chemical tracers for greater sensitivity and accuracy.
Detergents presence (anionic surfactant extractions)	Used to indicate presence of wash waters and sanitary sewage.	Recommended, but care needed during hazardous analyses (only for well-trained personnel). Accurate indicator of contamination during field tests.
Fluoride, ammonia and potassium measurements	Used to identify and distinguish between wash	Recommended, especially in conjunction with detergent analyses. Accurate indicator of major contamination sources

	waters and sanitary sewage.	and their relative contributions.
TV surveys and source investigations	Used to identify specific locations of inappropriate discharges, especially in industrial areas.	Recommended after outfall surveys indicate contamination in drainage system.
Coprostanol and other fecal sterol compounds	Used to indicate presence of sanitary sewage.	Possibly useful. Expensive analysis with GC/MSD. Not specific to human wastes or recent contamination. Most useful when analyzing particulate fractions of wastewaters or sediments.
Specific detergent compounds (LAS, fabric whiteners, and perfumes)	Used to indicate presence of sanitary sewage.	Possibly useful. Expensive analyses with HPLC. A good and sensitive confirmatory method.
Fluorescence	Used to indicate presence of sanitary sewage and wash waters.	Likely useful, but expensive instrumentation. Rapid and easy analysis. Very sensitive.
Boron	Used to indicate presence of sanitary sewage and wash waters.	Not very useful. Easy and inexpensive analysis, but recent laundry formulations in US have minimal boron components.
Pharmaceuticals (colfibric acid, aspirin, ibuprofen, steroids, illegal drugs, etc.)	Used to indicate presence of sanitary sewage.	Possibly useful. Expensive analyses with HPLC. A good and sensitive confirmatory method.
Caffeine	Used to indicate presence of sanitary sewage.	Not very useful. Expensive analyses with GC/MSD. Numerous false negatives, as typical analytical methods not suitably sensitive.
DNA profiling of microorganisms	Used to identify sources of microorganisms	Likely useful, but currently requires extensive background information on likely sources in drainage. Could be very useful if method can be simplified, but with less specific results.
UV absorbance at 228 nm	Used to identify presence of sanitary sewage.	Possibly useful, if UV spectrophotometer available. Simple and direct analyses. Sensitive to varying levels of sanitary sewage, but may not be useful with dilute solutions. Further testing needed to investigate sensitivity in field trials.
Stable isotopes of oxygen	Used to identify major sources of water.	May be useful in area having distant domestic water sources and distant groundwater recharge areas. Expensive and time consuming procedure. Can not distinguish between wastewaters if all have common source.
E. coli and enterococci bacteria	More specific indicators of sanitary sewage than coliform tests.	Recommended in conjunction with chemical tests. Relatively inexpensive and easy analyses, especially if using the simple IDEXX methods.

This project, a joint effort of the Center for Watershed Protection (CWP) and Dr. Robert Pitt with the University of Alabama is being conducted to complete a technical assessment of techniques and methods for identifying and correcting illicit and inappropriate discharges geared towards NPDES Phase II communities. The project has a three year duration. In the first half of the project, most of our effort will be directed to collecting data. The most cost effective and efficient techniques will be identified during this initial project period. In the second project half, the project team will develop draft guidance on methods and techniques to identify and correct illicit connections, test the efficacy of the draft guidance in four communities, complete a final "User's Manual for Identifying and Correcting Illicit and Inappropriate Discharges," and conduct training and dissemination.

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Appendix A
Field Equipment Summary

TABLE A-1 SUMMARY OF FIELD AND LABORATORY METHODS

Constituent	Method	Interferences
Acidity 1	titrimetric	not noted
Acidity 2	field titration kits	
Acidity 3	titrimetric	not noted
Alkalinity 1	pH - wet chemistry	
Alkalinity 2	titrimetric	not noted
Alkalinity 3	field titration kits	
Alkalinity 4	titrimetric	not noted
Alkalinity 5	titrimetric	standard interferences
Aluminum 1	comparative colorimetric	not noted
Aluminum 2	spectrophotometric	
Ammonia 1	comparative colorimetric	not noted
Ammonia 2	comparative colorimetric	standard interferences
Ammonia 3	comparative colorimetric	not noted
Ammonia 4	spectrophotometric	
Ammonia 5	Ion selective electrode	volatile amines
Ammonia 6	Ion selective electrode	volatile amines, Hg(+2)
Ammonia 7	comparative colorimetric	
Ammonium 1	indicator paper	not noted
Ammonium 2	titrimetric	standard interferences
Arsenic	spectrophotometric	
Bacteria, aerobic	dip strip/incubation	
Bacteria, anaerobic	dip strip/incubation	
Bacteria, total count 1	P/A color indicator	
Bacteria, total count 2	MF - Millipore samplers	
Bacteria, total count 3	membrane filtration	
Barium	spectrophotometric	
Benzotriazole	spectrophotometric	
Biochemical oxygen demand (rate)	manometric	
Boron	spectrophotometric	
Bromide 1	Ion selective electrode	I(-), CN(-), S(-2)
Bromide 2	Ion selective electrode	S(-2), I(-), CN(-), Cl(-), NH3
Bromine 1	comparative colorimetric	not noted
Bromine 2	comparative colorimetric	not noted
Bromine 3	spectrophotometric	
Cadmium 1	comparative colorimetric	not noted
Cadmium 2	spectrophotometric	
Cadmium 3	Ion selective electrode	Ag(+), Hg(+2), Cu(+2), Pb(+2), Fe(+2)
Calcium 1	Ion selective electrode	Zn(+2), Pb(+2), Fe(+2), Cu(+2)
Calcium 2	field titration kits	
Calcium 3	Ion selective electrode	None
Calcium 4	indicator paper	not noted
Calcium 5	titrimetric	standard interferences
Caprostanol	gas chromatography/mass spectrophotometry	
Carbon dioxide 1	titrimetric	not noted
Carbon dioxide 2	field titration kits	
Carbon dioxide 3	Ion selective electrode	volatile organic acids
Carbon dioxide 4	Ion selective electrode	volatile weak acids
Carbon dioxide 5	titrimetric	not noted
Carbon dioxide 6	titrimetric	standard interferences

Chemical oxygen demand	spectrophotometric

(continued)

TABLE A-1 SUMMARY OF FIELD AND LABORATORY METHODS (continued)

Constituent	Method	Interferences
Chloride 1	titrimetric	not noted
Chloride 2	field titration kits	
Chloride 3	Ion selective electrode	Br(-), I(-), CN(-), S(-2), OH(-)
Chloride 4	spectrophotometric	
Chloride 5	Ion selective electrode	standard interferences
Chloride 6	titrimetric	not noted
Chloride 7	Ion selective electrode	OH, S(-2), Br(-), I(-), CN(-)
Chloride 8	titrimetric	standard interferences
Chloride 9	indicator paper	not noted
Chlorine 1	comparative colorimetric	standard interferences
Chlorine 2	comparative colorimetric	not noted
Chlorine 3	comparative colorimetric	not noted
Chlorine 4	amperometric titrator	
Chlorine 5	ion selective electrode	strong oxidizing agents
Chlorine 6	spectrophotometric	
Chlorine 7	comparative colorimetric	
Chlorine 8	indicator paper	Br(-)
Chlorine 9	field titration kits	
Chlorine 10	titrimetric	not noted
Chlorine dioxide	spectrophotometric	
Chlorine/cyanide	indicator paper	not noted
Chromate 1	spectrophotometric	standard interferences
Chromate 2	comparative colorimetric	not noted
Chromate 3	indicator paper	not noted
Chromium 1	comparative colorimetric	not noted
Chromium 2	spectrophotometric	
Chromium 3	field titration kits	
Chromium (+3)	spectrophotometric	
Chromium (+6) 1	spectrophotometric	
Chromium (+6) 2	comparative colorimetric	
Cobalt	spectrophotometric	
Color 1	comparative colorimetric	not noted
Color 2	spectrophotometric	
Color 3	comparative colorimetric	
Conductivity 1	multi-meter, recording	
Conductivity 2	electrical conductance	
Conductivity 3	multi-meter, recording	
Conductivity 4	electrical resistance	
Copper 1	spectrophotometric	standard interferences
Copper 2	comparative calorimetric	not noted
Copper 3	spectrophotometric	
Copper 4	comparative calorimetric	
Copper 5	indicator paper	not noted
Copper (+2) 1	comparative colorimetric	standard interferences
Copper (+2) 2	ion selective electrode	Ag(+), Hg(+2), Cl(-), Br(-), Fe(+2)
Copper (+2) 3	ion selective electrode	S(-2), Ag(+), Hg(+2), Fe(+3), Cd(+2)
Cyanide 1	spectrophotometric	standard interferences
Cyanide 2	spectrophotometric	
Cyanide 3	comparative colorimetric	
Cyanide 4	ion selective electrode	I(-), S(-2)

Cyanide 5	ion selective electrode	S(-2), I(-), Br(-), Cl(-)

(continued)

TABLE A-1 SUMMARY OF FIELD AND LABORATORY METHODS (continued)

Constituent	Method	Interferences
Cyanuric acid	spectrophotometric	
Diethylhydroxylamine	spectrophotometric	
Diphenylamine	comparative colorimetric	standard interferences
E. Coli bacteria 1	ONPG/MUG colorimetric	
E. Coli bacteria 2	LT/MUG - MPN	
EDTA	field titration kits	
Erythorbic acid	spectrophotometric	
Fecal coliform bacteria	Membrane filtration	
Fecal streptococci bacteria	membrane filtration	
Fluoride 1	spectrophotometric	standard interferences
Fluoride 2	comparative colorimetric	not noted
Fluoride 3	Dedicated meter - ion selective	Al(+3), Fe(+3), La(+3), extreme pH
Fluoride 4	Ion selective electrode	Metal ions, pH<5 and pH>10
Fluoride 5	spectrophotometric	
Fluoride 6	Ion selective electrode	high pH
Fluoride 7	Dedicated meter - ion selective	
Fluorobromate	Ion selective electrode	many
Fluorescent dye tracer tablets		
Formaldehyde 1	spectrophotometric	standard interferences
Formaldehyde 2	titrimetric	not noted
Formaldehyde 3	spectrophotometric	
Formaldehyde 4	comparative colorimetric	
Formaldehyde 5	indicator paper	not noted
Fungi and yeast	dip strip/incubation	
Glycol 1	spectrophotometric	standard interferences
Glycol 2	comparative colorimetric	
Hardness 1	titrimetric	not noted
Hardness 2	Ion selective electrode	Ne(+)
Hardness 3	Ion selective electrode	Na(+), K(+)
Hardness 4	field titration kits	
Hardness 5	titrimetric	not noted
Hardness 6	indicator paper	not noted
Hardness 7	titrimetric	standard interferences
Hardness calcium	spectrophotometric	
Hardness magnesium	spectrophotometric	
Heavy metals 1	atomic adsorption spectrophotometry	
Heavy metals 2	titrimetric	not noted
Heavy metals 3	graphite furnace atomic adsorp. spectro.	
Heavy metals, particulates	Micro-chemical analyses	
Heavy metals, total	colorimetric	
Hydrazine 1	spectrophotometric	standard interferences
Hydrazine 2	comparative colorimetric	not noted
Hydrazine 3	spectrophotometric	
Hydrogen peroxide 1	spectrophotometric	standard interferences
Hydrogen peroxide 2	field titration kits	
Hydrogen sulfide	comparative colorimetric	
Hydroxide	titrimetric	not noted
Hypochtorite	comparative colorimetric	standard interferences
Iodine 1	comparative colorimetric	not noted
Iodine 2	comparative colorimetric	not noted

Iodine 3	Ion selective electrode	S(-2), CN(-), NH3, S203(-2)
Iodine 4	spectrophotometric	
Iodine 5	comparative colorimetric	
Iodine 6	Ion selective electrode	CN(-), S(-2)

(continued)

TABLE A-1 SUMMARY OF FIELD AND LABORATORY METHODS (continued)

Constituent	Method	Interferences
Iron 1	comparative colorimetric	not noted
Iron 2	spectrophotometric	standard interferences
Iron 3	comparative colorimetric	not noted
Iron 4	comparative colorimetric	
Iron 5	spectrophotometric	
Iron 6	indicator paper	not noted
iron (+3)	spectrophotometric	
iron bacteria	Microscopic	
Lead 1	comparative colorimetric	not noted
Lead 2	comparative colorimetric	standard interferences
Lead 3	spectrophotometric	
Lead 4	spectrophotometric	standard interferences
Lead 5	ion selective electrode	Ag(+), Hg(+2), Cu(+2), Cd(+2), Fe(+2)
Lead 6	ion selective electrode	Fe(+3), Hg(+2), Ag(+), S(-2)
Manganese 1	comparative colorimetric	standard interferences
Manganese 2	comparative colorimetric	not noted
Manganese 3	spectrophotometric	
Manganese 4	comparative colorimetric	
Manganese 5	indicator paper	not noted
Mercaptobenzothiazole	titrimetric	standard interferences
Molybdate	comparative colorimetric	
Molybdenum/Molybdate	spectrophotometric	
Nickel 1	comparative colorimetric	not noted
Nickel 2	spectrophotometric	
Nitrate 1	spectrophotometric	standard interferences
Nitrate 2	comparative colorimetric	not noted
Nitrate 3	spectrophotometric	
Nitrate 4	comparative colorimetric	
Nitrate 5	Dedicated meter - ion selective	ClO4(-), I(-), Br(-), NO2(-), Cl(-), HCO3
Nitrate 6	ion selective electrode	many
Nitrate 7	Ion selective electrode	Cl(-), ClO4(-), I(-), Br(-)
Nitrate 8	indicator paper	not noted
Nitrite 1	spectrophotometric	standard interferences
Nitrite 2	comparative colorimetric	not noted
Nitrite 3	ion selective electrode	volatile organic acids
Nitrite 4	spectrophotometric	
Nitrite 5	comparative colorimetric	
Nitrogen dioxide	ion selective electrode	CO2, volatile weak acids
Nitrogen, Kjeldahl	spectrophotometric	
oil in water 1	UV photometer	
oil in water 2	spectrophotometric	
organic compounds 1	Portable gas chromatography	
organic compounds 2	Portable gas chromatography	
Oxygen 1	spectrophotometric	
Oxygen 2	membrane	
Oxygen 3	polarographic electrode meter	
Oxygen 4	field titration kits	
Oxygen 5	titrimetric	not noted
Oxygen 6	ion selective electrode	n/a

Oxygen 7	spectrophotometric	standard interferences
Oxygen 8	comparative colorimetric	
Oxygen 9	comparative colorimetric	not noted
Oxygen 10	multi-meter, recording	
Oxygen 11	multi-meter, recording	
Oxygen 12	multi-meter, recording	
Oxygen 13	multi-meter, membrane	

(continued)

TABLE A-1 SUMMARY OF FIELD AND LABORATORY METHODS (continued)

Constituent	Method	Interferences
Ozone 1	spectrophotometric	
Ozone 2	comparative colorimetric	
Palladium	spectrophotometric	
Perchlorate	ion selective electrode	many
Permanganate	titrimetric	standard interferences
Peroxide	indicator paper	not noted
pH 1	pH electrode	Na(+)
pH 2	comparative colorimetric	standard interferences
pH 3	comparative colorimetric	
pH 4	comparative colorimetric	not noted
pH 5	pH probe	
pH 6	pH electrode	
pH 7	multi-meter, recording	
pH 8	litmus paper	
pH 9	multi-meter, recording	
Phenols 1	spectrophotometric	standard interferences
Phenols 2	comparative colorimetric	not noted
Phenols 3	spectrophotometric	
Phosphate 1	comparative colorimetric	not noted
Phosphate 2	comparative colorimetric	not noted
Phosphate 3	comparative colorimetric	
Phosphate (ortho)	spectrophotometric	standard interferences
Phosphonates	spectrophotometric	
Phosphorus 1	spectrophotometric	
Phosphorus 2	comparative colorimetric	
Plankton	microscopic	
Polyacrylic acid 1	spectrophotometric	
Polyacrylic acid 2	comparative colorimetric	
Potassium 1	dedicated meter - ion selective	low pH, NH4(+), Na(+)
Potassium 2	ion selective electrode	Cs(+), NH4(+4), low pH
Potassium 3	spectrophotometric	
Redox 1	ion selective electrode	
Redox 2	Ion selective electrode	
Redox 3	multi-meter, recording	
Redox 4	Ion selective electrode	
Residue, settleable	Imhoff cone	not noted
Salmonella bacteria 1	colorimetric	
Salmonella bacteria 2	membrane filtration	
Selenium	spectrophotometric	
Shigella bacteria	membrane filtration	
Silica 1	spectrophotometric	standard interferences

Silica 2	comparative colorimetric	not noted
Silica 3	spectrophotometric	
Silica 4	comparative colorimetric	
Silver	spectrophotometric	
Silver/sulfide 1	ion selective electrode	Hg(+2)
Silver/sulfide 2	ion selective electrode	Hg(+2)
Sodium 1	dedicated meter - ion selective	Ag(+), low pH, K(+), NH4(+))
Sodium 2	ion selective electrode	other high level cations
Sodium 3	ion selective electrode	

(Continued)

TABLE A-1 SUMMARY OF FIELD AND LABORATORY METHODS (continued)

Constituent	Method	Interferences
Sodium chromate	spectrophotometric	
Sulfate	spectrophotometric	
Sulfate	titrimetric	not noted
Sulfate	comparative colorimetric	
Sulfate	indicator paper	not noted
Sulfide	spectrophotometric	standard interferences
Sulfide	spectrophotometric	
Sulfide	comparative colorimetric	not noted
Sulfide	titrimetric	not noted
Sulfite	titrimetric	not noted
Sulfite	field titration kits	
Sulfite	titrimetric	standard interferences
Sulfite	indicator paper	not noted
Sulfur bacteria	microscopic	
Sulfur dioxide	ion selective electrode	volatile organic acids. C02. N02
Surfactants, anionic	spectrophotometric	
Surfactants	comparative colorimetric	
Surfactants	auto titration system	very few
Tannin and lignin	spectrophotometric	
Tannin and lignin	comparative colorimetric	
Temperature	multi-meter, recording	
Temperature	multi-meter, recording	
Temperature	multi-meter, recording	
Temperature	multi-meter	
Thiocyanate	ion selective electrode	many
Thiosutfate	titrimetric	standard interferences
Tolytriazole	spectrophotometric	
Total coliform bacteria	membrane filtration (MF)	
Total coliform bacteria	MF - portable water test kit	
Total coliform bacteria	MF - Millipore samplers	
Total coliform bacteria	membrane filtration	
Total coliform bacteria	ONPG/MUG colorimetric	
Toxicity	bacterial bioassay	
Toxicity	seed for SOD analyses	
Trihalomethanes (chloroform, etc.)	gas chromatography	
Turbidity	nephlemetry	standard interferences
Vapors	colorimetric	
Vapors	infrared absorbance	
Vapors	colorimetric	
Vapors, combustible	electrochemical cell	
Vapors, organic	photoionization	
Vapors, organic	portable gas chromatography	
Vapors, organic	portable gas chromatography	
Vapors, organic	portable gas chromatography	
Vapors, organic	portable gas chromatography	
Vapors, organic	portable gas chromatography	
Viruses	membrane filtration	
Volatile acid	spectrophotometric	
Yeast and mold	MF - Millipore samplers	
Yeast and mold	membrane filtration	
Zinc	spectrophotometric	standard interferences
Zinc	spectrophotometric	
Zinc	titrimetric	not noted

Table A-2. Summary of Procedures and Detection Limits

	Possible Field Procedure		Laboratory Method		Detection Limit (mg/L)	Upper Limit w/o Dilution (mg/L)
Constituent	Direct analysis	Prep. or field calibration needed	Normal	Advanced		
Acidity 1		X			<5,000	500
Acidity 2		X			100	160
Acidity 3		X			10,000	
Alkalinity 1	X				<1,000	225
Alkalinity 2		X			<3,000	300
Alkalinity 3		X			100	4,000
Alkalinity 4		X			10,000	
Alkalinity 5		X			100,000	10,000
Aluminum 1		X			<20	0.16
Aluminum 2		X			8	0.80
Ammonia 1		X			<100	2.70
Ammonia 2		X			<1,000	10,000
Ammonia 3		X			<250	2.50
Ammonia 4			X		5	2.50
Ammonia 5		X			8.5	17,000
Ammonia 6		X			10	17,000
Ammonia 7		X			100	3
Ammonium 1	X				10,000	400
Ammonium 2		X			100,000	10,000
Arsenic		X			2	0.20
Bacteria, aerobic			X			
Bacteria, anaerobic			X			
Bacteria, total count 1			X		qualitative only	
Bacteria, total count 2			X		qualitative only	
Bacteria, total count 3			X		qualitative only	
Barium		X			1,000	100
Benzotriazole		X			160	16
Biochemical oxygen demand (rate)			X		1,000	700
Boron		X			140	14
Bromide 1		X			40	80,000
Bromide 2		X			400	80,000
Bromine 1		X			<300	3
Bromine 2		X			<300	3
Bromine 3		X			45	4.50
Cadmium 1		X			<15	-1.2
Cadmium 2		X			0.8	0.08
Cadmium 3		X			10	11,000
Calcium 1		X			20	40,000
Calcium 2		X			200	4,000
Calcium 3		X			200	40,000
Calcium 4	X				25,000	250
Calcium 5		X			50,000	10,000
Caprostanol				X	1 to 10	
Carbon dioxide 1		X			<1,000	100
Carbon dioxide 2		X			200	1,000
Carbon dioxide 3		X			440	1,300

Carbon dioxide 4	X		4,400	440
Carbon dioxide 5	X		5,000	
Carbon dioxide 6	X		10,000	10,000
Chemical oxygen demand		X	1,500	150

(continued)

Table A-2. Summary of Procedures and Detection Limits (continued)

	Possible Field Procedure		Laboratory Method		Detection Limit (µg/L)	Upper Limit w/o Dilution (mg/L)
Constituent	Direct analysis	Prep. or field calibration needed	Normal	Advanced		
Chloride 1		X			<10,000	1,000
Chloride 2		X			100	10,000
Chloride 3		X			180	35,500
Chloride 4		X			200	20
Chloride 5		X			350	35,000
Chloride 6		X			500	
Chloride 7		X			1,800	35,500
Chloride 8		X			2,000	750,000
Chloride 9	X				60,000	3,600
Chlorine 1		X			<1,000	5,000
Chlorine 2		X			<250	3
Chlorine 3		X			<30	1
Chlorine 4			X		10	10
Chlorine 5		X			10	20
Chlorine 6		X			20	2
Chlorine 7		X			20	3.5
Chlorine 8	X				100	4
Chlorine 9		X			200	2,000
Chlorine 10		X			200	3
Chlorine dioxide		X			10	700
Chlorine/cyanide	X				4,000	120
Chromate 1		X			<1,000	10,000
Chromate 2		X			<10,000	100
Chromate 3	X				3,000	100
Chromium 1		X			<100	5
Chromium 2			X		6	0.6
Chromium 3		X			1,000	800
Chromium (+3)		X			0.20	20
Chromium (+6) 1		X			6	0.6
Chromium (+6) 2		X			100	1,000
Cobalt		X			20	2
Color 1		X			<10 APHA units	200 APHA units
Color 2		X			5 color units	500 color units
Color 3		X			5 color units	500 color units
Conductivity 1	X					
Conductivity 2	X					
Conductivity 3	X					
Conductivity 4	X					
Copper 1		X			<1,000	10,000
Copper 2		X			<50	7
Copper 3		X			3	0.21
Copper 4		X			50	3
Copper 5	X				10,000	300
Copper (+2) 1		X			<100	10
Copper (+2) 2		X			0.06	6,300
Copper (+2) 3		X			30	63,000
Cyanide 1		X			<100	50

Cyanide 2	X	2	0.2
Cyanide 3	X	10	0.3
Cyanide 4	X	13	260
Cyanide 5	X	200	260

(continued)

Table A-2. Summary of Procedures and Detection Limits (continued)

Constituent	Possible Field Procedure		Laboratory Method		Detection Limit (mg/L)	Upper Limit w/o Dilution (mg/L)
	Direct analysis	Prep. or field calibration needed	Normal	Advanced		
Cyanuric acid		X			500	50
Diethylhydroxylamine		X			5	0.45
Diphenylamine		X			300,000	3,000
E. Coli bacteria 1			X		>1 org/100 mL qualitative	
E. Coli bacteria 2			X		>1 org/100 mL qualitative	
EDTA		X			10,000	200
Erythorbic acid		X			20	1.6
Fecal coliform bacteria			X			
Fecal streptococci bacteria			X			
Fluoride 1		X			<15	2
Fluoride 2		X			<150	2.7
Fluoride 3		X			2	saturation
Fluoride 4		X			9.5	19.000
Fluoride 5		X			20	2
Fluoride 6		X			20	saturation
Fluoride 7	X					
Fluorobromate		X			610	86,000
Fluorescent dye tracer tablets	X					
Formaldehyde 1		X			<1,000	5,000
Formaldehyde 2		X			<10,000	100,000
Formaldehyde 3		X			4	0.35
Formaldehyde 4		X			500	5
Formaldehyde 5	X				10,000	100
Fungi and yeast			X			
Glycol 1		X			<5,000	40
Glycol 2		X			qualitative only	
Hardness 1		X			<3,000	300
Hardness 2		X			80	40,000
Hardness 3		X			80	40,000
Hardness 4		X			100	4,000
Hardness 5		X			1,000	
Hardness 6	X				5,000	425,000
Hardness 7		X			50,000	100,000
Hardness calcium		X			40	4
Hardness magnesium		X			40	4
Heavy metals 1				X	low – many metals	
Heavy metals 2		X			qualitative test only	
Heavy metals 3				X	very low – many metals	
Heavy metals, particulates			X		qualitative – many compounds	
Heavy metals, total		X			<10,000	qualitative
Hydrazine 1		X			<100	500
Hydrazine 2		X			<30	0.3
Hydrazine 3		X			5	0.5
Hydrogen peroxide 1		X			<150	10,000
Hydrogen peroxide 2		X			200	10
Hydrogen sulfide		X			10	55

Hydroxide	X	<100,000	10,000
Hypochtorite	X	0.3%	12%
Iodine 1	X	<100	1
Iodine 2	X	<250	2.5
Iodine 3	X	5	127,000
Iodine 4	X	70	7
Iodine 5	X	500	2.5
Iodine 6	X	640	130,000

(continued)

Table A-2. Summary of Procedures and Detection Limits (continued)

	Possible Field Procedure		Laboratory Method		Detection Limit (µg/L)	Upper Limit w/o Dilution (mg/L)
Constituent	**Direct analysis**	**Prep. or field calibration needed**	**Normal**	**Advanced**		
Iron 1		X			<100	10
Iron 2		X			<250	10,000
Iron 3		X			<500	5
Iron 4		X			2	10
Iron 5		X			15	3
Iron 6	X				3,000	500
iron (+3)		X			30	3
iron bacteria				X		
Lead 1		X			<15	1.20
Lead 2		X			<5	0.05
Lead 3		X			2	0.16
Lead 4		X			5	0.15
Lead 5		X			200	20,000
Lead 6		X			210	210,000
Manganese 1		X			<200	2,000
Manganese 2		X			<50	3
Manganese 3		X			10	20
Manganese 4		X			50	10
Manganese 5	X				5,000	500
Mercaptobenzothiazole		X			50,000	10,000
Molybdate		X			200	50
Molybdenum/Molybdate		X			30	35
Nickel 1		X			<50	6
Nickel 2		X			20	1.8
Nitrate 1		X			<200	250
Nitrate 2		X			<200	2
Nitrate 3		X			5	30
Nitrate 4		X			20	50
Nitrate 5		X			50	14,000
Nitrate 6		X			100	14,000
Nitrate 7		X			310	310,000
Nitrate 8	X				10,000	500
Nitrite 1		X			<100	2,000
Nitrite 2		X			<5	0.40
Nitrite 3		X			2	920
Nitrite 4		X			3	150
Nitrite 5		X			10	2,000
Nitrogen dioxide		X			180	230
Nitrogen, Kjeldahl			X		1,500	150
oil in water 1				X	100	10
oil in water 2		X			850	85
organic compounds 1		X			quantitative- many compounds	
organic compounds 2		X			quantitative- many compounds	
Oxygen 1		X			<1	13
Oxygen 2	X				<1,000	20
Oxygen 3	X				<1,000	20
Oxygen 4		X			<1,000	100

Oxygen 5		X			<1,000	10
Oxygen 6		X			<1,000	14
Oxygen 7		X			1	10
Oxygen 8		X			1	20
Oxygen 9		X			200	
Oxygen 10	X					
Oxygen 11	X					
Oxygen 12	X					
Oxygen 13	X					

(continued)

Table A-2. Summary of Procedures and Detection Limits (continued)

	Possible Field Procedure		Laboratory Method		Detection Limit (μg/L)	Upper Limit w/o Dilution (mg/L)
Constituent	**Direct analysis**	**Prep. or field calibration needed**	**Normal**	**Advanced**		
Ozone 1		X			14	1.4
Ozone 2		X			50	2.3
Palladium		X			2,500	250
Perchlorate		X			700	100,000
Permanganate		X			50,000	500
Peroxide	X				1,000	100
pH 1	X				0 pH units	14 pH units
pH 2		X			3 pH units	11 pH units
pH 3		X			3 pH units	11.6 pH units
pH 4		X			3 pH units	11 pH units
pH 5	X					
pH 6	X					
pH 7	X					
pH 8	X					
pH 9	X					
Phenols 1		X			<1,000	12,000
Phenols 2		X			<50	0.5
Phenols 3		X			2	0.2
Phosphate 1		X			<2,500	100
Phosphate 2		X			<500	5
Phosphate 3		X			100	50
Phosphate (ortho)		X			<400	10,000
Phosphonates		X			25	125
Phosphorus 1		X			25	45
Phosphorus 2		X			100	50
Plankton				X		
Polyacrylic acid 1		X			200	20
Polyacrylic acid 2		X			1,000	20
Potassium 1		X			8	39,000
Potassium 2		X			40	39,000
Potassium 3		X			70	7
Redox 1	X				-2,000 mv	+2,000 mv
Redox 2	X					

Redox 3	X				
Redox 4	X				
Residue, settleable		X		n/a	
Salmonella bacteria 1			X		
Salmonella bacteria 2			X		
Selenium		X		10	1
Shigella bacteria			X		
Silica 1		X		<1,000	200
Silica 2		X		<1,000	10
Silica 3		X		16	100
Silica 4		X		20	800
Silver		X		6	0.6
Silver/sulfide 1		X		10	30,000
Silver/sulfide 2		X		15	>30,000
Sodium 1		X		2	saturation
Sodium 2		X		23	
Sodium 3	X			230	2,300

(continued)

Table A-2. Summary of Procedures and Detection Limits (continued)

	Possible Field Procedure		Laboratory Method		Detection Limit (μg/L)	Upper Limit w/o Dilution (mg/L)
Constituent	Direct analysis	Prep. or field calibration needed	Normal	Advanced		
Sodium chromate		X			10,000	1,100
Sulfate		X			650	65
Sulfate		X			25,000	
Sulfate		X			50,000	200
Sulfate	X				200,000	1,600
Sulfide		X			<150	10,000
Sulfide		X			6	0.60
Sulfide		X			500	1,000
Sulfide		X			2,000	
Sulfite		X			<2,000	200
Sulfite		X			1,000	1,600
Sulfite		X			2,000	600,000
Sulfite	X				10,000	500
Sulfur bacteria				X		
Sulfur dioxide		X			60	640
Surfactants, anionic		X			3	0.28
Surfactants		X			50	1
Surfactants			X			
Tannin and lignin		X			90	9
Tannin and lignin		X			500	150
Temperature	X					
Temperature	X					
Temperature	X					
Temperature	X					
Thiocyanate		X			290	58,000
Thiosutfate		X			5,000	1,000
Tolytriazole		X			160	16
Total coliform bacteria			X			
Total coliform bacteria		X				
Total coliform bacteria			X			
Total coliform bacteria			X			
Total coliform bacteria			X		>1 org/100 mL	qualitative
Toxicity				X		
Toxicity			X			
Trihalomethanes (chloroform, etc.)				X	<0.10000	
Turbidity		X			<1 NTU	90 NTU
Vapors		X			quantitative - many compounds	
Vapors	X				quantitative - many compounds	
Vapors		X			quantitative - many compounds	
Vapors, combustible	X				qualitative - hydrocarbons	
Vapors, organic	X				qualitative - many compounds	
Vapors, organic		X			qualitative - many compounds	
Vapors, organic		X			qualitative - many compounds	
Vapors, organic		X			qualitative - many compounds	
Vapors, organic		X			qualitative - many compounds	
Vapors, organic		X			qualitative - many compounds	
Viruses				X		
Volatile acid		X			28,000	2,800
Yeast and mold			X			

Yeast and mold		X		
Zinc	X		<300	3
Zinc	X		20	2
Zinc	X		500	

TABLE A-3. SUMMARY OF TRAINAING REQUIREMENTS AND EQUIPMENT AVAILABILITY

Constituent	**Sample Volume (mL)**	**Equipment Expense**	**Training Requirements**	**Manufacturer**
Acidity 1	25	none	low	Hanna (available from Cole-Parmer)
Acidity 2	small	low	moderate	Hach
Acidity 3	small	none	low	Taylor
Alkalinity 1	n/a	low	low	Orion
Alkalinity 2	15	none	low	Hanna (available from Cole-Parmer)
Alkalinity 3	small	low	moderate	Hach
Alkalinity 4	small	none	low	Taylor
Alkalinity 5	small	none	low	CHEMetrics
Aluminum 1	small	none	low	Taylor
Aluminum 2	small	low	low	Hach
Ammonia 1	small	none	low	Taylor
Ammonia 2	small	low	low	CHEMetrics
Ammonia 3	5	none	low	Hanna (available from Cole-Parmer)
Ammonia 4	small	low	low	Hach
Ammonia 5	1 L	moderate	moderate	HNU Systems
Ammonia 6	1 L	moderate	moderate	Orion
Ammonia 7	small	low	low	Hach
Ammonium 1	in-situ	none	low	EM (available from Markson)
Ammonium 2	small	none	low	CHEMetrics
Arsenic	small	low	low	Hach
Bacteria, aerobic	small	moderate	low	Easicult (available from Markson)
Bacteria, anaerobic	small	moderate	low	Easicult (available from Markson)
Bacteria, total count 1	small	moderate	moderate	Hach
Bacteria, total count 2	in-situ	moderate	moderate	Millipore
Bacteria, total count 3	small	moderate	moderate	Sanaline
Barium	small	low	low	Hach
Benzotriazole	small	low	low	Hach
Biochemical oxygen demand (rate)	2 L	low	moderate	Hach
Boron	small	low	low	Hach
Bromide 1	1 L	moderate	moderate	HNU Systems
Bromide 2	1 L	moderate	moderate	Orion
Bromine 1	25	none	low	Hanna (available from Cole-Parmer)
Bromine 2	small	none	low	Taylor
Bromine 3	small	low	low	Hach
Cadmium 1	small	none	low	Taylor
Cadmium 2	small	low	low	Hach
Cadmium 3	1 L	moderate	moderate	Orion
Calcium 1	1 L	moderate	moderate	Orion
Calcium 2	small	low	moderate	Hach
Calcium 3	1 L	moderate	moderate	HNU Systems
Calcium 4	in-situ	none	low	EM (available from Markson)
Calcium 5	small	none	low	CHEMetrics
Caprostanol	moderate	high	high	several sources
Carbon dioxide 1	50	none	low	Hanna (available from Cole-Parmer)
Carbon dioxide 2	small	low	moderate	Hach
Carbon dioxide 3	1 L	moderate	moderate	HNU Systems
Carbon dioxide 4	1 L	moderate	moderate	Orion
Carbon dioxide 5	small	none	low	Taylor

Carbon dioxide 6	small	none	low	CHEMetrics
Chemical oxygen demand	small	low	low	Hach

(continued)

TABLE A-3. SUMMARY OF TRAINAING REQUIREMENTS AND EQUIPMENT AVAILABILITY (continued)

Constituent	Sample Volume (mL)	Equipment Expense	Training Requirements	Manufacturer
Chloride 1	50	none	low	Hanna (available from Cole-Parmer)
Chloride 2	small	low	moderate	Hach
Chloride 3	1 L	moderate	moderate	HNU Systems
Chloride 4	small	low	low	Hach
Chloride 5	small	low	low	Hach
Chloride 6	small	none	low	Taylor
Chloride 7	1 L	moderate	moderate	Orion
Chloride 8	small	none	low	CHEMetrics
Chloride 9	in-situ	none	low	ETS (available from Markson)
Chlorine 1	small	low	low	CHEMetrics
Chlorine 2	5	none	low	Hanna (available from Cole-Parmer)
Chlorine 3	small	none	low	Taylor
Chlorine 4	1 L	low	moderate	Hach
Chlorine 5	1 L	moderate	moderate	Orion
Chlorine 6	small	low	low	Hach
Chlorine 7	small	low	low	Hach
Chlorine 8	in-situ	none	low	ETS (available from Markson)
Chlorine 9	small	low	moderate	Hach
Chlorine 10	small	none	low	Taylor
Chlorine dioxide	small	low	low	Hach
Chlorine/cyanide	in-situ	none	low	EM (available from Markson)
Chromate 1	small	low	low	CHEMetrics
Chromate 2	small	none	low	Taylor
Chromate 3	in-situ	none	low	EM (available from Markson)
Chromium 1	small	none	low	Taylor
Chromium 2	small	low	low	Hach
Chromium 3	small	low	moderate	Hach
Chromium (+3)	small	low	low	Hach
Chromium (+6) 1	small	low	low	Hach
Chromium (+6) 2	small	low	low	Hach
Cobalt	small	low	low	Hach
Color 1	small	none	low	Taylor
Color 2	small	low	low	Hach
Color 3	small	low	low	Hach
Conductivity 1	in-situ	moderate	low	Hydrolab
Conductivity 2	in-situ	low	low	Extech
Conductivity 3	in-situ	moderate	low	Solomat
Conductivity 4	in-situ	low	low	YSI
Copper 1	small	low	low	CHEMetrics
Copper 2	small	none	low	Taylor
Copper 3	small	low	low	Hach
Copper 4	small	low	low	Hach
Copper 5	in-situ	none	low	EM (available from Markson)
Copper (+2) 1	small	low	low	CHEMetrics
Copper (+2) 2	1 L	moderate	moderate	Orion
Copper (+2) 3	1 L	moderate	moderate	HNU Systems
Cyanide 1	small	low	low	CHEMetrics
Cyanide 2	small	low	low	Hach
Cyanide 3	small	low	low	Hach
Cyanide 4	1 L	moderate	moderate	HNU Systems

Cyanide 5	1 L	moderate	moderate	Orion

(continued)

TABLE A-3. SUMMARY OF TRAINAING REQUIREMENTS AND EQUIPMENT AVAILABILITY (continued)

Constituent	Sample Volume (mL)	Equipment Expense	Training Requirements	Manufacturer
Cyanuric acid	small	low	low	Hach
Diethylhydroxylamine	small	low	low	Hach
Diphenylamine	small	none	low	CHEMetrics
E. Coli bacteria 1	small	moderate	moderate	Coliert (from Access)
E. Coli bacteria 2	small	moderate	moderate	Hach
EDTA	small	low	moderate	Hach
Erythorbic acid	small	low	low	Hach
Fecal coliform bacteria	small	moderate	moderate	Sanaline
Fecal streptococci bacteria	small	moderate	moderate	Millipore
Fluoride 1	small	low	low	Hach
Fluoride 2	small	none	low	Taylor
Fluoride 3	small	low	moderate	Hach
Fluoride 4	1 L	moderate	moderate	HNU Systems
Fluoride 5	small	low	low	Hach
Fluoride 6	1 L	moderate	moderate	Orion
Fluoride 7	small	low/moderate	low	Orion
Fluorobromate	1 L	moderate	moderate	Orion
Fluorescent dye tracer tablets	n/a	low	low	many
Formaldehyde 1	small	low	low	CHEMetrics
Formaldehyde 2	5	none	low	Hanna (available from Cole-Parmer)
Formaldehyde 3	small	low	low	Hach
Formaldehyde 4	small	low	low	Hach
Formaldehyde 5	in-situ	none	low	EM.(available from Markson)
Fungi and yeast	small	moderate	low	Easicult (available from Markson)
Glycol 1	small	low	low	CHEMetrics
Glycol 2	small	low	low	Hach
Hardness 1	50	none	low	Hanna (available from Cole-Parmer)
Hardness 2	1 L	moderate	moderate	HNU Systems
Hardness 3	1 L	moderate	moderate	Orion
Hardness 4	small	low	moderate	Hach
Hardness 5	small	none	low	Taylor
Hardness 6	in-situ	none	low	ETS (available from Markson)
Hardness 7	small	none	low	CHEMetrics
Hardness calcium	small	low	low	Hach
Hardness magnesium	small	low	low	Hach
Heavy metals 1	moderate	moderate	moderate	several sources
Heavy metals 2	small	none	low	Taylor
Heavy metals 3	small	high	high	several sources
Heavy metals, particulates	small	moderate	high	PMN Labs
Heavy metals, total	small	low	low	Hach
Hydrazine 1	small	low	low	CHEMetrics
Hydrazine 2	small	none	low	Taylor
Hydrazine 3	small	low	low	Hach
Hydrogen peroxide 1	small	low	low	CHEMetrics
Hydrogen peroxide 2	small	low	moderate	Hach
Hydrogen sulfide	small	low	low	Hach
Hydroxide	50	none	low	Hanna (available from Cole-Parmer)
Hypochtorite	small	none	low	CHEMetrics
Iodine 1	small	none	low	Taylor

Iodine 2	25	none	low	Hanna (available from Cole-Parmer)
Iodine 3	1 L	moderate	moderate	Orion
Iodine 4	small	low	low	Hach
Iodine 5	small	low	low	Hach
Iodine 6	1 L	moderate	moderate	HNU Systems

(continued)

TABLE A-3. SUMMARY OF TRAINAING REQUIREMENTS AND EQUIPMENT AVAILABILITY (continued)

Constituent	Sample Volume (mL)	Equipment Expense	Training Requirements	Manufacturer
Iron 1	small	none	low	Taylor
Iron 2	small	low	low	CHEMetrics
Iron 3	5	none	low	Hanna (available from Cole-Parmer)
Iron 4	small	low	low	Hach
Iron 5	small	low	low	Hach
Iron 6	in-situ	none	low	EM (available from Markson)
iron (+3)	small	low	low	Hach
iron bacteria	small	moderate	high	Millipore
Lead 1	small	none	low	Taylor
Lead 2	small	none	low	CHEMetrics
Lead 3	small	low	low	Hach
Lead 4	small	low	low	Hach
Lead 5	1 L	moderate	moderate	Orion
Lead 6	1 L	moderate	moderate	HNU Systems
Manganese 1	small	none	low	CHEMetrics
Manganese 2	small	none	low	Taylor
Manganese 3	small	low	low	Hach
Manganese 4	small	low	low	Hach
Manganese 5	in-situ	none	low	EM (available from Markson)
Mercaptobenzothiazole	small	none	low	CHEMetrics
Molybdate	small	low	low	Hach
Molybdenum/Molybdate	small	low	low	Hach
Nickel 1	small	none	low	Taylor
Nickel 2	small	low	low	Hach
Nitrate 1	small	low	low	CHEMetrics
Nitrate 2	small	none	low	Taylor
Nitrate 3	small	low	low	Hach
Nitrate 4	small	low	low	Hach
Nitrate 5	small	low	moderate	Hach
Nitrate 6	1 L	moderate	moderate	Orion
Nitrate 7	1 L	moderate	moderate	HNU Systems
Nitrate 8	in-situ	none	low	EM (available from Markson)
Nitrite 1	small	low	low	CHEMetrics
Nitrite 2	small	none	low	Taylor
Nitrite 3	1 L	moderate	moderate	HNU Systems
Nitrite 4	small	low	low	Hach
Nitrite 5	small	low	low	Hach
Nitrogen dioxide	1 L	moderate	moderate	Orion
Nitrogen, Kjeldahl	small	low	low	Hach
oil in water 1	continuous	moderate	moderate	Teledyne
oil in water 2	small	low	low	Hach
organic compounds 1	moderate	high	high	HNU Systems
organic compounds 2	moderate	high	high	Sentex
Oxygen 1	small	low	low	Hach
Oxygen 2	in-situ	low	low	Extech
Oxygen 3	in-situ	low	low	Hach
Oxygen 4	small	low	moderate	Hach
Oxygen 5	10	none	low	Hanna (available from Cole-Parmer)
Oxygen 6	1 L	moderate	moderate	Orion

Oxygen 7	small	low	low	CHEMetrics
Oxygen 8	small	low	low	Hach
Oxygen 9	small	none	low	Taylor
Oxygen 10	in-situ	moderate	low	Hydrolab
Oxygen 11	in-situ	moderate	low	Solomat
Oxygen 12	in-situ	moderate	low	YSI
Oxygen 13	in-situ	low	low	YSI

(continued)

TABLE A-3. SUMMARY OF TRAINAING REQUIREMENTS AND EQUIPMENT AVAILABILITY (continued)

Constituent	Sample Volume (mL)	Equipment Expense	Training Requirements	Manufacturer
Ozone 1	small	low	low	Hach
Ozone 2	small	low	low	Hach
Palladium	small	low	low	Hach
Perchlorate	1 L	moderate	moderate	Orion
Permanganate	small	none	low	CHEMetrics
Peroxide	in-situ	none	low	EM (available from Markson)
pH 1	in-situ	low	low	Hach
pH 2	small	none	low	CHEMetrics
pH 3	small	low	low	Hach
pH 4	small	none	low	Taylor
pH 5	in-situ	low	low	Extech
pH 6	in-situ	low	low	HNU Systems
pH 7	in-situ	moderate	low	Hydrolab
pH 8	in-situ	low	low	many
pH 9	in-situ	moderate	low	Solomat
Phenols 1	small	low	low	CHEMetrics
Phenols 2	small	none	low	Taylor
Phenols 3	small	low	low	Hach
Phosphate 1	small	none	low	Taylor
Phosphate 2	5	none	low	Hanna (available from Cole-Parmer)
Phosphate 3	small	low	low	Hach
Phosphate (ortho)	small	low	low	CHEMetrics
Phosphonates	small	low	low	Hach
Phosphorus 1	small	low	low	Hach
Phosphorus 2	small	low	low	Hach
Plankton	moderate	moderate	high	Millipore
Polyacrylic acid 1	small	low	low	Hach
Polyacrylic acid 2	small	low	low	Hach
Potassium 1	small	low	moderate	Hach
Potassium 2	1 L	moderate	moderate	Orion
Potassium 3	small	low	low	Hach
Redox 1	in-situ	low	low	Hach
Redox 2	in-situ	moderate	low	HNU Systems
Redox 3	in-situ	moderate	low	Hydrolab
Redox 4	in-situ	moderate	low	Orion
Residue, settleable	small	none	low	Taylor
Salmonella bacteria 1	small	moderate	high	Dynatech
Salmonella bacteria 2	small	moderate	high	Millipore
Selenium	small	low	low	Hach
Shigella bacteria	small	moderate	high	Millipore
Silica 1	small	low	low	CHEMetrics
Silica 2	small	none	low	Taylor
Silica 3	small	low	low	Hach
Silica 4	small	low	low	Hach
Silver	small	low	low	Hach
Silver/sulfide 1	1 L	moderate	moderate	Orion
Silver/sulfide 2	1 L	moderate	moderate	HNU Systems
Sodium 1	small	low	moderate	Hach

Sodium 2	1 L	moderate	moderate	HNU Systems
Sodium 3	in-situ	low	low	Extech

(continued)

TABLE A-3. SUMMARY OF TRAINAING REQUIREMENTS AND EQUIPMENT AVAILABILITY (continued)

Constituent	Sample Volume (mL)	Equipment Expense	Training Requirements	Manufacturer
Sodium chromate	small	low	low	Hach
Sulfate	small	low	low	Hach
Sulfate	small	none	low	Taylor
Sulfate	small	low	low	Hach
Sulfate	in-situ	none	low	EM (available from Markson)
Sulfide	small	low	low	CHEMetrics
Sulfide	small	low	low	Hach
Sulfide	small	none	low	Sensidyne
Sulfide	small	none	low	Taylor
Sulfite	50	none	low	Hanna (available from Cole-Parmer)
Sulfite	small	low	moderate	Hach
Sulfite	small	none	low	CHEMetrics
Sulfite	in-situ	none	low	EM (available from Markson)
Sulfur bacteria	small	moderate	high	Millipore
Sulfur dioxide	1 L	moderate	moderate	HNU Systems
Surfactants, anionic	small	low	low	Hach
Surfactants	small	low	low	Hach
Surfactants	small	moderate	moderate	Orion
Tannin and lignin	small	low	low	Hach
Tannin and lignin	small	low	low	Hach
Temperature	in-situ	moderate	low	Hydrolab
Temperature	in-situ	moderate	low	Solomat
Temperature	in-situ	moderate	low	YSI
Temperature	in-situ	low	low	YSI
Thiocyanate	1 L	moderate	moderate	Orion
Thiosutfate	small	none	low	CHEMetrics
Tolytriazole	small	low	low	Hach
Total coliform bacteria	small	moderate	moderate	Hach
Total coliform bacteria	small	moderate	moderate	Millipore
Total coliform bacteria	in-situ	moderate	moderate	Millipore
Total coliform bacteria	small	moderate	moderate	Sanaline
Total coliform bacteria	small	moderate	moderate	Cotiert (from Access)
Toxicity	small	high	moderate	Microbics (Azur Environmental)
Toxicity	1 L	moderate	low	Polytox (available from Markson)
Trihalomethanes (chloroform, etc.)	etc.) moderate	high	high	several sources
Turbidity	small	low	low	Hach
Vapors	n/a	low	moderate	Draeger
Vapors	n/a	high	high	Foxboro
Vapors	n/a	low	moderate	Sensidyne
Vapors, combustible	n/a	moderate	low	Gas Tech
Vapors, organic	n/a	moderate	low	HNU Systems
Vapors, organic	n/a	high	high	Environmental Technologies
Vapors, organic	n/a	high	high	Foxboro
Vapors, organic	n/a	high	high	Microsensor Technology
Vapors, organic	n/a	high	high	Sentex
Vapors, organic	n/a	high	high	Thermal Environmental
Viruses	>100 gallons	moderate	high	Millipore
Volatile acid	small	low	low	Hach
Yeast and mold	in-situ	moderate	moderate	Millipore
Yeast and mold	small	moderate	moderate	Sanaline

Zinc	small	low	low	CHEMetrics
Zinc	small	low	low	Hach
Zinc	small	none	Low	Taylor

TABLE A-4. RESULTS FROM SEWAGE DILUTION STUDY

	% Sewage in Springwater											
Parameter	0.0	0.1	1.0	5.0	10.0	25.0	50.0	75.0	90.0	99.0	99.9	100.0
Conductivity (μS/cm)												
expected	350	350.12	350.20	356	362	380	410	440	458	468.8	469.88	470
observed	350	.50	350	351	355	371	400	435	451	470	470	470
% error	0	0.03	0.06	1.40	1.93	2.11	2.44	1.14	1.53	0.26	2.03	0
Fluoride (mg/L)												
expected	0.06	0.06	0.07	0.10	0.14	0.27	0.48	0.69	0.82	0.89	0.90	0.90
observed	0.06	0.07	0.09	0.11	0.14	0.28	0.47	0.65	0.78	0.85	0.89	0.90
% error	0	-16.67	-28.57	-10.00	0	-3.70	2.08	5.80	4.88	4.67	10.2	0
Hardness (mg/L as $CaCO_3$)												
expected	227	226.89	225.94	221.7	216.4	200.5	174	147.5	131.6	122.06	121.11	121
observed	227	232	229	218	217	199	176	148	128	122	121	121
% error	0	-2.25	-1.35	1.66	-0.28	0.75	-1.15	-0.34	2.74	0.05	0.09	0
Detergent (mg/L)												
expected	0	0.01	0.07	0.33	0.66	1.65	3.3	4.95	5.94	6.54	6.59	6.6
observed	0	0	0.05	0.31	0.62	1.60	3.28	4.68	5.46	6	6.6	6.6
% error	0	100	28.57	6.06	6.06	3.03	6.06	5.45	8.08	8.26	-0.1	0
Fluorescence (% scale)												
expected	7	7.46	11.55	29.75	52.5	120.75	234.5	348.25	416.5	457.45	461.5	462
observed	7	7	10	28	50	114	224	335	390	448	462	462
% error	0	6.17	13.42	5.88	4.76	5.59	4.48	3.80	6.36	2.06	-.11	0

(continued)

TABLE A-4. (continued)

	% Sewage in Springwater											
Parameter	0.0	0.1	1.0	5.0	10.0	25.0	50.0	75.0	90.0	99.0	99.9	100.0
Potassium (mg/L)												
expected	0.72	0.72	0.76	0.93	1.14	1.77	2.82	3.87	4.5	4.88	4.92	4.92
observed	0.72	0.73	0.78	0.95	1.18	1.79	2.85	3.96	4.62	5.02	4.96	4.92
% error	0	-1.39	-2.63	-2.15	-3.5	-1.13	-1.06	-2.33	-2.67	-2.66	-0.81	0
Ammonia (mg/L)												
expected	0.02	0.33	0.15	0.68	1.35	3.34	6.66	9.98	11.97	13.17	13.29	13.3
observed	0.02	0.04	0.13	0.687	1.42	3.52	7.11	10.19	11.67	13.06	13.16	13.3
% error	0	-20.19	14.92	0.58	-5.34	-5.39	-6.76	-2.10	2.5	0.81	0.95	0
Color (units)												
expected	0	0.03	0.3	1.5	3	7.5	15	22.5	27	29.7	29.97	30
observed	0	0	0	3	4	7	13	20	27	30	30	30
% error	0	100	100	-100	-25	6.67	13.33	11.11	0	-1.01	-1.01	0
pH (units)												
expected	7.02	7.02	7.02	7.03	7.04	7.07	7.12	7.17	7.20	7.22	7.22	7.22
observed	7.02	7.08	7.11	7.13	7.15	7.15	7.15	7.15	7.15	7.21	7.20	7.22
% error	0	0.9	1.3	1.4	1.6	1.1	0.4	-0.3	-0.7	-0.2	-0.3	0
Toxicity (% reduction)												
expected	0	0.08	0.82	4.09	8.17	20.43	40.85	61.28	73.53	80.90		81.7
observed	0	0	0	0	2.38	23.80	61.40	77.5	78.50	80.70	NA	81.7
% error	0	-100	-100	-100	-70.87	16.50	50.31	26.49	6.76	-0.25		0

NA: Data not available

TABLE A-5. RESULTS FROM SEPTAGE DILUTION STUDY

	% Septage in Springwater											
Parameter	0.0	0.1	1.0	5.0	10.0	25.0	50.0	75.0	90.0	99.0	99.9	100.0
Conductivity (µS/cm)												
expected	340	340.58	345.85	369.25	398.5	486.25	632.5	778.75	866.5	919.15	924.42	925
observed	340	342	345	351	390	480	610	740	820	905	924	925
% error	0	-4.2	0.25	4.95	2.13	1.29	3.56	4.98	5.37	1.54	0.05	0
Fluoride (mg/L)												
expected	0.26	0.26	0.26	0.28	0.31	0.38	0.51	0.63	0.70	1.75	0.75	0.75
observed	0.26	0.27	0.27	0.29	0.30	0.36	0.49	0.60	0.69	0.73	0.73	0.75
% error	0	-3.85	-3.85	-3.57	3.23	5.26	3.92	4.76	1.43	2.66	2.66	0
Detergent (mg/L)												
expected	0	0.02	0.24	1.2	2.4	6	12	18	21.6	23.76	23.98	24
observed	0	0	0.25	1.2	2.5	5.80	12.6	18	21	24	24	24
% error	0	100	-4.17	0	-4.17	3.33	-5	0	2.78	-1.01	-0.08	0
Fluorescence (% scale)												
expected	7	8.64	2324	88.20	169.40	413	819	1225	1468.6	1614.76	1629.38	1631
observed	7	7.2	20	77.8	158.6	441.1	768.2	1194	1362.8	1492.6	1529.4	1631
% error	0	16.67	13.94	11.79	6.38	-6.8	6.2	6.61	7.2	7.56	6.14	0

(continued)

TABLE A-5. (Continued)

	% Septage in Springwater											
Parameter	0.0	0.1	1.0	5.0	10.0	25.0	50.0	75.0	90.0	99.0	99.9	100.0
Potassium												
(mg/L)												
expected	1.2	1.22	1.39	2.17	2.95	6.03	10.85	15.68	18.57	20.31	20.48	20.5
observed	1.2	1.22	1.36	20.7	2.95	5.55	10.9	16	18.8	20	20.5	20.5
% error	0	0	2.16	4.61	0	7.96	-0.56	2.04	-1.24	1.53	0.10	0
Ammonia												
(mg/L)												
expected	0.08	0.14	0.64	2.90	5.72	14.19	28.30	42.40	50.87	55.95	56.45	56.51
observed	0.08	0.09	0.56	2.71	6	13.45	26.91	39.86	51.68	52.77	54.91	56.51
% error	0	34.03	13.08	6.60	-4.84	5.20	4.89	5.98	-1.60	5.68	2.73	0
Color												
(units)											1039.0	
expected	0	1.04	10.4	52	104	260	520	780	936	1029.6	1040	1040
observed	0	0	10	50	100	270	485	810	885	945	-0.10	1040
% error	0	100	3.85	3.85	3.85	-3.85	6.73	-3.85	5.45	8.22		0
pH												
(units)												
expected	7.30	7.30	7.30	7.31	7.32	7.36	7.42	7.48	7.52	7.54		7.54
observed	7.30	7.33	7.36	7.37	7.36	7.36	7.36	7.37	7.45	7.50	NA	7.54
% error	0	0.4	0.8	0.8	0.5	0	-0.8	-2.0	-0.9	-0.5		0
Toxicity												
(% reduction)												
expected	0	0.08	0.81	4.04	8.08	20.19	40.39	60.58	72.69	79.96	80.69	80.77
observed	0	0	0	0	12.33	36.43	50.03	68.57	72.70	74.13	79.73	80.77
% error	0	-100	-100	-100	52.60	80.43	23.87	13.19	0.01	-7.29	-1.20	0

NA: Data not available

TABLE A-6. RESULTS FROM METAL PLATING BATH DILUTION STUDY

	% Metal Plating Bath Waste in Springwater											
Parameter	0.0	0.1	1.0	5.0	10.0	25.0	50.0	75.0	90.0	99.0	99.9	100.0
Conductivity (µS/cm)												
expected	320	324.68	364.8	544	768	1440	2560	3680	4352	4755.2	4795.52	4800
observed	320	328	368	525	775	1500	2700	3850	4320	4750	4800	4800
% error	0	-1.08	-0.88	3.69	-0.91	-4.17	-5.47	-4.62	0.74	0.11	-0.09	0
Fluoride (mg/L)												
expected	0.10	0.10	0.12	0.19	0.28	0.54	0.98	1.42	1.68	1.84	1.86	1.86
observed	0.10	0.10	0.13	0.20	0.28	0.55	1.00	1.38	1.66	1.86	1.88	1.86
% error	0	0	-8.33	-5.26	0	-1.85	-2.04	2.81	1.19	-1.09	-1.08	1.86
Hardness (mg/L as $CaCO_3$)												
expected	222	228.56	227.53	249.65	277.3	360.25	498.5	636.75	719.7	769.47	774.95	775
observed	222	228	237	242	263	345	485	625	700	760	769	775
% error	0	-2.44	-4.16	3.06	5.16	4.23	2.71	1.84	2.74	1.23	0.70	0
Detergent (mg/L)												
expected	0	0.01	0.1	0.5	1	2.5	5	7.5	9	9.9	9.99	10
observed	0	0	0.09	0.48	1.06	2.4	4.65	7.6	9.2	9.68	9.79	10
% error	0	100	10.00	4.00	-6.00	4.00	7.00	-1.38	-2.22	2.22	2.00	0
Fluorescence (% scale)												
expected	6	6.10	7.04	11.2	16.4	32	58	84	99.6	108.96	109.90	110
observed	6	6	8	11	15	30	54	79	93	104	108	110
% error	0	1.64	-13.64	1.79	8.53	6.25	6.90	5.9	6.62	4.55	1.73	0

(continued)

TABLE A-6. (Continued)

	% Metal Plating Bath Waste in Springwater											
Parameter	0.0	0.1	1.0	5.0	10.0	25.0	50.0	75.0	90.0	99.0	99.9	100.0
Potassium (mg/L)												
expected	1.21	1.66	5.70	23.65	46.09	113.41	225.61	337.80	405.12	445.51	449	450
observed	1.21	1.99	6.32	25	48	117	230	350	420	442	444	450
% error	0	-19.88	-10.88	-5.71	-4.14	-3.17	-1.95	-3.61	-3.67	0.79	1.11	0
Ammonia (mg/L)												
expected	0	0	0.03	0.15	0.31	0.76	1.53	2.29	2.75	3.01	3.05	3.05
observed	0	0	0.02	0.16	0.29	0.74	1.62	2.29	2.75	3.01	3.05	3.05
% error	0	0	33.33	-6.67	6.45	2.63	-5.56	0	0	0	0	0
Color (units)												
expected	0	0.21	2.12	10.6	21.2	53	106	159	190.8	209.88	211.79	212
observed	0	0	3	10	20	55	110	162	194	216	212	212
% error	0	100	-41.5	5.67	5.67	-3.78	-3.78	-1.89	-1.68	-2.92	-0.01	0
pH (units)												
expected	7.90	7.90	7.91	7.93	7.96	8.05	8.20	8.35	8.44	8.49	8.50	8.50
observed	7.90	7.89	7.88	7.87	7.87	7.94	8.18	8.41	8.48	8.50	8.51	8.50
% error	0	-0.13	-0.38	-0.76	-1.13	-1.37	-0.24	0.72	0.47	0.12	0.12	0
Toxicity (% reduction)												
expected	0	0.1	1	5	10	25	50	75	90	99	99	100
observed	0	10.81	40.40	44.60	96.50	100	100	100	100	100	NA	100
% error	0	10710	3940	792	865	300	100	33.33	11.11	1.01		0

NA: Data not available

TABLE A-7. PROBABILITY VALUES FOR LOG-PROBABILITY DISTRIBUTIONS FOR LOW, MEDIUM, AND HIGH SAMPLE VARIATIONS

	Low Sample Variability	Medium Sample Variability	High Sample Variability
COV (s/x):	0.16	0.83	1.67
Range Ratio (x_{90}/x_{10}):	1.5	10	100
Probability that conc. will be greater than shown		Relative Concentrations:	
99	0.70	0.12	0.014
98	0.73	0.16	0.23
95	0.78	0.23	0.05
90 (x_{90})	0.80	0.32	0.1
80	0.88	0.48	0.22
70	0.92	0.63	0.39
60	0.96	0.81	0.64
50 (median)	1.0	1.0	1.0
40	1.04	1.3	1.6
30	1.08	1.6	2.6
20	1.12	2.2	4.5
10 (x_{10})	1.20	3.2	10
5	1.29	4.5	19
2	1.34	6.5	42
1	1.41	8.3	70

Appendix B
Statistical Plots for Equipment Selection

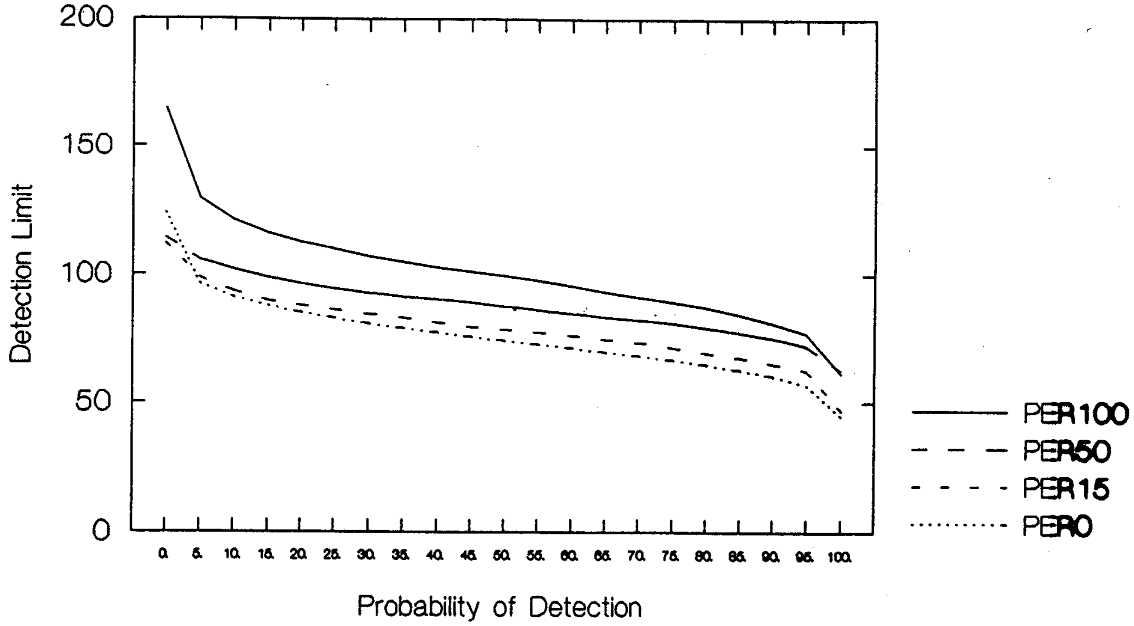


Figure B-1. Required detection limits for contaminant (low variation) to base (low variation) concentration ratio of 1.33 (75L-100L).

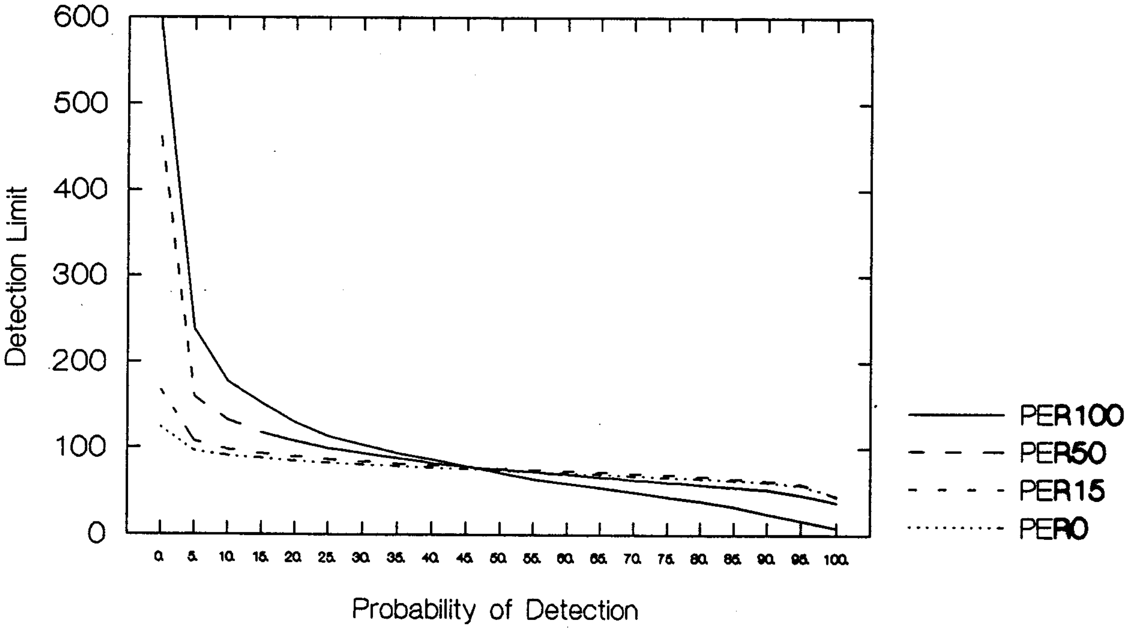


Figure B-2. Required detection limits for contaminant (low variation) to base (medium variation) concentration ratio of 1.33 (75L-100M).

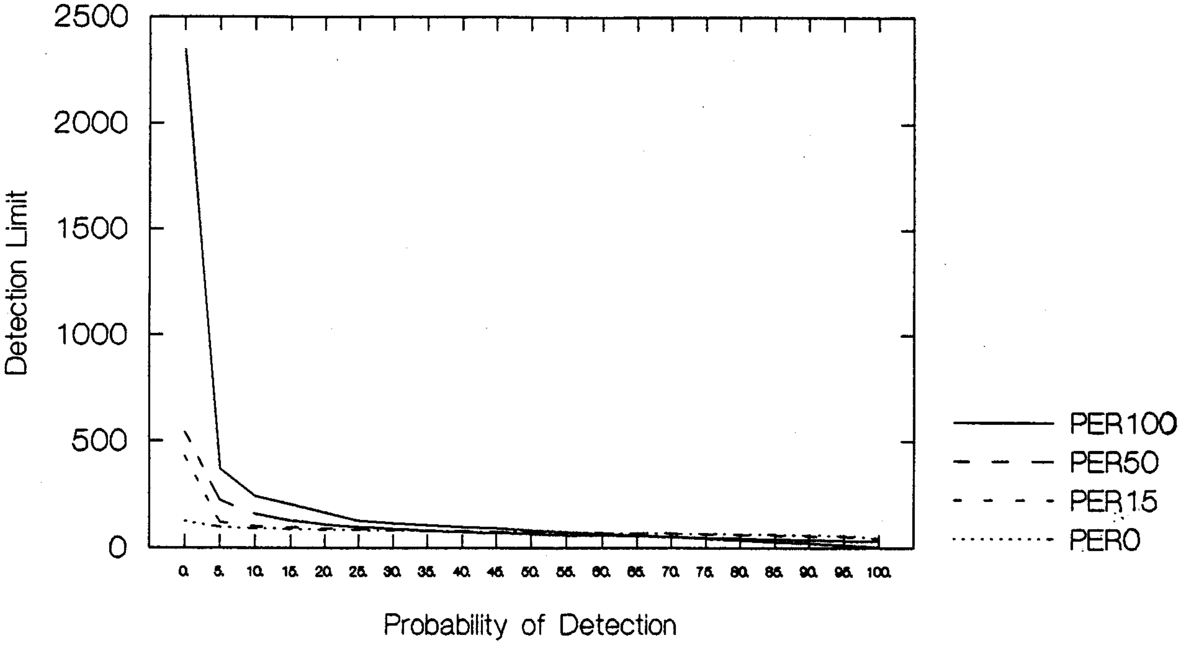


Figure B-3. Required detection limits for contaminant (low variation) to base (high variation) concentration ratio of 1.33 (75L-100H).

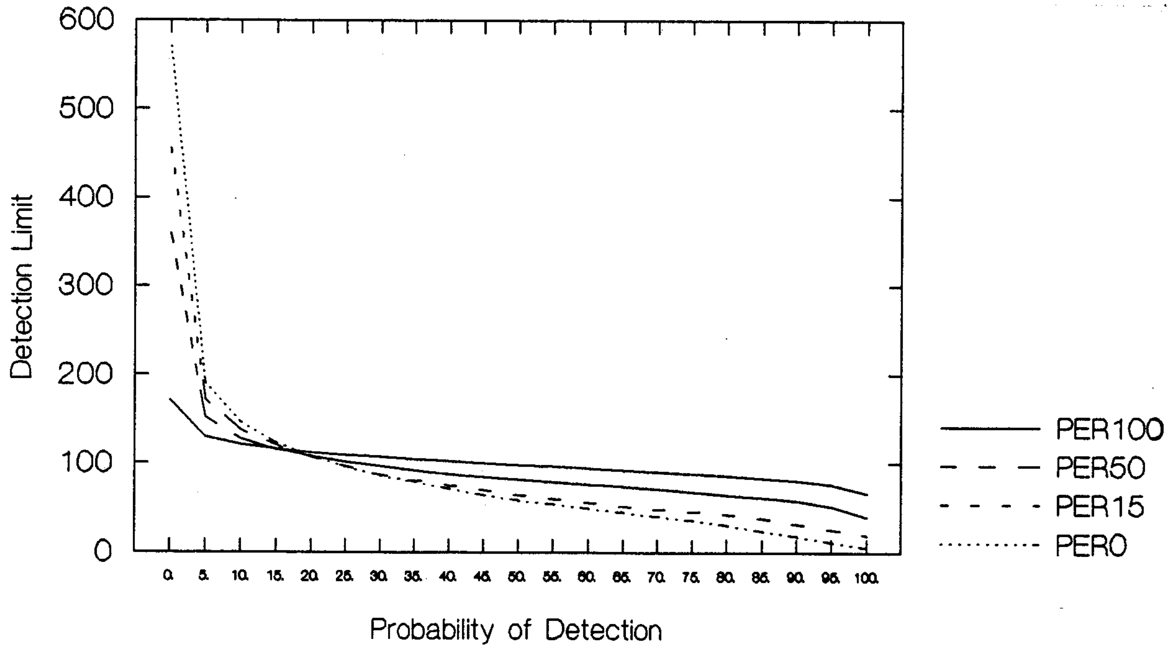


Figure B-4. Required detection limits for contaminant (medium variation) to base (low variation) concentration ratio of 1.33 (75M-100L).

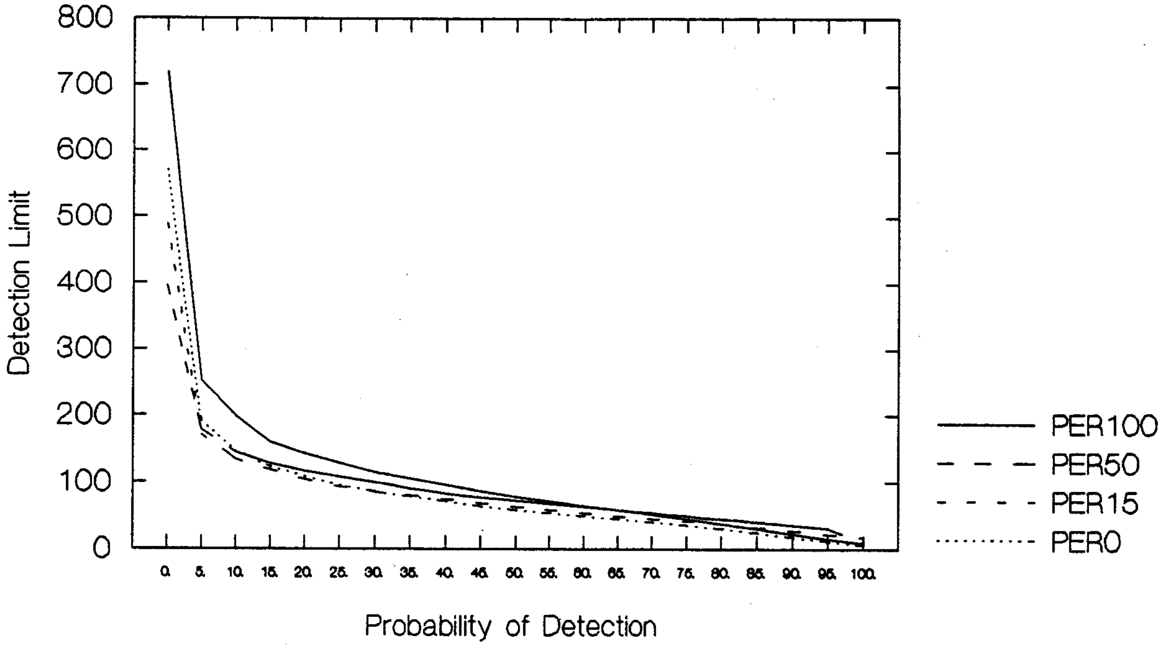


Figure B-5. Required detection limits for contaminant (medium variation) to base (medium variation) concentration ratio of 1.33 (75M-100M).

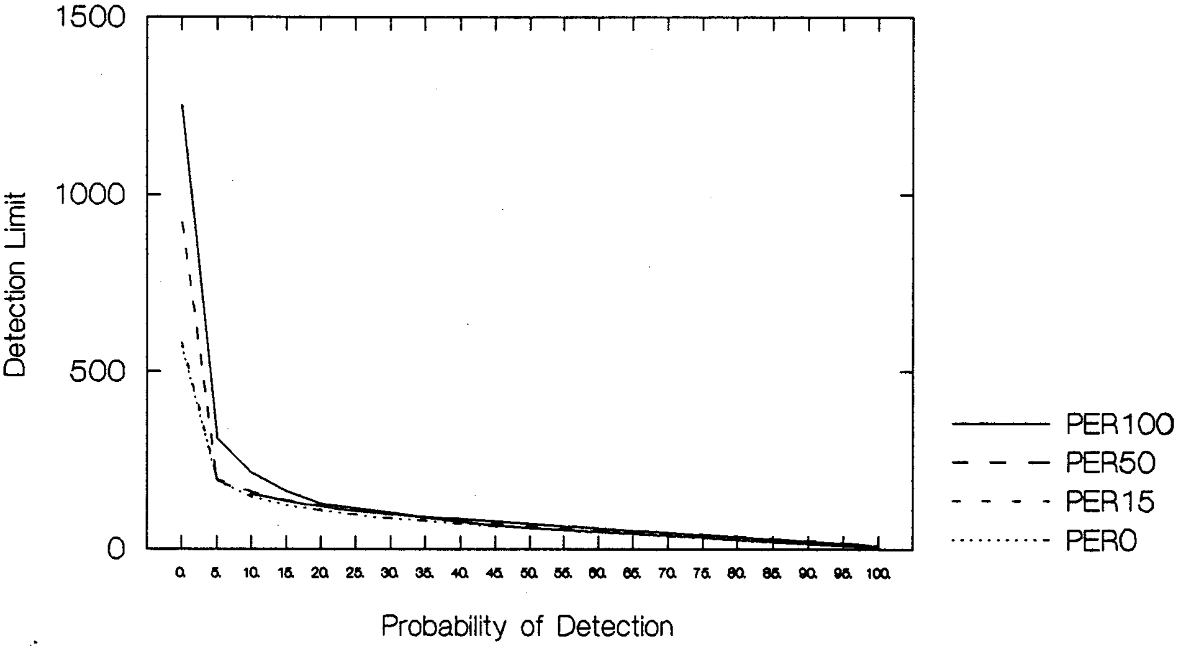


Figure B-6. Required detection limits for contaminant (medium variation) to base (high variation) concentration ratio of 1.33 (75M-100H).

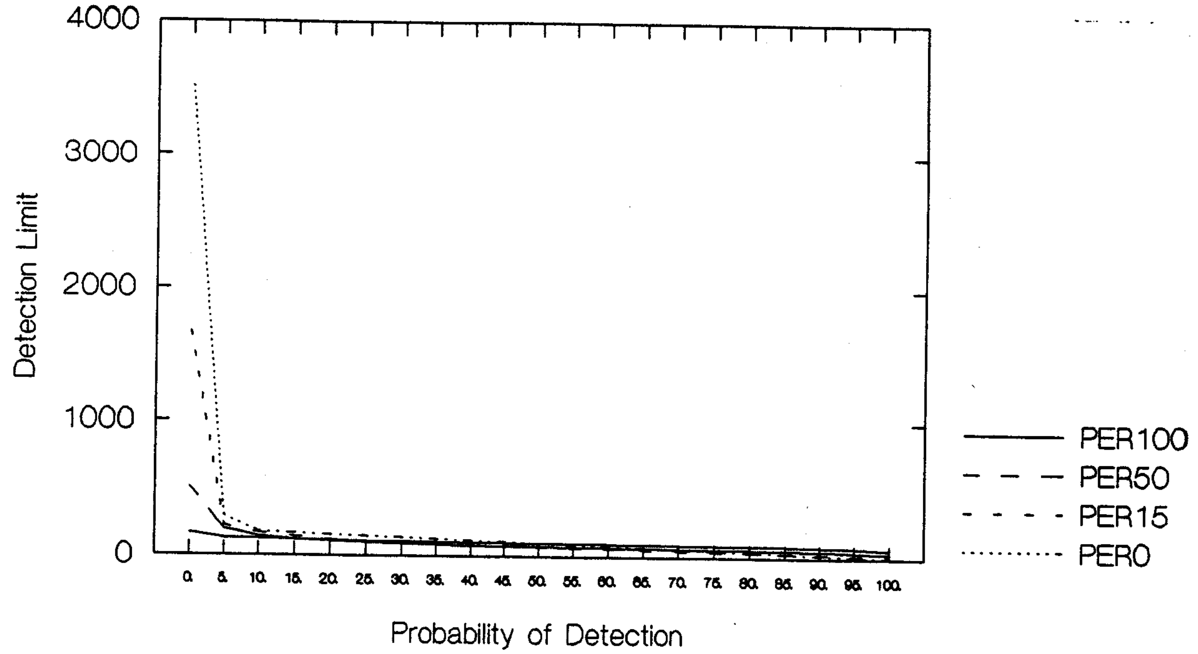


Figure B-7. Required detection limits for contaminant (high variation) to base (low variation) concentration ratio of 1.33 (75H-100L).

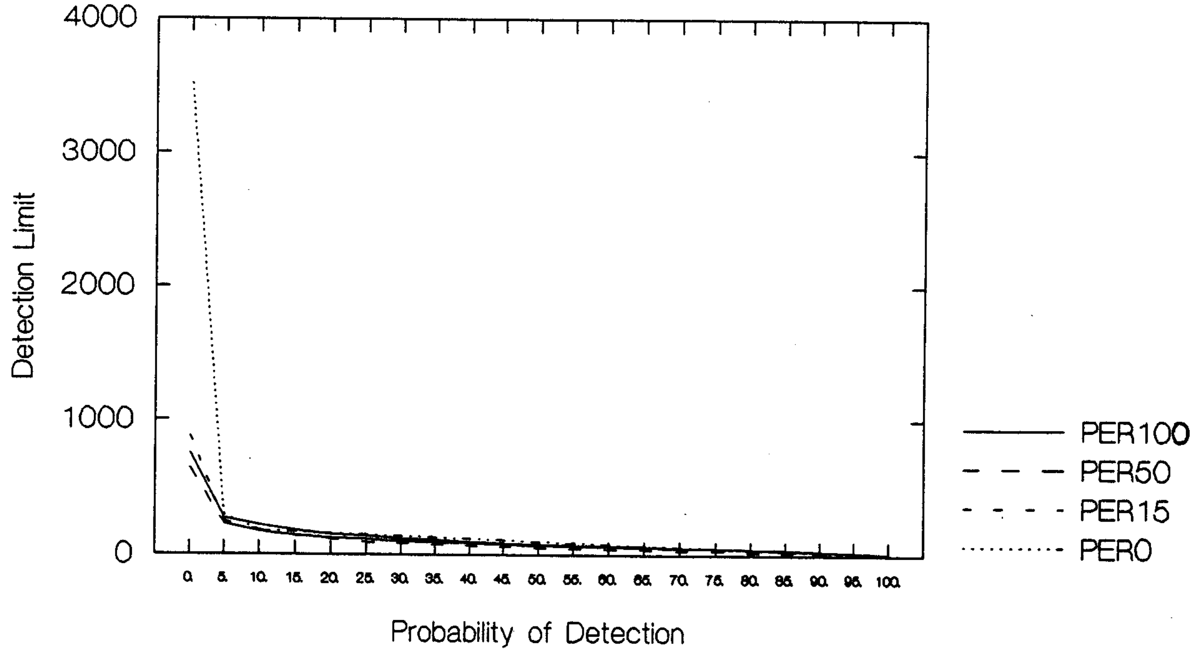


Figure B-8. Required detection limits for contaminant (high variation) to base (medium variation) concentration ratio of 1.33 (75H-100M).

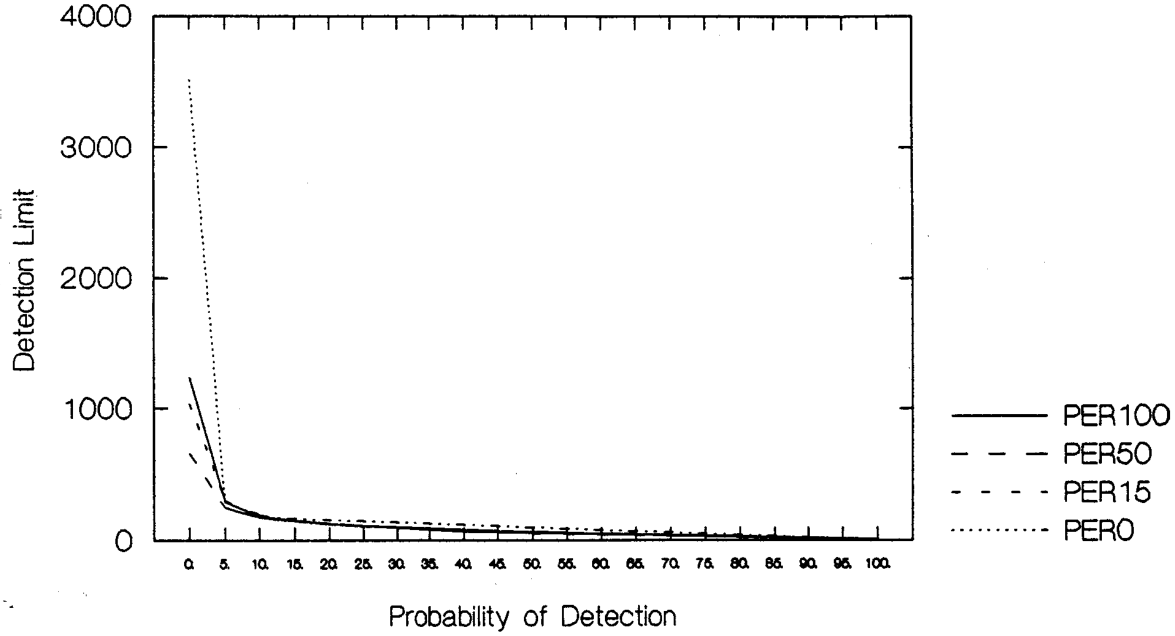


Figure B-9. Required detection limits for contaminant (high variation) to base (high variation) concentration ratio of 1.33 (75H-100H).

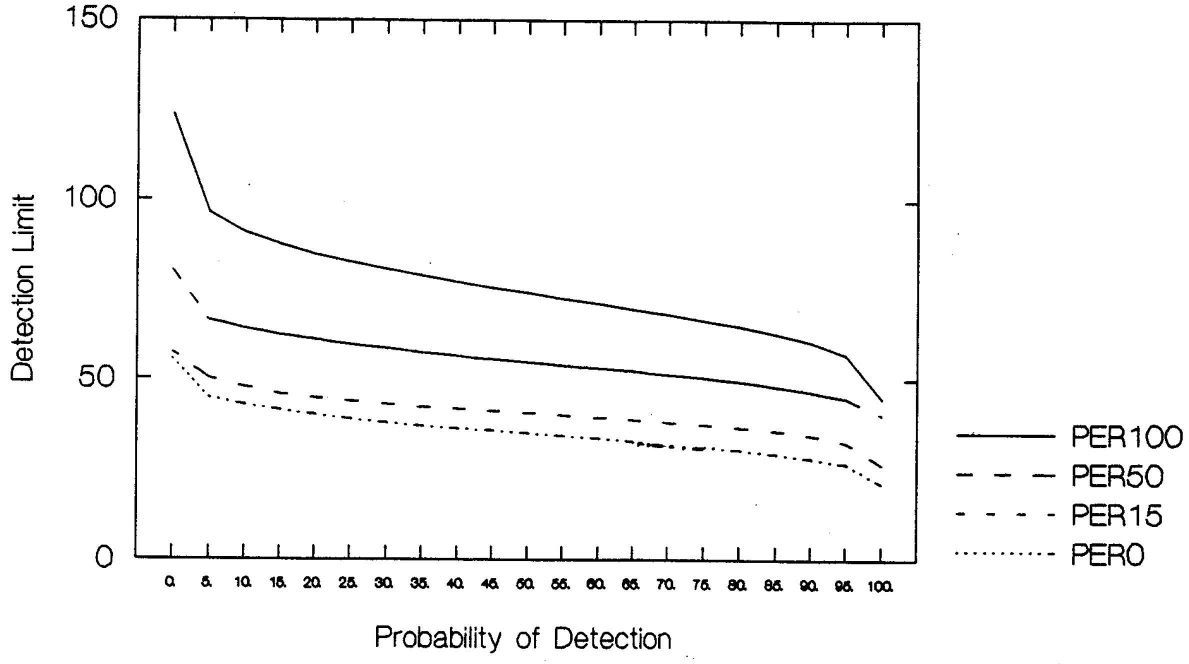


Figure B-10. Required detection limits for contaminant (low variation) to base (low variation) concentration ratio of 2.14 (35L-75L).

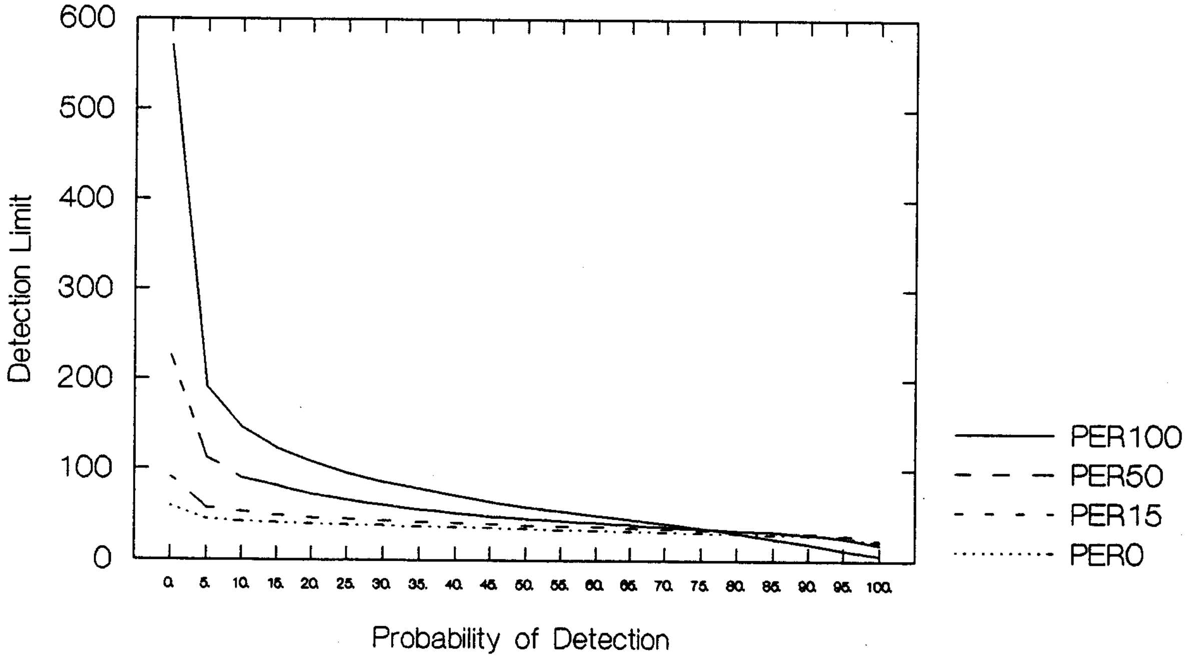


Figure B-11. Required detection limits for contaminant (low variation) to base (medium variation) concentration ratio of 2.14 (35L-75M).

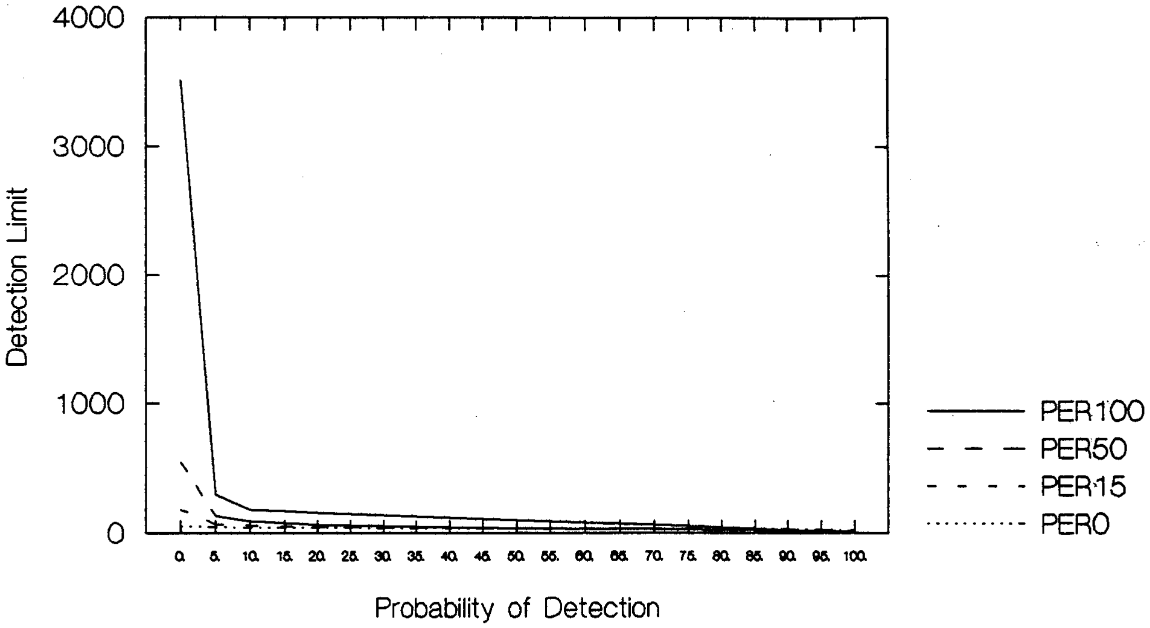


Figure B-12. Required detection limits for contaminant (low variation) to base (high variation) concentration ratio of 2.14 (35L-75H).

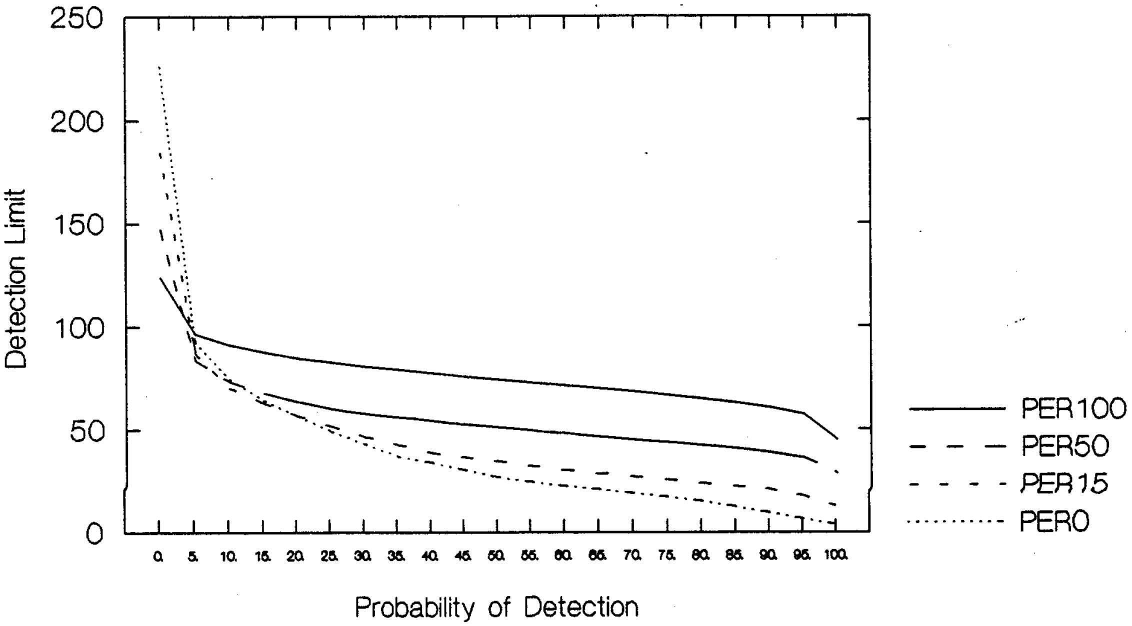


Figure B-13. Required detection limits for contaminant (medium variation) to base (low variation) concentration ratio of 2.14 (35M-75L).

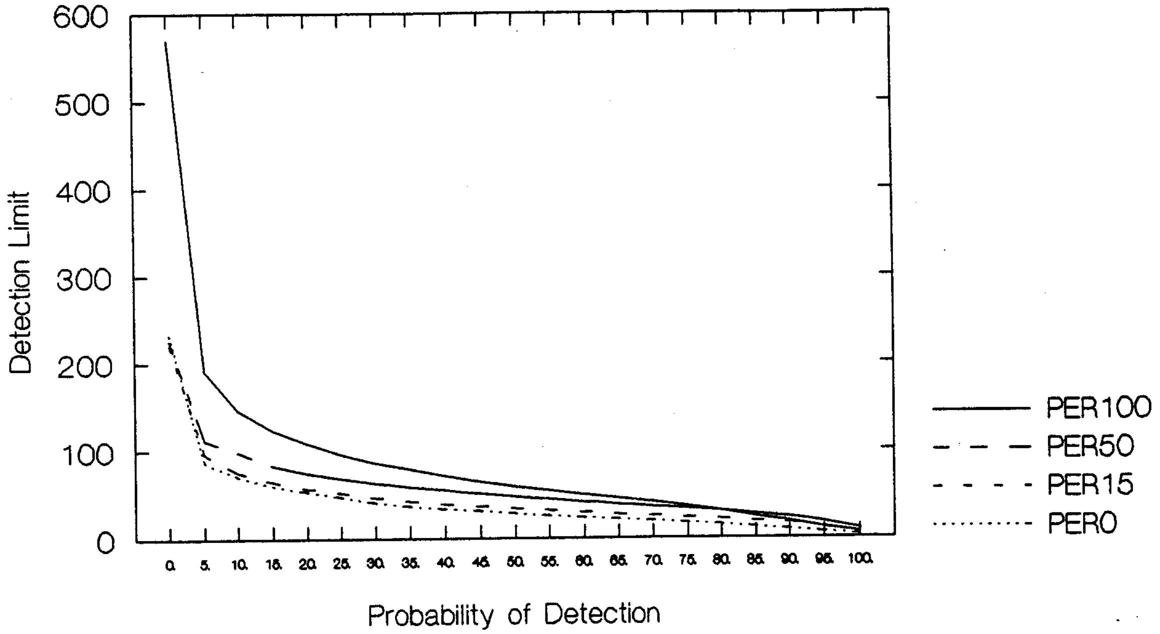


Figure B-14. Required detection limits for contaminant (medium variation) to base (medium variation) concentration ratio of 2.14 (35M-75M).

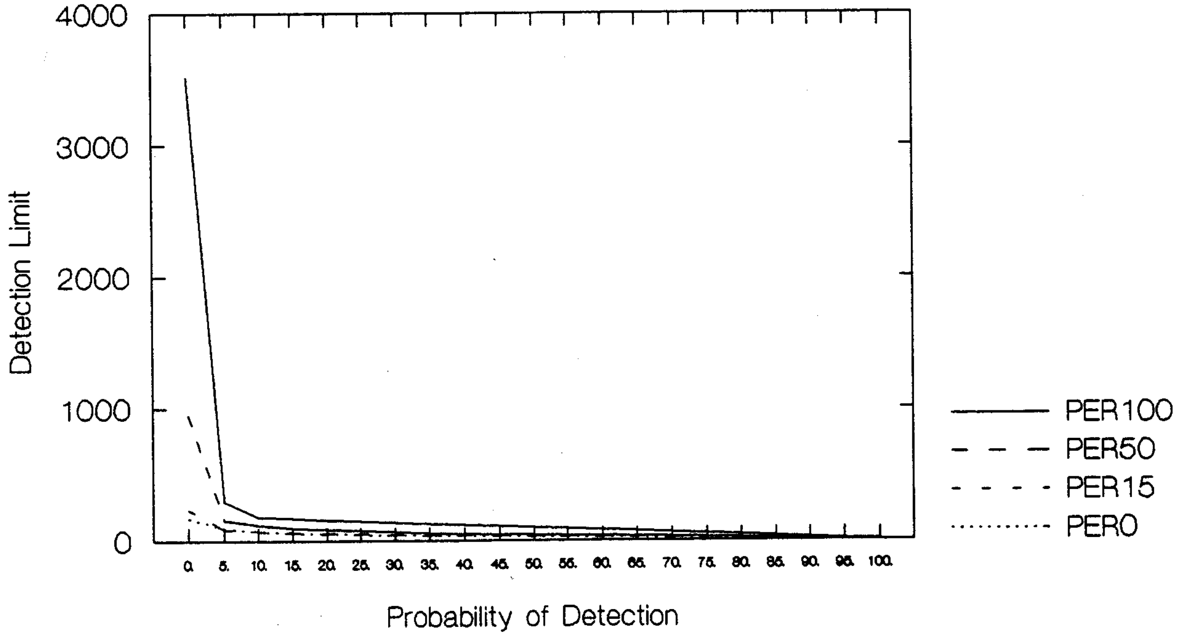


Figure B-15. Required detection limits for contaminant (medium variation) to base (high variation) concentration ratio of 2.14 (35M-75H).

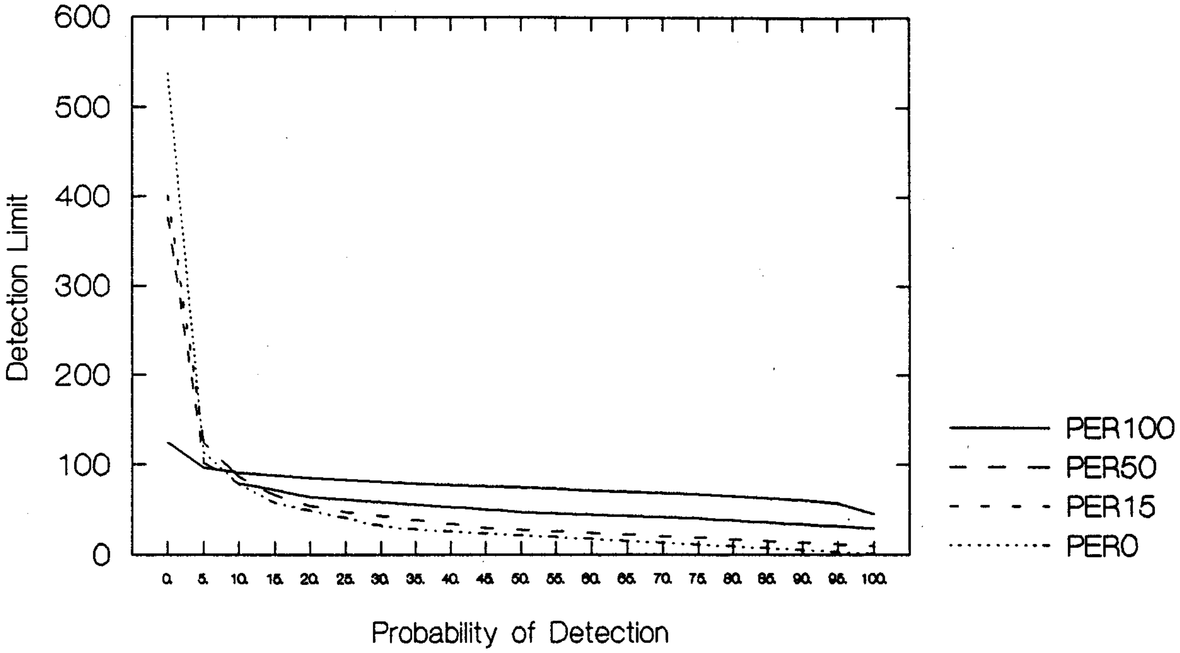


Figure B-16. Required detection limits for contaminant (high variation) to base (low variation) concentration ratio of 2.14 (35H-75L).

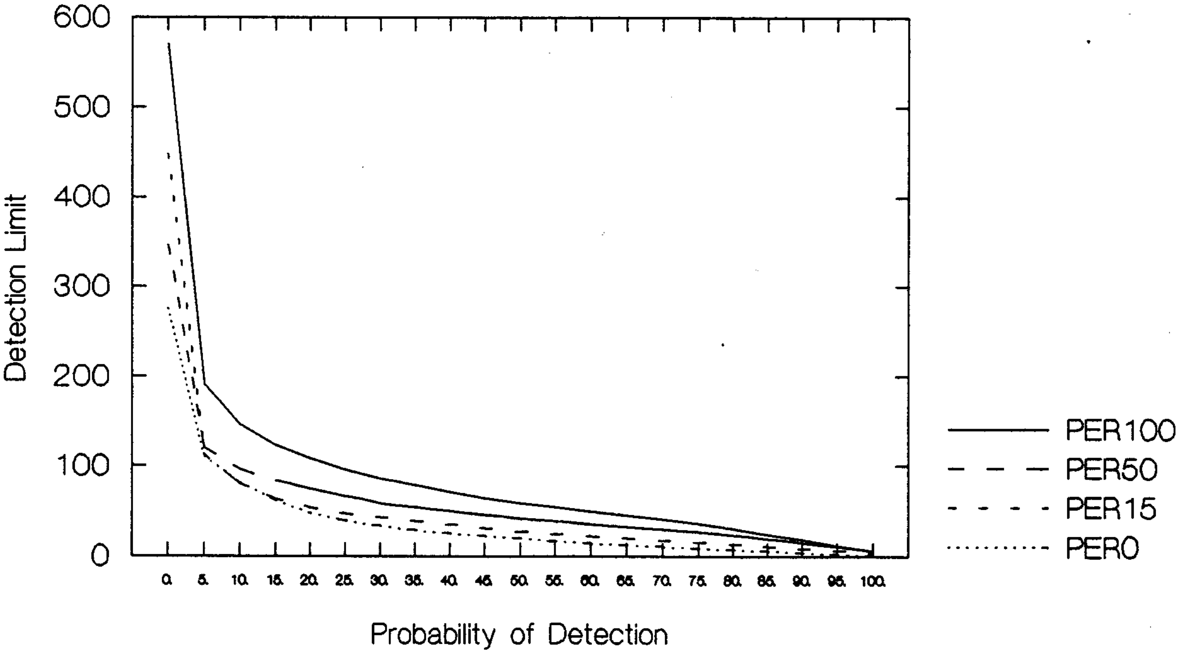


Figure B-17. Required detection limits for contaminant (high variation) to base (medium variation) concentration ratio of 2.14 (35H-75M).

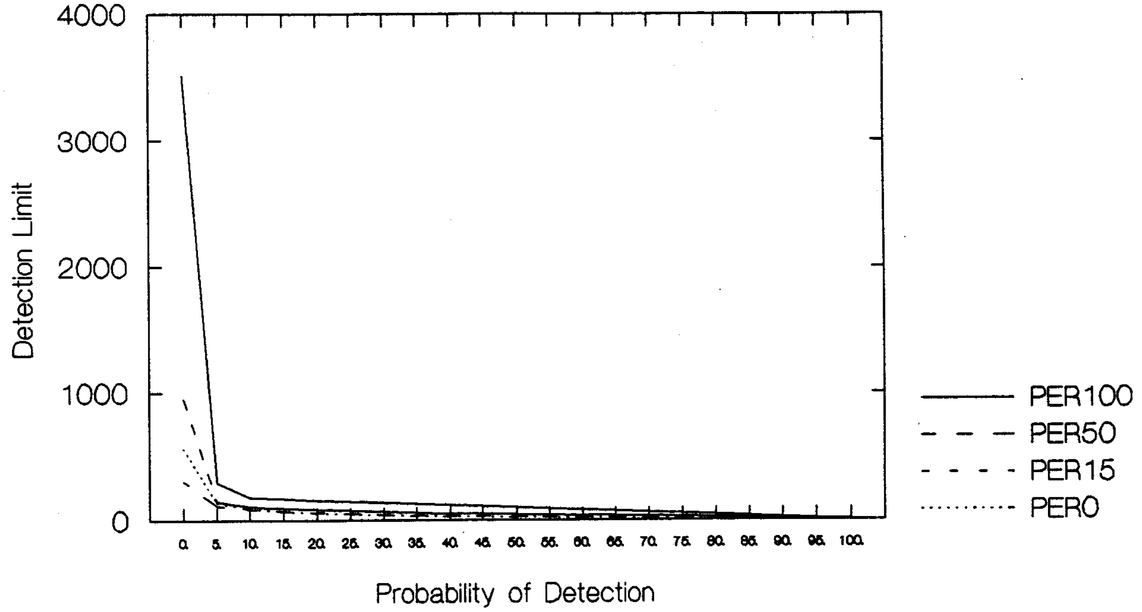


Figure B-18. Required detection limits for contaminant (high variation) to base (high variation) concentration ratio of 2.14 (35H-75H).

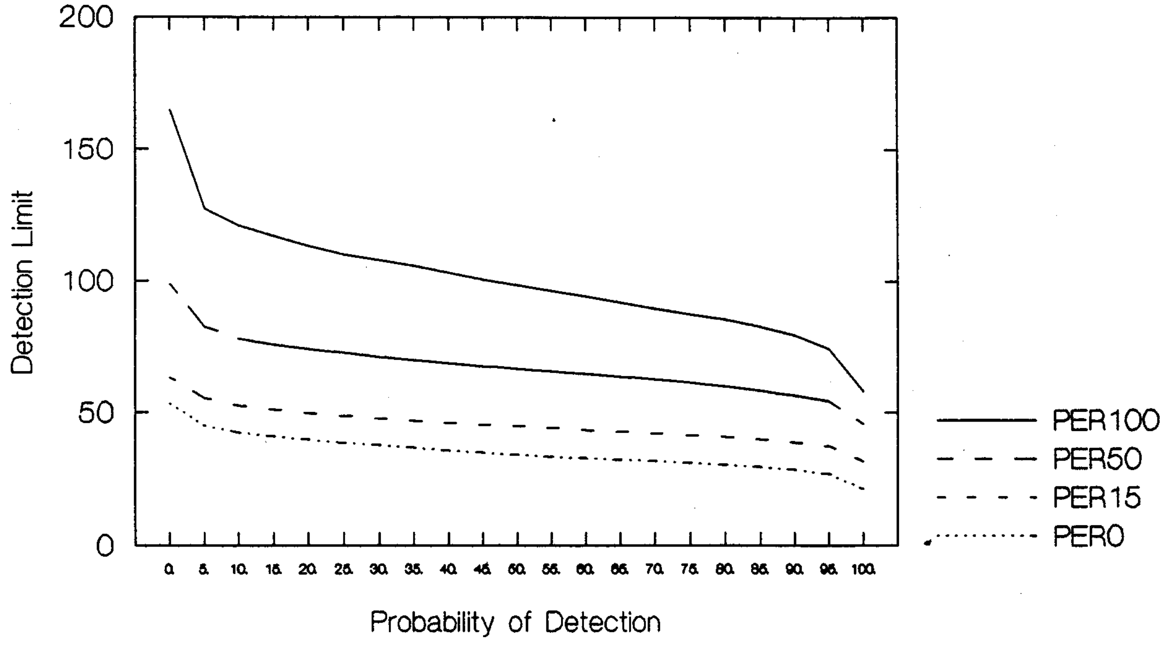


Figure B-19. Required detection limits for contaminant (low variation) to base (low variation) concentration ratio of 2.86 (35L-100L).

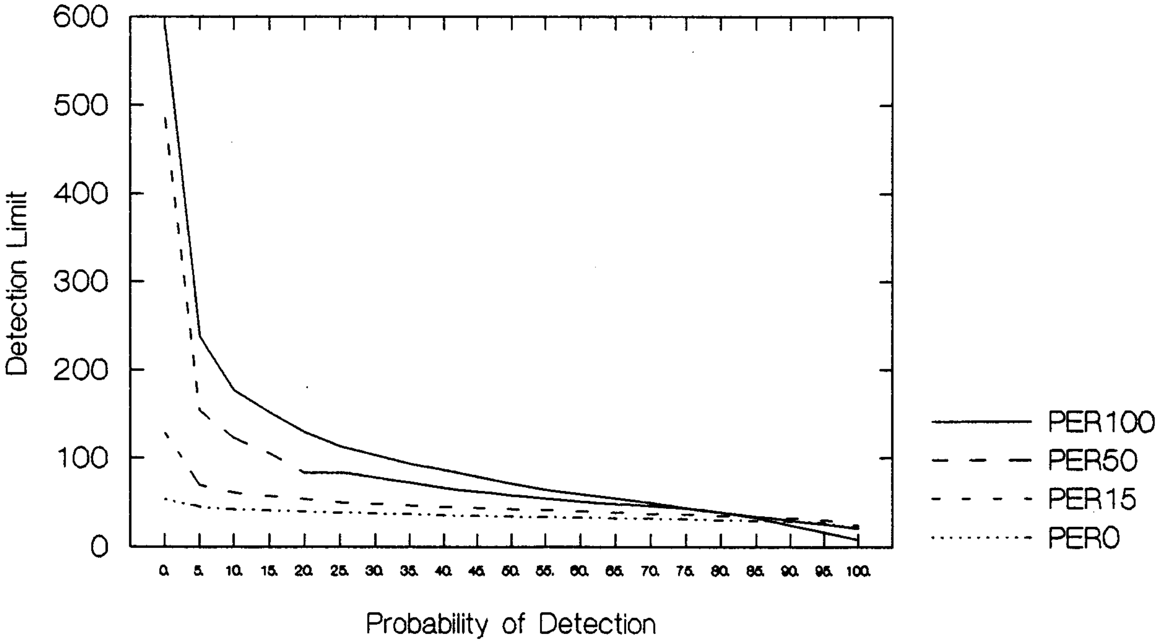


Figure B-20. Required detection limits for contaminant (low variation) to base (medium variation) concentration ratio of 2.86 (35L-100M).

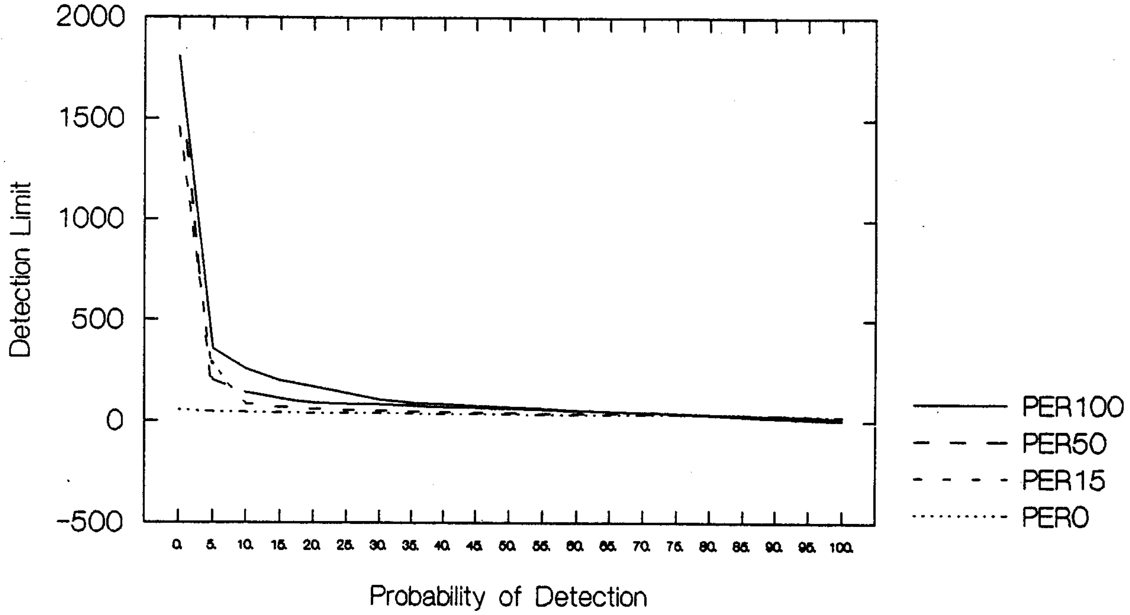


Figure B-21. Required detection limits for contaminant (low variation) to base (high variation) concentration ratio of 2.86 (35L-100H).

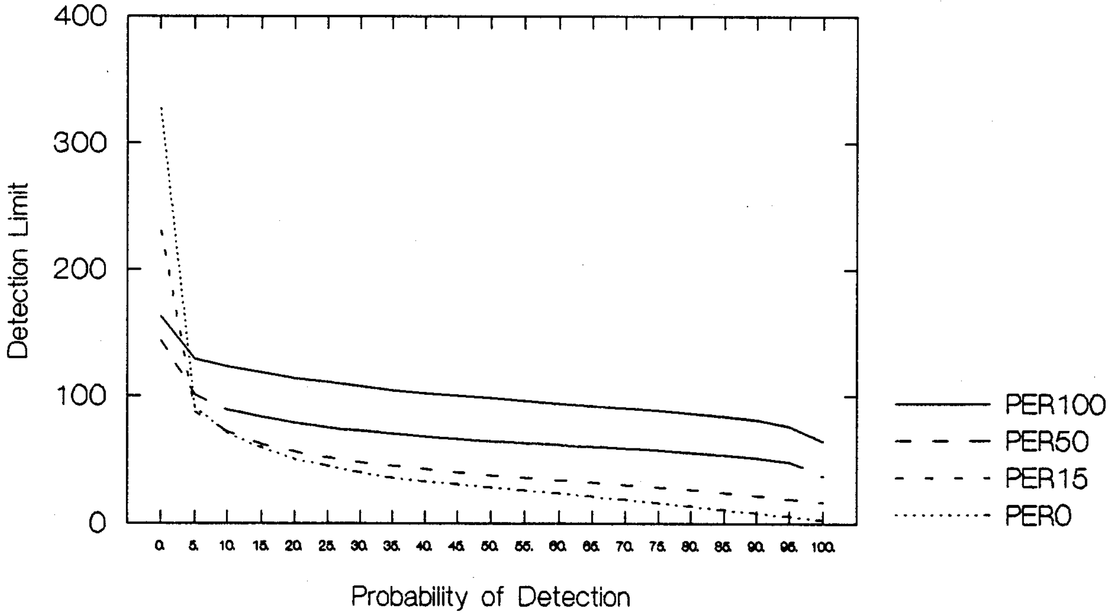


Figure B-22. Required detection limits for contaminant (medium variation) to base (low variation) concentration ratio of 2.86 (35M-100L).

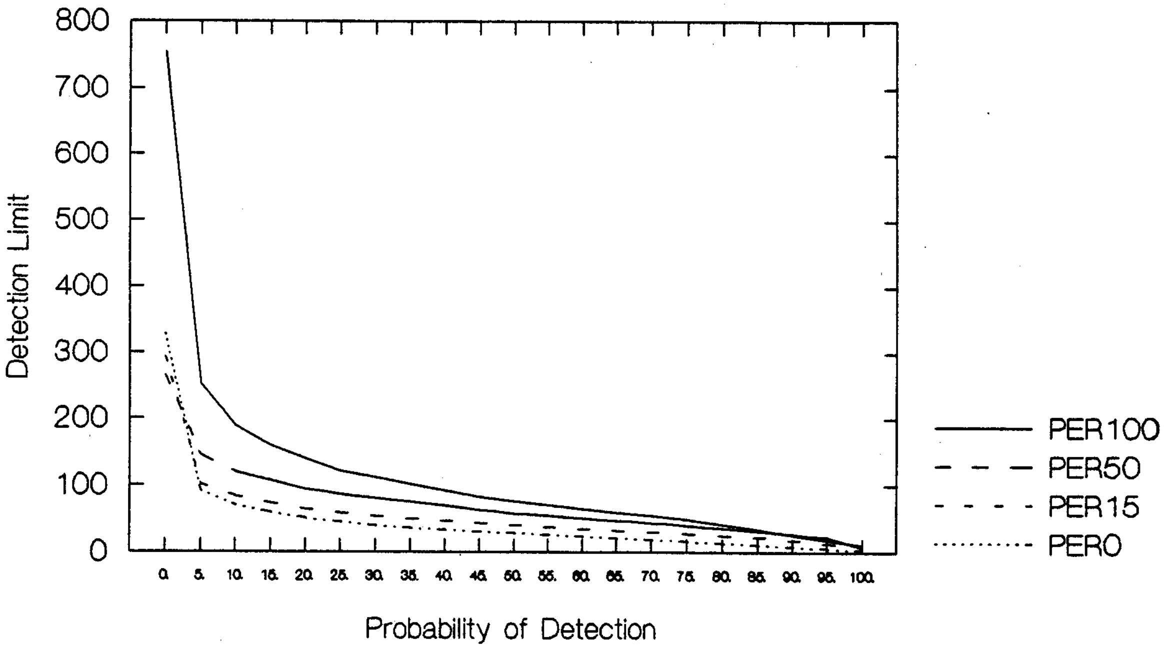


Figure B-23. Required detection limits for contaminant (medium variation) to base (medium variation) concentration ratio of 2.86 (35M-100M).

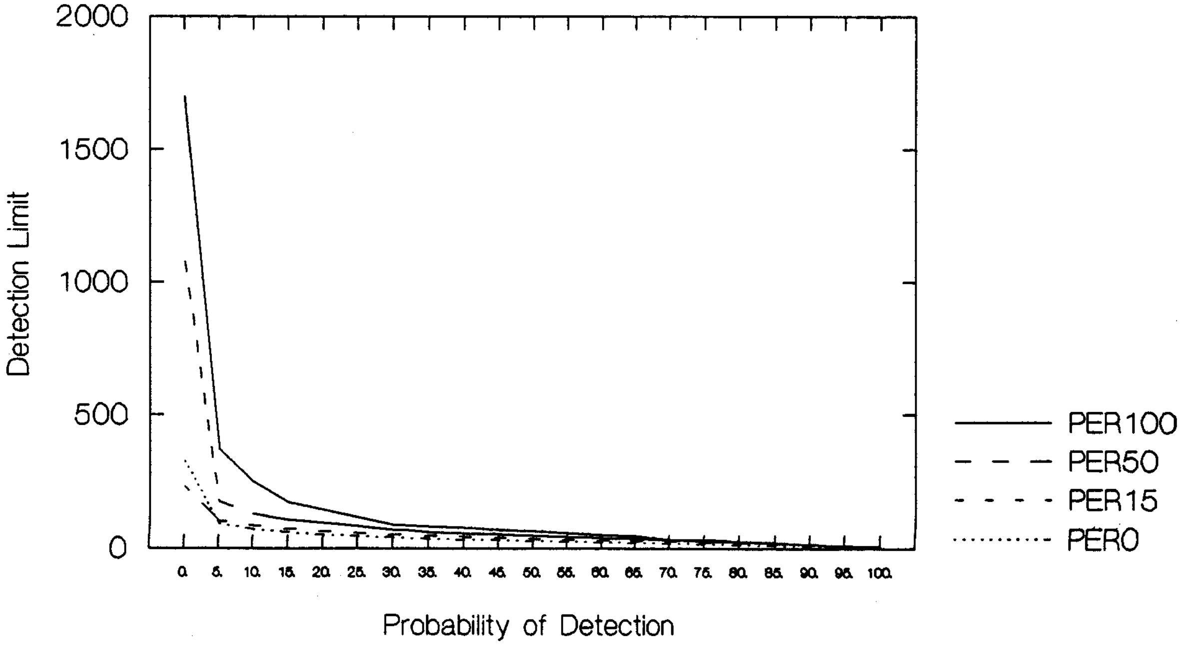


Figure B-24. Required detection limits for contaminant (medium variation) to base (high variation) concentration ratio of 2.86 (35M-100H).

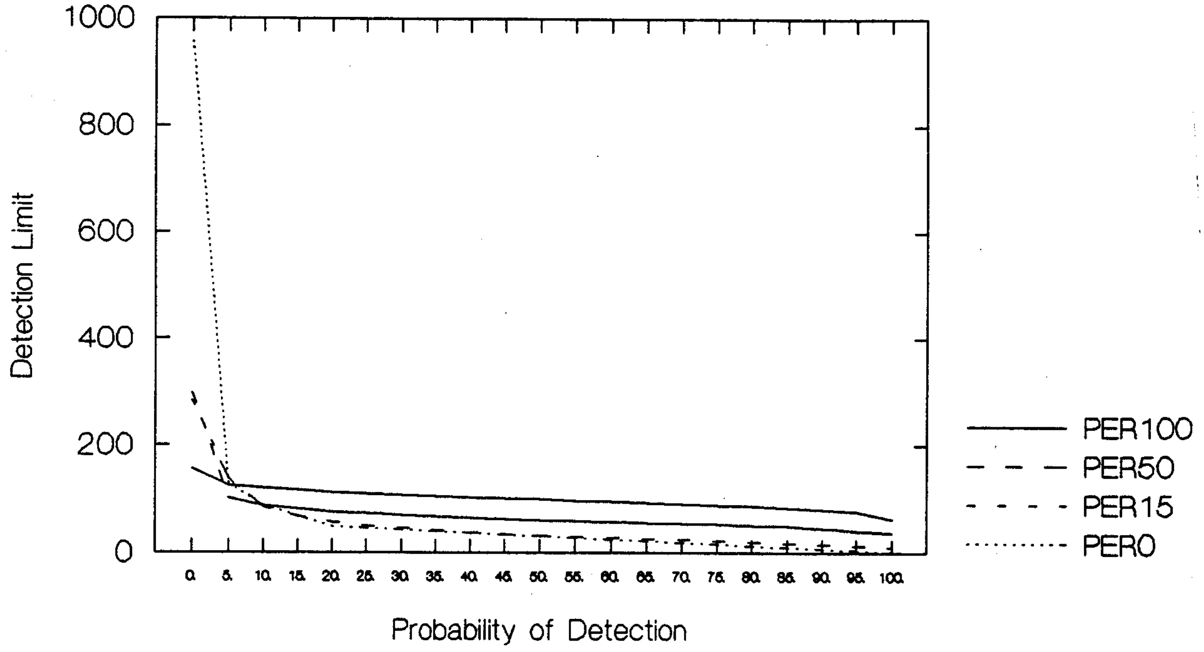


Figure B-25. Required detection limits for contaminant (high variation) to base (low variation) concentration ratio of 2.86 (35H-100L).

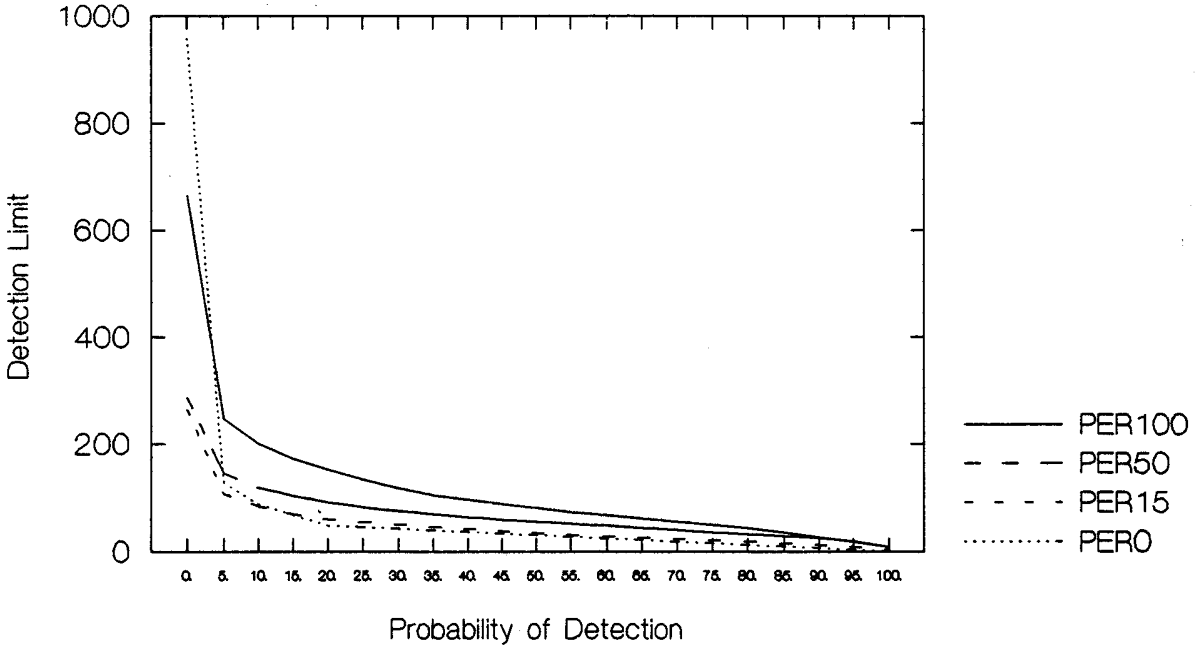


Figure B-26. Required detection limits for contaminant (high variation) to base (medium variation) concentration ratio of 2.86 (35H-100M).

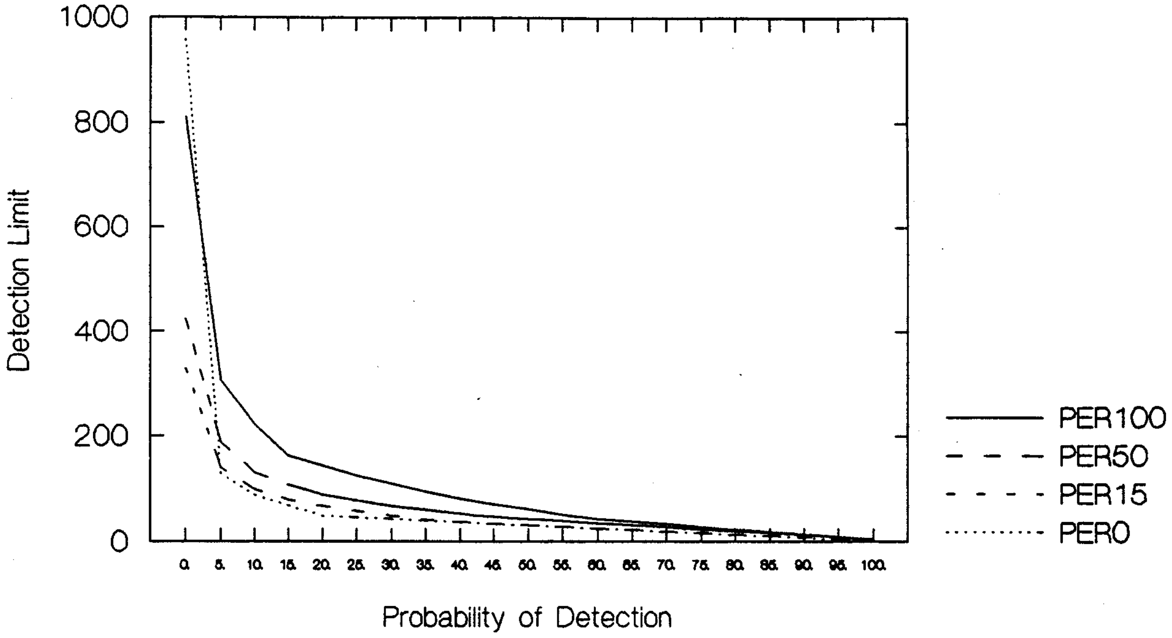


Figure B-27. Required detection limits for contaminant (high variation) to base (high variation) concentration ratio of 2.86 (35H-100H).

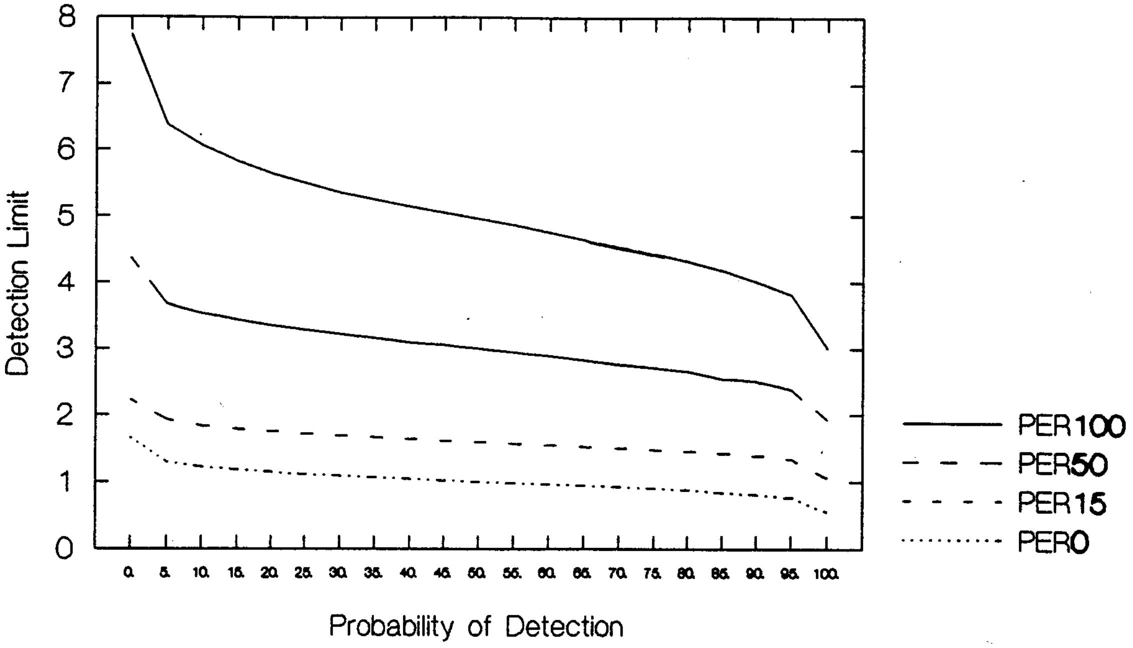


Figure B-28. Required detection limits for contaminant (low variation) to base (low variation) concentration ratio of 5 (1L-5L).

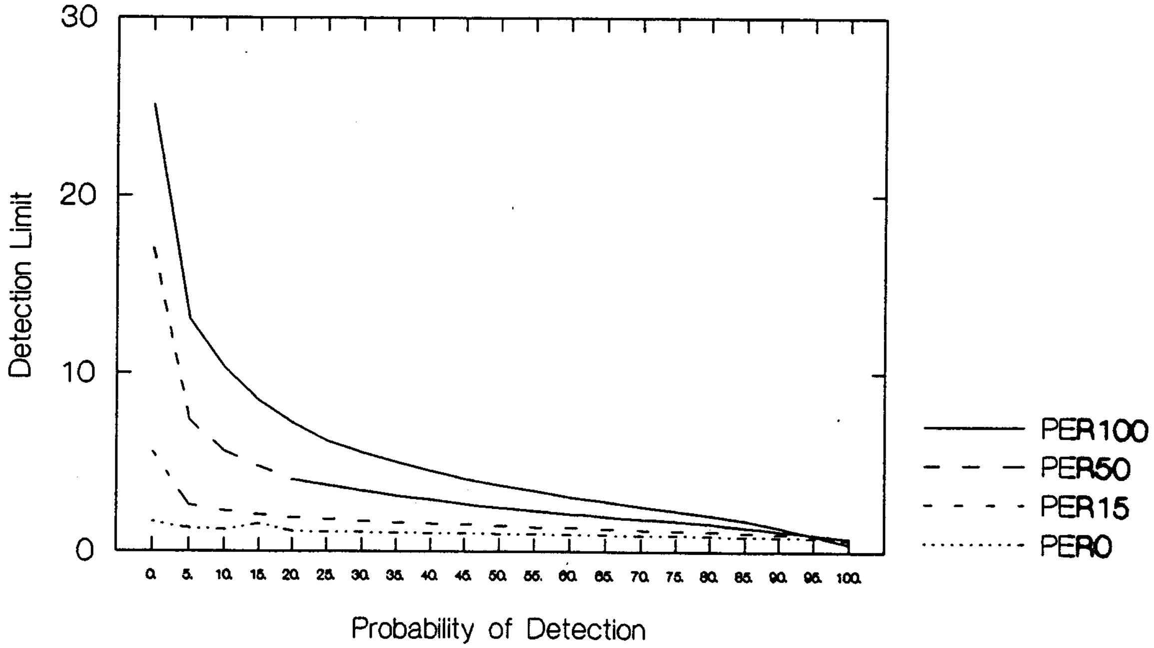


Figure B-29. Required detection limits for contaminant (low variation) to base (medium variation) concentration ratio of 5 (1L-5M).

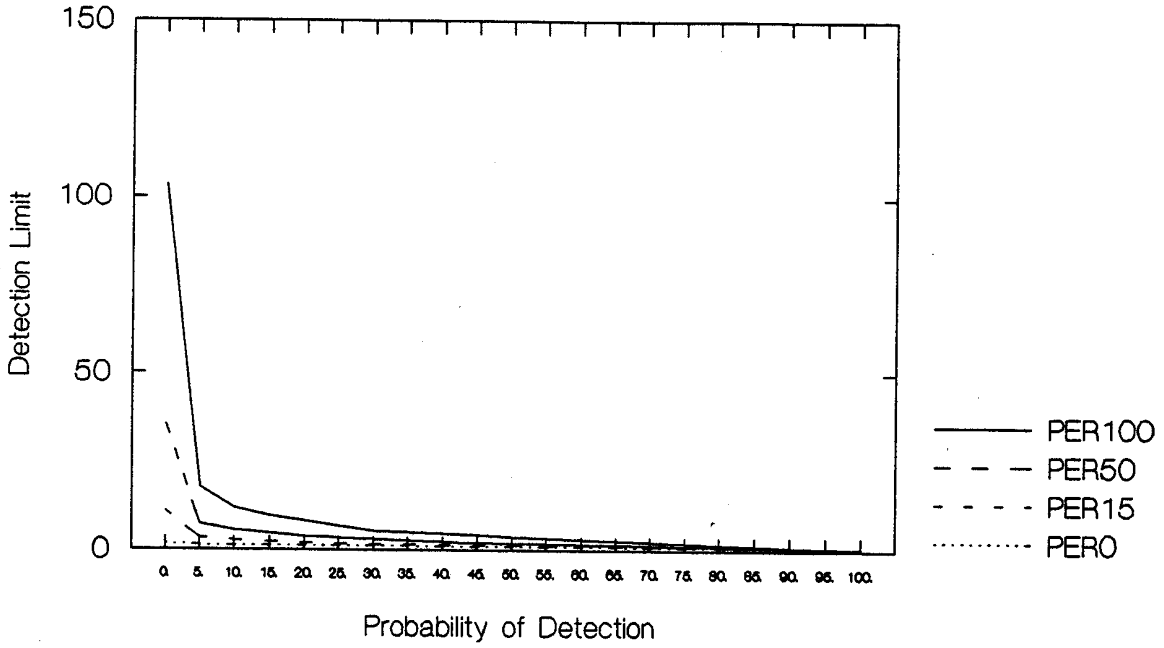


Figure B-30. Required detection limits for contaminant (low variation) to base (high variation) concentration ratio of 5 (1L-5H).

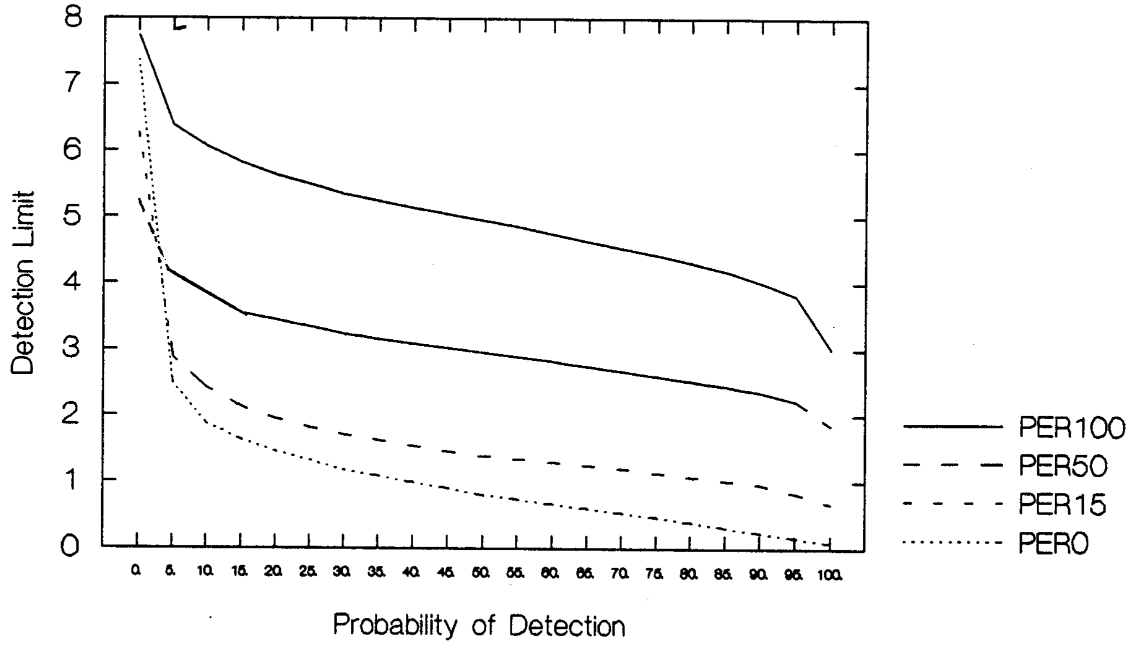


Figure B-31. Required detection limits for contaminant (medium variation) to base (low variation) concentration ratio of 5 (1M-5L).

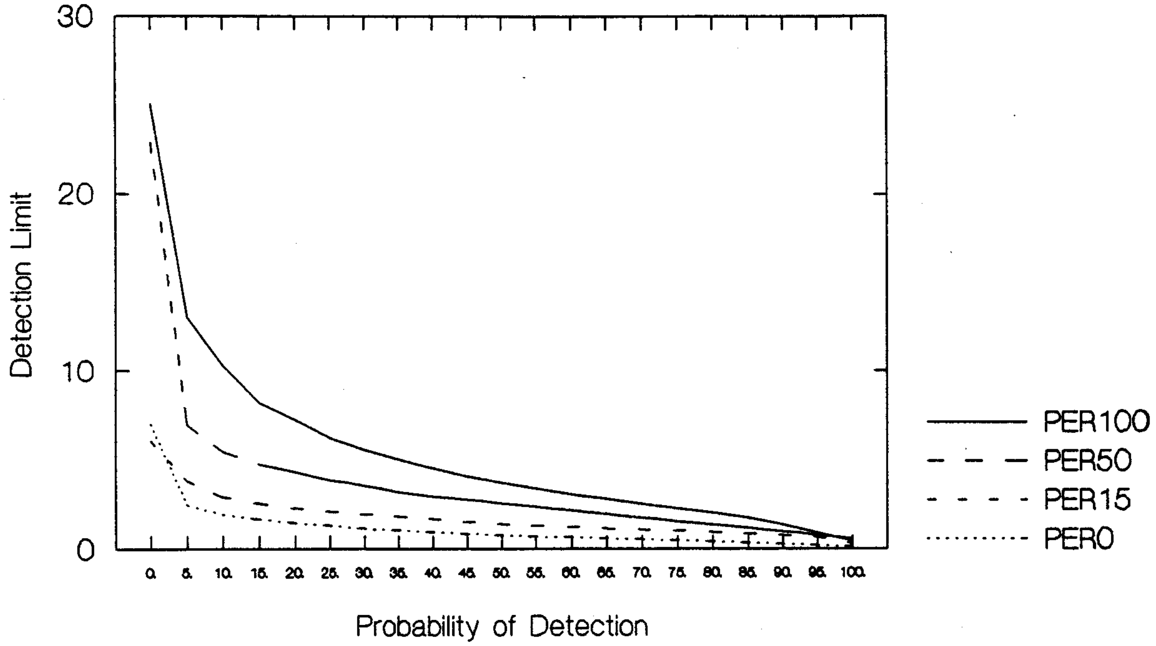


Figure B-32. Required detection limits for contaminant (medium variation) to base (medium variation) concentration ratio of 5 (1M-5M).

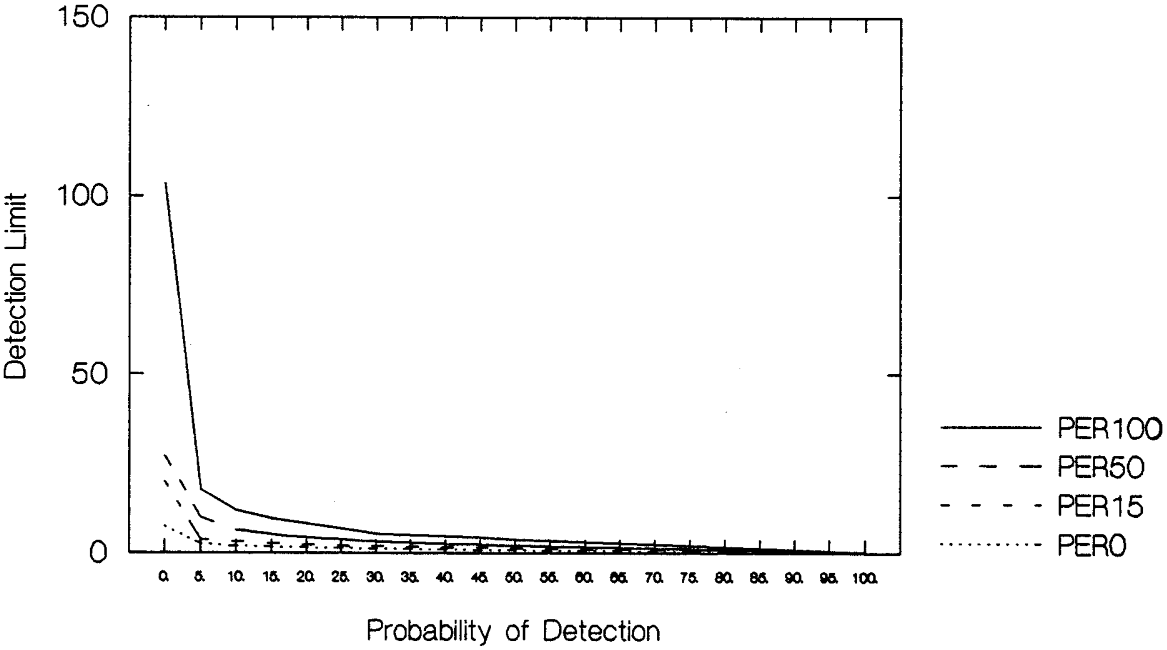


Figure B-33. Required detection limits for contaminant (medium variation) to base (high variation) concentration ratio of 5 (1M-5H).

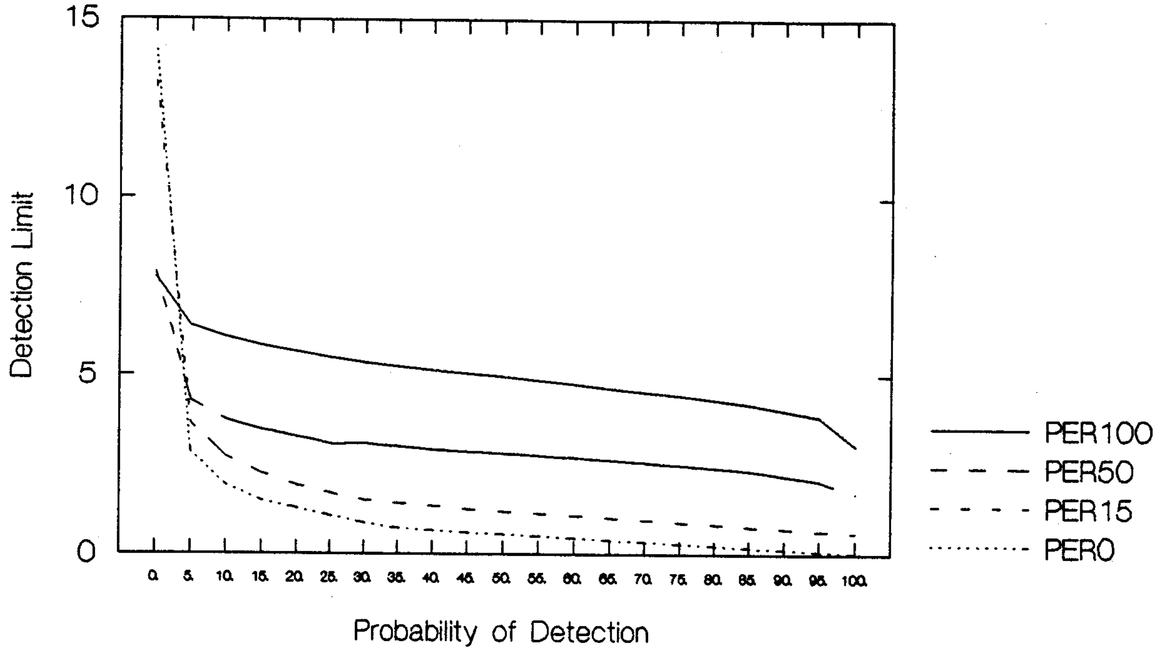


Figure B-34. Required detection limits for contaminant (high variation) to base (low variation) concentration ratio of 5 (1H-5L).

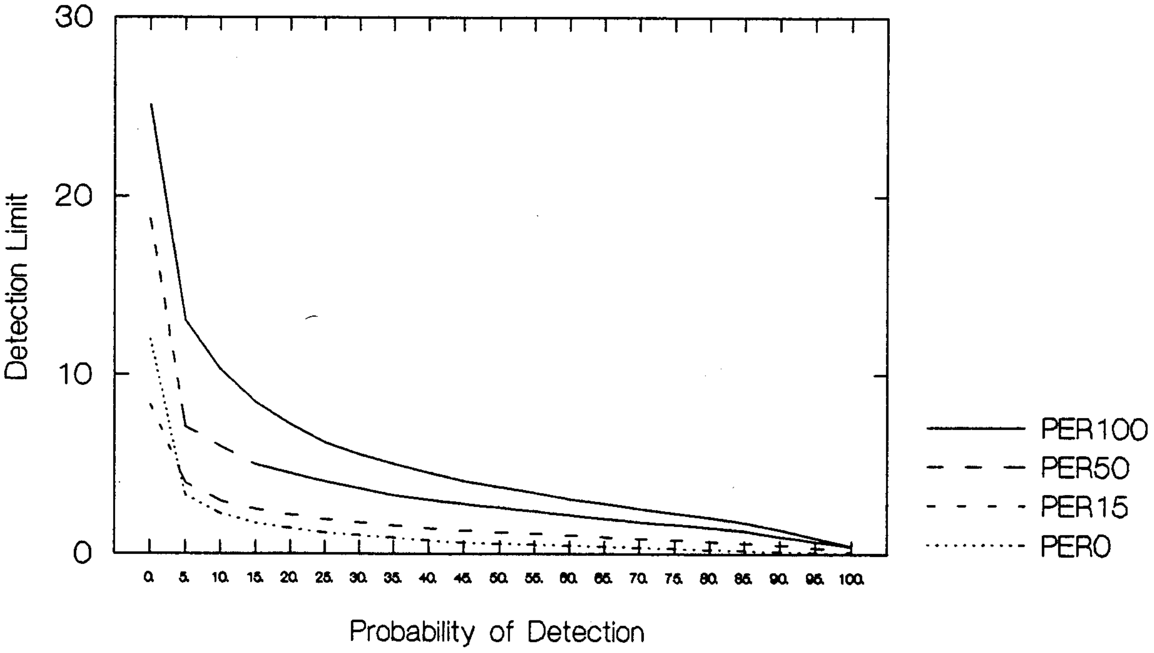


Figure B-35. Required detection limits for contaminant (high variation) to base (medium variation) concentration ratio of 5 (1H-5M).

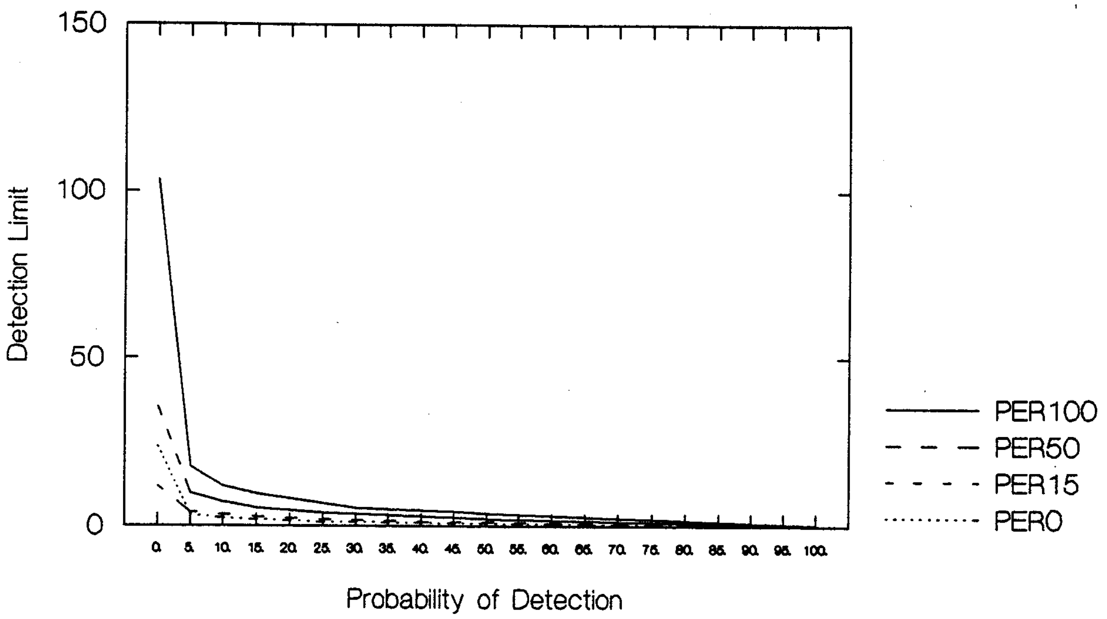


Figure B-36. Required detection limits for contaminant (high variation) to base (high variation) concentration ratio of 5 (1H-5H).

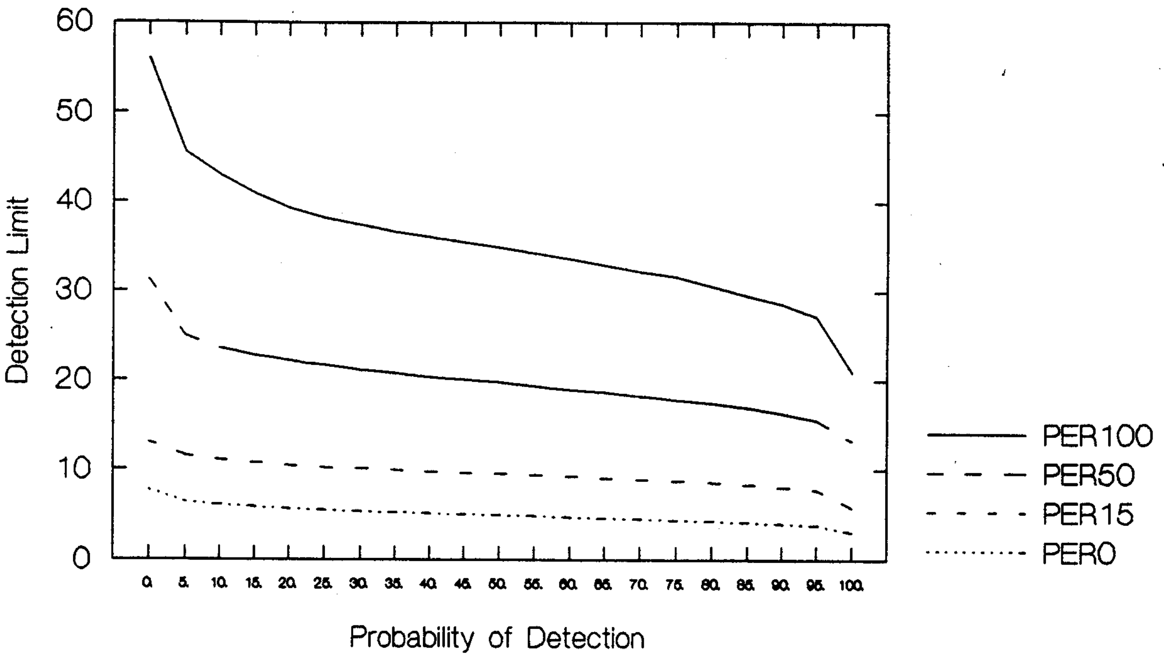


Figure B-37. Required detection limits for contaminant (low variation) to base (low variation) concentration ratio of 7 (5L-35L).

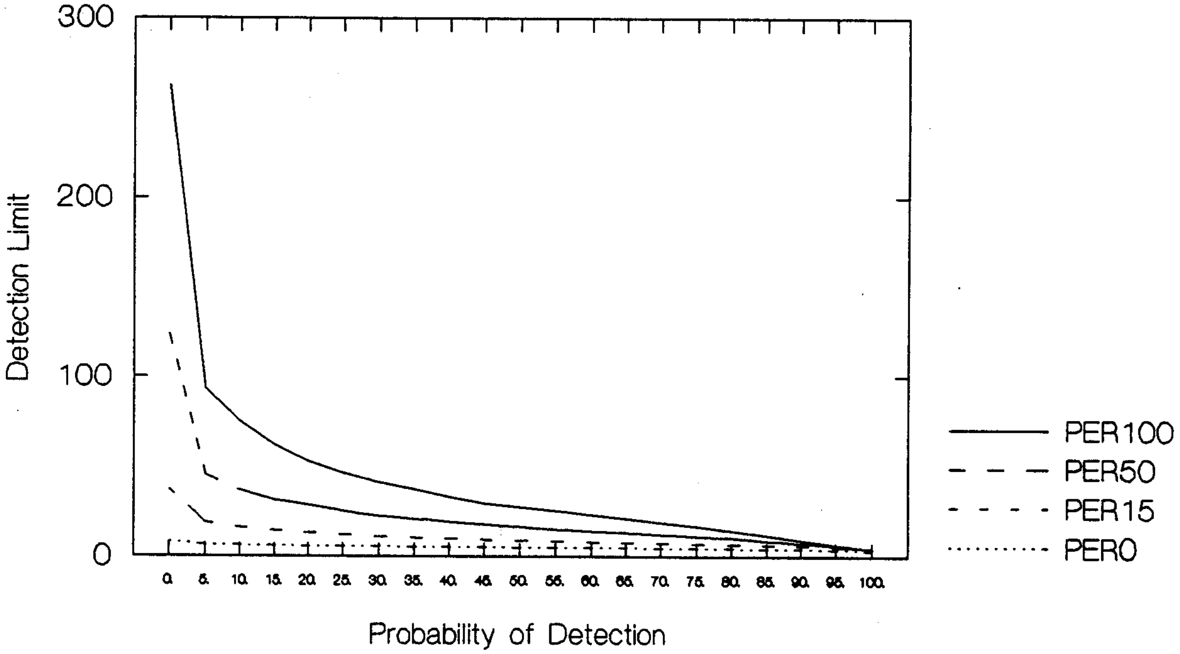


Figure B-38. Required detection limits for contaminant (low variation) to base (medium variation) concentration ratio of 7 (5L-35M).

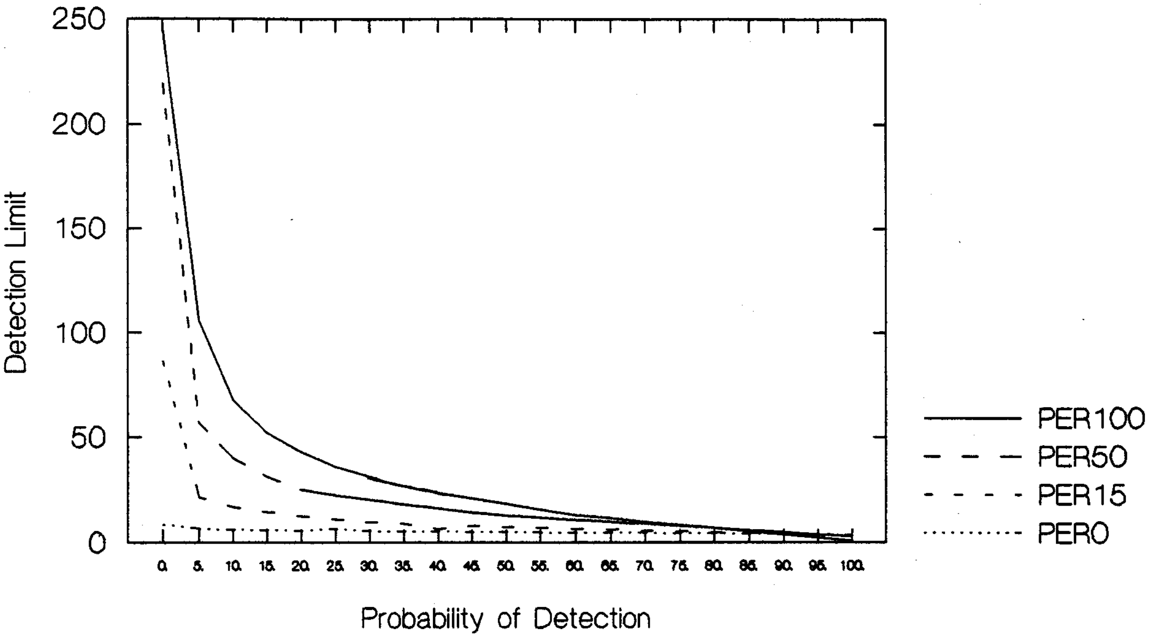


Figure B-39. Required detection limits for contaminant (low variation) to base (high variation) concentration ratio of 7 (5L-35H).

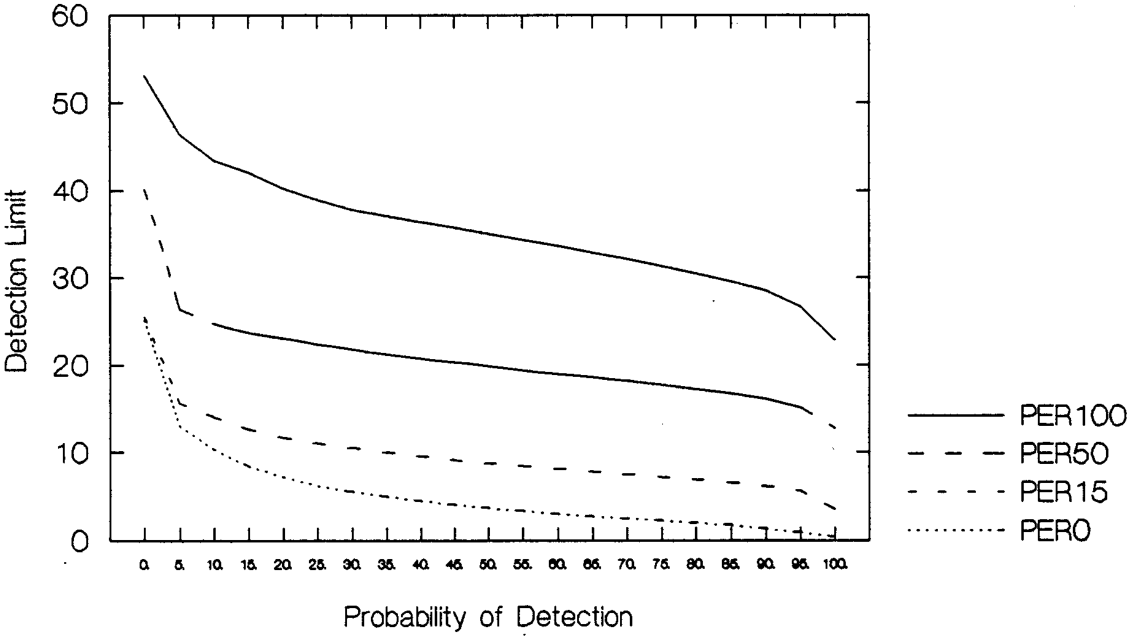


Figure B-40. Required detection limits for contaminant (medium variation) to base (low variation) concentration ratio of 7 (5M-35L).

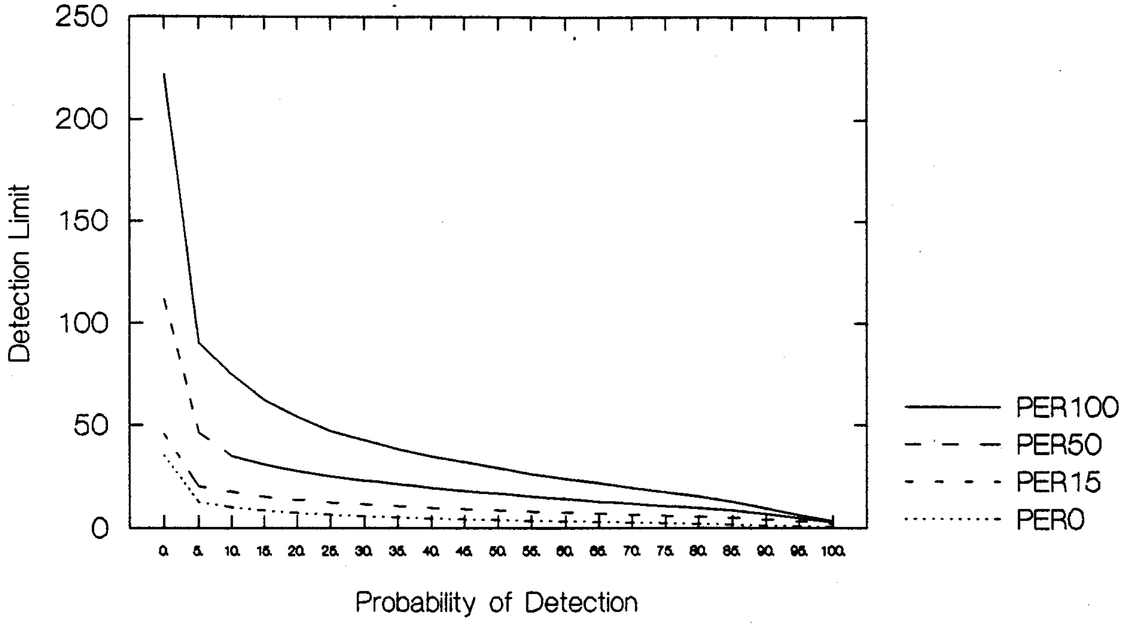


Figure B-41. Required detection limits for contaminant (medium variation) to base (medium variation) concentration ratio of 7 (5M-35M).

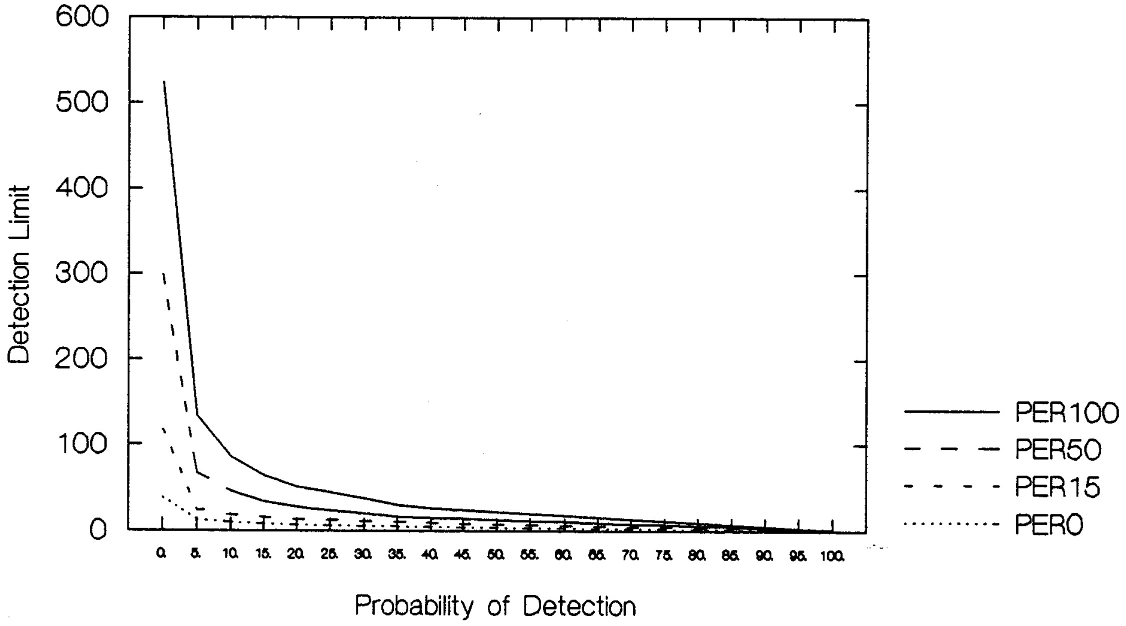


Figure B-42. Required detection limits for contaminant (medium variation) to base (high variation) concentration ratio of 7 (5M-35H).

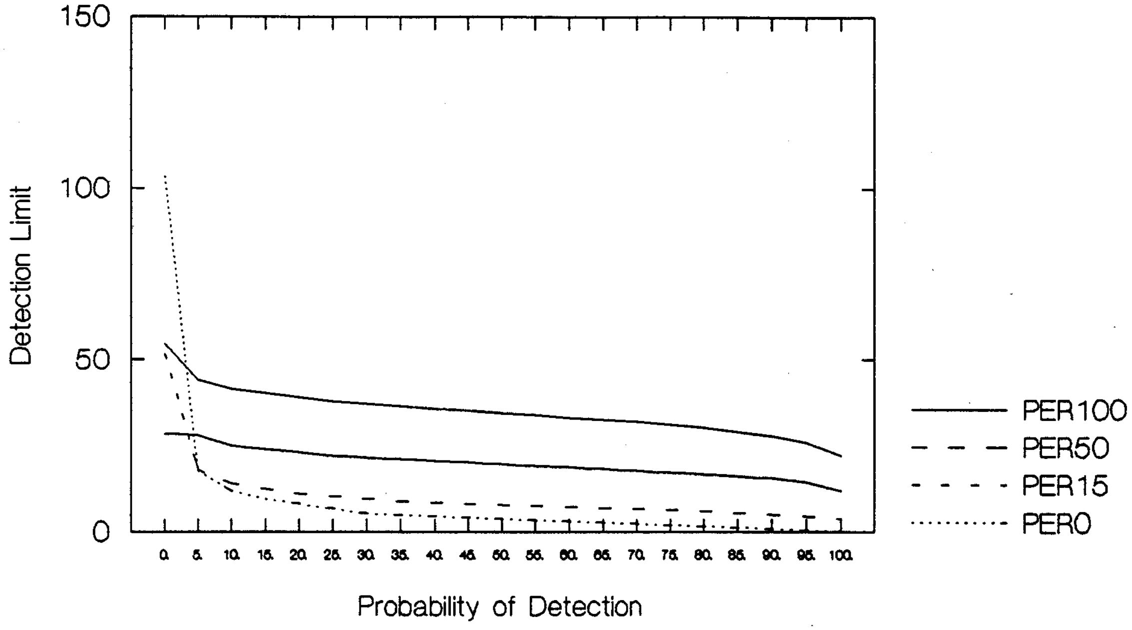


Figure B-43. Required detection limits for contaminant (high variation) to base (low variation) concentration ratio of 7 (5H-35L).

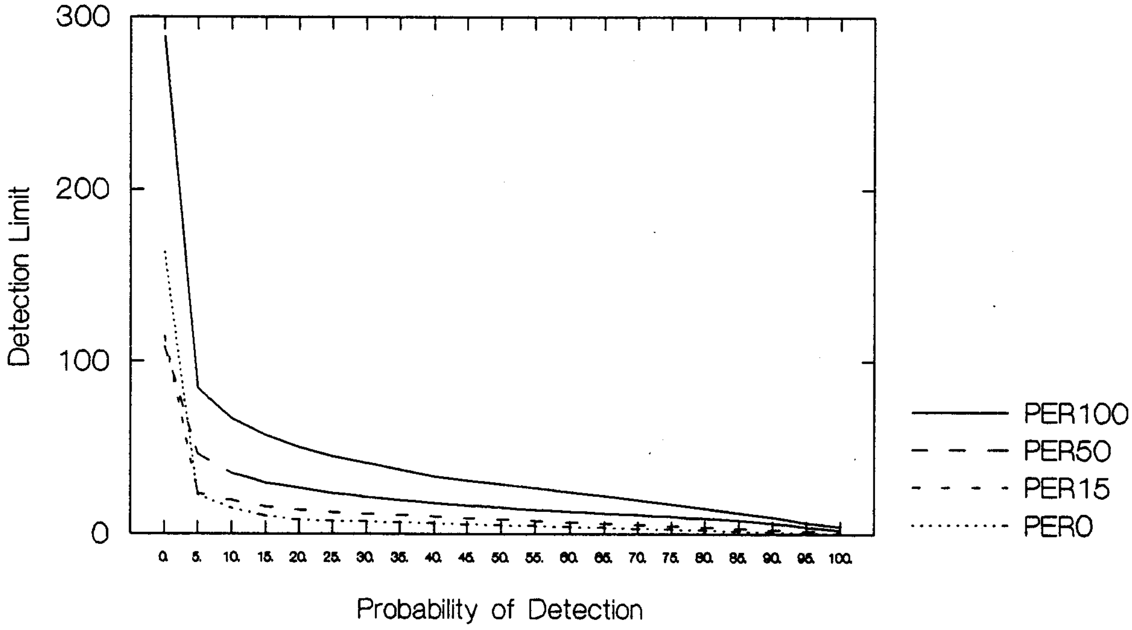


Figure B-44. Required detection limits for contaminant (high variation) to base (medium variation) concentration ratio of 7 (5H-35M).

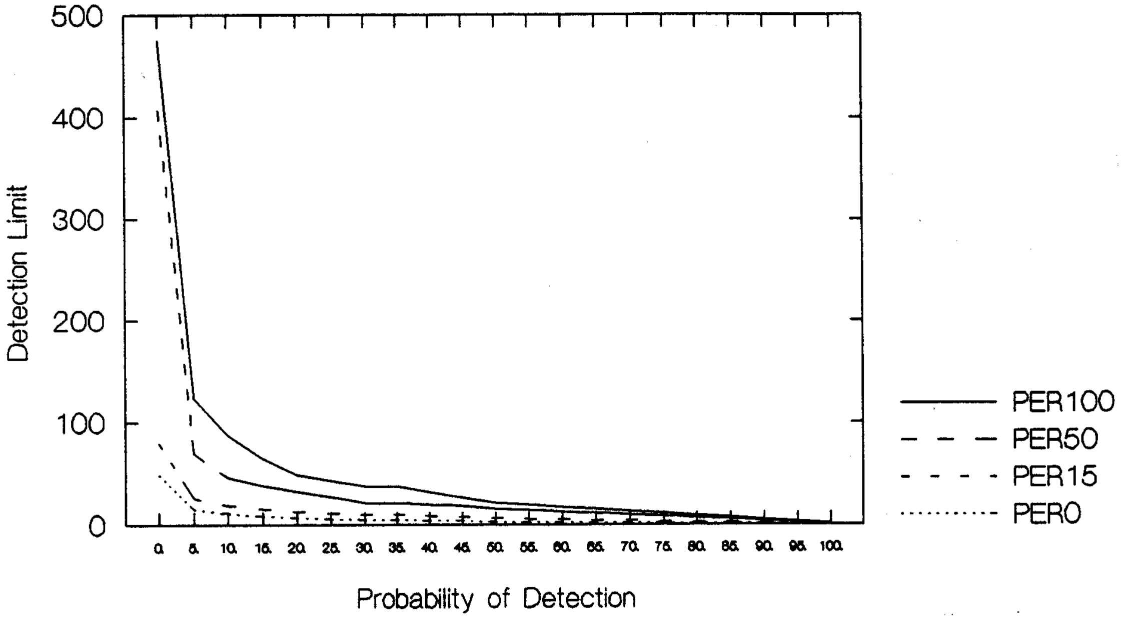


Figure B-45. Required detection limits for contaminant (high variation) to base (high variation) concentration ratio of 7 (5H-35H).

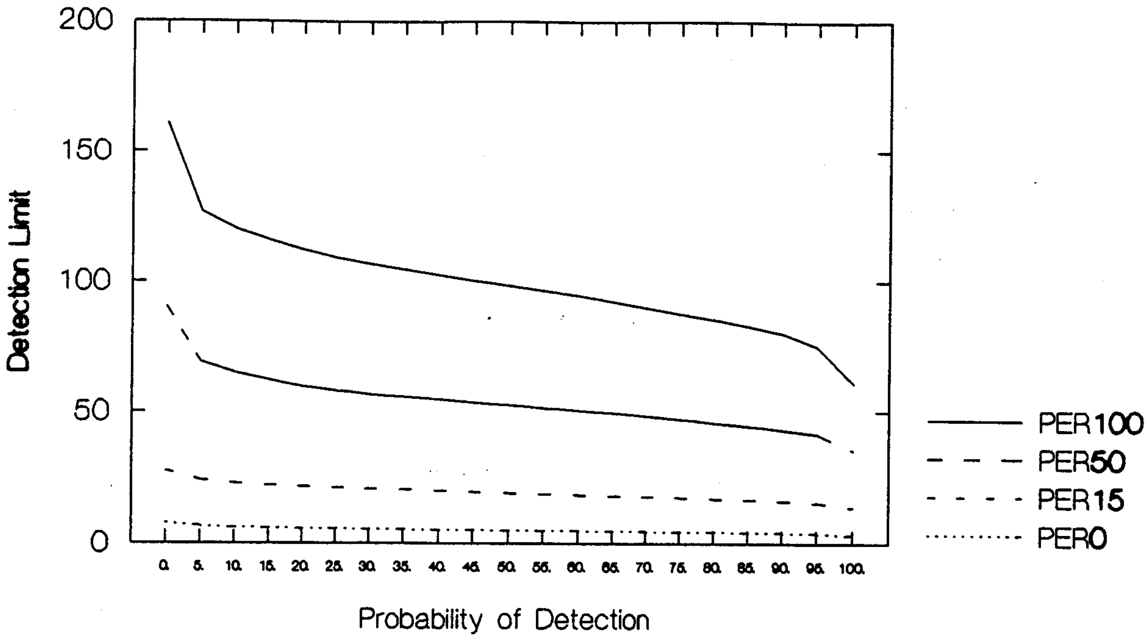


Figure B-46. Required detection limits for contaminant (low variation) to base (low variation) concentration ratio of 20 (5L-100L).

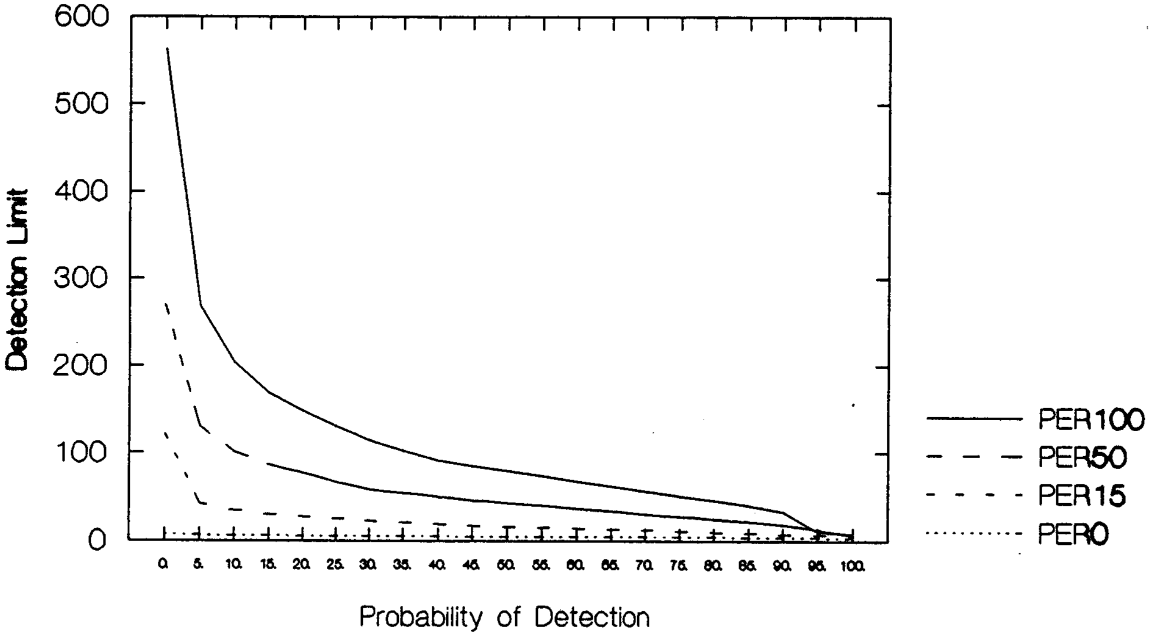


Figure B-47. Required detection limits for contaminant (low variation) to base (medium variation) concentration ratio of 20 (5L-100M).

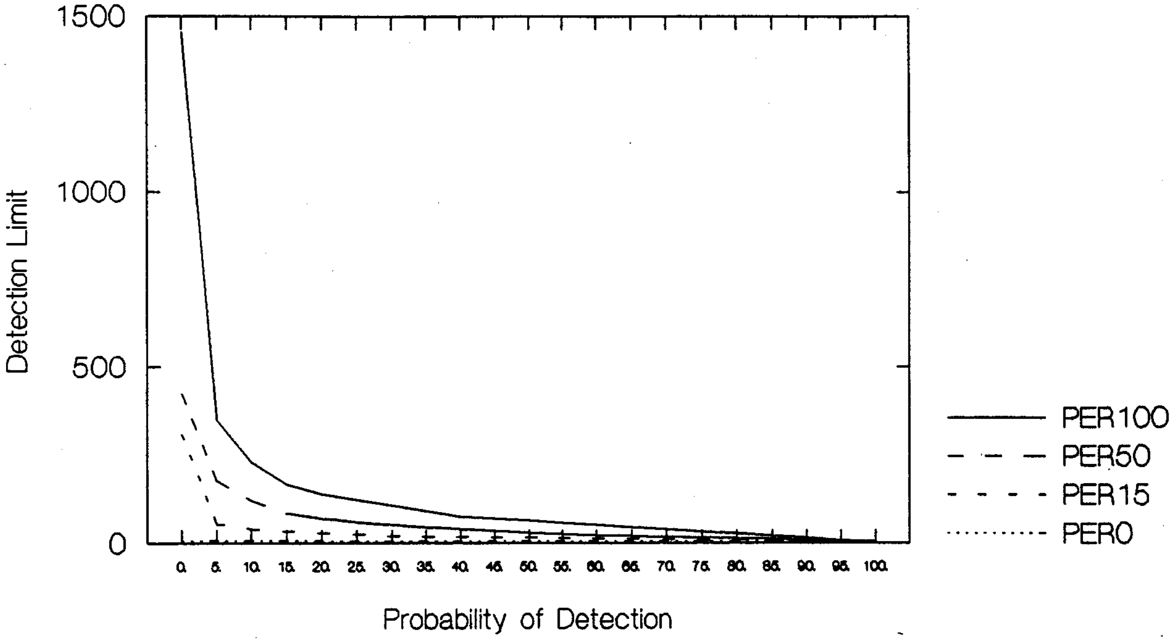


Figure B-48. Required detection limits for contaminant (low variation) to base (high variation) concentration ratio of 20 (5L-100H).

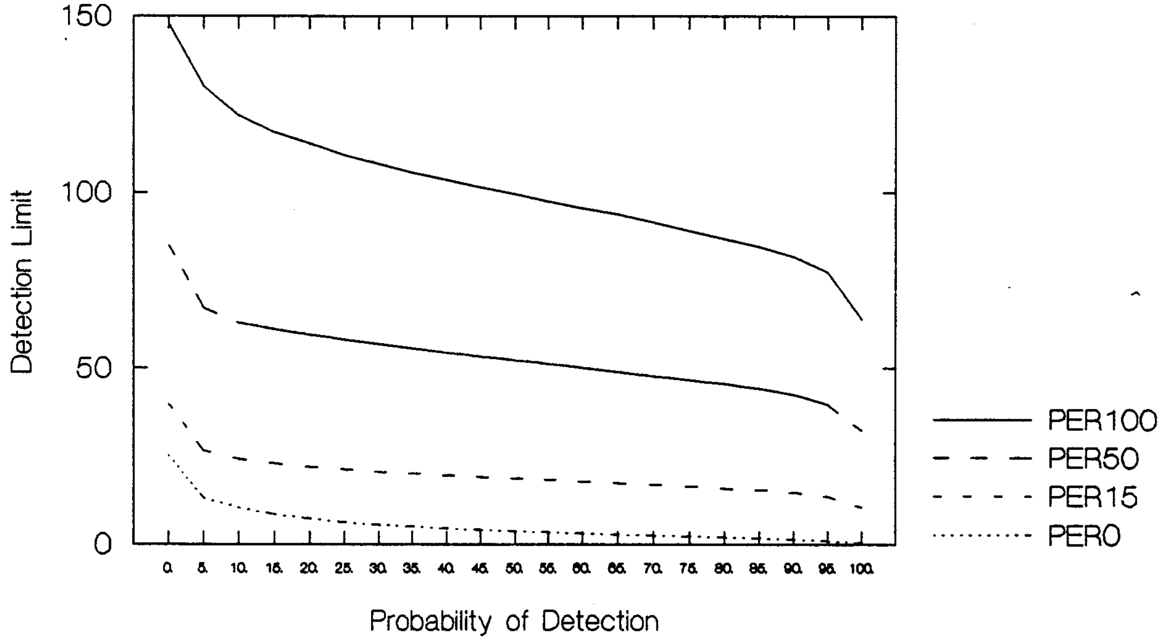


Figure B-49. Required detection limits for contaminant (medium variation) to base (low variation) concentration ratio of 20 (5M-100L).

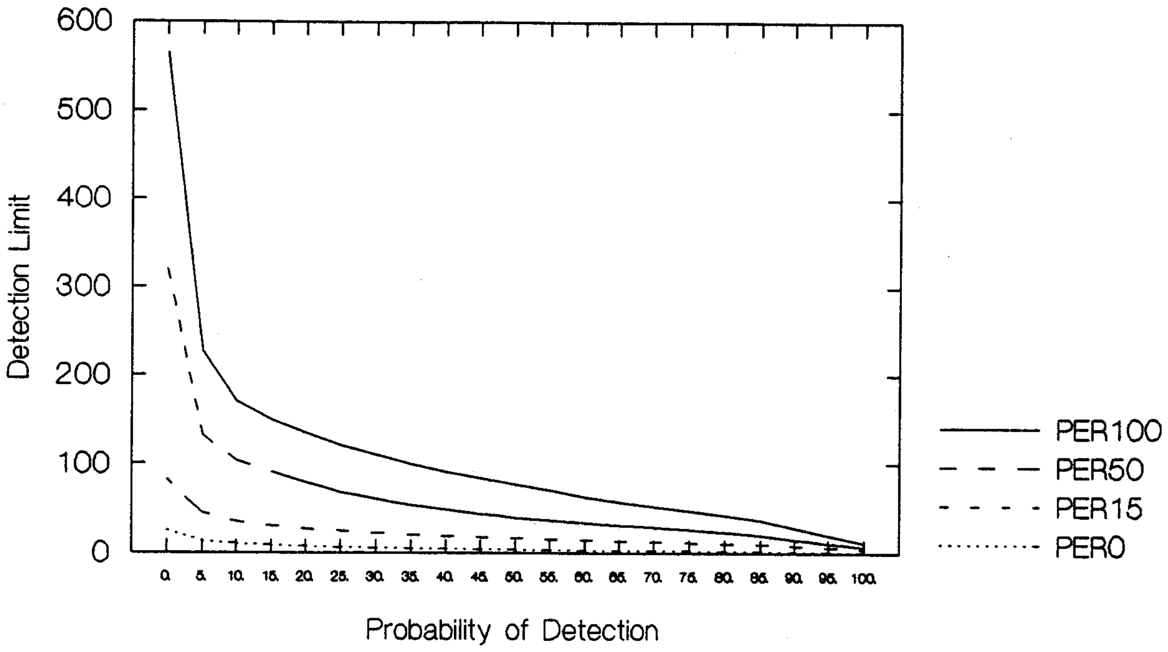


Figure B-50. Required detection limits for contaminant (medium variation) to base (medium variation) concentration ratio of 20 (5M-100M).

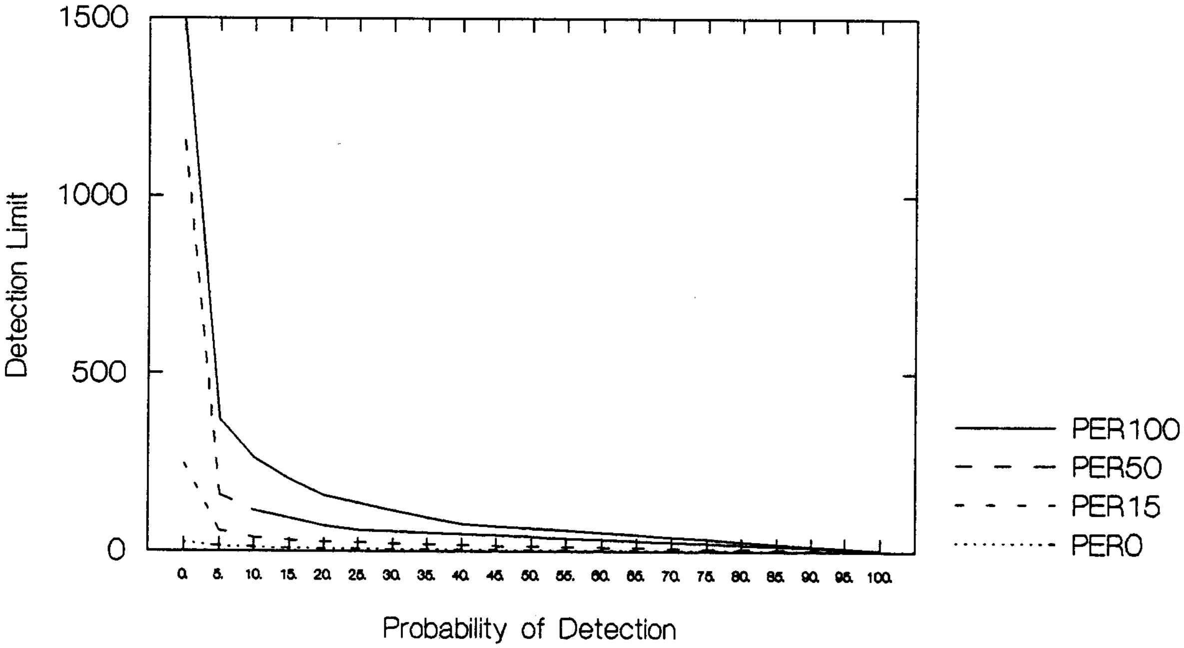


Figure B-51. Required detection limits for contaminant (medium variation) to base (high variation) concentration ratio of 20 (5M-100H).

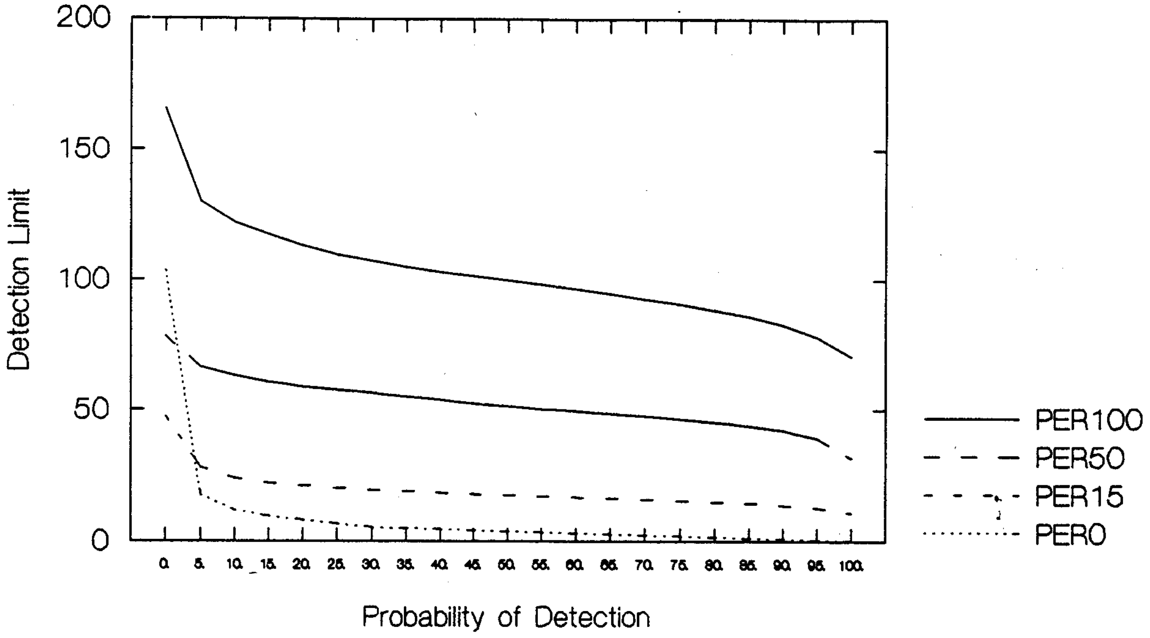


Figure B-52. Required detection limits for contaminant (high variation) to base (low variation) concentration ratio of 20 (5H-100L).

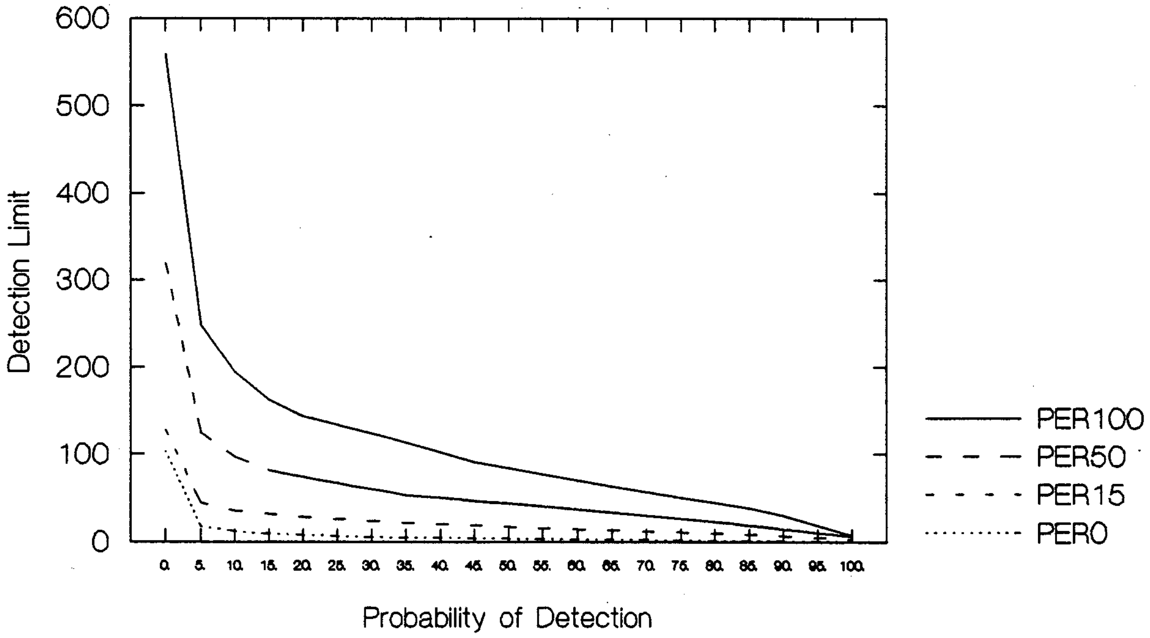


Figure B-53. Required detection limits for contaminant (high variation) to base (medium variation) concentration ratio of 20 (5H-100M).

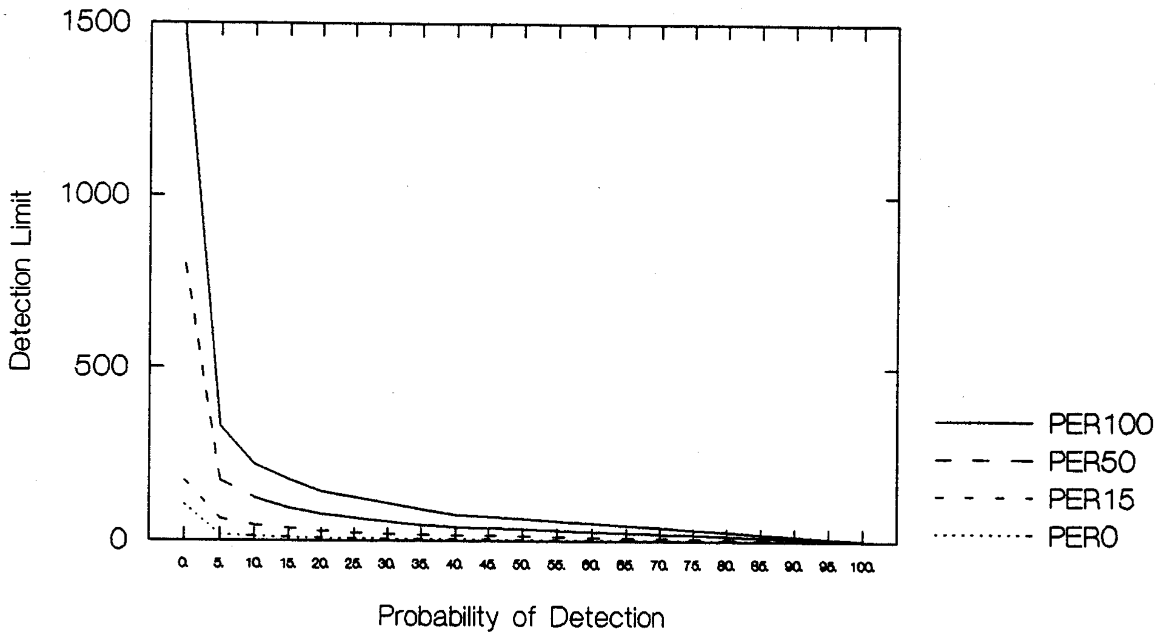


Figure B-54. Required detection limits for contaminant (high variation) to base (high variation) concentration ratio of 20 (5H-100H).

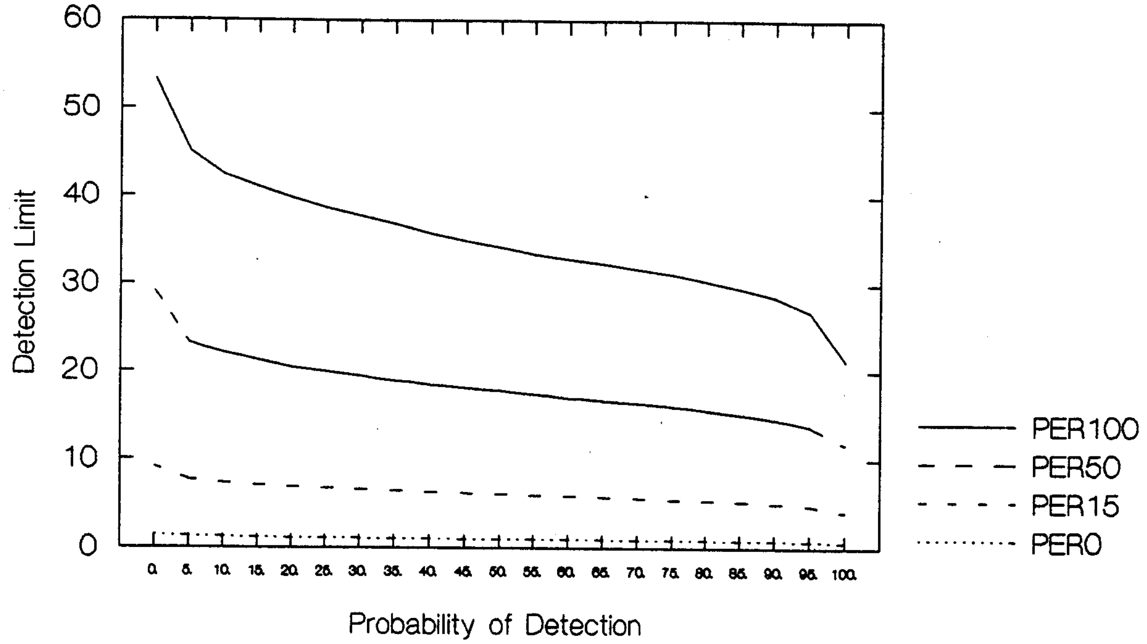


Figure B-55. Required detection limits for contaminant (low variation) to base (low variation) concentration ratio of 35 (1L-35L).

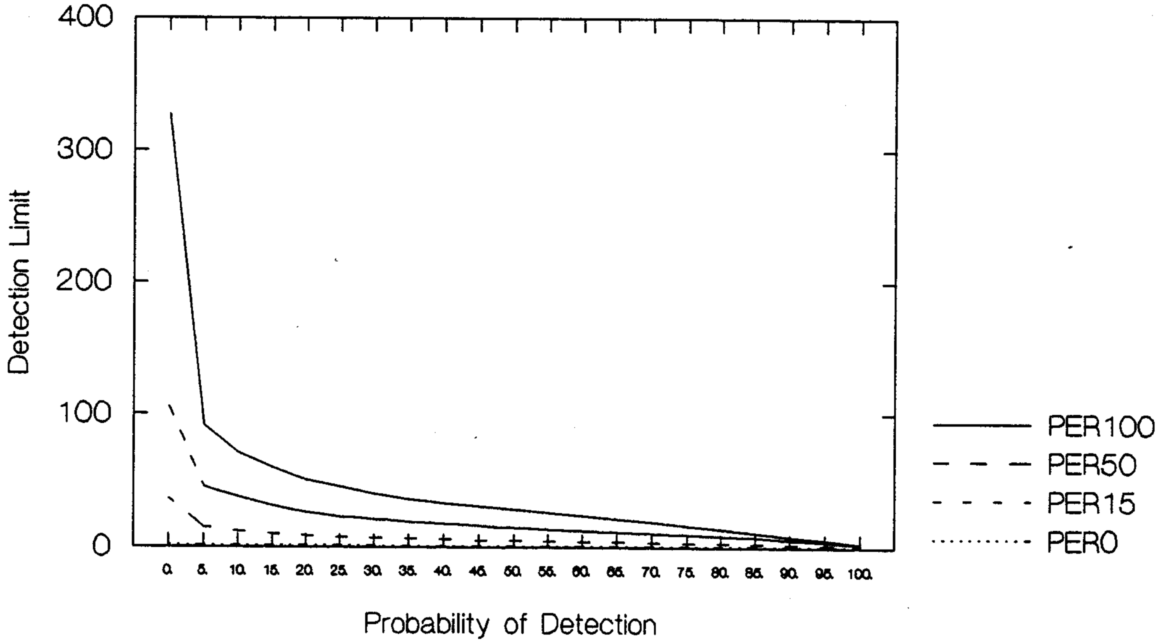


Figure B-56. Required detection limits for contaminant (low variation) to base (medium variation) concentration ratio of 35 (1L-35M).

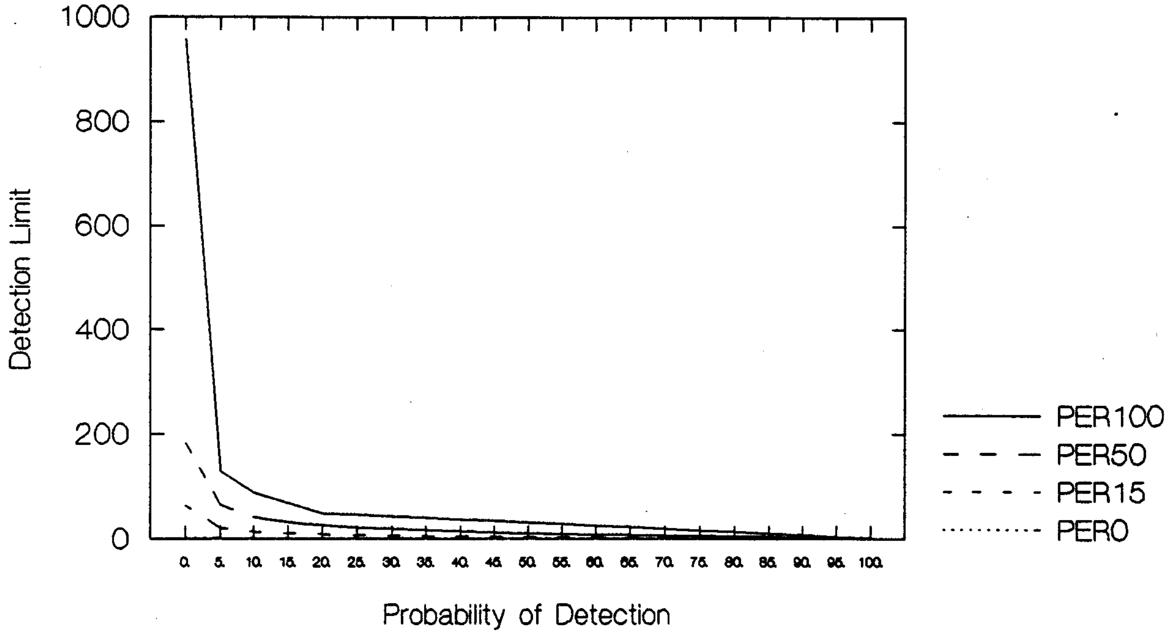


Figure B-57. Required detection limits for contaminant (low variation) to base (high variation) concentration ratio of 35 (1L-35H).

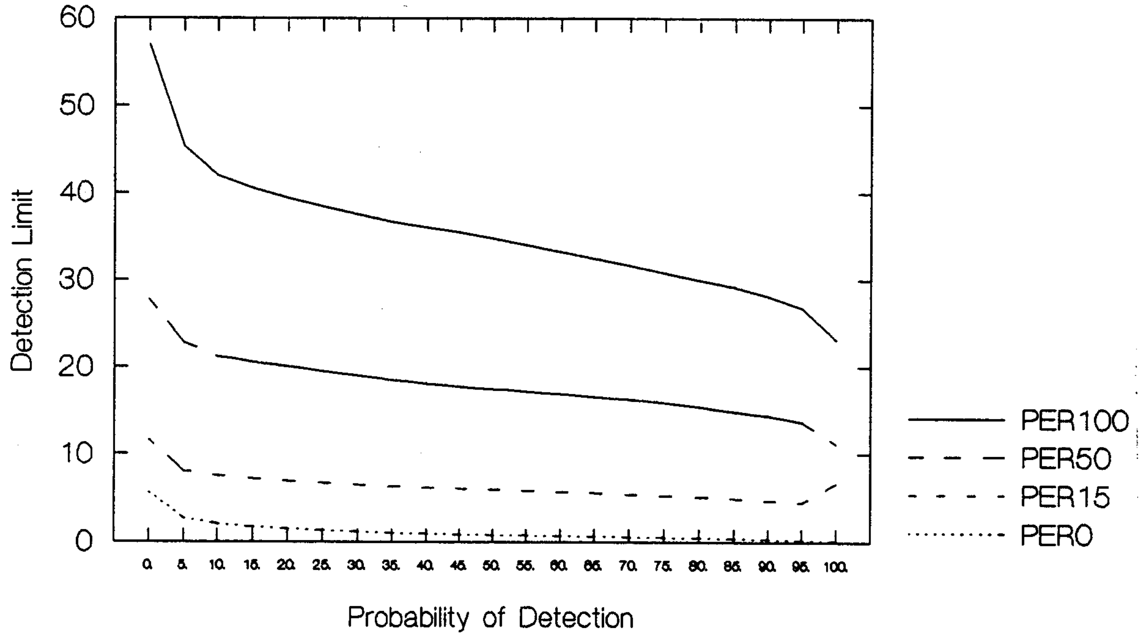


Figure B-58. Required detection limits for contaminant (medium variation) to base (low variation) concentration ratio of 35 (1M-35L).

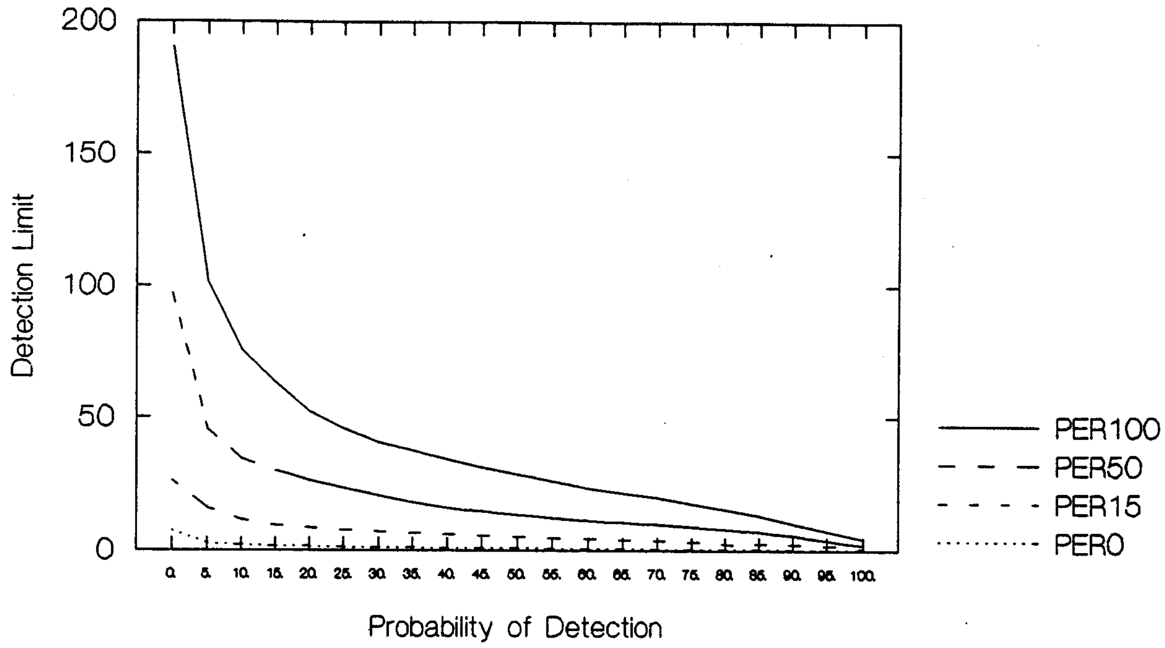


Figure B-59. Required detection limits for contaminant (medium variation) to base (medium variation) concentration ratio of 35 (1M-35M).

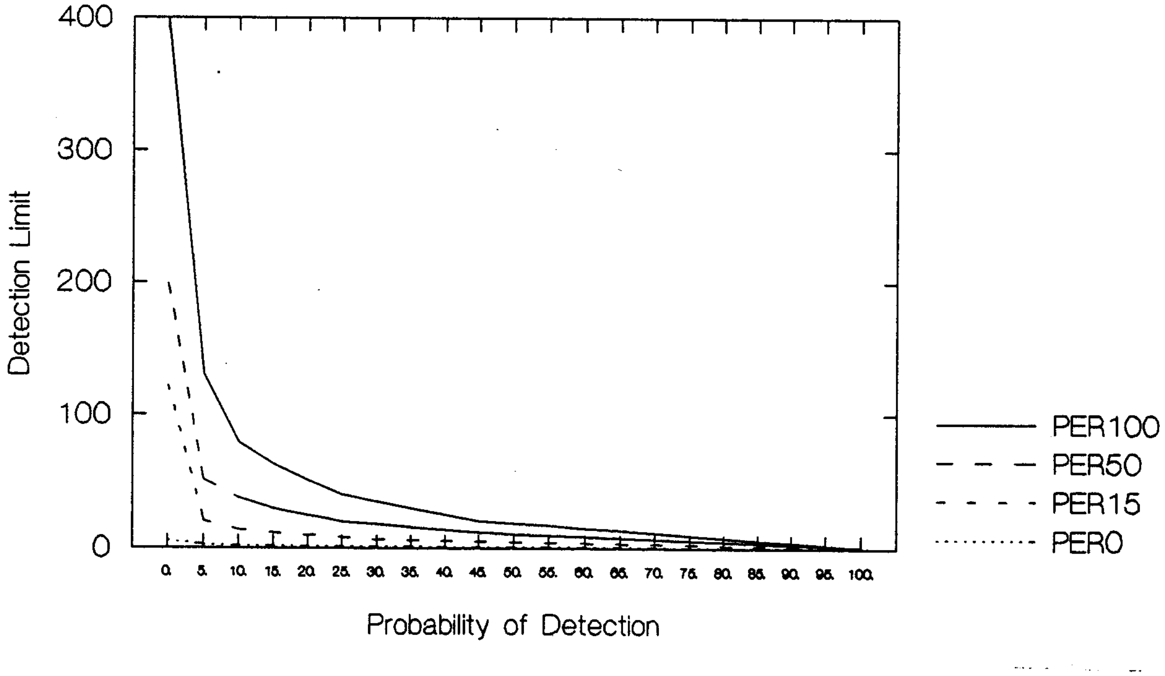


Figure B-60. Required detection limits for contaminant (medium variation) to base (high variation) concentration ratio of 35 (1M-35H).

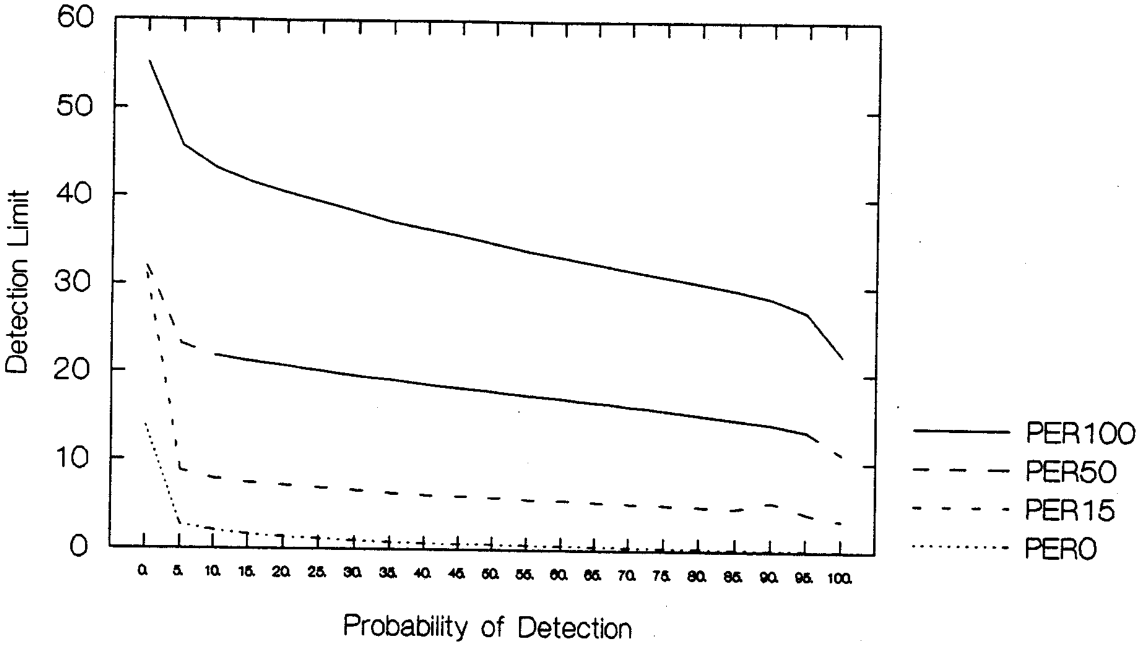


Figure B-61. Required detection limits for contaminant (high variation) to base (low variation) concentration ratio of 35 (1H-35L).

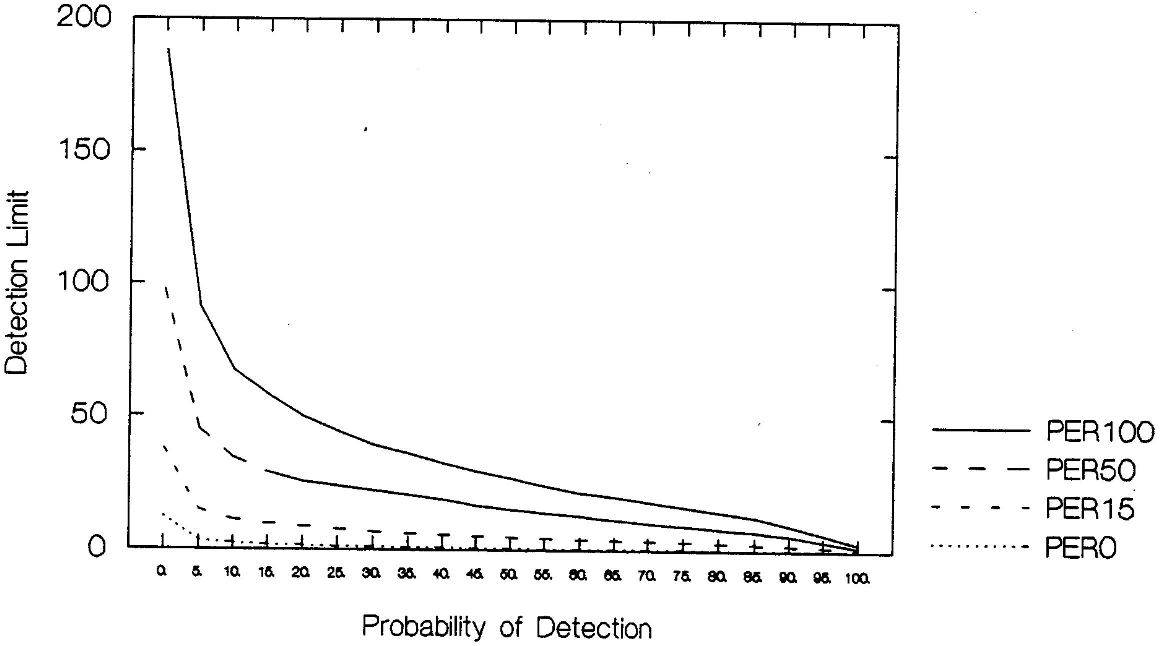


Figure B-62. Required detection limits for contaminant (high variation) to base (medium variation) concentration ratio of 35 (1H-35M).

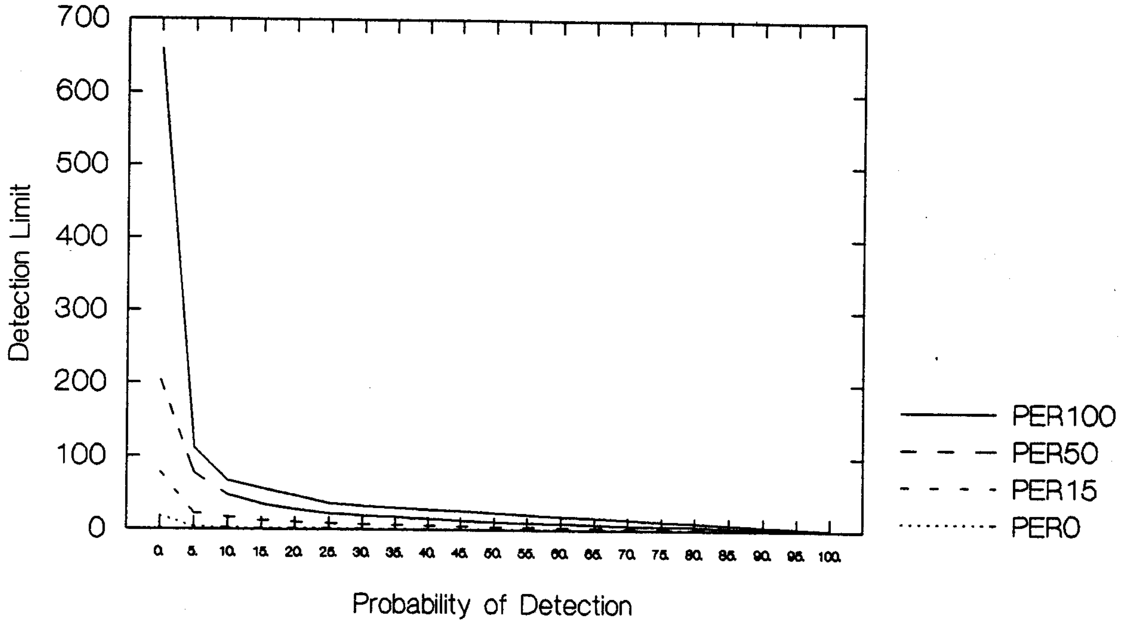


Figure B-63. Required detection limits for contaminant (high variation) to base (high variation) concentration ratio of 35 (1H-35H).

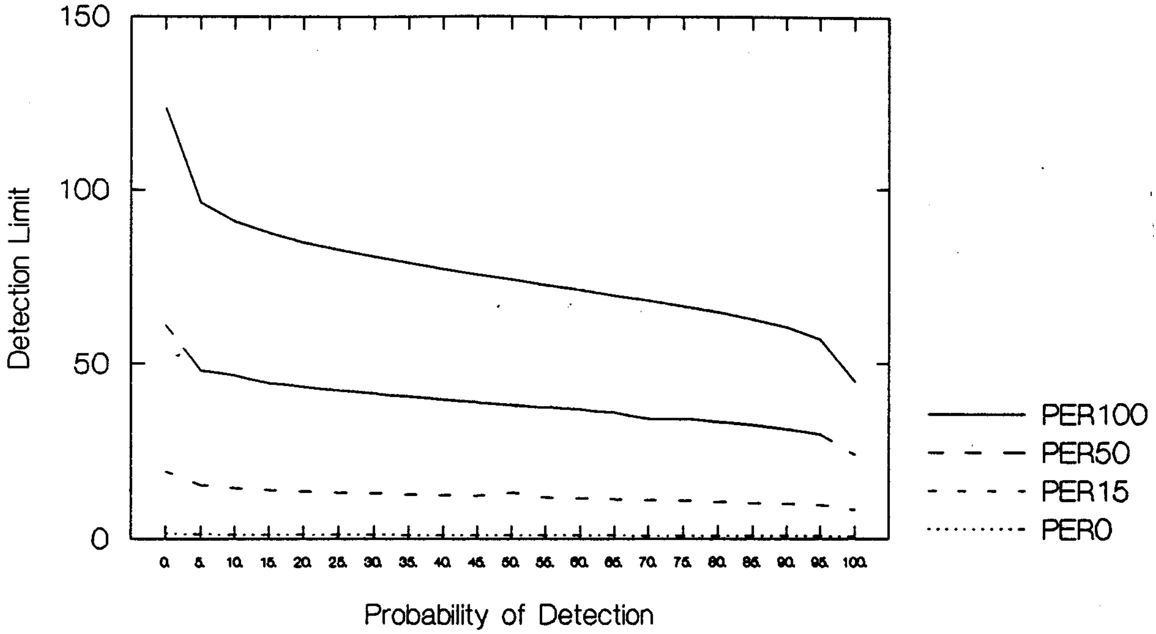


Figure B-64. Required detection limits for contaminant (low variation) to base (low variation) concentration ratio of 75 (1L-75L).

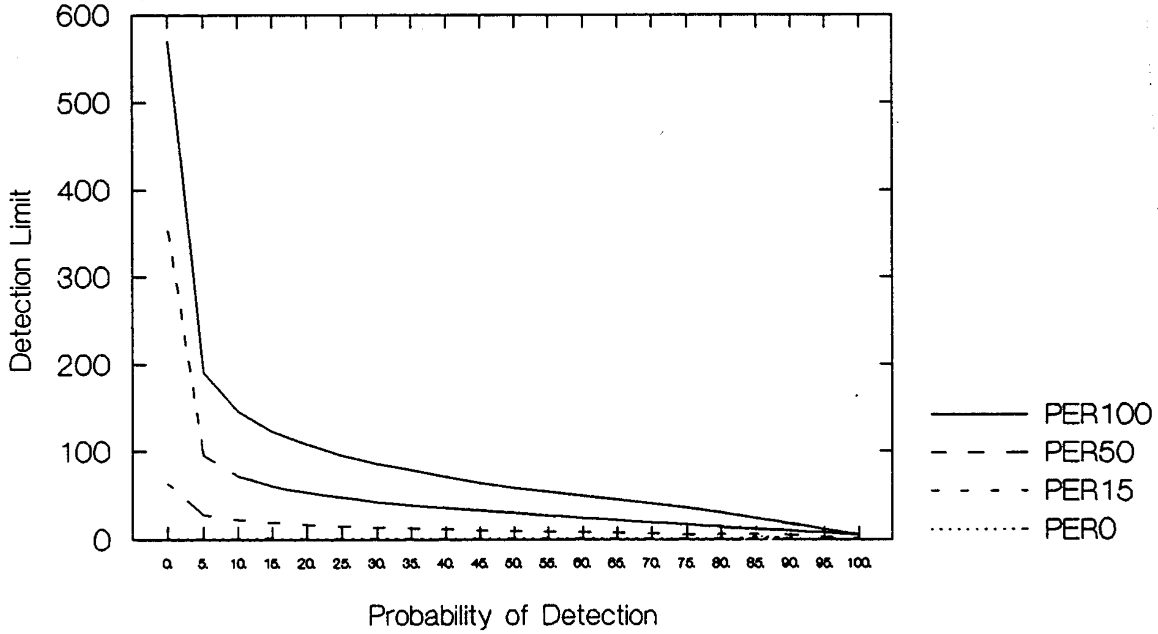


Figure B-65. Required detection limits for contaminant (low variation) to base (medium variation) concentration ratio of 75 (1L-75M).

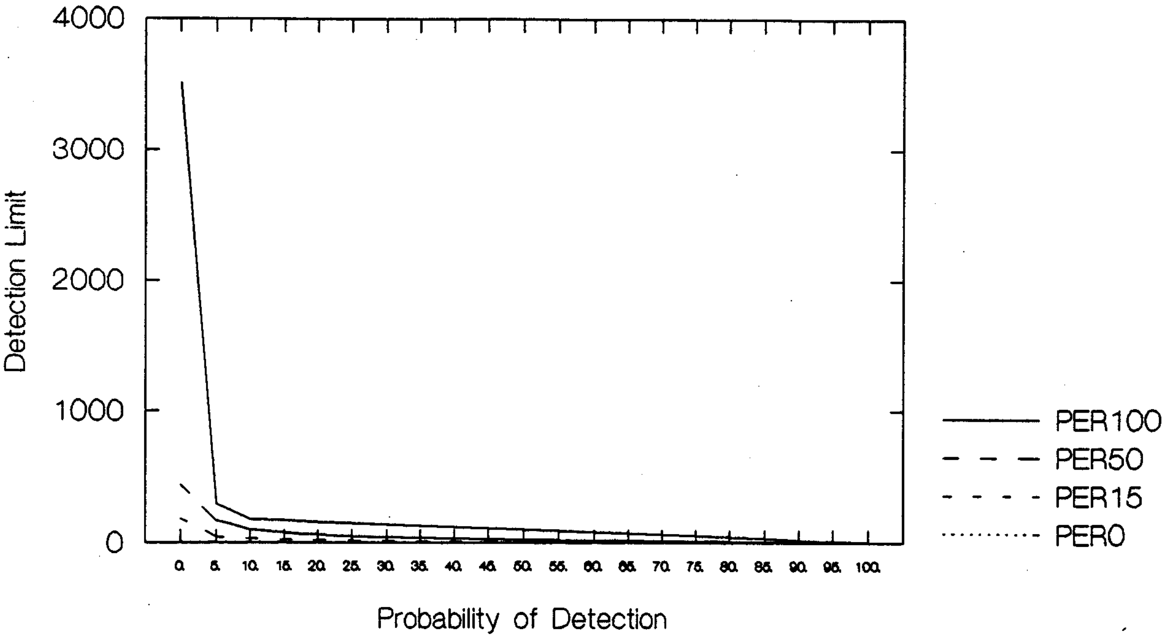


Figure B-66. Required detection limits for contaminant (low variation) to base (high variation) concentration ratio of 75 (1L-75H).

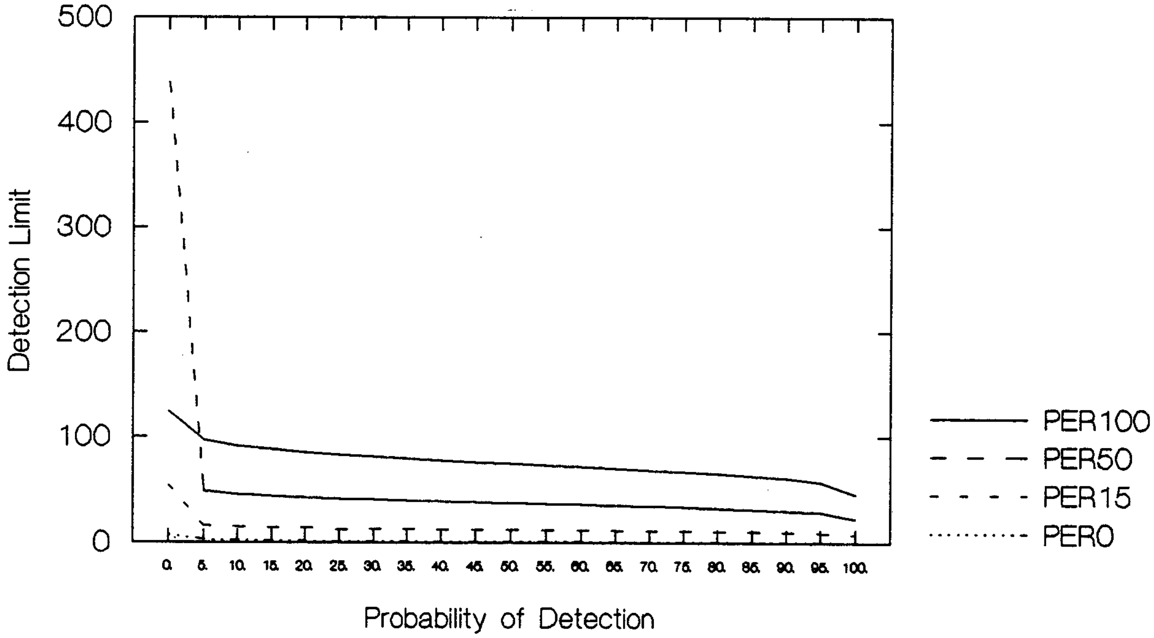


Figure B-67. Required detection limits for contaminant (medium variation) to base (low variation) concentration ratio of 75 (1M-75L).

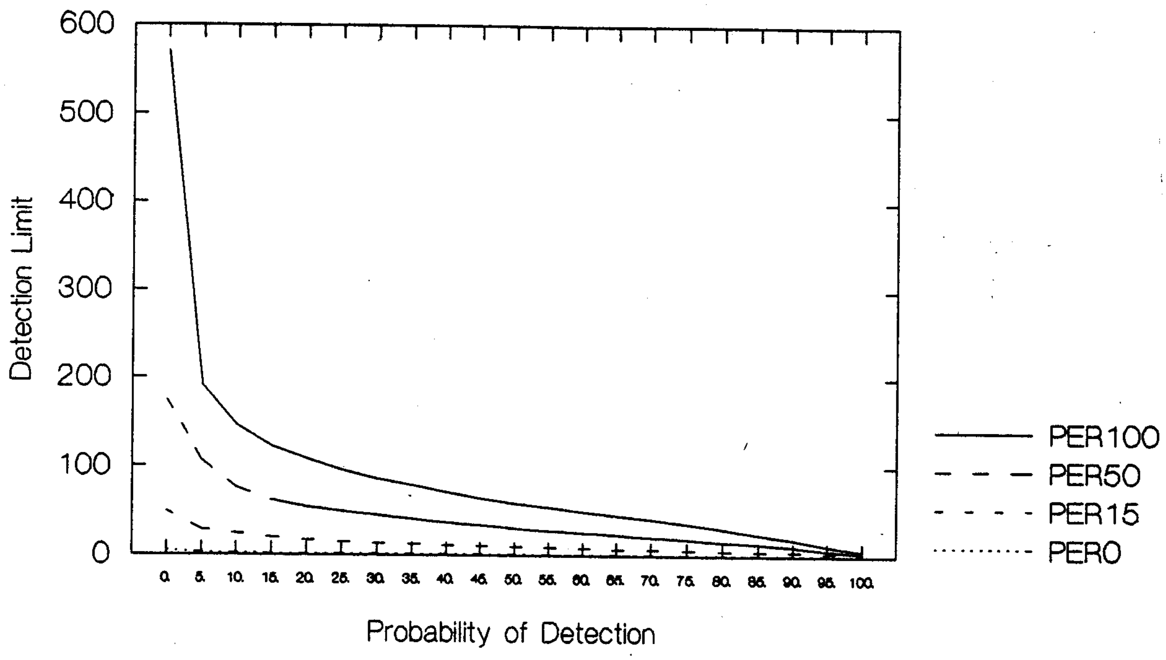


Figure B-68. Required detection limits for contaminant (medium variation) to base (medium variation) concentration ratio of 75 (1M-75M).

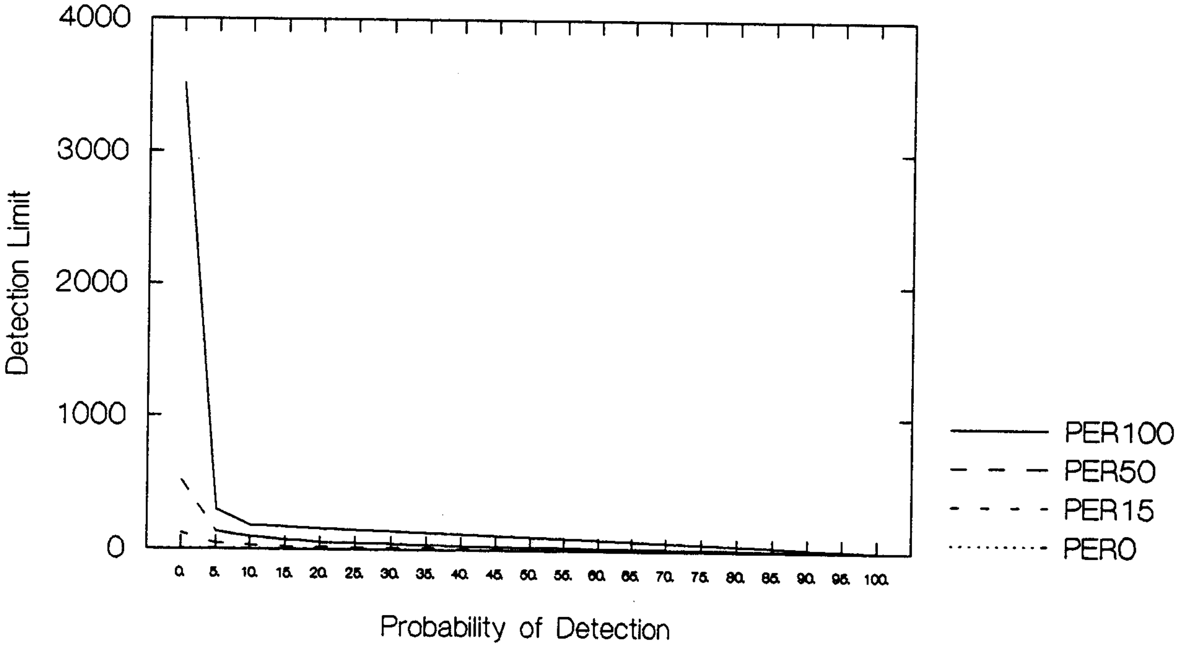


Figure B-69. Required detection limits for contaminant (medium variation) to base (high variation) concentration ratio of 75 (1M-75H).

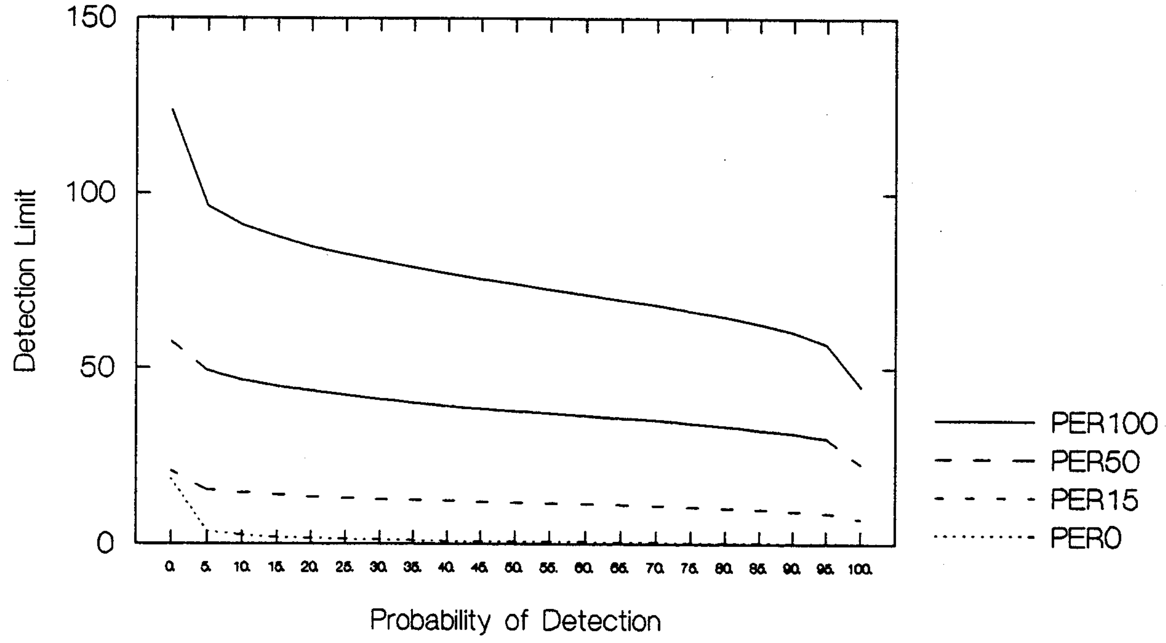


Figure B-70. Required detection limits for contaminant (high variation) to base (low variation) concentration ratio of 75 (1H-75L).

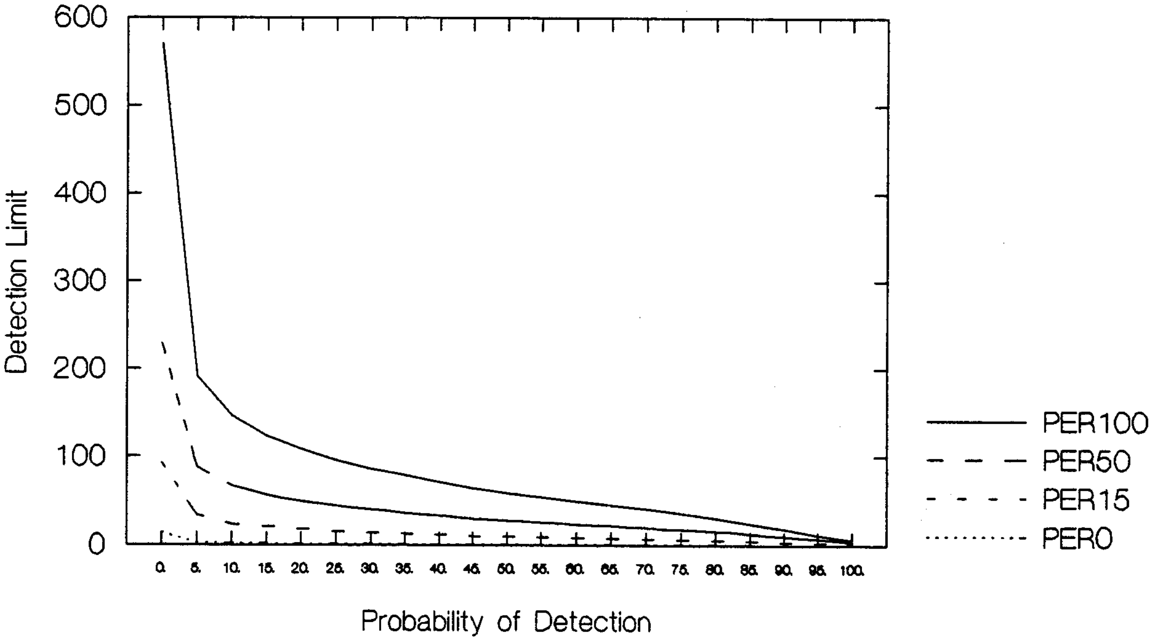


Figure B-71. Required detection limits for contaminant (high variation) to base (medium variation) concentration ratio of 75 (1H-75M).

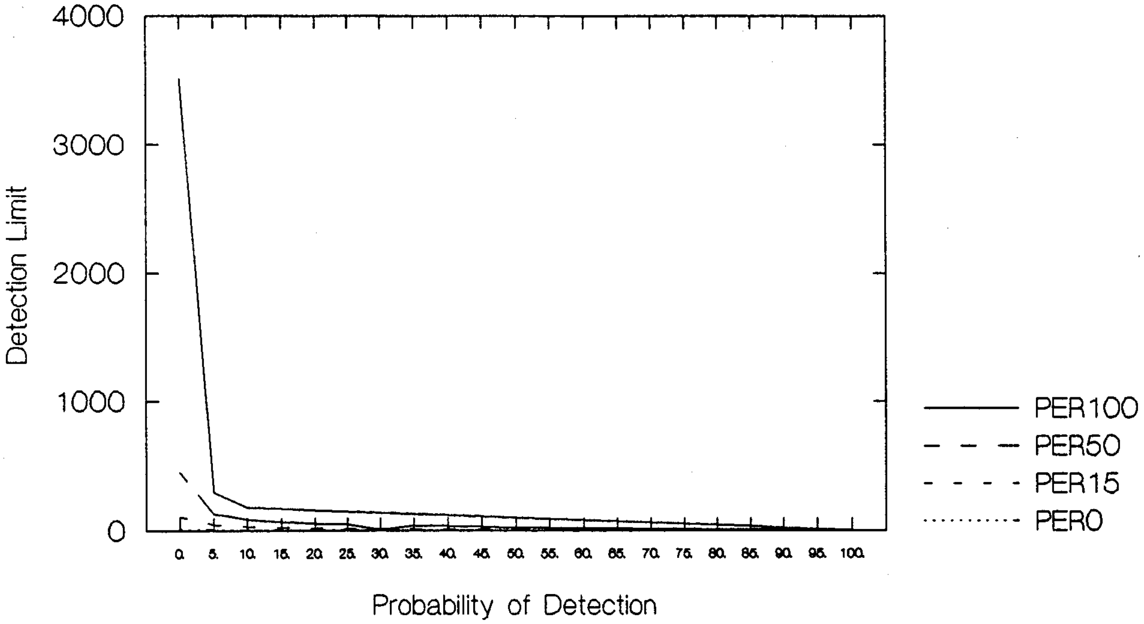


Figure B-72. Required detection limits for contaminant (high variation) to base (high variation) concentration ratio of 75 (1H-75H).

Appendix C
Case Studies of Non-Stormwater Discharges into Separate Storm Sewer Systems

Introduction

Many different local and regional units of government have investigated local problems associated with non-stormwater discharges into storm drainage systems. This appendix summarizes several case studies that have been conducted in various locations in North America. This information has been very useful in developing the strategy presented earlier in this report. Other local studies were also reviewed, and referenced, during the development of this report.

Allen Creek Drain, Ann Arbor, Michigan

Agency

Washtenaw County Health Department, Washtenaw County Drain Commissioner. Director of Environmental Health, P.O. Box 8647, Ann Arbor, Michigan, 48107.

Initial Alert to Problem

Several surveys, beginning as early as 1963, identified bacterial and chemical contamination of the Allen Creek storm drainage system. Studies in 1963, 1978 and 1979 found that discharges from the Allen Creek storm drain contained significant quantities of fecal coliform and fecal streptococci. The 1979 study also documented high pollutant loads of solids, nitrates and metals.

Nature of Non-Stormwater Contamination

A large number of inappropriate storm drain connections originating from businesses were found, especially within automobile related facilities. Chemical pollutants, such as detergents, oil, grease, radiator wastes and solvents were causing potential problems. Sanitary sewage was not found to be as large of a problem as originally thought.

Procedures Employed to Identify Contaminant Sources

A four phase plan was developed to identify sources of contamination resulting from inappropriate storm sewer connections.

Phase 1: Comprehensive Drain Survey--

The main stem and accessible lateral branches of the storm drainage system were surveyed by County personnel. This survey was to identify the origin of suspicious connections to the storm drain that were causing the continuous dry-weather discharges found by consultants during the 1970's. The resulting list of suspicious connections provided target areas for future investigations.

Phase 2: Intensive Bacteriological Study--

The main stem, major lateral branches and the outfall of the storm drainage system were sampled weekly over a nine month period for fecal coliform and fecal streptococci bacteria in an effort to locate areas where the expected sanitary sewage was entering the storm drain. A large number of sampling locations were used in order to better isolate individual source locations and to minimize the effects of dilution on bacteria concentrations.

Phase 3: Priority I Business Survey and Dye-Testing Program--
Priority I businesses were designated as those directly involved with the storage and/or use of petroleum products. A letter explaining the pollution control project was mailed to each business owner/manager (see Attachment C-1). County personnel then visited each individual business in an effort to determine the type, use, storage and disposal of petroleum products and other hazardous chemicals and whether plumbing fixtures and floor drains showed any signs of chemicals being discharged into storm drains. A standardized survey form was used to record this information and a rough sketch of the facility was also made (See Attachment C-2).

Survey results formed the basis for dye-testing priorities. Liquid or powdered fluorescent tracing dyes were used for the dye-tests so that wastewater would be brightly colored and easily distinguished. Observers located at the closest accessible storm drain and sanitary sewer manholes recorded the destination of the colored wastewater from each individual floor drain and plumbing fixture.

Phase 4: Priority II Business Survey and Dye-Testing Program--
Businesses designated as Priority II were those indirectly involved with the use of petroleum products or directly involved with other types of potentially hazardous chemicals. Following the completion of Phase 3, Priority II businesses were surveyed and dye-tested in the manner described above.

Corrective Action

Letters describing the survey findings was sent to owners where storm drain connections were found, after the dye-testing of the businesses in priority groups I and II. The letter described the problem and identified the appropriate official to be consulted with regard to corrective action. As a follow-up, site meetings were held with business owners and inspections of corrections were performed as they were completed.

Of the 160 businesses dye-tested, 61 (38%) were found to have improper storm drain connections, very few of which were sanitary sewage. Ninety-two percent of these improper connections were corrected as of December 31, 1986. The elimination of these storm drain connections prevented thousands of gallons of contaminated water from entering the Huron River from the Allen Creek storm drainage system annually. Eight sampling locations along the main stem and major lateral branches of the storm drainage system were established and monitored for 37 chemicals during rain events. From 1984 to 1986, 32 (86%) of these chemicals showed a decrease in concentrations while only 2 (5%) showed an increase. In spite of this improvement, chemical concentrations in wastewater at the Allen Creek outfall were still greater than those from the control station much of the time.

Discussion

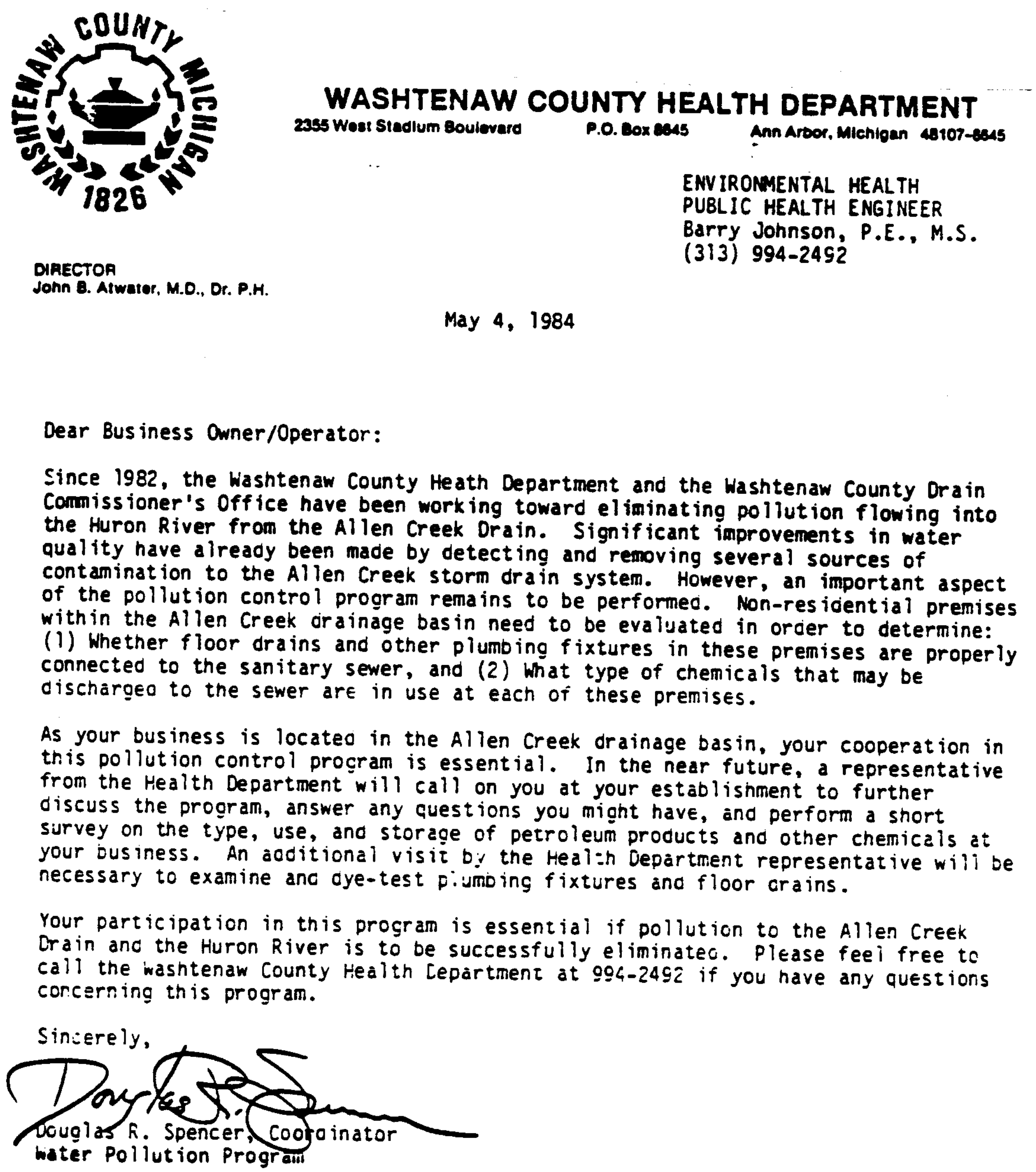
Due in part to information obtained during this project, the Huron River Pollution Abatement District was established on January 1, 1987. This effort enlists the support of Ann Arbor and Ypsilanti as well as all of Washtenaw County in a five year program (The Huron River Pollution Abatement Program) to limit the impact of non-point source pollution on the district's water quality.

References

Schmidt, Stacy D. and Douglas R. Spencer. “The Magnitude of Improper Waste Discharges in an Urban Stormwater System”, *Journal Water Pollution Control Federation*, July 1986.

Washtenaw County Drain Commissioner and Washtenaw County Health Department. *Allen Creek Drain Water Quality Survey* - Status Report. September 1984.

Washtenaw County Statutory Drainage Board. *Huron River Pollution Abatement Program*. September 1987.



WASHTENAW COUNTY HEALTH DEPARTMENT
2355 West Stadium Boulevard P.O. Box 8645 Ann Arbor, Michigan 48107-8645

ENVIRONMENTAL HEALTH
PUBLIC HEALTH ENGINEER
Barry Johnson, P.E., M.S.
(313) 994-2492

DIRECTOR
John B. Atwater, M.D., Dr. P.H.

May 4, 1984

Dear Business Owner/Operator:

Since 1982, the Washtenaw County Heath Department and the Washtenaw County Drain Commissioner's Office have been working toward eliminating pollution flowing into the Huron River from the Allen Creek Drain. Significant improvements in water quality have already been made by detecting and removing several sources of contamination to the Allen Creek storm drain system. However, an important aspect of the pollution control program remains to be performed. Non-residential premises within the Allen Creek drainage basin need to be evaluated in order to determine: (1) Whether floor drains and other plumbing fixtures in these premises are properly connected to the sanitary sewer, and (2) What type of chemicals that may be discharged to the sewer are in use at each of these premises.

As your business is located in the Allen Creek drainage basin, your cooperation in this pollution control program is essential. In the near future, a representative from the Health Department will call on you at your establishment to further discuss the program, answer any questions you might have, and perform a short survey on the type, use, and storage of petroleum products and other chemicals at your business. An additional visit by the Health Department representative will be necessary to examine and dye-test plumbing fixtures and floor drains.

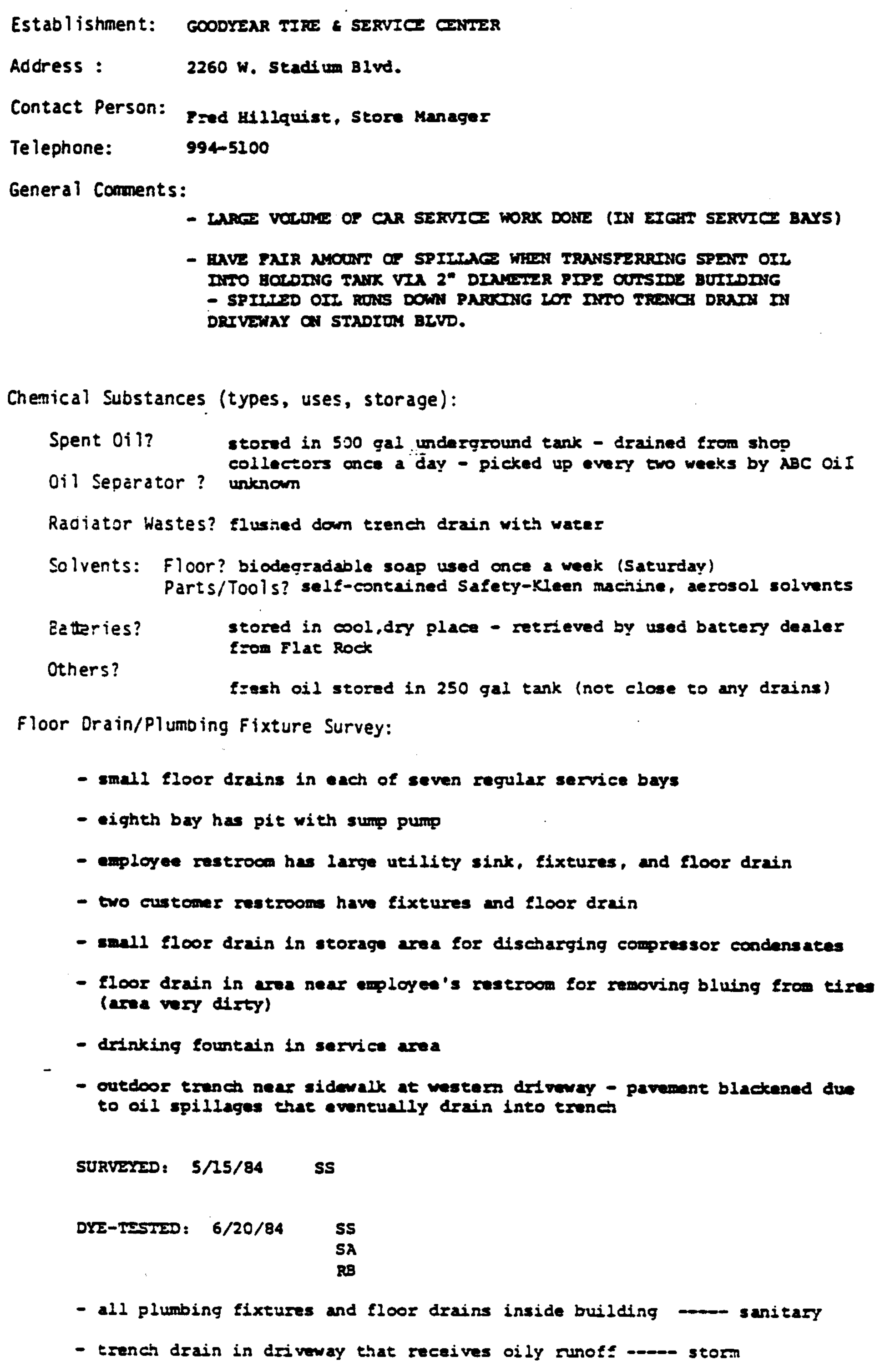
Your participation in this program is essential if pollution to the Allen Creek Drain and the Huron River is to be successfully eliminated. Please feel free to call the Washtenaw County Health Department at 994-2492 if you have any questions concerning this program.

Sincerely,

Douglas R. Spencer

Douglas R. Spencer, Coordinator
Water Pollution Program

Attachment C-1. Letter from Washtenhaw Co. Health Department to business operators explaining program.



Establishment: GOODYEAR TIRE & SERVICE CENTER

Address : 2260 W. Stadium Blvd.

Contact Person: Fred Hillquist, Store Manager

Telephone: 994-5100

General Comments:

- LARGE VOLUME OF CAR SERVICE WORK DONE (IN EIGHT SERVICE BAYS)
- HAVE FAIR AMOUNT OF SPILLAGE WHEN TRANSFERRING SPENT OIL INTO HOLDING TANK VIA 2" DIAMETER PIPE OUTSIDE BUILDING - SPILLED OIL RUNS DOWN PARKING LOT INTO TRENCH DRAIN IN DRIVEWAY ON STADIUM BLVD.

Chemical Substances (types, uses, storage):

Spent Oil? stored in 500 gal underground tank - drained from shop collectors once a day - picked up every two weeks by ABC Oil

Oil Separator ? unknown

Radiator Wastes? flushed down trench drain with water

Solvents: Floor? biodegradable soap used once a week (Saturday)

Parts/Tools? self-contained Safety-Kleen machine, aerosol solvents

Batteries? stored in cool,dry place - retrieved by used battery dealer from Flat Rock

Others? fresh oil stored in 250 gal tank (not close to any drains)

Floor Drain/Plumbing Fixture Survey:

- small floor drains in each of seven regular service bays
- eighth bay has pit with sump pump
- employee restroom has large utility sink, fixtures, and floor drain
- two customer restrooms have fixtures and floor drain
- small floor drain in storage area for discharging compressor condensates
- floor drain in area near employee's restroom for removing bluing from tires (area very dirty)
- drinking fountain in service area
- outdoor trench near sidewalk at western driveway - pavement blackened due to oil spillages that eventually drain into trench

SURVEYED: 5/15/84 SS

DYE-TESTED: 6/20/84 SS
SA
RB

- all plumbing fixtures and floor drains inside building ----- sanitary
- trench drain in driveway that receives oily runoff ----- storm

Attachment C-2. Example on-site survey form used in Allen Creek project.

Fort Worth, Texas

Agency

Fort Worth Health Department, Storm Drain Team. 1800 University Drive, Fort Worth, Texas, 76107.

Initial Alert to Problem

The Texas Water Code required all cities with more than 5000 inhabitants to plan abatement of pollution from generalized sources, such as from storm sewers. Because the public, especially children, had easy access to the City's storm drainage system, the Fort Worth Health Department developed this program to evaluate, maintain and/or improve the water quality within these drainages.

Nature of Non-Stormwater Contamination

This program has been underway since June of 1985. Investigations to date indicate few direct connections from industries to storm drains. Illegal dumping, storm runoff, accidental spills and direct discharges into the street or adjacent creeks seem to account for the majority of industrial pollution entering the storm drainage system.

Major additional problems stemmed from septic tanks, self-management of liquid wastes by industry and construction of municipal overflow bypasses from the sanitary sewer to the storm drains. Figure C-1 provides information on some of the major sources of drainage system contamination which were identified and addressed during this period. Metals were found in receiving water sediments, but not in dry weather discharges.

Procedures Employed to Identify Contaminant Sources

Problem Detection--

Approximately 200 stormwater outfalls discharge into the Trinity River within the city of Fort Worth. Citizen referrals, helicopter surveillance flights, patrols by city personnel and an innovative city wide-water quality assessment program were used to target the most contaminated outfalls.

The Fort Worth Water Quality Assessment Program for Storm Drainages was based on the premise that poor water quality can be detected by the careful observation of aquatic environmental features and the use of simplified versions of conventional chemical and physical tests. It was designed to be inexpensive and require minimal training of the personnel involved. Stormwater outfalls with dry-weather flows were located and evaluated on rainless days using the special target-area survey report (See Attachment C-3). Public accessibility of the candidate sites, and their proximity to the drinking water supply, was also noted.

Based on this information, 24 target sites were selected for the initial phase of the program. A control site was located upstream from industrial and residential activity. All target and control sites were surveyed monthly and results were recorded on a Target Area Tabulation Sheet (See Attachment C-4). Sediment samples were collected annually and analyzed for cadmium, lead, chromium, nickel, copper and zinc.

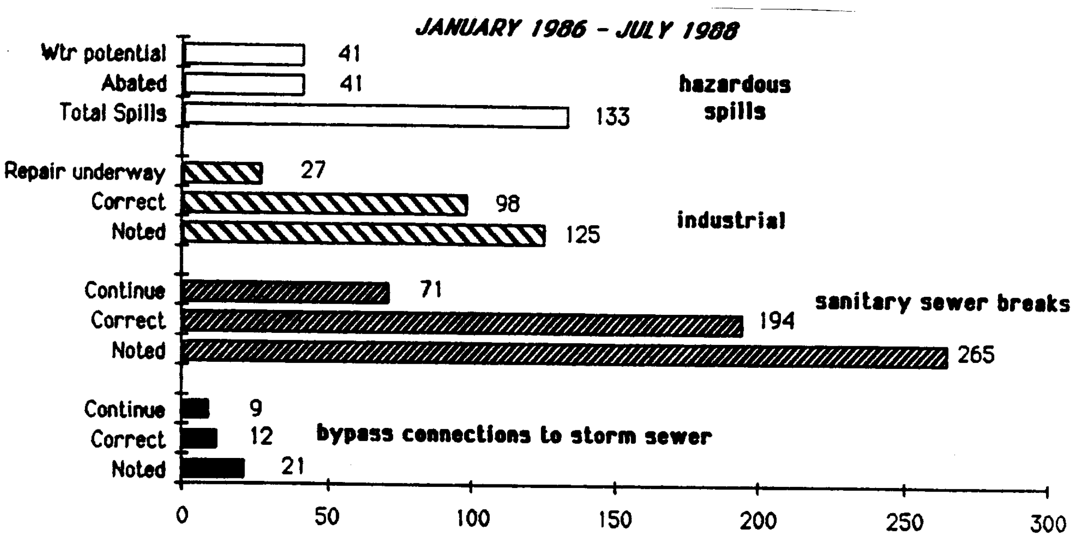


Figure C-1. Fort Worth, TX, drainage way contamination.

ATTACHMENT C-3. TARGET AREA SURVEY REPORT USED IN FORT WORTH PROJECT

(+) UNDESIREABLE (/) PRESENT (-) NOT NOTED

SITE ________________ DATE __________ DAY ___________ TIME ___________ WEATHER _________________

LOCATION ____

____

BIOLOGICAL

MAMMALS ________________________

FISH ____________________________

TURTLES _________________________

BIRDS ___________________________

FROGS/TADPOLES _________________

OTHER __________________________

ALGAE __________________________

* SEWAGE BACTERIA ______________

CATTAIL _________________________

OTHER __________________________

EUTROPHICATION ________________

OTHER __________________________

AQUATIC INSECTS ______________

* MOSQUITOES _________________

TUBIFEX WORMS _______________

SNAILS _______________________

CRAWFISH ____________________

* FISH KILL ___________________

OTHER _______________________

REMARKS ____

____

____

PHYSICAL

WATER TEMP _____________

* COLOR __________________

* ODOR ___________________

* CLARITY _________________

AIR TEMP ____________________________

* HYDROCARBONS _____________________

* SCUM (TYPE) ________________________

SEWAGE _____________________________

WATER FLOW _____________________

TRASH ___________________________

OTHER ___________________________

REMARKS ____

____

____

CHEMICAL

* pH ______________________

CHLORINE ____________________________

OTHER ___________________________

* NESSLER ________________

SAMPLE #_____________________ # ____________________

REMARKS ____

____

____

* UNDESIREABLE FREATURES FOR PROFILES OBSERVER ____

ATTACHMENT C-4. TARGET AREA TABULATION SHEET OF UNDESIREABLE CHARACTERISTICS AS USED IN FORT WORTH

Date:

		SITE #																			
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
O	Septic																				
D	Hydrocarbon																				
O	Other																				
R																					
P	Color																				
H	Clarity																				
Y	Scum																				
S	Hydrocarbon																				
	Trash																				
	Other																				
	Turtles																				
	Fish																				
	Frogs																				
	Tadpoles																				
	Mammals																				
B	Birds																				
I	Other																				
O																					
L	Mosquitoes																				
O	Tube worms																				
G	Crayfish																				
I	Snails																				
C	Other																				
A																					
L	Cattail																				
	Algae																				
	Sewage bact.																				
	Other																				
	Eutrophy																				
	FISH KILLS																				
	Other																				
C	pH																				
H	Nessler																				
E	Chlorine																				
M	Other																				
A	Fecal Coli																				
N	Sample #																				
A	Bioassay																				
L	Other																				

Source Identification--
Following the detection of a storm drainage pollution problem, the source of the problem was investigated. Field testing equipment was used in conjunction with laboratory analyses for determining specific chemical constituents. On-site biotoxicity tests were carried out when warranted. A storm drainage survey was also conducted, when necessary, followed by smoke and dye testing where appropriate. Pollutants in open channels could sometimes be physically traced upstream to their source.

Corrective Action
Responsible parties were notified of code violations and necessary clean-up and/or repair actions. Follow-up checks were made to insure that appropriate action had been taken. In cases where the responsible party was unwilling to make necessary corrections, the news media was notified.

The success of this program was judged by a decline in the number of undesirable features at the target outfalls. An average of 44 undesirable observations per month were made in 1986 (522 total), compared to an average of 21 undesirable observations per month in 1988. Figure C-2 compares the number of undesirable features observed at the 24 target sites each month from 1986 to 1988.

Discussion
The Fort Worth drainage water pollution control program was developed and implemented by the Fort Worth Public Health Department and is on-going. The program is being carried out at an annual cost of approximately $7000 (excluding salaries) and utilizes only 2-3 persons.

References
Falkenbury, John. *Water Quality Standard Operating Procedures*. City of Fort Worth Public Health Department, 1800 University Drive, Fort Worth, Texas 76107. 1987.
Falkenbury, John. *City Of Fort Worth Water Pollution Control Program Overview*. Fort Worth Public Health Department, 1800 University Drive, Fort Worth, Texas 76107. 1988.
Moore, A.H. and Dena Hoffpauir. *Biotoxicity Testing*. Fort Worth Health Department, 1800 University Drive, Fort Worth, Texas 76107. 1988.

Toronto, Ontario

Agency
Ontario Ministry of the Environment, Toronto, Ontario, Canada.

Initial Alert to Problem
Recent studies conducted by the Ministry of the Environment showed that tributary watersheds within Metropolitan Toronto had a high impact on water quality along the Lake Ontario waterfront. The Humber River and Tributary Dry-Weather Outfall Study was initiated to identify and sample all stormwater outfalls having dry-weather flows in the Humber River Basin of Metropolitan Toronto.

Nature of Non-Stormwater Contamination
Stormwater outfalls contributing significant quantities of nutrients, phenols and metals, as well as fecal coliforms, were discovered. Industrial and sanitary sewer cross-connections were suspected, as well as contaminated runoff from facilities such as meat packing plants.

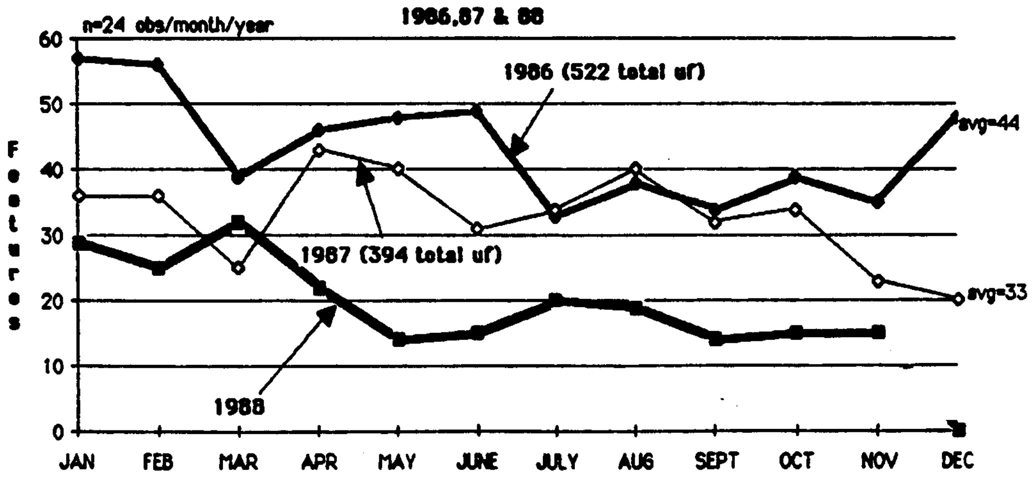


Figure C-2. Fort Worth, TX, undesirable features for 24 target areas.

Procedures Employed to Identify Contaminant Sources

Two two-person field crews carried out mapping and outfall sampling screening surveys. As the study progressed, outfalls were prioritized based on chemical loadings and bacteria levels. Only the most contaminated outfalls were extensively sampled.

First Screening--

Crews proceeded upstream within each stream tributary reach and located, photographed and described as many outfalls as possible. An identification number was assigned to each outfall. During this initial survey, 432 outfalls were mapped, of which 157 had dry-weather flows. Samples were collected from outfalls having dry-weather flows. Flow rates were recorded and field tests were also made (See Attachment C-5). Samples were tested in the lab for many contaminants and outfalls with effluents exceeding preliminary guidelines (See Table C-1) were designated "contaminated" and were further studied.

Second Screening--

Crews re-sampled effluent from contaminated stormwater outfalls. Municipal maps and lists, and information from earlier studies, were also used to locate any outfalls which had been overlooked during the first screening. These outfalls were then located, described and sampled. By the end of the second screening, a total of 624 outfalls had been mapped, 366 (59%) had dry-weather flows. After all samples were tested, the results were compared to a second set of "high threshold" contamination guidelines (See Table C-2) and the most contaminated outfalls were identified for extensive sampling.

Extensive Sampling--

A total of 84 outfalls identified during the second screening were sampled on three occasions during dry-weather in November and December. Samples were taken only for the parameters which exceeded the high threshold guidelines (BOD, COD, and bacteria was treated as one test group to facilitate basin-wide analysis). A total of 60 outfalls were assigned priority for future investigations, based on the fact that they each contributed more than 1% of the total dry-weather load for at least one chemical, while 29 outfalls were identified as significant sources of fecal coliform and fecal streptococci.

Corrective Action

This study terminated with the identification of significant outfalls. Investigations to locate actual sources of the contaminants were to be undertaken by the respective municipalities.

References

Gartner Lee and Assoc. *Toronto Area Watershed Management Strategy Study - Humber River and Tributary Dry Weather Outfall Study*. Technical Report #1. Ontario Ministry of the Environment. Toronto, Ontario. 1983.

Huron River, Washtenaw County, Michigan

Agency

Washtenaw County Drainage Board, James E. Murray, Chairman. Huron River Pollution Abatement Program Project Coordinator, Washtenaw County Environmental Health Bureau, P.O. Box 8645, Ann Arbor, Michigan, 48107-8645.

Initial Alert to Problem

The impact of urban stormwater on the Huron River had been well documented. In 1966, University of Michigan researchers concluded that illegal connections into storm drains had a significant impact on the water quality of the Huron River. Subsequent studies yielded similar conclusions, especially with regard to high fecal coliform counts. During the early 1980's, studies conducted by the towns of Ann Arbor (The Allen Creek Drain Water Quality Survey, described previously) and Ypsilanti identified chemical contamination as well.

ATTACHMENT C-5. FIELD DATA SHEET USED IN TORONTO'S HUMBER RIVER OUTFALL STUDY

FIELD DATA SHEET
Humber River Outfall Study

Outfall # ________ Date :_____/_____/______ Time: _________ Crew:

____

Weather: Today:

____

Yesterday:

____

River: Humber Main Black Creek Humber West Other: ________________________

Reach: A B C D E F Borough: Etobicoke Toronto

G H I J K L York North York

M N O P Q

Location:

____

(sketch on back of sheet)

Outfall Description: Size: ____________________ Diameter W X H: _______________

Material: __________________ Shape: _______________________

Active: Y/N Photographed: Y/N # ___________________________

Samples Collected: Bacteria Routine Chemical

Metals Organics

Other: ____

Flow Rate: Velocity: ____

Depth: ____

Sketch cross-section shape (on back of sheet)

Field Tests: D.O. ________________mg/L Air Temp: _____________^{o}C

pH _________________ Water Temp: ___________^{o}C conductivity: _________ μmhos

Observations: Color Odour Erosion Impacts Land Use Other

Accessibility: Easy Difficult Road Manhole Boat Only

Is the outfall otherwise mapped? Map: _______________ # _________________________

TABLE C-1. GUIDELINES USED IN TORONTO TO SELECT OUTFALLS FOR SAMPLING DURING SECOND SCREENING (LOW THRESHOLD)

Parameter	Outfall Re-Sampled If Concentration Exceeded (mg/L)
BOD_5	20
COD	25
TKN	5
NH_3	1
Tot-P	1
Sol-P	1
Fe, Cu, Zn, Pb, Cr	1
Suspended Solids	15

TABLE C-2. GUIDELINES USED IN TORONTO TO SELECT OUTFALLS FOR SAMPLING (HIGH THRESHOLD)

Parameter	Outfall Effluent Intensively-Sampled of Levels Exceeded (mg/L)
BOD_5	50
COD	50
TKN	5
NH_3	1
Tot-P	1
Sol-P	1
Fe,	5
Cu, Zn, Pb, Cr	1
Suspended Solids	100
Phenols	5 µg/L
Fecal Streptococci	10,000/100 ml
Fecal Coliforms	50,000/100 ml

Nature or Non-Stormwater Contamination

This on-going, five year study is investigating sanitary as well as chemical contamination from the more than 60 storm drain outfalls found discharging into the Huron River in Washtenaw County. Information from the sampling program to date indicates very elevated levels of nitrate, ammonia nitrogen, total phosphorus, and fecal coliform bacteria at the storm drain outfalls and in the river, as compared to the control station.

Procedures Employed to Identify Contaminant Sources

Methods used to identify sources of contamination include sampling the storm sewer systems and the river, and surveying buildings (including dye-testing).

Sampling-- Sampling efforts include permanent sampling stations, grab samples from the river and storm drain systems and soil samples. Permanent sampling stations are located at the outfalls of the three major storm drain systems in the area, the Allen Creek Drain in Ann Arbor; the Owen Drain in Ypsilanti; and the Beyer Drain in Ypsilanti Township. These stations have 24-hour composite samplers and flow meters. Chemical constituents were selected to cover a wide range of water quality indicators. Weekly composite samples are taken for primary analyses and samples are analyzed biweekly for a secondary list of constituents (See Table C-3). Grab samples from four stations on the Huron River (including one upstream control station) are collected and analyzed biweekly for the primary and secondary constituents as well as dissolved oxygen. All storm drain manholes are checked for improper connections and water quality problems. Grab samples collected from storm sewers are used for locating industrial discharges, and isolating residential neighborhoods that have sanitary wastewater discharges into the storm sewer. Grab samples from storm sewers are also used for complaint investigations. Soil samples are collected from industrial areas which have discharged to septic tank drainfields in the past.

Survey/Dye Test-- Commercial, industrial, and other buildings are surveyed to determine use, storage and disposal practices of chemicals and hazardous materials. An outline of the building's plumbing scheme is also obtained. Where applicable, a company's small quantity generator number, Pollution Incident Prevention Plan, National Pollutant Discharge Elimination System permit and Material Safety Data Sheets are examined. A dye-test is then made of each plumbing fixture and floor drain. Businesses having improper storm sewer connections are notified and given correction alternatives.

Corrective Action

As of January 1, 1989, dye testing had been completed at 1067 establishments. A total of 154 (14%) improper connections were discovered, including connections in restaurants, dormitories, car washes and several auto repair facilities. Only 29 (19%) of these problems had been corrected by the end of the year. County personnel have reported a marked reduction in the number of complaint calls related to oil slick discharges from the Allen Creek drain. This was thought to be a result of locating and correcting discharges from automotive service stations along the Creek corridor.

Discussion

Since federal and state funds were not available, a new approach was used to generate local money to fund this project. A special assessment district was established along the Huron River. Property owners within this district will have an assessment added to their property tax bill for the next five years. Assessment rates are based on use and size of the property, and range from $4.50 a year for the typical home owner, to $200.00 per year for large commercial enterprises. The money generated by the district is utilized to cover all costs of the inspection program including personnel, consulting fees, lab services, administration, equipment purchases, etc.

References

Washtenaw County Statutory Drainage Board. *Huron River Pollution Abatement Program*. September 1987.

Murray, James E. Washtenaw County Drain Commissioner. *Statement To The Board Of Commissioners*. December 1985.

Office of the Washtenaw County Drain Commissioner. *Huron River Pollution Abatement Project 1988 Summary*. 1988.

TABLE C-3. CONSTITUENTS ANALYZED DURING HURON RIVER INVESTIGATIONS

Drain Samples:

Group I	Group II
Oil and grease	Nitrate
Total Suspended Solids	Ammonia
Total Phosphorus	Toxicity
Total Organic Carbon	Zinc
Cadmium	Chloride
Chromium	
Lead	
Fecal Coliform	
pH	
Conductivity	

River Samples:

Group I	Group II
Oil and grease	Nitrate
Total Suspended solids	Ammonia
Total Phosphorus	Toxicity
Total Organic Carbon	Zinc
Cadmium	Chloride
Chromium	BOD_5
Lead	Turbidity
Fecal Coliform	Total Dissolved Solids
pH	
Conductivity	

Soil/Sediment Samples:

- Volatile organics
- Base/neutral/acid organics
- Metals
- Cyanide
- Phenolics

Rideau River, Ottawa, Ontario

A study of the lower Rideau River in the Regional Municipality of Ottawa-Carleton was conducted to establish the causes of bacteriological water quality degradation in the urbanized reach of the river and to analyze the impacts of future urbanization. Earlier programs had identified and corrected many cross-connections between sanitary sewers and stormwater sewers. Bacteriological water quality improved, but swimming standards at beaches were still not obtained.

Pollution from combined sewer overflows, urban stormwater runoff and feces from birds on bridges was known to occur but was largely unquantified. This study quantified these sources and identified additional sources along the lower Rideau River. The sources of bacteriological pollution were investigated under dry-weather conditions and during rainfall events.

A pollution abatement plan for the fully urbanized reach within the City of Ottawa was recommended. This plan initially focused on correcting local dry weather sources of pollution, including pigeon control, repairing leaks from sanitary sewers, and eliminating cross-connections between storm and sanitary sewers. It was recommended that stormwater quality controls be included in all new urban developments to control runoff pollution.

Reference

Ontario Ministry of the Environment. *Rideau River Stormwater Management Study*. Toronto, Ontario. 1983.

Sacramento, California

The City of Sacramento is currently undertaking a project to identify pollutant discharges and illegal connections into the stormwater drainage system. Recent studies identified potentially toxic substances associated with urban runoff in concentrations that could potentially impair beneficial uses of the Lower American River in the City and County of Sacramento. Bioassays by Foe (1987) demonstrated acute toxicity in some stormwater. In a 1984-85 study, Montoya (1987) found that slightly less than half the water discharged from Sacramento's stormwater drainage system was not directly attributable to precipitation. High concentrations of copper, lead, zinc, cadmium, chromium, arsenic and nickel were documented. Mass loading estimates of copper, lead and zinc from Sacramento urban runoff discharges were several times higher than similar estimates computed for the Sacramento Regional Treatment Plant secondary effluent.

The proposed study will characterize storm drainage discharge quality, evaluate its toxicity by bioassay, identify remedial measures to improve quality, and recommend actions to reduce water quality impairments in the river. Initially, testing for a broad range of pollutants will be carried out at four locations which are representative of the various land use categories found in the project area. Sufficient sampling and analysis will be conducted to establish water quality conditions during dry weather, first storm of season, and major storm events. Monitoring is planned to continue for a two year period.

References

Montoya, Barry L. *Urban Runoff Discharges From Sacramento, California*. Submitted to California Regional Water Quality Control Board, Central Valley Region, CVRWQCB Report Number 87-1SPSS. 1987.

Johnson, Melvin H. and Douglas M. Fraleigh. *Workplan for Federal Clean Water Act Section 205 (j) (2) Grant*. Submitted by the City of Sacramento, Flood Control and Sewer Division, in cooperation with the County of Sacramento, Division of Water Resources. 1988.

Inner Grays Harbor, Washington

Investigations into persistent water quality problems at Grays Harbor were initiated as early as the 1930's. Current investigations focus primarily on survival of coho salmon, however, a variety of water quality problems are of concern, including low dissolved oxygen, bacterial contamination and potentially toxic industrial discharges (Beyer 1979).

During a dry-weather survey in July of 1987, the lower reaches of the Chehalis, Wishkah, and Hoquiam Rivers, as well as inner Grays Harbor, were inspected and approximately 90 urban storm drains were located and mapped. The 29 drains having dry-weather flows at the time were sampled for a variety of pollutants, including fecal coliforms, ammonia, nitrate and nitrite, total phosphorus, total solids, total non-volatile solids, total suspended solids, non-volatile suspended solids, and turbidity. Visual observations and field measurements of temperature, pH and specific conductance were also made. Results were compared to pollutant levels expected in typical urban runoff, as characterized by the EPA NURP report (1983). Nineteen of the drains sampled exhibited anomalous pollutant levels (at least one parameter outside approximate 95 percent distribution interval for typical urban runoff). Eight drains were suspect, based on visual characteristics. Six drains were included in both categories. The outfalls were then prioritized for further study. At least one drain was later found to receive a residential sanitary sewage connection which has since been corrected. This drain exhibited no unusual visual characteristics, but was found to have atypical pH and total suspended solids levels. Notably, fecal coliform levels were within the typical range.

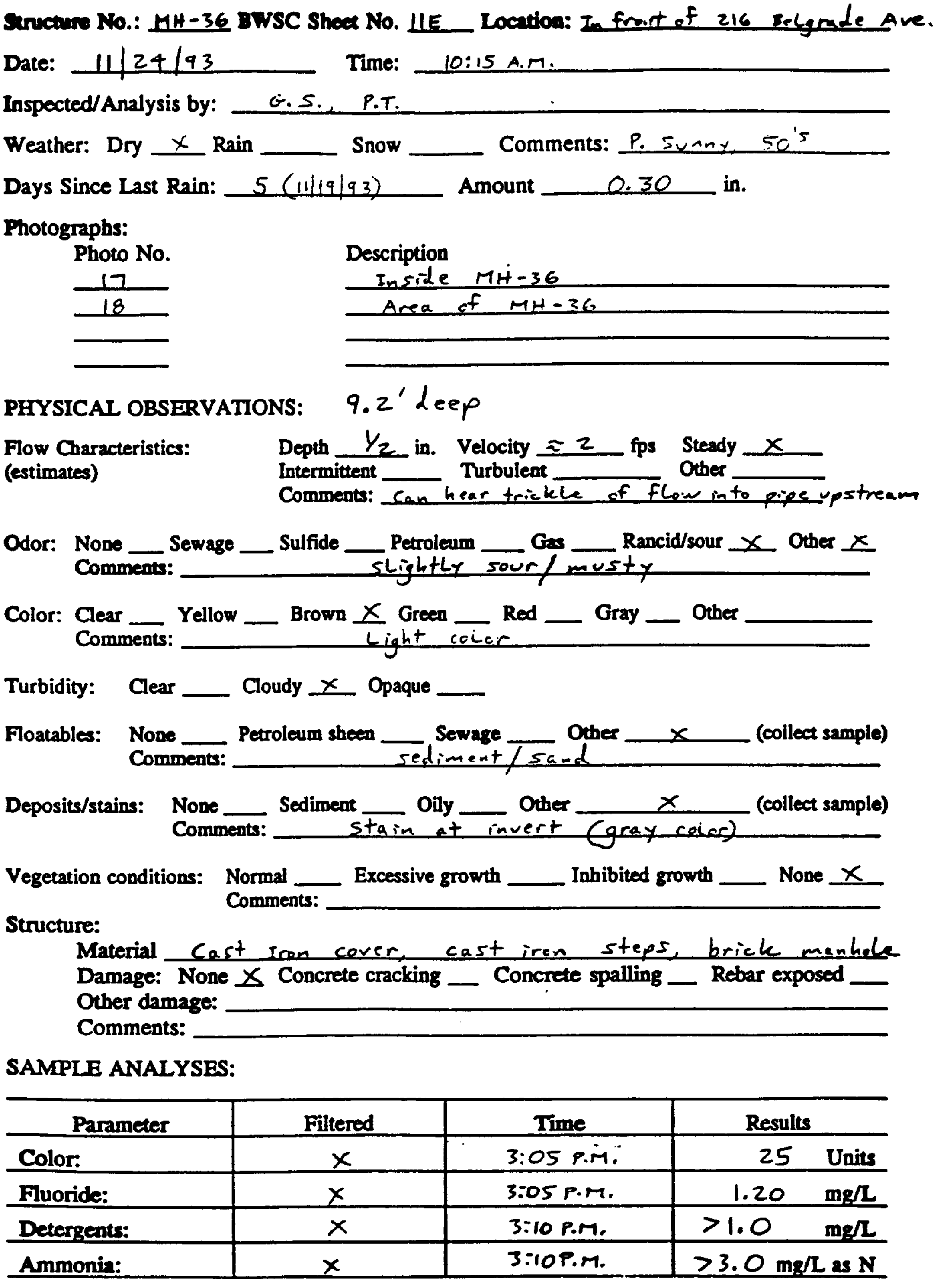
References
Beyer, D.L., P.A. Kingsbury, and J.E. Butts. *History and Current Status of Water Quality and Aquatic Ecology Studies in the Lower Chehalis River and Grays Harbor, Washington*. Prepared for Washington Public Power Supply System. 1979.
Pelletier, G.J. and T.A. Determan. *Urban Storm Drain Inventory, Inner Gray Harbor.* Prepared for Washington State Department of Ecology, Water Quality Investigations Section, Olympia, Washington. 1988.

Boston, Massachusetts

A flow and quality monitoring study was carried out in Boston in 1993 and 1994 by Metcalf and Eddy (1994) using the draft procedures presented in the User's Guide (Pitt, *et al*. 1993) prepared as part of this research. A field screening program was conducted to determine the relative levels of contamination at various locations in the Stony Brook drainage system. This information provided insight as to whether water quality impacts in the vicinity of the outfall discharge location were due to dry weather contamination sources, CSOs, or stormwater discharges. Field screening activities took place during dry weather, and emphasized characterization of base flows in the brooks and overflow conduits that comprised the system. This screening program consisted of field inspection and utilization of test kits to determine relative levels of contamination. Grab samples were collected from various structures within the Stoney Brook system and field test kits were used to measure color, fluoride, ammonia nitrogen, and detergents.

Inspection forms (Attachment C-6) were filled out for each inspection activity noting obvious outflow conditions, photograph information, and water quality conditions. During eight days of dry-weather sampling, numerous inappropriate discharges of sanitary sewage into the drainage system were identified using these procedures and a modified flow chart approach. Differences in tracer concentrations in Boston source waters required that the numeric values presented in the User's Guide (Pitt, *et al*. 1993) be slightly changed.

Reference
Metcalf & Eddy. *Draft 1993 Flow and Quality Monitoring Program and Results*. Prepared for the Massachusetts Water Resources Authority. Boston, Massachusetts. March 1994.



Structure No.: MH-36 **BWSC Sheet No.** 11E **Location:** In front of 216 Belgrade Ave.

Date: 11/24/93 **Time:** 10:15 A.M.

Inspected/Analysis by: G.S., P.T.

Weather: Dry X Rain ___ Snow ___ **Comments:** P. Sunny 50's

Days Since Last Rain: 5 (11/19/93) **Amount** 0.30 in.

Photographs:

Photo No.	Description
17	Inside MH-36
18	Area of MH-36

PHYSICAL OBSERVATIONS: 9.2' deep

Flow Characteristics: (estimates) Depth 1/2 in. Velocity ≈ 2 fps Steady X
Intermittent ___ Turbulent ___ Other ___
Comments: Can hear trickle of flow into pipe upstream

Odor: None ___ Sewage ___ Sulfide ___ Petroleum ___ Gas ___ Rancid/sour X Other X
Comments: slightly sour/musty

Color: Clear ___ Yellow ___ Brown X Green ___ Red ___ Gray ___ Other ___
Comments: Light color

Turbidity: Clear ___ Cloudy X Opaque ___

Floatables: None ___ Petroleum sheen ___ Sewage ___ Other X (collect sample)
Comments: sediment/sand

Deposits/stains: None ___ Sediment ___ Oily ___ Other X (collect sample)
Comments: stain at invert (gray color)

Vegetation conditions: Normal ___ Excessive growth ___ Inhibited growth ___ None X
Comments:

Structure:
Material Cast Iron cover, cast iron steps, brick manhole
Damage: None X Concrete cracking ___ Concrete spalling ___ Rebar exposed ___
Other damage:
Comments:

SAMPLE ANALYSES:

Parameter	Filtered	Time	Results
Color:	X	3:05 P.M.	25 Units
Fluoride:	X	3:05 P.M.	1.20 mg/L
Detergents:	X	3:10 P.M.	>1.0 mg/L
Ammonia:	X	3:10 P.M.	>3.0 mg/L as N

Attachment C-6. Massachusetts Water Resources Authority (MWRA) Stony Brook system (Boston) investigation field screening inspection form.

Appendix D
Village Creek Mapping Demonstration Project Activities

This appendix describes the mapping activities that were associated with the Birmingham demonstration project. It includes specific information sources that were utilized and presents the final drainage area maps and summary tables. This appendix supplements the information presented in Section 11.

To properly document inappropriate pollutant entries into a storm drainage system, a substantial amount of mapping activities must be carried out, as previously summarized in Section 3. This information is listed below:

1. High quality topographic maps of the receiving water's drainage area.
2. Location, size, type, and drainage area of each stormwater outfall in the study area.
3. Land use and zoning maps of the entire drainage area.
4. Location and description of commercial, industrial, agricultural, and residential activities in the study area, with attention drawn to illicit storm drain connections.

An investigation of a storm drainage system should incorporate mapping and preliminary drainage area evaluation in the early stages. A complete picture of the drainage area can be developed using detailed topographic maps in combination with the corresponding land use and zoning maps. Evaluation of the maps will reveal areas and outfalls of concern within the drainage area. Storm drain outfalls which have in their drainage area commercial or industrial operations which are likely to produce non-stormwater entries into the storm drainage system can be investigated for evidence of these discharges.

The first step in mapping is to obtain good quality topographic maps of the drainage area. While United States Geological Survey (USGS) 7-½ minute quadrangle maps are important to use for these activities, the course contour interval (20 foot for the Birmingham area) will present problems when trying to identify individual outfall drainage areas. For most areas, a contour interval of 1 to 5 feet will expedite the mapping by increasing the accuracy of the final drainage area boundaries. The City of Birmingham engineering department had maps with 1-foot contour intervals which were especially helpful. One problem with obtaining topographic maps from a municipal source is that the maps usually end at the city limit.

It will be helpful to make two copies of each map, one to work with, and another to keep as a master copy. Vellum copies seem to be the best choice for maps with small contour intervals because of the contrast between the vellum and the contour lines. If the contour intervals are greater, blueline reproductions will save some money. If USGS maps are all that are available, they will need to be enlarged to several times their original size. Obviously this will not increase the accuracy of the maps, but it will provide room to draw drainage areas and label storm outfalls without crowding. Even if more detailed maps are available, the enlarged USGS maps are helpful as they will provide a complete picture of the drainage area and adjacent receiving waters in a relatively small space. It will also be helpful to ask the city engineers for storm drainage maps and a listing of known outfalls. At this point, the drainage area for the receiving water as a whole should be drawn on the maps. This is not a complex step, but care should be taken as it is important.

While this mapping is being completed, a field team needs to investigate the receiving waters for the specific locations of stormwater outfalls. It is important to locate as many outfalls as possible and to take accurate notes as to their location, size, and type. Locating outfalls is not trivial. For this reason, the field team needs to examine the banks of the receiving water every time samples are being taken to find outfalls that have been overlooked on previous trips. Once a list of outfalls and their locations has been completed, this information can be transferred to the maps. Each outfall should be labeled clearly on the maps using the same numbering system that has been developed by the field team.

The maps should now show the total drainage area of the receiving water and every outfall as reported by the field team. The next step is to detail the drainage area of each outfall. Identifying the individual outfall drainage areas is the most daunting map work that will be done. Several factors contribute to the difficulty of the task. The first problem is that the drainage areas will have to be developed mostly using topographic maps. While this is the logical method, it must be understood that there is an inherent error associated with assuming that storm drainage pipes flow in the same direction as surface flow. Certainly it is standard practice to follow the topography, but it is not uncommon for a drainage pipe to cross a drainage divide. On the reach of Village Creek selected in this study, for example, the only National Pollutant Discharge Elimination System (NPDES) permit issued is to an industry that, based upon the topographic maps, is not even physically located in the Village Creek drainage area. To complicate matters further, municipal storm drainage maps, when available, typically show only the relatively new outfalls associated with new developments and do not accurately show the older outfalls.

Another problem with using surface topography to define storm drainage areas is that it is impractical to draw drainage divides reflecting grading and small drainage patterns on individual lots. The best decision may be to draw the drainage divides by following the surface topography. Thus, if the surface topography indicates a drainage divide crosses the roof of a building, it is assumed that there is a drainage divide on the roof. In most situations this will not be a realistic assumption, but it is impractical, if not impossible, to visit each rooftop and parking lot to determine detailed flow directions. A similar problem can arise when an outfall is actually an illicit process discharge from a commercial or industrial operation rather than a storm drain. In these cases the outfall is not dependent upon the topography at all.

There may be outfalls where a drainage area cannot be easily determined because of a lack of information about the storm sewer There is a general lack of accurate information about the location of storm sewer pipes. It is important to obtain as much storm drainage system information from the city engineers as possible. However, the information should not be blindly accepted. In several cases, the city in this study had plans which did not correspond to actual pipe locations. Given this, it is sometimes up to the field team to attempt to follow a pipe to its inlet in order to identify the actual drainage area. This is difficult at best because of interconnections between pipes which cannot be seen from the surface. Detailed storm drainage surveys are time consuming and costly. It is therefore recommended that basic drainage divides be based on surface topography and available drainage maps. However, detailed surveys need to be conducted for outfalls that are determined to be a problem based upon the physical and chemical outfall surveys.

When the field team is locating and identifying the outfalls, clues to the purpose of the outfall can often be found. This information is often very helpful in determining a drainage area for individual outfalls. Air conditioner drain pipes, for example, are often small p.v.c. pipes. In a similar fashion, the field team may be able to identify sanitary sewer relief pipes and obvious discharges from nearby commercial or industrial operations. In each of these cases, the outfall can be very important, although there is no actual “storm” drainage area.

Regular sampling can begin as soon as the field team feels confident that the great majority of the outfalls have been located. The field team should develop two field sheets (Tables D-1 and D-2) while taking samples at the outfalls. Table D-1 is a listing of the outfalls for this study. The Village Creek outfall listing was revised on almost every trip, which is an indicator of the difficulty of locating all of the outfalls. As predicted, there were several instances in which the University of Alabama at Birmingham field team could not relate an outfall to the city of Birmingham's “official” list.

Table D-2 is the Village Creek non-stormwater flow evaluation field sheet which shows the observations that should be recorded as each sample is taken. As the sample is taken, one member of the field team can survey the outfall for signs of non-stormwater discharges, as described in Section 7

The maps should detail the total drainage area, each outfall, and the drainage area for each outfall. The next addition to the maps is land use within the drainage area. The city land use and zoning maps should be very accurate and useful indicators. Because tax revenue varies with land use, municipalities keep good records of current land use. The drainage area should be divided into at least three main land use categories: residential, commercial, and industrial (Agricultural can be added if applicable). Other important land use information such as areas served by septic tanks, abandoned land fills, and old industrial areas should also be drawn on the maps. The different land use categories should be drawn on the same maps that have the drainage areas. The city will probably not allow the zoning maps to be taken out of the office. However, as only a simplified version of the city's zoning maps is needed, the work goes fairly quickly and, with permission, can be completed efficiently done in their office.

Once the commercial and industrial land uses have been mapped, the rest of the drainage area will most likely be residential, with some open space and institutional areas. Except for poorly maintained septic tanks and sewage leak problems, the majority of pollutant entries from residential areas are of a very short duration. Landscaping, vehicle maintenance, and car washing are typical problems that can be detected at an outfall, but not easily traced to a specific source. As the majority of “shade tree” mechanics operate on the week-ends, these are the times when the field team should drive through these areas. Depending on the area, there may also be some agricultural zones within the drainage area which would obviously be of importance. The “agricultural” zoning laws may allow a great variety of land uses, and each agricultural activity that may be suspect should be documented.

After the drainage area has been divided into the main land use areas, it is necessary to determine the specific critical activities within these areas. All industrial activities need to be noted and described, but only selected commercial activities likely pose a significant water quality threat during dry weather. The commercial operations of most interest are: laundry and dry cleaning stores (including hotels and hospitals which have similar facilities); vehicle service businesses (including parts stores, auto repair shops, new and used car dealers, body shops, car washes, wrecker services and gas stations), restaurants; and any other commercial operation which may be suspect. Common sense can dictate whether or not a business is suspect. Contractor yards containing construction materials are an example of a business which will not be encountered often, but nonetheless are important.

To properly locate the critical land use activities in the drainage area, it is necessary to drive throughout the drainage area. Using the maps, a field team can visit each commercial and industrial area to locate and describe businesses that are present. At each location that contains a business of concern, the name should be recorded and the business should be numbered. A field sheet, such as Table D-3, should be completed for each site. A quick survey of each site will reveal any obvious problems. A direct process connection will most likely be visible only in those situations where the facility lies adjacent to the receiving water. Physical and chemical testing of the dry-weather flow at the appropriate outfall will reveal any sub-surface connection to the storm sewer. Indirect discharge can be observed as surface flow from the facility. Stains or discoloring of the pavement can be the result of intermittent surface flow. Often these stains follow a path from the facility to a storm drain. Though septic system failure is visible only in some cases, any sign of such a failure should also be noted. The location should also be highlighted on the topographic maps. If the business lies near a drainage divide, the lot can be examined and the divide can be re-drawn to reflect the true drainage pattern.

The discharge from each critical activity has distinct characteristics. In the Village Creek study, there were two instances when restaurants seemed to be a culprit. In both cases, the smell of the restaurant from the storm drain outfall was unmistakable. In one case, a fish kill seemed to coincide with a distinct smell of doughnuts. Peering over the bank of the creek revealed a doughnut shop across the street. In the second, case a yellow-orange sludge lined the bottom of the storm drain pipe. The smell was familiar, but could not be identified until a look over the bank revealed a Mexican restaurant not far away. Another smell connected the two, and identified the sludge as cheese. For reasons similar to these, restaurants and food processors are included on the list of “suspect” businesses as frequent offenders. There are several car washes in the Village Creek drainage area. While most of these retain the wash water in a pit for discharge to the sanitary waste water system, one of the car washes used manual washing methods outside. A considerable amount of wash water was directed to a nearby storm drain. This problem can be expected on a more sporadic basis as schools and other organizations hold fund raising car washes in parking lots.

Auto body shops, auto repair shops and car dealers have the potential to be the most flagrant offenders. Filthy auto repair shops not only cause wet weather runoff problems, but if the parking lot is rinsed, or cars are washed or drained outside, there is a dry-weather runoff problem as well. Body shops use paints and solvents, while repair shops have parts baths which require an expensive method of disposal. All too often the disposal is into a nearby body of water via a nearby storm drain. These offenses can be long term, flagrant, and shamelessly obvious. There is one offender of this nature in the Village Creek drainage area. It is a used car dealer which does repair and body work in-house. Village Creek lies about 10 or 15 feet behind the building and several cast iron pipes run directly from the building to the creek bank. The grass on the creek bank is matted down and blackened from the frequent discharges. The discharges consist of a base flow which is a steady drip, and fairly regular slug flows lasting 2 or 3 minutes. From the analysis of the flow, it seems to be the parts solvent being drained. During other studies, small plating businesses have also been found to be frequent illicit dischargers, and outfalls associated with these activities should be checked frequently. Laundries and dry cleaners have also been found to be frequent offenders. In some cases, operators store the screens from the dry cleaning machines in the yard behind the building. There, the screens are either hosed off or rained upon. In other cases the runoff is more direct. One hotel in the Village Creek study seems to dispose of laundry wash water directly into the storm drain. When confronted, the problem abated for a time and then resumed.

Table D-4 contains the actual Village Creek critical land uses, while Table D-5 lists the outfalls containing industrial and commercial operations in their drainage areas. In the Village Creek drainage area that was studied, two of the outfalls had very large drainage areas and contained the majority of the industrial and commercial operations. The majority of the outfalls had small drainage areas with little or no activity of interest.

Also given in this appendix are copies of watershed drainage maps locating each of the specific industrial and commercial activities noted in these tables, the major land uses, drainage areas, and outfall locations.

TABLE D-1. VILLAGE CREEK OUTFALL DESCRIPTIONS

Outfall #	History of Flow	Pipe Size and Type	Location
1		6'x6' conc.	Robison Drive
2		30" conc.	left - between Laurel Dr. and Robison Dr.
3(abcde)		e) 36"conc.	under Annie Laurel Dr
4(ab)		24" conc.	under Dalton Rd.
5		6" steel	left - from house (Downstream Dalton)
6		16" conc.	left - road drain (Downstream Dalton)
7(abc)		a) 6'x10'	crossing to North Roebuck elementary
		b) 36" conc.	
		c) 12" conc.	
8		16" conc.	right - drains ball park (60'down from 7)
9		open ditch	right - downstream ball park behind houses
10(abc)		a) 16" conc.	under Redlane Road
		b) 18"x36"	
		c) gutter in	
10z			right
Dry Branch			left - large
11		2" steel	lying in creek bed
12		6" pvc	crossed creek - sewage leaking
13		3'x8' open ditch	left just upstream of golf course
14	Y	3" pvc	right - golf course
14z	Y	open ditch	right - golf course
15		10" conc.	left - golf course
16	Y	3" pvc	left - golf course
spring runs in			
16z		12" conc.	right - golf course
16zz		10" conc.	left - golf course
17		18" clay	right - corner of West Blvd & 1st Ave
18(ab)		a) 18" clay	under 86th street
		b) 2' conc.	
19(ab)		4" irons	left - behind East Lake Auto Sales (ELA)
20	Y	3'x4' stone	left - behind ELA
21	Y	6" iron	left - behind ELA
22	Y	4"	left - behind ELA, buried in grass
23		4" iron	left - behind ELA
24		2" plastic	left - behind ELA
25		4" with vinyl sleeve	left - behind ELA
26	Y	48" conc.	right - between ELA and Big Ed's
27		18" conc.	right – above 85th St. crossing
28		16"	left - just above85th St. crossing
29		several	under 85th street
29z	Y	5'x12' stone	left - immediately below 85th St. crossing
30		12" conc.	left - below 85th
31(ab)	Y	16" conc.	left - behind hotel
32			left - above 84th
33		48" brick	under 84th st.
34		16" clay	right - below 84th
35		16" clay	right - below 84th
36		6" steel	.right - below 84th
37		submerged	right - in creek overflow cap - just above #38
38	Y	36" aluminum	right - below 84th

39	Y	12" steel	right - below 84th
40	Y	open ditch	left - just above overhead pipe crossing
40z	Y		
41		14" clay	left - below park bridge
42	Y	36" conc.	left - below park bridge
43		18" conc.	left - back and above creek

(continued)

TABLE D-1. VILLAGE CREEK OUTFALL DESCRIPTIONS (continued)

Outfall #	History of Flow	Pipe Size and Type	Location
44		spillway	East Lake Spillway
45	Y	4'x6' conc.	left - just below spillway
46		6" plastic	located with #45
47		18" conc.	left - back and above creek - just above a pipe crossing
48	Y	36" conc.	left - just above 80th St. crossing
49			right - look for small stone wall
50		9" iron	under 80th St.
51			below 80th St.
52	Y	42" conc.	left - below 80th St.
53	Y	6'x6'	left - above Oporto-Madrid crossing
54		12" clay	above Oporto-Madrid
55		30" conc.	left - above Oporto-Madrid crossing
56		21" iron	left - above Oporto-Madrid crossing
57		18" conc.	left - above Oporto-Madrid crossing
58		24" conc.	right - downstream Oporto-Madrid
59		21" conc.	left - downstream Oporto-Madrid
60	Y	48" conc.	left - downstream Oporto-Madrid
60a	Y	36" conc.	right - back from creek
61(abcd)		16" clay	left - at 75th St. crossing
62		open ditch	left - downstream75th St.
63		48" conc.	right - downstream75th St.
64	Y	open ditch	left - about 200 ft. above airport underground
65	Y	open ditch	right - just above airport underground

TABLE D-2. SAMPLE OUTFALL EVALUATION SHEET

Sample #19

Outfall # 65 Photograph # 21 Date: 11/14/91

Location: last outfall above enclosed reach

Weather: Air temp: 58°F Rain: Y [✓ N] Sunny [✓ Cloudy]

Outfall Flow Estimate: 5 L/sec

Industrial or commercial activity in drainage area? [✓ Y] N

Describe: airport maintenance

PHYSICAL OBSERVATIONS:

Odor: none sewage sulfur oil gas rancid-sour other

Color: clear yellow brown green red [✓ gray] other

HACH color=30 units

Turbidity: clear cloudy [✓ opaque]

Floatables: [✓ none] oil sheen sewage other

Deposits/Stains: [✓ none] sediment oily describe

Vegetation Conditions/growth: [✓ normal] excessive inhibited

Damage to outfall structure:

[✓ none] cracking spalling peeling corrosion

other

identify structure

extent

ANALYSES:			**EQUIPMENT USED:**
Specific conductivity:	225	µS/cm	YSI 33
Temperature:	13	°C	YSI 33
Flouride:	0.87	mg/L	Accu-vac
Hardness:	137	mg/L	digital titrator
Surfactants:	0	mg/L	extraction & color.
Flourescence:	52	% of scale	Turner 111
Potassium:	2.3	mg/L	HACH DR/2000
Ammonia:	BDL	mg/L as N	DR/2000 direct Nessler
pH:	7.74		Fisher Accumet
chlorine:	0.01	mg/L	Accu-vac

TABLE D-3. POTENTIAL DISCHARGER EVALUATION SHEET

Name of facility: ____

Description: ____

Location: ____

Outfall # ________________ Photograph:________________ ID#______________________

Zoning: Agricultural   Residential   Industrial   Commercial

Evidence of direct process connection? Y   N

Describe: ____

____

____

Evidence of indirect discharge? Y   N

Describe: ____

____

____

Equipment or material stored outside? Y   N

Describe: ____

____

____

Evidence of septic system failure? Y   N

Describe: ____

____

____

Notes: ____

____

____

____

____

TABLE D-4. COMMERCIAL AND INDUSTRIAL OPERATIONS IN THE VILLAGE CREEK DRAINAGE AREA

Site #	Business	Description
1	The Dobbins Co.	N.A.
2	?	Looks like auto shop, may be out of business
3	American Legion	N.A.
4	Hill Crest Hospital	Laundry
5	Southtrust Processing	N.A.
6	Food Fair	N.A.
7	Security Training	N.A.
8	Chevron	Gas station
9	Handy TV	N.A.
10	Fullilove Automotive	Auto repair (large and dingy looking)
11	STS Auto Clinic	Auto repair
12	Birmingham Corvette	Sales (repair ?)
13	Metro Yamaha	Sales and service
14	Citgo	Gas station
15	Select Car Corner	Auto sales
16	Auto Zone	Auto parts
17	Bo's Home Improvement	Car sales
18	McCay Tire Co.	Auto service
19	Harley-Davidson	Sales and service
20	Jebs Auto Sales	Auto sales
21	Showcase Cars	Auto sales
22	East Lake Auto Clinic	Auto repair
23	Trammel Auto Sales	Auto sales
24	Axiom Auto Sales	Auto sales
25	J & J Auto Brokers	Auto sales
26	Byrd's Tire and Auto Service	Auto repair
27	Motors Auto Sales	Auto sales
28	MTO Motors Auto Sales	Auto sales
29	Gallery of Cars Inc.	Auto sales and service
30	NAPA Auto Parts	Auto parts
31	Payless Used Tires	Auto service and car wash (dingy). Wash cars outside (direct runoff)
32	Chevron	Gas and car wash
33	Don Bland Body Shop	Auto repair
34	Bama Motel	Laundry
35	Exxon	Gas and car wash
36	Airport Service St.	Gas station
37	Dandy RV Sales	Sales and service
38	Magic City Kawasaki	Sales
39	Ellis Wrecker Service	Next to and seems to work with #40
40	Herren's Paint and Body Shop	Auto repair
41	Jim Crocker Auto	Auto sales
42	Exxon	Gas station
43	Tony's Auto Sales	Auto sales
44	East Lake Auto Parts	Auto parts and machine shop
45	Gene's Auto Service	Auto repair
46	E1 Rancho Motel	Laundry
47	Anchor Motel	Laundry
48	Tucker Paint and Body Shop	Large auto repair (several buildings)
49	Allens Auto Sales	Auto sales
50	East Lake Auto Sales	Sales and service
51	Easy Food Mart	Gas station

52	Plaza Motel	Laundry
53	Mild to Wild Van Conversions	Sales and service
54	Phillips 66	Gas station
55	85th St. Laundry	Laundry and dry cleaning
56	Highlander Laundry	Laundry and dry cleaning
R1	East Lake Grill	Restaurant

(continued)

TABLE D-4. COMMERCIAL AND INDUSTRIAL OPERATIONS IN THE VILLAGE CREEK DRAINAGE AREA (continued)

Site #	Business	Description
57	Marty's Transmissions	Auto repair
58	Southeastern Dry Cleaners	Parts and service for laundries
59	Car Care 2000	Auto Repair
60	C & R Laundry	Laundry and dry cleaning
61	Regal Cleaners	Laundry and dry cleaning
62	Express Oil Change	Auto service
63	Phillips 66	Gas only
R2	Egg-A-Day	Restaurant
64	Burch and Sons Refrigeration Systems	Keeps ammonia and freon in-house (water coming from bay door)
65	Self Serve Car Wash	6 bays
66	Conoco Gas Station	Gas only
67	Shell Gas Station	Gas and auto service
68	Allens Auto Sales	Sales and repair
69	Chevron Gas Station	Gas only
70	Phillips 66 Car Wash	Big tunnel type
71	Roebuck Chrysler	New car dealer
R3	Catfish Cabin	Restaurant
72	Lake Highland Gas St.	Looks closed
73	Dave Smith Auto Trim	Vinyl tops
R4	Arby's	Restaurant
74	Roebuck Mazda	New car dealer
75	World Sales Used Cars	Used cars
76	Magic City Auto Bro.	Used cars
77	? Used Cars	Used cars
R5	Pasquales Pizza	Restaurant
78	? Cleaners	Laundry and dry cleaning
R6	E1-Gringo	Restaurant
R7	Shoney's	Restaurant
R8	Pizza Hut	Restaurant
79	Safelite Auto Glass	Installation
80	Unocal 76 Gas St.	Gas and auto repair
81	BP Gas Station	Gas only
82	House Of Cars	Used cars (closed)
R9	Krystal	Restaurant
R10	Pioneer Cafeteria	Restaurant
83	Metro Transmission	Auto repair
R11	Baskin-Robbins	Restaurant
R12	Subway Sandwiches	Restaurant
R13	Waffle House	Restaurant
84	Parkway Inn	Laundry
R14	Milo's	Restaurant
R15	Denny's	Restaurant
85	Shell Gas Station	Gas only
86	Dan Tucker Auto Sales	Used cars

87	Chevron Gas Station	Gas and auto repair
R16	McDonald's	Restaurant
R17	Arlie's	Restaurant
88	Royal Honda	New car dealer
89	National Tire Wholesale	Tires and auto repair
R18	Blimpie's	Restaurant
R19	Chucke-Cheese	Restaurant
R20	Mrs. Winners	Restaurant
R21	Chick-Fil-A	Restaurant
90	Eastern Glass	Auto glass and trim
91	Gray's Auto Service	Auto repair
R22	Spud's Pub	Restaurant
92	Quality Cleaners	Laundry & dry cleaning

(continued)

TABLE D-4. COMMERCIAL AND INDUSTRIAL OPERATIONS IN THE VILLAGE CREEK DRAINAGE AREA (continued)

Site #	Business	Description
93	McNuts Radiator	Auto repair
94	Shop-A-Snak	Gas
95	Goodyear	Tires and auto repair
96	Automotive Service Group	Auto repair
R23	Pork Palace	Restaurant
97	Bob's Laundry	Laundry and dry cleaning
98	K-Mart Auto	Auto repair
99	Union 76	Gas only
R24	Steak and Ale	Restaurant
100	Exxon	Gas and repair
101	Gargus Pontiac	New car dealer
102	Chevron	Gas only
103	Sam's Used Cars	Used car dealer
104	Firestone	Auto repair and tires
R25	Taco Bell	Restaurant
105	Dun Rite Cleaners	Laundry and dry cleaning
106	Bel Aire Cleaners	Laundry and dry cleaning
107	Berthons Cleaners	Very big (main store?)
R26	Rally's Hamburgers	Restaurant
108	PTL Auto & Tire	Auto repair and tires
109	Mr. Transmission	Auto repair-signs of very dirty runoff
110	Serra Hyundai	New car dealer
111	Champion Lincoln	New car dealer
112	Jiffy Lube	Oil change
R27	Sadies Buffet	Restaurant
R28	Burger King	Restaurant
R29	Giovanni's	Restaurant
113	Bussey Metal Co.	Metal (tin) shop
114	Anderson Construction Materials	Metal and wood
115	Villa Construction	Materials (rolls of insulation) outside
R30	Kelly's Hamburgers	Restaurant
R31	Contri Brother's	Restaurant
R32	Huddle House	Restaurant
R33	Bobbie's	Restaurant
R34	Burger King	Restaurant
R35	Andrews BBQ	Restaurant

R36	Taco Bell	Restaurant
R37	Church's Chicken	Restaurant
R38	Rally's Hamburgers	Restaurant
R39	Joe and Debs	Restaurant
R40	Subway	Restaurant
116	L & L Auto	Used cars
117	Beasley Auto Repair	Auto repair
R41	Southeastern Meats	Butcher
R42	Fran's Famous	Restaurant
R43	El Palacio	Restaurant
R44	Big East Grill	Restaurant
118	Curry's Auto Paint	Paint and body shop
R45	Krispy Kreme	Restaurant
119	N' and Out	Gas station
R46	Big Bull and Red Place	Restaurant
120	Coin Op Laundry	Laundry

TABLE D-5. OUTFALLS CONTAINING FACILITIES OF CONCERN IN THEIR DRAINAGE AREA

Outfall #			Gas Stations with:							
UAB	**B'ham**	**# of activities**	**Gas only**	**Gas and service**	**Car wash**	**Wash and service**	**Auto repair**	**Auto parts**	**Wrecker service**	**Body shop**
Dry Branch	BD1-BD6	43	3	3			8			1
20	B182	3	1							
26	B177	2			1					
28	B175	4								1
29(z)	B174	2								1
40	B163	7	2						1	1
60(a)	B146	1					1			
	B138	1		1						
62	B137	2					1			
64	B133	33	2		1	1	5	1		1
65	B132	1								

Drainage areas with no known commercial or industrial activity of concern:

1, 2, 3a, 3b, 3c, 3d, 3e, 4a, 4b, 5, 7a, 7b, 7c, 8, 9, 10a, l0b, l0c, l0z, B198, 11, 12, 13, 14, 14z, 15, 16, 16z, B190, 16zz, B188, B187, 17, 18a, 18b, 19ab, 21, 22, 23, 24, 25, 27, 29, B173, 30, 31ab, 32, 33, 34, 35, 36, 37, 38, 39, B162, 40z, 41, B159, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51,B, 51, B154, 52, 53, 54, 55, 56, 57, 58, 59, 60, B144, 61a, 61b, 61c, 61d, B139, 63, B135, and 65

Outfall #		**Used car dealer**	**New car dealer**	**Metal shop**	**Construction**	**Laundry/Dry cleaner**	**Restaurant**
UAB	**B'ham**						
Dry Branch	BD1-BD6	5	2			4	17
20	B182					1	1
26	B177		1				
28	B175	1					2
29(z)	B174					1	
40	B163	3					
60(a)	B146						
	B138						
62	B137	1					
64	B133	10	2	1	2	3	4
65	B132						

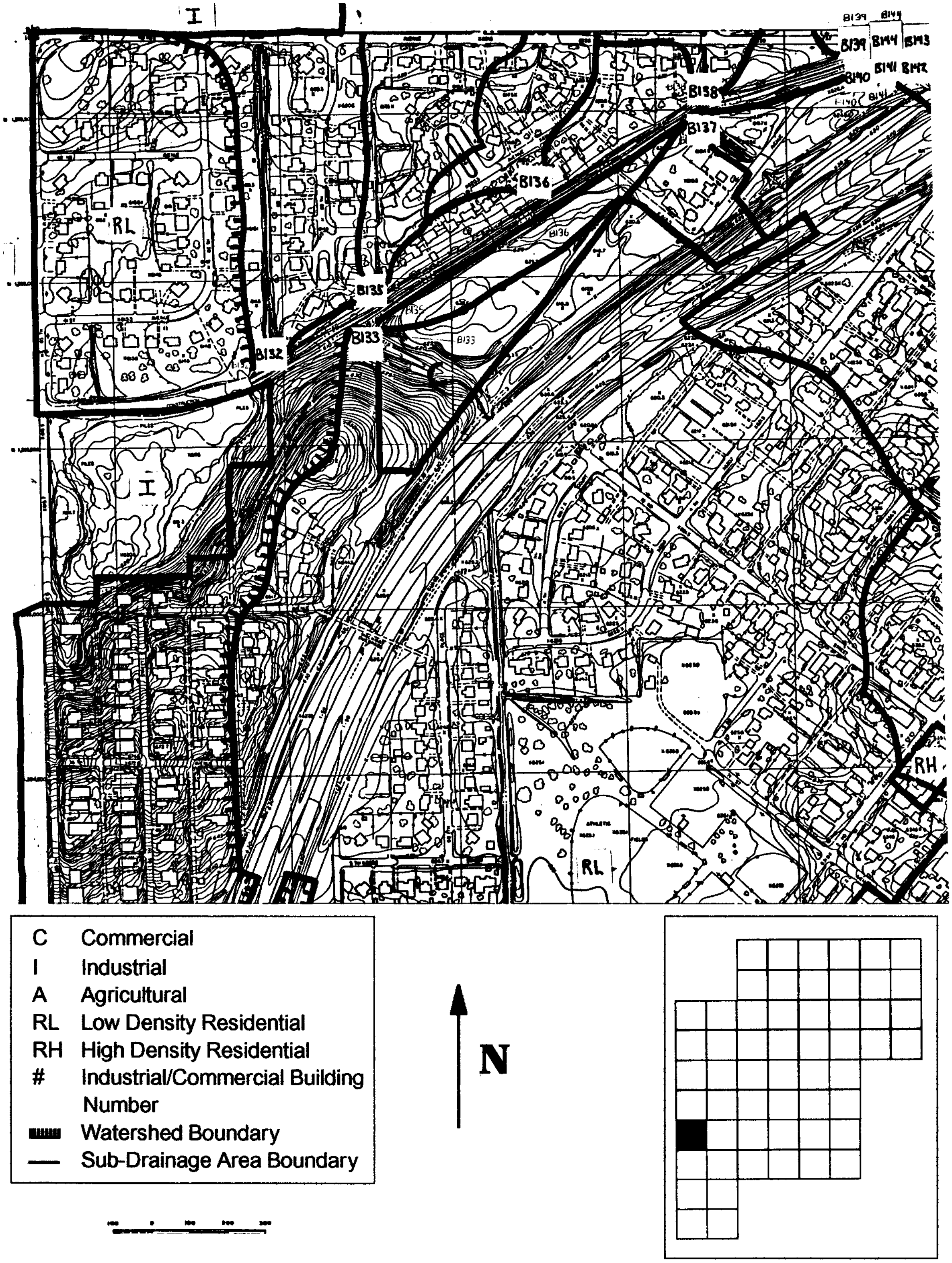


Figure D-1. 72nd Street and 4th Ave. example area showing outfall numbers along Village Creek and associated drainage areas.

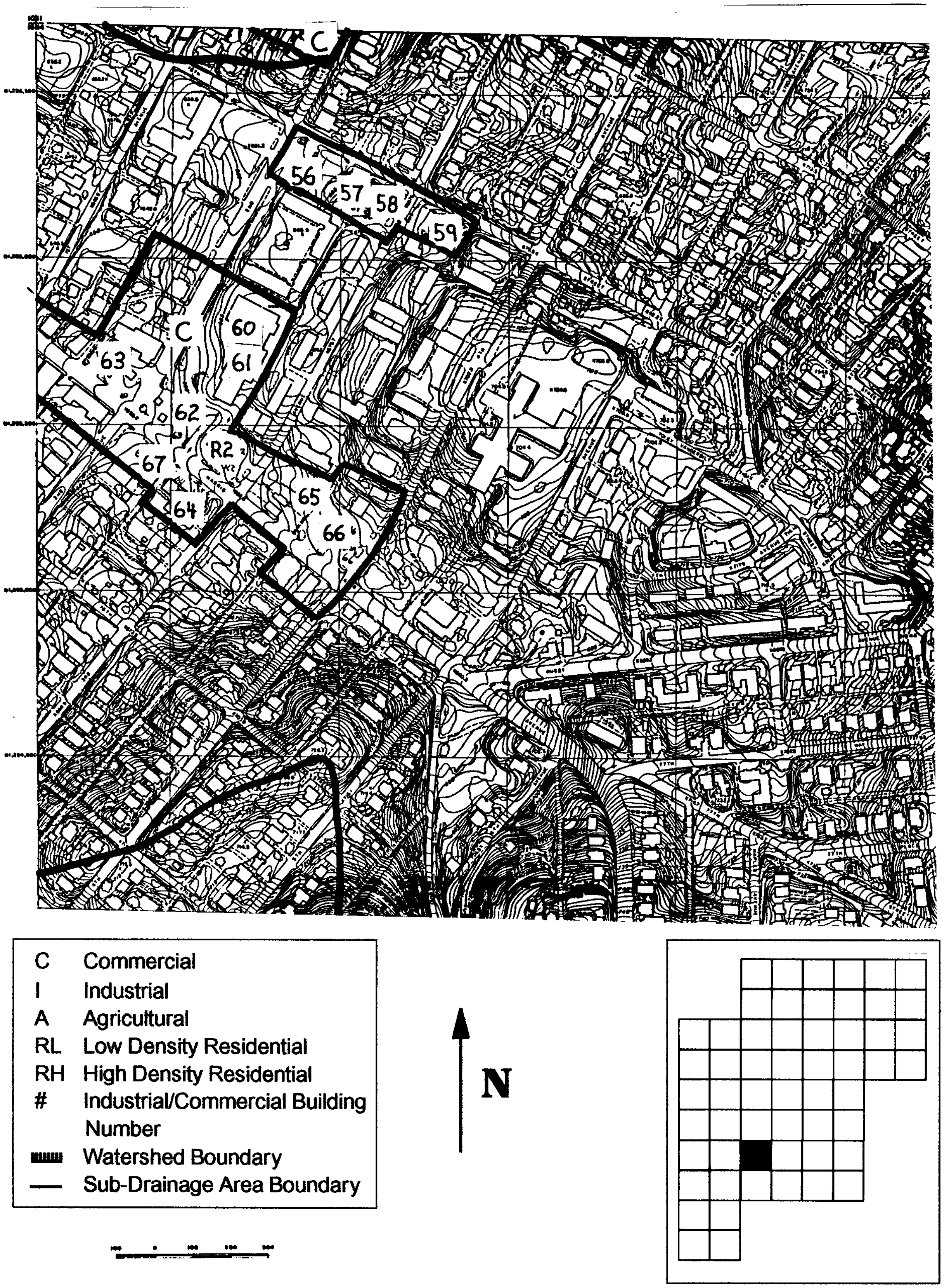


Figure D-2. Oporto-Madrid Ave. and Rugby Ave. example area showing specific commercial establishments in drainage areas.

Appendix E
Source Area Statistical Tests for Birmingham Demonstration Project

TABLE E-1. SPRING WATER SAMPLES

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25 % reduc.)	Copper (mg/L)	Phenols (mg/L)
1	310	0.09	231	0	11	0.83	0.02	6.92	0	0.00	0	NA	NA
2	288	0.01	239	0	4	0.76	0.00	6.89	0	0.00	0	NA	NA
3	327	0.01	255	0	5	0.69	0.01	7.01	0	0.00	0	NA	NA
4	310	0.03	248	0	5	0.72	0.05	6.98	0	0.01	0	0	0
5	301	0.05	240	0	10	0.74	0.00	7.00	0	0.01	0	0	0
6	295	0.00	243	0	2	0.73	0.00	6.87	0	0.00	0	0	0
7	298	0.03	241	0	6	0.56	0.00	6.99	0	0.00	0	0	0
8	290	0.03	229	0	8	0.72	0.00	6.95	0	0.00	0	0	0
9	295	0.05	233	0	10	0.76	0.00	6.99	0	0.01	0	0	0
10	298	0.01	239	0	7	0.77	0.01	7.01	0	0.00	0	0	0
mean	301	0.03	240	0	7	0.73	0.01	6.96	0	0.00	0	0	0
st. dev.	11.6	0.03	7.83	0	2.9	0.07	0.02	0.05	0	0.00	0	0	0
95%conf limits (mean +/-)	6.87	0.02	4.63	0	1.7	0.04	0.01	0.03	0	0.00	0	0	0
median	298	0.03	240	0	7	0.74	0.00	6.99	0	0.00	0	0	0
COV	0.04	1.00	0.03	--	0.43	0.10	2.00	0.01	--	--	--	--	--
distribution	normal	normal	normal	uniform	normal	normal	l-norm	normal	uniform	uniform	uniform	uniform	uniform

NA: Data not available

TABLE E-2. SHALLOW GROUND WATER SAMPLES

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25 % reduc.)	Copper (mg/L)	Phenols (mg/L)
1	5	0.08	5	0	7	NA	NA	NA	5	0.04	0	0.01	0
2	5	0.03	22	0	12	NA	NA	NA	20	0.00	0	0.01	0
3	32	0.14	18	0	160	NA	NA	7.8	35	0.08	0	0.00	0
4	128	0.07	41	0	34	1.70	0.38	6.2	0	0.02	0	0.00	0
5	119	0.05	38	0	22	2.15	0.89	5.4	0	0.00	0	0.00	0
6	77	0.04	29	0	15	0.81	0.08	6.4	10	0.01	0	0.00	0
7	31	0.05	32	0	8	0.91	0.05	6.5	5	0.00	0	0.00	0
8	43	0.06	35	0	11	0.89	0.09	6.7	0	0.00	0	0.00	0
9	46	0.04	27	0	17	1.01	0.13	6.4	5	0.01	0	0.00	0
10	28	0.07	26	0	13	0.83	0.08	6.3	0	0.00	0	0.00	0
mean	51	0.06	27	0	30	1.19	0.24	6.46	8	0.02	0	0.00	0
st. dev.	43.3	0.03	10.5	0	46.4	0.53	0.31	0.66	11.4	0.03	0	0.00	0
95%conf limits (mean +/-)	34.6	0.03	8.48	0	37.1	0.42	0.25	0.53	9	0.02	0	0.00	0
median	38	0.06	28	0	14	0.91	0.09	6.40	5	0.01	0	0.00	0
COV	0.84	0.50	0.39	--	1.55	0.44	1.26	0.10	1.42	1.50	--	--	--
distribution	normal	l-normal	normal	uniform	l-normal	normal	normal	normal	l-normal	normal	uniform	uniform	uniform

NA: Data not available

TABLE E-3. SAMPLES FROM IRRIGATION OF LANDSCAPED AREAS

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25) (% reduc.)	Copper (mg/L)	Phenols (mg/L)
1	109	0.98	42.3	0	132.1	6.46	0.28	6.88	5	0.03	0.0	0.00	0.00
2	119	0.93	39.0	0	218.6	9.42	0.24	6.90	15	0.05	0.0	0.00	0.00
3	92	1.65	41.4	0	267.6	3.21	0.55	7.09	15	0.08	0.0	0.00	0.00
4	98	1.94	40.4	0	199.9	6.32	0.40	7.04	10	0.02	0.0	0.00	0.00
5	107	0.97	39.4	0	231.6	5.44	0.41	6.90	10	0.03	0.0	0.00	0.00
6	110	0.81	38.0	0	242.0	6.71	0.37	7.02	13	0.00	0.0	0.00	0.00
7	100	0.93	39.0	0	212.4	6.49	0.31	7.01	10	0.03	0.0	0.00	0.00
8	102	0.89	41.0	0	201.2	4.98	0.48	6.89	7	0.01	0.0	0.00	0.00
9	106	0.91	42.0	0	223.6	5.79	0.35	6.91	5	0.00	0.0	0.00	0.00
10	107	0.98	39.0	0	215.0	6.01	0.32	6.98	10	0.00	0.0	0.00	0.00
mean	105	0.90	40.2	0	214.4	6.08	0.37	6.96	10	0.03	0.0	0.00	0.00
st. dev.	7.28	0.10	1.47	0	35.20	1.56	0.09	0.08	3.62	0.03	0.00	0.00	0.00
95%conf. limits (mean +/-)	5.83	0.08	1.18	0	28.17	1.25	0.07	0.06	2.90	0.02	0.00	0.00	0.00
median	106	0.93	39.9	0	216.80	6.17	0.36	6.95	10	0.03	0.0	0.00	0.00
COV	0.07	0.11	0.04	--	0.16	0.26	0.25	0.01	0.36	1.00	--	--	--
distribution	normal	normal	normal	uniform	normal	normal	normal	bi-modal	normal	normal	uniform	uniform	uniform

NA: Data not available

TABLE E-4. RESIDENTIAL/COMMERCIAL SANITARY SEWAGE SAMPLES

Sample #	Collection Date	Collection Time	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)
1	1-Aug	10 p.m.	265	0.90	149	0.96	240	5.25
2	2-Aug	12 a.m.	320	0.72	161	3.80	200	4.79
3	2-Aiug	2 a.m.	360	0.46	172	0.58	170	3.44
4	2-Aug	4 a.m.	350	0.58	181	0.54	155	3.09
5	2-Aug	6 a.m.	410	0.74	167	0.54	205	4.51
6	2-Aug	8 a.m.	435	0.87	154	0.99	265	5.88
7	2-Aug	10 a.m.	410	1.08	150	0.48	265	5.99
8	2-Aug	12 p.m.	400	0.77	145	3.60	270	5.70
9	2-Aug	2 p.m.	410	0.83	149	0.54	280	7.50
10	2-Aug	4 p.m.	460	0.93	151	0.95	265	7.20
11	2-Aug	6 p.m.	410	0.88	156	0.98	265	6.78
12	2-Aug	8 p.m.	430	0.88	158	0.96	300	7.56
13	4-Aug	6 p.m.	550	0.69	145	4.20	280	7.00
14	4-Aug	8 p.m.	460	0.64	133	4.40	280	6.73
15	4-Aug	10 p.m.	500	0.74	123	0.97	265	6.05
16	5-Aug	12 a.m.	420	0.60	142	0.99	227	4.03
17	5-Aug	2 a.m.	360	0.54	148	0.65	175	3.55
18	5-Aug	4 a.m.	365	0.43	158	0.64	120	4.94
19	5-Aug	6 a.m.	390	0.60	142	0.62	230	7.47
20	5-Aug	8 a.m.	500	1.04	126	0.65	310	7.13
21	5-Aug	10 a.m.	450	0.80	125	0.96	315	6.87
22	5-Aug	12 p.m.	430	0.97	126	0.98	310	6.88
23	5-Aug	2 p.m.	420	0.85	126	0.90	300	7.07
24	5-Aug	4 p.m.	460	0.83	122	0.94	290	7.55
25	6-Aug	6 p.m.	440	0.81	127	2.40	280	7.14
26	6-Aug	8 p.m.	435	0.66	123	1.60	290	6.75
27	6-Aug	10 p.m.	400	0.77	120	0.97	265	6.12
28	7-Aug	12 a.m.	390	0.67	133	0.96	210	5.06
29	7-Aug	2 a.m.	340	0.44	149	0.89	175	3.59
30	7-Aug	4 a.m.	400	0.43	141	0.76	170	3.57
31	7-Aug	6 a.m.	420	0.68	138	0.98	300	6.65
32	7-Aug	8 a.m.	465	1.04	136	0.95	260	5.68
33	7-Aug	10 a.m.	460	0.94	141	3.00	280	6.69
34	7-Aug	12 p.m.	460	0.89	138	3.60	285	6.93
35	7-Aug	2 p.m.	490	0.85	135	4.00	265	7.11
36	7-Aug	4 p.m.	450	0.83	155	2.00	270	6.69
mean			420	0.76	143	1.50	251	5.97
st.dev.			55.14	0.17	15.04	1.22	49.88	1.36
95% conf. limits (mean +/-)			18.01	0.06	4.91	0.40	16.33	0.45
median			420	0.79	142	0.96	265	6.67
COV			0.13	0.23	0.11	0.82	0.20	0.23
distribution			normal	normal	normal	normal	normal	normal

(continued)

TABLE E-4. (continued)

Sample #	Collection Date	Collection Time	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25) (% reduc.)	Copper (mg/L)	Phenols (mg/L)
1	1-Aug	10 p.m.	8.59	7.35	42	0.01	23.8	0.01	0.00
2	2-Aug	12 a.m.	7.25	7.23	10	0.03	29.2	0.00	0.00
3	2-Aiug	2 a.m.	5.02	7.33	12	0.03	30.3	0.00	0.00
4	2-Aug	4 a.m.	5.22	7.24	8	0.01	26.0	0.00	0.00
5	2-Aug	6 a.m.	13.04	7.35	11	0.02	16.3	0.00	0.00
6	2-Aug	8 a.m.	14.23	7.30	12	0.00	23.8	0.00	0.00
7	2-Aug	10 a.m.	13.03	7.17	15	0.01	20.6	0.01	0.00
8	2-Aug	12 p.m.	9.67	6.97	31	0.00	21.7	0.02	0.00
9	2-Aug	2 p.m.	8.00	6.98	28	0.00	15.3	0.00	0.00
10	2-Aug	4 p.m.	8.81	7.12	22	0.00	11.0	0.00	0.00
11	2-Aug	6 p.m.	7.82	7.03	23	0.00	17.4	0.00	0.00
12	2-Aug	8 p.m.	7.32	7.09	21	0.05	19.5	0.01	0.00
13	4-Aug	6 p.m.	10.03	7.21	75	0.00	43.3	NA	NA
14	4-Aug	8 p.m.	9.18	6.94	61	0.03	47.2	NA	NA
15	4-Aug	10 p.m.	11.82	7.10	45	0.00	41.7	NA	NA
16	5-Aug	12 a.m.	11.04	6.89	49	0.00	41.1	NA	NA
17	5-Aug	2 a.m.	6.38	7.10	26	0.02	46.7	NA	NA
18	5-Aug	4 a.m.	6.00	7.05	19	0.01	49.6	NA	NA
19	5-Aug	6 a.m.	12.83	7.16	22	0.00	52.2	NA	NA
20	5-Aug	8 a.m.	19.49	7.06	50	0.01	52.8	NA	NA
21	5-Aug	10 a.m.	12.34	6.88	60	0.00	37.8	NA	NA
22	5-Aug	12 p.m.	10.67	7.00	64	0.00	48.9	NA	NA
23	5-Aug	2 p.m.	8.57	6.98	54	0.01	47.8	NA	NA
24	5-Aug	4 p.m.	9.25	7.06	48	0.00	53.3	NA	NA
25	6-Aug	6 p.m.	11.00	7.03	62	0.02	65.4	NA	NA
26	6-Aug	8 p.m.	9.99	6.98	48	0.04	99.6	NA	NA
27	6-Aug	10 p.m.	10.66	7.01	43	0.10	99.4	NA	NA
28	7-Aug	12 a.m.	8.29	7.06	15	0.03	40.5	NA	NA
29	7-Aug	2 a.m.	5.53	7.13	16	0.00	4.2	NA	NA
30	7-Aug	4 a.m.	5.84	7.13	18	0.01	3.1	NA	NA
31	7-Aug	6 a.m.	17.28	7.16	42	0.02	54.0	NA	NA
32	7-Aug	8 a.m.	15.74	7.18	68	0.00	98.3	NA	NA
33	7-Aug	10 a.m.	10.99	7.03	80	0.00	68.6	NA	NA
34	7-Aug	12 p.m.	10.03	7.08	54	0.00	71.9	NA	NA
35	7-Aug	2 p.m.	7.43	6.86	52	0.01	69.7	NA	NA
36	7-Aug	4 p.m.	8.58	7.11	58	0.03	71.9	NA	NA
mean			9.92	7.09	38	0.01	43.4	0.00	0.00
st.dev.			3.33	0.13	20.95	0.02	25.47	0.01	0.00
95% conf. limits (mean +/-)			1.09	0.04	6.84	0.01	8.32	0.00	0.00
median			9.46	7.09	42	0.01	42.5	0.00	0.00
COV			0.34	0.02	0.55	2.00	0.59	--	--
distribution			L-normal	normal	normal	L-normal	normal	uniform	uniform

NA: Data not available

TABLE E-5. RESIDENTIAL SEPTIC TANK DISCHARGE SAMPLES

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25) (% reduc.)	Copper (mg/L)	Phenols (mg/L)
1	82	0.75	252	0.03	511	30.06	117.80	7.23	38	0.03	100	NA	NA
2	108	0.70	186	0.00	547	32.06	124.60	7.38	38	0.01	100	NA	NA
3	56	0.62	186	0.00	536	27.26	114.40	7.16	18	0.00	100	NA	NA
4	397	1.19	36	10.00	266	8.16	26.07	6.61	68	0.01	100	NA	NA
5	482	0.70	29	5.00	321	8.83	135.75	6.53	87	0.03	100	NA	NA
6	362	1.12	36	12.00	351	8.16	26.77	6.67	77	0.00	100	NA	NA
7	812	0.92	80	0.50	466	20.85	89.60	6.63	54	0.00	100	NA	NA
8	812	1.55	84	0.15	431	23.25	91.60	6.59	64	0.01	100	NA	NA
9	762	1.26	82	0.57	471	22.25	86.10	6.54	91	0.03	100	NA	NA
10	432	0.61	45	2.50	455	24.51	95.90	7.39	55	0.20	100	0.00	0.00
11	297	0.42	53	1.00	253	18.66	107.80	6.19	10	0.00	100	0.00	0.00
12	236	0.56	61	0.50	463	21.73	99.30	6.59	100	0.19	100	0.40	0.00
13	327	0.87	63	0.45	339	31.81	113.20	6.72	100	0.20	100	0.35	0.00
mean	502	0.93	57	3.27	382	18.82	87.21	6.65	70.60	0.07	100	0.19	0.00
st. dev.	209.87	0.36	20.52	4.35	84.95	7.97	35.11	0.30	27.28	0.09	0.00	0.22	0.00
95%conf. limits (mean +/-)	114.09	0.20	11.16	2.37	46.18	4.33	19.09	0.16	14.83	0.05	0.00	0.12	0.00
median	414	0.90	57	0.79	391	21.29	93.75	6.60	72.50	0.02	100	0.18	0.00
COV	0.42	0.39	0.36	1.33	0.22	0.42	0.40	0.04	0.39	1.28	0.00	1.16	--
distribution	normal	normal	log-normal	log-normal	normal	normal	normal	normal	normal	normal	uniform	bi-modal	uniform

NA: Data not available

TABLE E-6. COMMERCIAL CARWASH SAMPLES

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25) (% reduc.)	Copper (mg/L)	Phenols (mg/L)
1	448	16.5	145	50.4	1325	22.00	0.28	6.49	380	0.00	100	0.00	0.00
2	450	11.5	149	52.2	1350	22.00	0.32	6.46	340	0.00	100	0.00	0.00
3	550	12.5	152	52.5	1400	78.40	0.20	7.11	190	0.00	100	0.00	0.00
4	490	15.5	150	49.0	1100	40.70	0.23	6.90	190	0.01	100	0.00	0.00
5	495	12.5	158	56.7	1075	47.70	0.19	6.84	190	0.00	100	0.00	0.00
6	470	8.0	160	50.3	1095	35.40	0.14	6.77	240	0.02	100	0.00	0.00
7	480	10.2	172	38.0	1005	48.20	0.23	6.76	200	0.08	100	NA	NA
8	473	11.8	165	49.0	1155	46.20	0.25	6.67	175	0.23	100	NA	NA
9	492	12.3	159	43.5	1190	16.70	0.19	6.40	160	0.12	100	0.00	0.00
10	505	12.2	155	48.0	1205	39.60	0.36	6.80	150	0.15	100	0.00	0.00
mean	485	12.3	157	49.0	1190	42.69	0.24	6.72	222	0.07	100	0.00	0.00
st. dev.	9.41	2.40	8.07	5.14	130.79	15.92	0.07	0.22	77.46	0.08	0.00	0.00	0.00
95%conf. limits (mean +/-)	8.23	1.49	5.00	3.19	81.06	9.87	0.04	0.14	48.01	0.05	0.00	0.00	0.00
median	485	12.3	157	49.7	1173	43.45	0.23	6.77	190	0.05	100	0.00	0.00
COV	0.06	0.19	0.05	0.10	0.11	0.37	0.28	0.03	0.35	1.14	0.00	--	--
distribution	normal	normal	normal	normal	normal	normal	normal	normal	normal	bi-modal	uniform	uniform	uniform

NA: Data not available

TABLE E-7. COMMERCIAL LAUNDRY SAMPLES

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25) (% reduc.)	Copper (mg/L)	Phenols (mg/L)
1	752	15.89	32	37.0	1169.6	3.47	0.94	9.37	25	0.57	100	NA	NA
2	462	23.98	40	21.5	1144.6	3.97	0.96	9.40	59	0.51	100	NA	NA
3	422	54.48	38	17.0	844.6	3.37	0.62	8.37	61	0.44	100	NA	NA
4	589	42.48	36	32.5	819.6	3.67	0.70	8.60	43	0.38	100	NA	NA
5	657	48.98	34	35.0	1169.6	3.57	0.84	9.10	49	0.21	100	NA	NA
6	565	31.48	37	31.0	1094.6	3.27	0.91	9.20	30	0.33	100	NA	NA
7	485	22.48	38	20.0	994.6	3.77	0.78	9.41	55	0.42	100	NA	NA
8	715	26.98	33	25.0	1019.6	2.57	0.88	9.05	38	0.47	100	0.00	0.00
9	545	35.98	32	24.0	1019.6	3.67	0.69	9.36	57	0.33	100	0.00	0.00
10	437	25.48	37	26.0	969.9	3.47	0.84	9.12	50	0.35	100	0.00	0.00
mean	563	32.82	36	26.9	1024.6	3.48	0.82	9.10	47	0.40	100	0.00	0.00
st. dev.	115.81	12.45	2.78	6.69	124.61	0.38	0.12	0.35	12.41	0.10	0.00	0.00	0.00
95%conf. limits (mean +/-)	68.44	7.36	1.64	3.96	73.64	0.22	0.07	0.21	7.33	0.06	0.00	0.00	0.00
median	555	29.23	37	25.5	1019.6	3.52	0.84	9.16	50	0.40	100	0.00	0.00
COV	0.21	0.38	0.08	0.25	0.12	0.11	0.14	0.04	0.27	0.26	0.00	--	--
distribution	normal	normal	normal	normal	normal	normal	normal	normal	normal	normal	uniform	uniform	uniform

NA: Data not available

TABLE E-8. RADIATOR WASTE SAMPLES

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as $CaCO_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25) (% reduc.)	Copper (mg/L)	Phenols (mg/L)
1	4250	136.5	0	17.4	20850	3230	16.9	6.95	2933	0.04	100	NA	NA
2	3350	177.0	0	13.8	24000	2446	32.4	6.99	3000	0.02	100	NA	NA
3	4200	172.5	32	14.7	20500	3473	21.0	6.25	3066	0.06	100	NA	NA
4	3321	133.3	12	14.2	21940	2694	18.1	7.01	3000	0.03	100	NA	NA
5	3289	129.8	0	15.1	22210	2902	22.3	6.85	3000	0.04	100	NA	NA
6	3510	121.5	12	18.3	22240	2907	12.2	6.50	3000	0.00	100	NA	NA
7	1900	183.0	0	13.5	22650	2282	8.9	7.61	2933	0.03	100	NA	NA
8	2510	124.5	0	13.5	22250	2364	90.1	7.38	3000	0.03	100	NA	NA
9	2987	170.1	0	14.6	21920	2899	23.8	6.98	3066	0.02	100	NA	NA
10	3466	145.0	0	15.3	21900	2821	17.5	7.11	3000	0.03	100	NA	NA
mean	3278	149.3	5.6	15.04	22046	2801	26.3	6.96	3000	0.03	100	NA	NA
st. dev.	704.32	23.76	10.53	1.62	952.08	374.89	23.32	0.39	44.33	0.02	0.00	NA	NA
95%conf. limits (mean +/-)	436.54	14.73	6.53	1.00	590.10	323.36	14.45	0.24	27.48	0.01	0.00	NA	NA
median	3335	140.8	0	14.65	22075	2864	24.5	6.99	3000	0.03	100	NA	NA
COV	0.21	0.16	1.88	0.11	0.04	0.13	0.89	0.06	0.01	0.52	0.00	NA	NA
distribution	normal	normal	normal	normal	normal	normal	normal	normal	normal	normal	uniform	NA	NA

NA: Data not available

TABLE E-9. PLATING BATH WASTE SAMPLES

Sample #	Conductivity (µS/cm)	Fluoride (mg/L)	Hardness (mg/L) (as CaCO$_3$)	Detergent (mg/L)	Fluoresc. (% scale)	Potassium (mg/L)	Ammonia (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (I25) (% reduc.)	Copper (mg/L)	Phenols (mg/L)
1	16200	9.00	1408	15.0	640.0	774	105.00	1.78	60	0.12	100	0.27	0
2	3620	1.68	950	1.8	505.0	552	74.20	4.82	90	0.27	100	0.00	0
3	8500	1.86	775	10.0	77.5	1730	3.05	5.20	368	0.01	89.4	0.00	0
4	9700	6.00	1452	9.0	225.0	186	139.37	6.15	70	0.08	100	0.21	0
5	10200	5.52	1476	11.4	390.0	220	29.33	3.36	90	0.00	100	0.32	0
6	7000	5.85	1818	1.5	88.0	490	76.00	8.60	50	0.04	68.4	0.07	0
7	8000	6.00	2433	1.6	75.0	356	58.60	7.60	50	0.03	90.5	0.05	0
8	12500	7.95	1484	6.9	510.5	380	60.90	3.10	75	0.02	100	0.35	0
9	8100	4.20	1398	3.9	147.5	1100	101.00	2.50	110	0.00	100	0.48	0
10	19700	3.20	1091	7.0	275.0	4300	9.05	6.20	75	0.19	100	0.00	0
mean	10352	5.13	1429	6.8	293.4	1009	65.65	4.93	104	0.08	94.8	0.18	0.00
st. dev.	4681.35	2.41	464.03	4.63	206.61	1247.85	43.37	2.25	94.71	0.09	10.15	0.17	0.00
95%conf. limits (mean +/-)	2901.53	1.49	287.61	2.87	128.06	773.42	26.88	1.39	58.70	0.06	6.29	0.11	0.00
median	9100	5.69	1430	6.9	250.0	521	67.55	5.01	75	0.04	100	0.14	0.00
COV	0.45	0.47	0.32	0.68	0.70	1.24	0.66	0.46	0.91	1.20	0.11	0.94	--
distribution	normal	normal	normal	normal	normal	log-normal	normal	normal	normal	normal	bi-modal	uniform	uniform

TABLE E-10. MANN-WHITNEY U TEST ALPHA VALUES FOR CONDUCTIVITY

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.0002	0.0002	0.0000	0.0002	0.0002	0.0002	0.0036	0.0257	0.0002
RADIATOR			0.0002	0.0000	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003
SPRING				0.0000	0.0012	0.0002	0.0002	0.0002	0.0002	0.0001
SEWAGE					0.9894	0.0002	0.0004	0.0001	0.0001	0.0000
SEPTAGE						0.2413	0.2730	0.0014	0.0014	0.0002
LAUNDRY							0.2413	0.0014	0.0014	0.0002
CARWASH								0.0014	0.0014	0.0002
IRRIGATION									0.0233	0.0014
SHALLOW GROUND										0.0014
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

TABLE E-11. MANN-WHITNEY U TEST ALPHA VALUES FOR FLUORIDE

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.0002	0.0001	0.0001	0.4727	0.0002	0.0002	0.1289	0.0014	0.0002
RADIATOR			0.0001	0.0000	0.0002	0.0002	0.0002	0.0014	0.0014	0.0002
SPRING				0.0000	0.0001	0.0001	0.0001	0.0011	0.0348	0.0001
SEWAGE					0.2308	0.0000	0.0000	0.0094	0.0001	0.0000
SEPTAGE						0.0002	0.0002	0.8501	0.0014	0.0002
LAUNDRY							0.0002	0.0014	0.0014	0.0002
CARWASH								0.0014	0.0014	0.0002
IRRIGATION									0.0051	0.0014
SHALLOW GROUND										0.0014
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

TABLE E-12. MANN-WHITNEY U TEST ALPHA VALUES FOR HARDNESS

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.0002	0.0001	0.0000	0.4727	0.0001	0.0002	0.0002	0.0002	0.0002
RADIATOR			0.0002	0.0000	0.0002	0.0001	0.0002	0.0002	0.0019	0.0002
SPRING				0.0000	0.0001	0.0001	0.0001	0.0002	0.0011	0.0127
SEWAGE					0.0000	0.0000	0.0046	0.0000	0.0000	0.0000
SEPTAGE						0.0265	0.0002	0.1405	0.0022	0.0002
LAUNDRY							0.0001	0.0008	0.0346	0.0001
CARWASH								0.0002	0.0002	0.0002
IRRIGATION									0.0013	0.0002
SHALLOW GROUND										0.0002
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

TABLE E-13. MANN-WHITNEY U TEST ALPHA VALUES FOR DETERGENT

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.0001	1.0000	0.0000	0.0001	0.0001	0.0001	0.8919	0.8919	0.0001
RADIATOR			0.0001	0.0000	0.0002	0.0003	0.0002	0.0008	0.0008	0.001
SPRING				0.0000	0.0001	0.0001	0.0001	0.8919	0.8919	0.0001
SEWAGE					0.7798	0.0000	0.0000	0.0000	0.0000	0.0001
SEPTAGE						0.0002	0.0002	0.0008	0.0008	0.0494
LAUNDRY							0.0002	0.0008	0.0008	0.0002
CARWASH								0.0008	0.0008	0.0002
IRRIGATION									1.0000	0.0008
SHALLOW GROUND										0.0008
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

TABLE E-14. MANN-WHITNEY U TEST ALPHA VALUES FOR FLUORESCENCE

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.0002	0.0290	0.0000	0.0002	0.0002	0.0002	0.0014	0.0014	0.0002
RADIATOR			0.0001	0.0000	0.0002	0.0002	0.0002	0.0014	0.0014	0.0002
SPRING				0.0000	0.0001	0.0001	0.0001	0.0011	0.0057	0.0001
SEWAGE					0.0002	0.0000	0.0000	0.0813	0.0001	0.9257
SEPTAGE						0.0002	0.0002	0.0029	0.0014	0.3447
LAUNDRY							0.0173	0.0014	0.0014	0.0002
CARWASH								0.0014	0.0014	0.0002
IRRIGATION									0.0082	0.7042
SHALLOW GROUND										0.0057
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

TABLE E-15. MANN-WHITNEY U TEST ALPHA VALUES FOR POTASSIUM

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.0002	0.0001	0.0000	0.0002	0.0002	0.0002	0.0002	0.1571	0.0002
RADIATOR			0.0001	0.0000	0.0002	0.0002	0.0002	0.0002	0.0142	0.0028
SPRING				0.0000	0.0001	0.0001	0.0001	0.0011	0.0293	0.0001
SEWAGE						0.0001	0.0000	0.5314	0.0048	0.0000
SEPTAGE						0.0002	0.0017	0.0040	0.0008	0.0002
LAUNDRY							0.0002	0.0262	0.0142	0.0002
CARWASH								0.0014	0.0282	0.0002
IRRIGATION									0.0008	0.0014
SHALLOW GROUND										0.0008
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

TABLE E-16. MANN-WHITNEY U TEST ALPHA VALUES FOR AMMONIA

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.0002	0.0025	0.0000	0.0002	0.0002	0.0002	0.0002	0.0008	0.0002
RADIATOR			0.0001	0.0001	0.0010	0.0002	0.0002	0.0002	0.0008	0.0640
SPRING				0.0000	0.0001	0.0001	0.0001	0.0001	0.0007	0.0001
SEWAGE					0.0000	0.0000	0.0000	0.0000	0.0000	0.0010
SEPTAGE						0.0002	0.0002	0.0002	0.0008	0.2413
LAUNDRY							0.0002	0.0002	0.2049	0.0002
CARWASH								0.0125	0.4469	0.0002
IRRIGATION									1.0000	0.0014
SHALLOW GROUND										0.0142
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

TABLE E-17. MANN-WHITNEY U TEST ALPHA VALUES FOR pH

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.5708	1.0000	0.0007	0.0211	0.0002	0.0211	0.7863	0.2888	0.0376
RADIATOR			0.7513	0.1224	0.0640	0.0002	0.0494	1.0000	0.2293	0.0211
SPRING				0.0008	0.0022	0.0001	0.0035	0.6511	0.1704	0.0221
SEWAGE					0.0001	0.0000	0.0000	0.0355	0.1095	0.0042
SEPTAGE						0.0002	0.2899	0.0108	0.2888	0.0312
LAUNDRY							0.0002	0.0014	0.0058	0.0003
CARWASH								0.0197	0.2031	0.0257
IRRIGATION									0.2410	0.0577
SHALLOW GROUND										0.1573
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

TABLE E-18. MANN-WHITNEY U TEST ALPHA VALUES FOR CHLORINE

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		0.0008	0.0001	0.0000	0.0025	0.2730	0.0013	0.0040	0.0029	0.0022
RADIATOR			0.0008	0.0058	0.6501	0.0002	0.7913	0.9136	0.4159	0.6232
SPRING				0.0648	0.0317	0.0001	0.0620	0.0014	0.0875	0.0060
SEWAGE					0.1621	0.0000	0.1359	0.0441	0.4291	0.0184
SEPTAGE						0.0002	0.9699	0.8283	0.7042	0.6501
LAUNDRY							0.0002	0.0014	0.0014	0.0002
CARWASH								0.7863	0.4808	0.7624
IRRIGATION									0.4712	0.7042
SHALLOW GROUND										0.3028
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

TABLE E-19. MANN-WHITNEY U TEST ALPHA VALUES FOR TOXICITY

	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING	NEUTRALIZED TAP
TAPWATER	0.0002	0.0001	0.5314	0.0002	0.0002	0.0002	0.0014	0.0014	0.002	0.0058
RADIATOR		0.0000	0.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.3787	0.0001
SPRING			0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	0.0001	0.0001
SEWAGE				0.0000	0.0000	0.2716	0.0000	0.0000	0.0000	0.0535
SEPTAGE					1.0000	0.2696	0.0000	0.0000	0.3787	0.0001
LAUNDRY						0.7989	0.0000	0.0000	0.3787	0.0001
CARWASH							0.0000	0.0000	0.3787	0.0001
IRRIGATION								1.0000	0.0008	0.0008
SHALLOW GROUND									0.0008	0.0008
PLATING										0.0002

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference

TABLE E-20. MANN-WHITNEY U TEST ALPHA VALUES FOR COPPER

	TAPWATER	RADIATOR	SPRING	SEWAGE	SEPTAGE	LAUNDRY	CARWASH	IRRIGATION	GROUND	PLATING
TAPWATER		*	0.2696	0.8501	0.665	0.4705	1.0000	0.3374	0.594	0.1376
RADIATOR			*	*	*	*	*	*	*	*
SPRING				0.2716	0.2696	0.7341	1.0000	0.8973	0.4777	0.0209
SEWAGE					0.5083	0.5083	0.2716	0.3531	0.7210	0.0570
SEPTAGE						0.4706	0.2696	0.3374	0.4555	1.0000
LAUNDRY							0.7989	0.9151	0.7491	0.0897
CARWASH								0.9485	0.4777	0.0209
IRRIGATION									0.5752	0.0393
SHALLOW GROUND										0.0577
PLATING										

NOTE: Difference tested at the 95% confidence level
Values ≥ 0.05 denote no significant difference
* = unknown

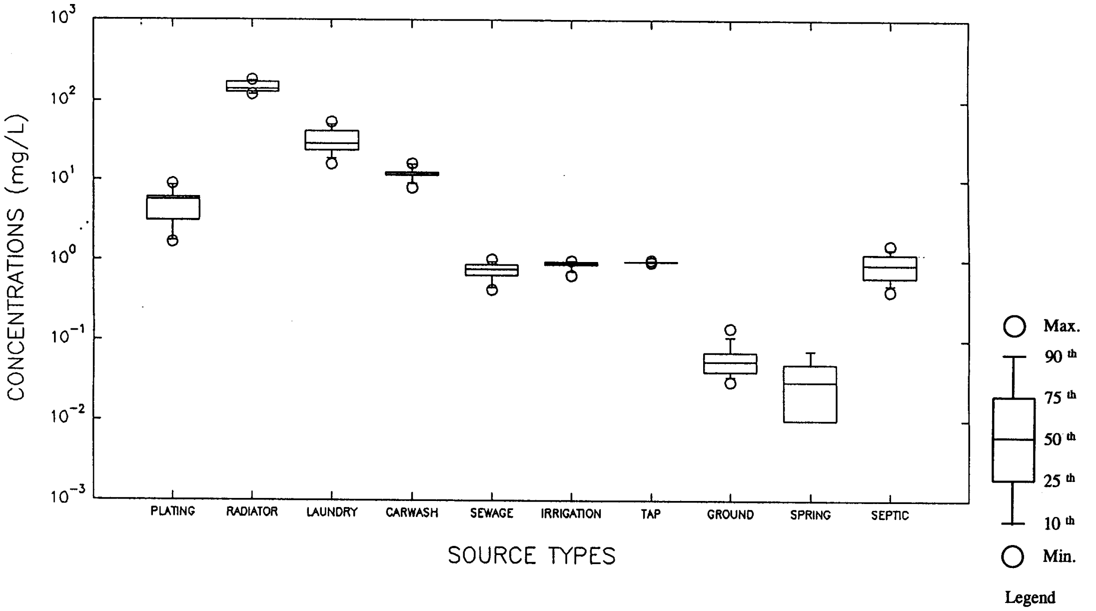


Figure E-1. Fluoride comparisons for different source area flows.

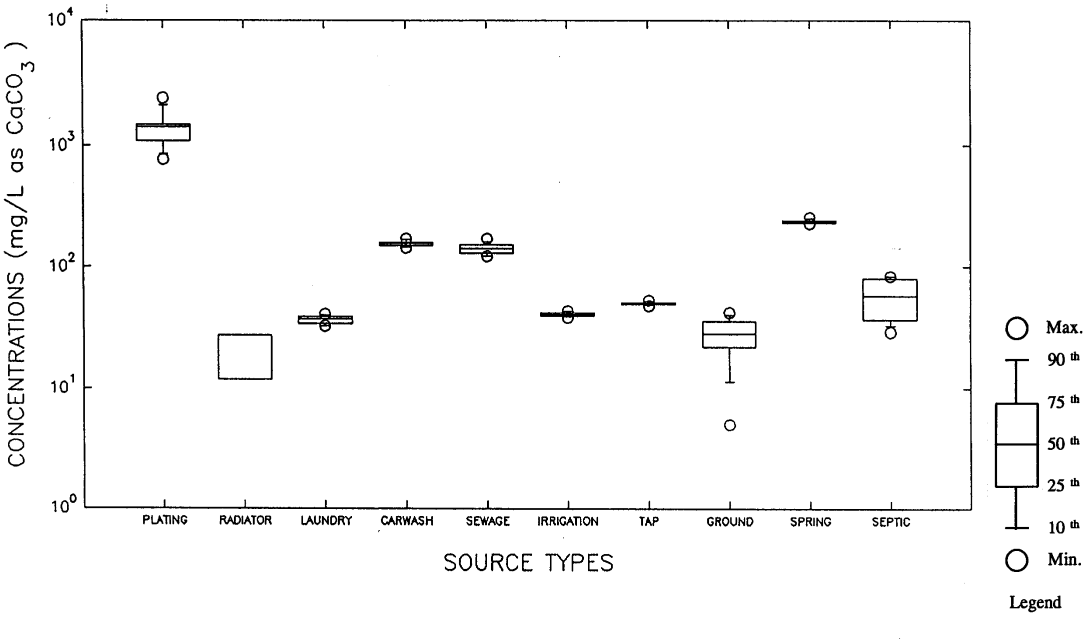


Figure E-2. Hardness comparisons for different source area flows.

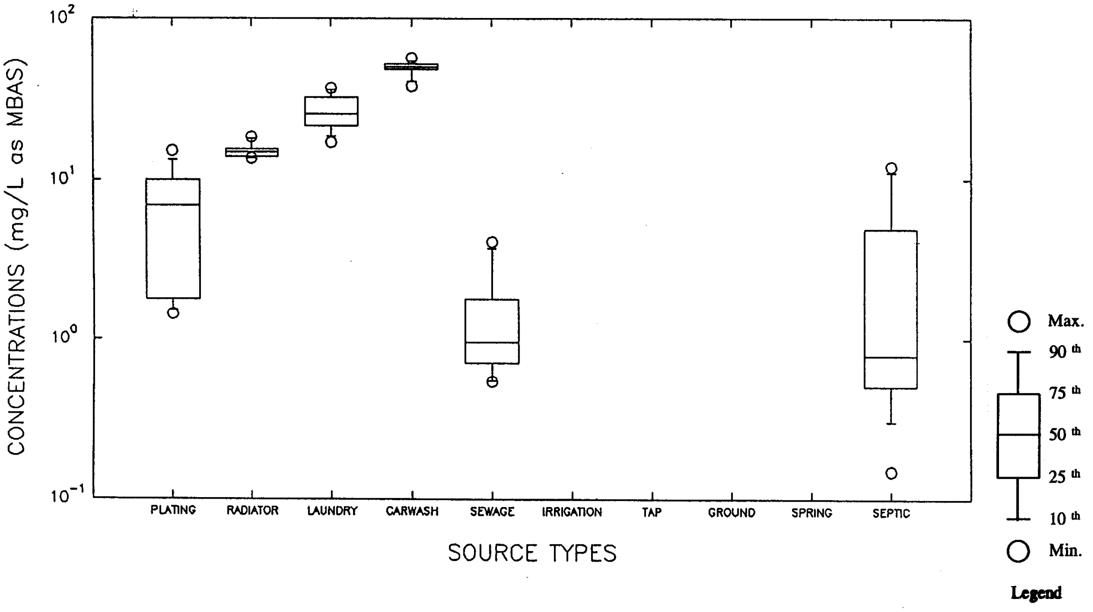


Figure E-3. Detergent comparisons for different source area flows.

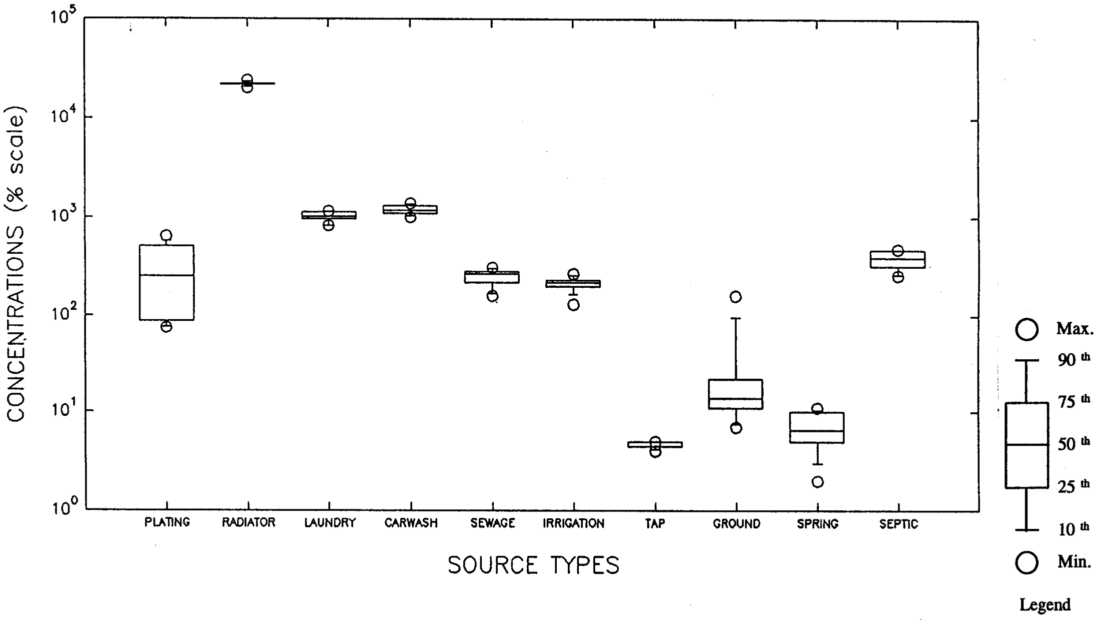


Figure E-4. Fluorescence comparisons for different source area flows.

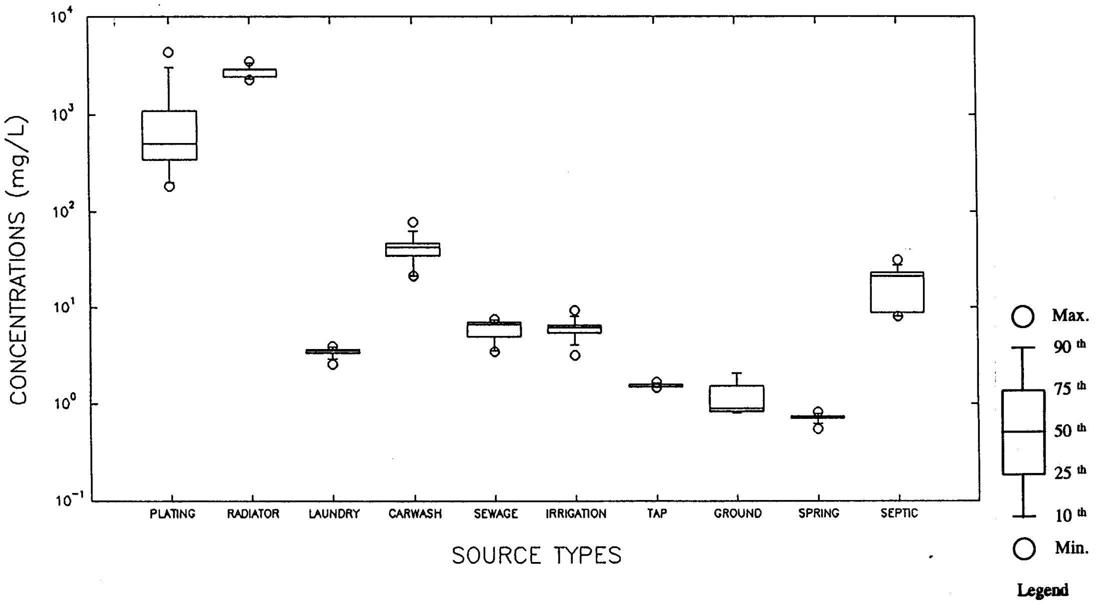


Figure E-5. Potassium comparisons for different source area flows.

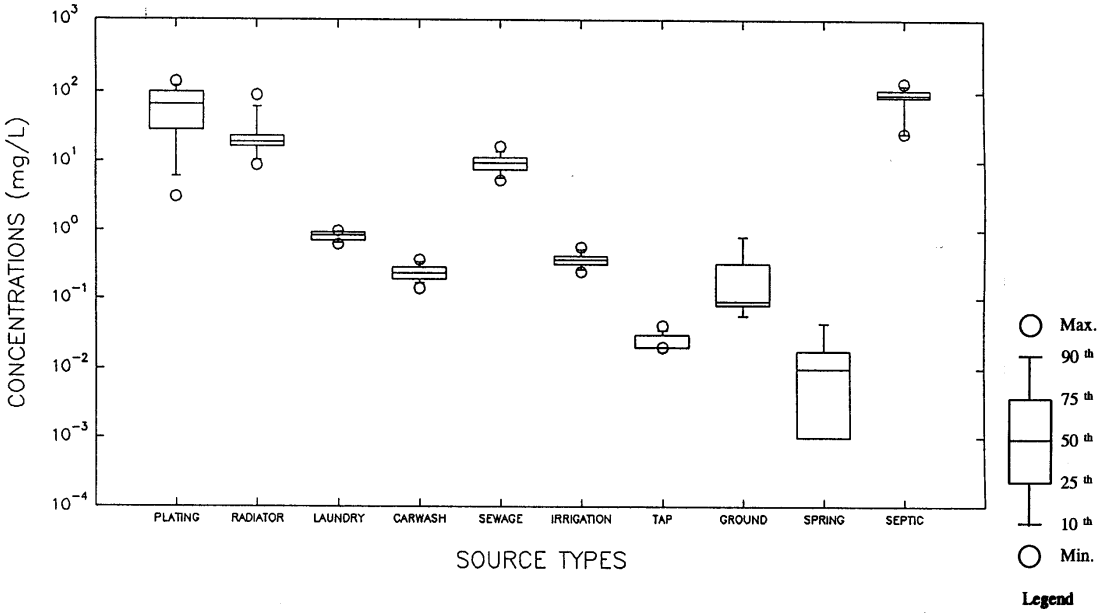


Figure E-6. Ammonia comparisons for different source area flows.

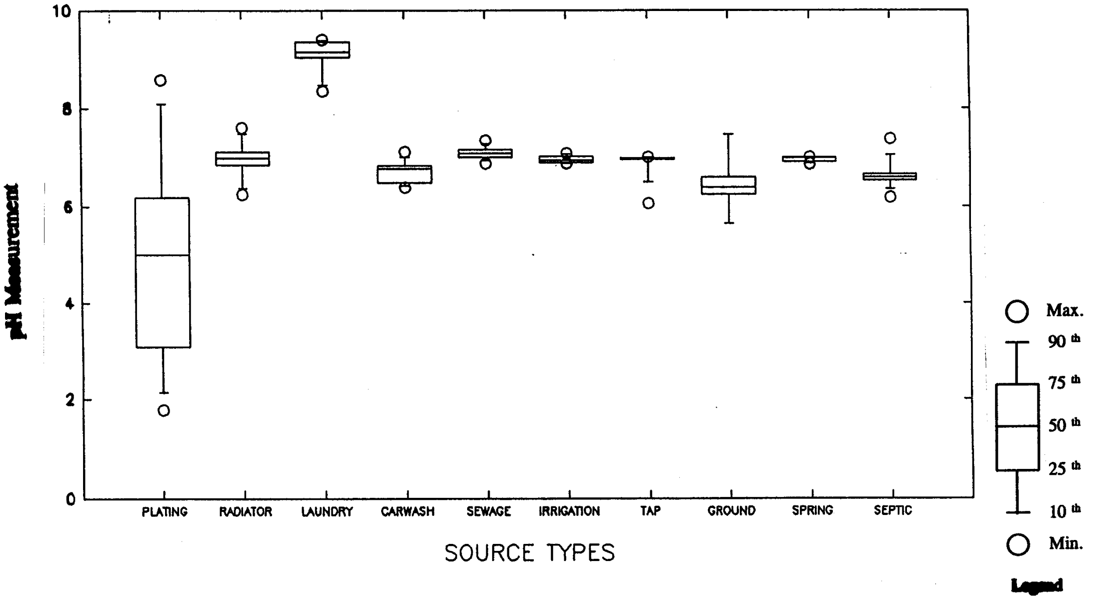


Figure E-7. pH comparisons for different source area flows.

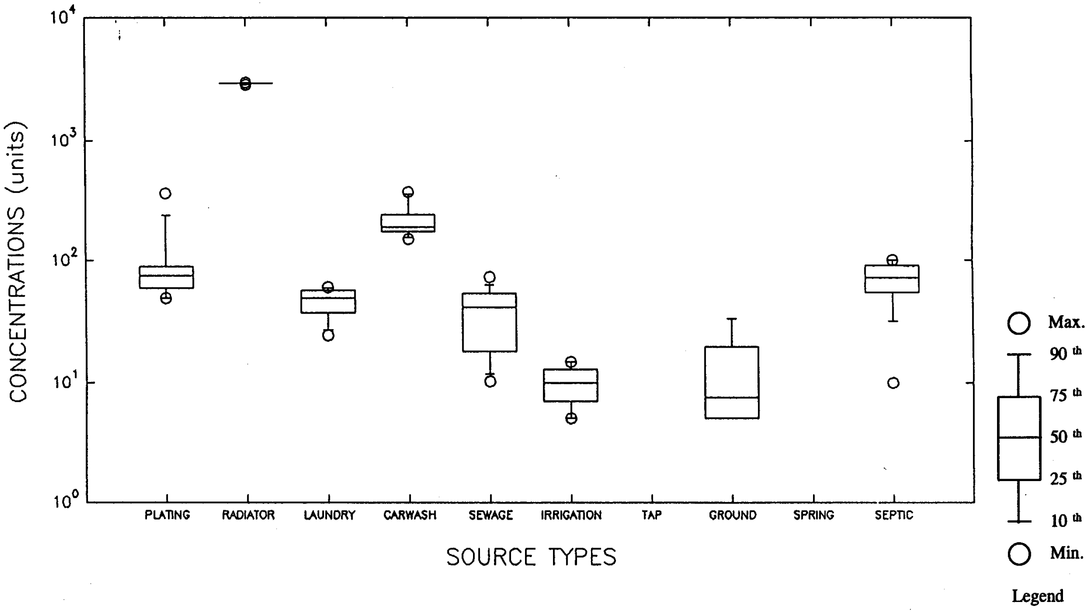


Figure E-8. Color comparisons for different source area flows.

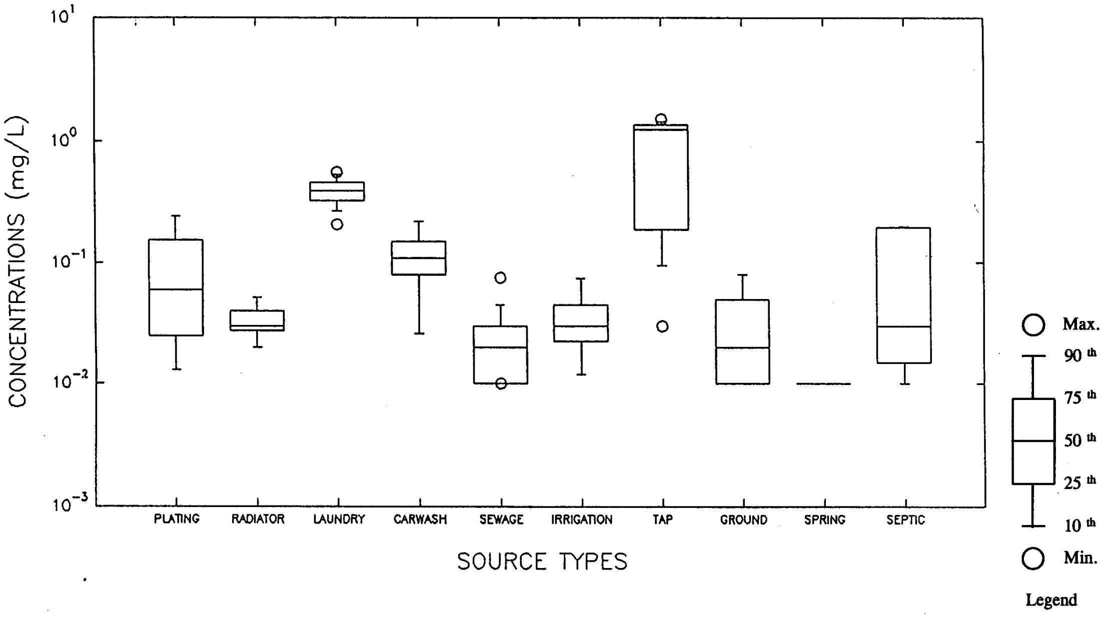


Figure E-9. Chlorine comparisons for different source area flows.

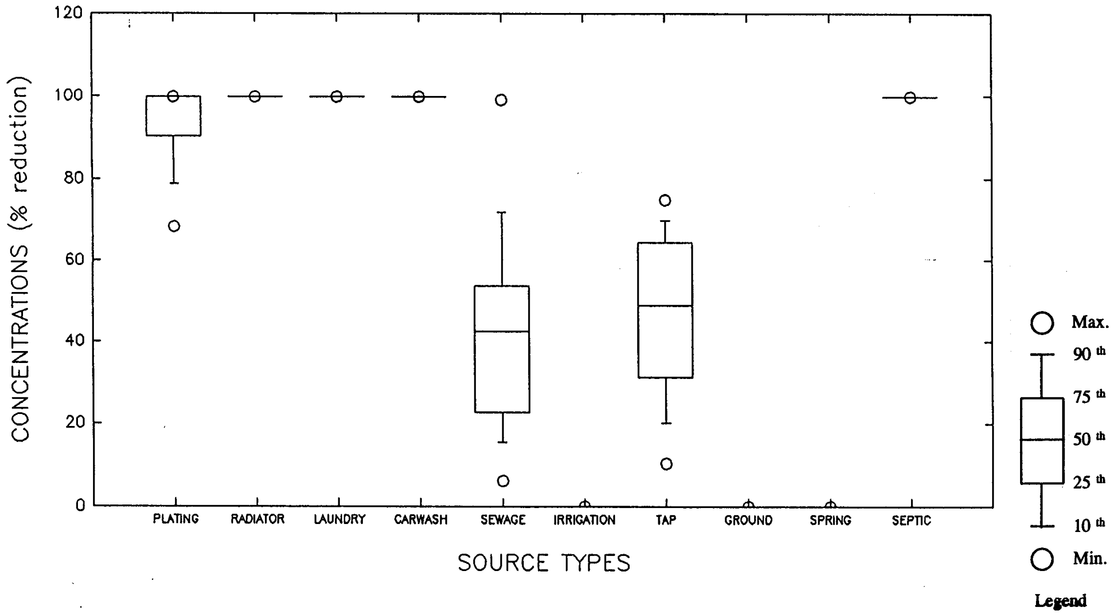


Figure E-10. Microtox comparisons for different source area flows.

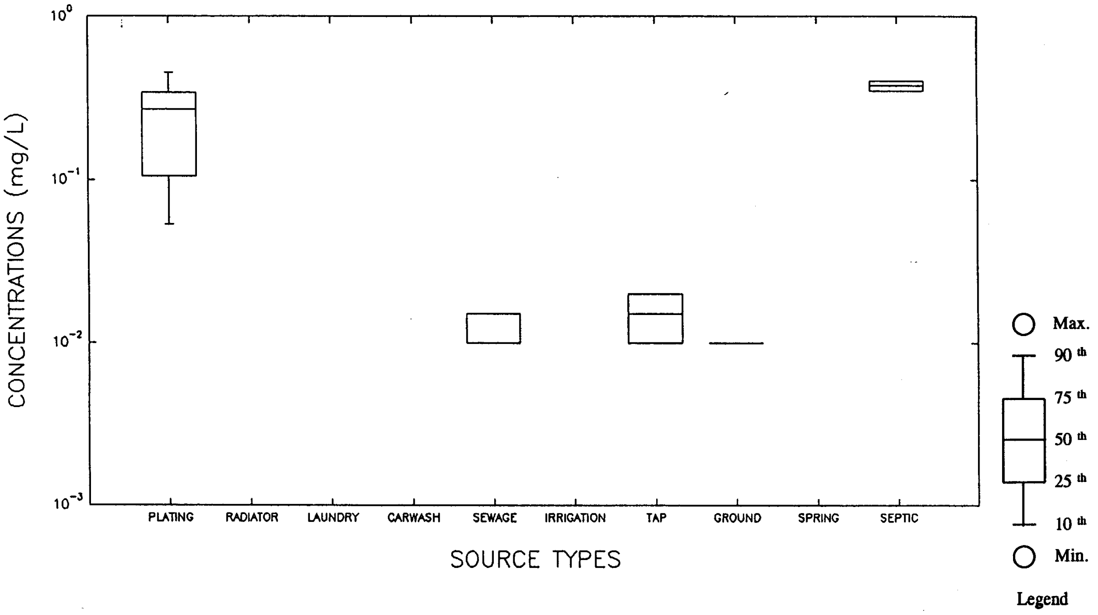


Figure E-11. Copper comparisons for different source area flows.

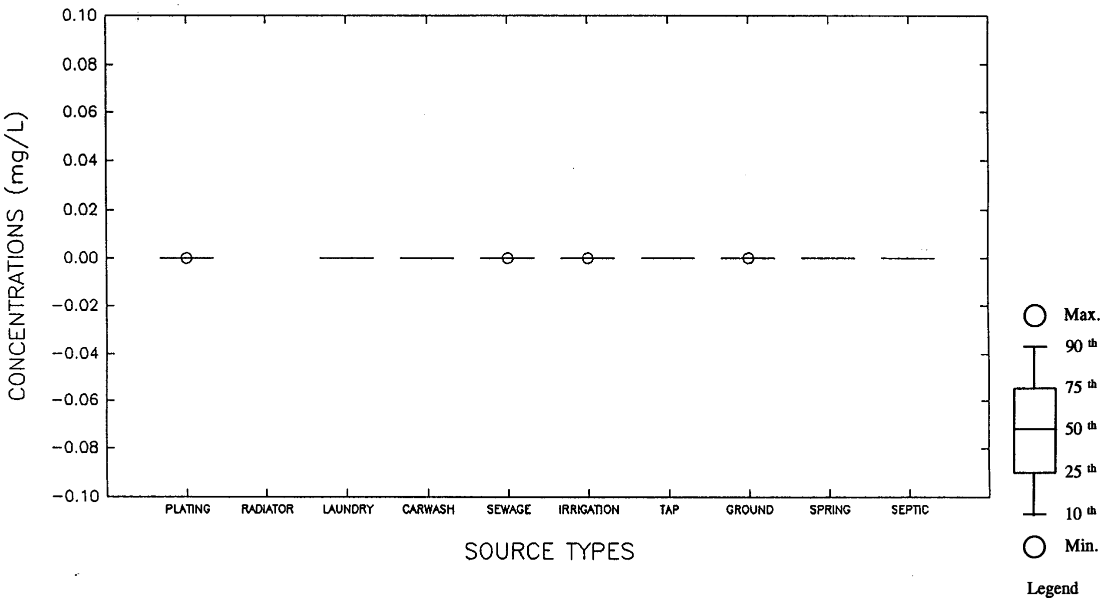


Figure E-12. Phenol comparisons for different source area flows.

Appendix F
Outfall Sample Analytical Results for Birmingham, AL, Verification Tests

Table F-1. Analysis Results for Outfall Samples

Outfall #	Collection Dates	Flow (GPM)	Conductivity (µmhos/cm)	Fluoride (mg/L)	Hardness (mg/L) (CaCO3)	Deterg. (mg/L)	Floresc. (% scale)	K (mg/L)	NH_3 (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (% red.)	Cu (mg/L)	Phenol (mg/L)
14	9/18/90	0.22	375	0.07	195	0	12	0.65	0	7.07	0	0	0		
	1/15/91	0.35	325	0.05	250	0	7	0.6	0	6.98	0	0			
	3/26/91	drip	372	0.07	208	0	13	0.67	0	7.1	0	0			
	4/17/91	drip													
	6/18/91	drip													
	7/25/91	drip													
	10/15/91	drip													
	9/15/92	drip													
*	3/3/93	drip	327	0.04	240	0	9	0.69	0	7.01	0	0	0	0	0
14z	9/18/90	ND													
	1/15/91	ND													
	3/26/91	ND													
	4/17/91	ND													
	6/18/91	18.7	255	0.26	205	0	10	0.86	0	8.16	0	0.01	28.1	0	0
	7/25/91	none													
	10/15/91	none													
	9/15/92	none													
16	9/18/90	none													
	1/15/91	none													
	3/26/91	none													
	4/17/91	none													
	6/18/91	0.1	329	0.05	245	0	8	0.58	0	6.96	0	0	0	0	0
	7/25/91	none													
	10/25/91	none													
	9/15/92	none													

Table F-1. Analysis Results for Outfall Samples (continued)

Outfall #	Collection Dates	Flow (GPM)	Conductivity (µmhos/cm)	Fluoride (mg/L)	Hardness (mg/L) (CaCO3)	Deterg. (mg/L)	Floresc. (% scale)	K (mg/L)	NH_3 (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (% red.)	Cu (mg/L)	Phenol (mg/L)
20	9/24/90	11.7	175	0.92	83	0	38	2.48	0.01	7.55	0	0.01	0		
	1/15/91	12.4	160	0.8	79	0.02	25	2.1	0.12	7.29	0	0			
	3/26/91	18.7	180	0.83	90	0	32	2.68	0.01	7.48	0	0			
	4/17/91	26	240	0.73	111	0	30	2.02	0.14	7.34	0	0.02	5.2		
	6/18/91	70.1	330	0.69	165	0	12	2.7	0.1	7.59	0	0.01			
	7/25/91	74.8	335	0.66	180	0	10	2.86	0.07	7.67	0	0.04			
	10/15/91	10.1	164	0.84	81	0	27	2.05	0.03	7.33	0	0	4.1		
	9/15/92	33	200	0.67	115	0	57	2.15	0.01	7.39	0	0.01		0	0
*	3/3/93	21.4	188	0.61	127	0	13	1.98	0.03	7.11	0	0.02	2.4	0	0
21	9/24/90	2.3	305	2.39	38*	9.5	262	3.46	0.06	7.24	65	0.02	72.4		
	1/15/91	3	310	2.5	int	10.1	300	3.75	0.08	7.18	60	0			
	3/26/91	3.1	285	2.3	int	9.7	295	4.02	0.03	7.2	60	0.01			
	4/17/91	drip													
	6/18/91	none													
	7/25/91	none													
	10/15/91	2.9	415	3	int	15.7	350	4.98	0.13	7.19	100	0.07	99.9	0.03	0.04
*	9/15/92	3.5	480	2.8	85	20	491	5.08	0.11	7.04	120	0.09	99.9	0.04	0.03
22	9/24/90	1	175	2.73	58*	9.5	89	1.74	0.04	6.95	25	0.27	89		
	1/15/91	1	213	2.61	int	10	97	2.98	0.07	6.91	22	0.21			
	3/26/91	1	195	2.5	int	9.7	80	3.26	0.06	7.01	20	0.2			
	4/17/91	drip													
	6/18/91	none													
	7/25/91	none													
	10/15/91	none													
	9/15/92	3	130	1.69	63	14	99	3.79	0.07	6.99	22	0.25	99.9	0.03	0
24	9/24/90	none													
	1/15/91	none													
	3/26/91	none													
	4/17/91	none													
	6/18/91	none													
	7/25/91	none													
	10/15/91	none													
	9/15/92	0.1	190	0	59	0	160				180			0	0

Table F-1. Analysis Results for Outfall Samples (continued)

Outfall #	Collection Dates	Flow (GPM)	Conductivity (µmhos/cm)	Fluoride (mg/L)	Hardness (mg/L) (CaCO3)	Deterg. (mg/L)	Floresc. (% scale)	K (mg/L)	NH_3 (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (% red.)	Cu (mg/L)	Phenol (mg/L)
26	9/24/90	112.2	380	0.08	243	0	9	0.74	0.01	7.8	0	0	0		
	1/15/91	120	385	0.07	240	0	9.5	0.71	0	7.78	0	0			
	3/26/91	84.2	360	0.07	245	0	7	0.8	0	7.8	0	0			
	4/17/91	74.8	350	0.09	231	0	10	0.75	0.01	7.71	0	0.01			
	6/18/91	94.6	382	0.09	238	0	9.5	0.8	0	7.82	0	0.01			
	7/25/91	105.2	385	0.1	222	0	9	0.86	0	7.92	0	0			
	10/15/91	150	341	0.03	235	0	11	0.79	0	7.75	0	0.01	0		
	9/15/92	185	321	0	216	0	14	0.81	0	7.72	0	0	0	0	0
*	3/3/93	142	358	0.07	239	0	8	0.72	0.01	7.68	0	0	0	0	0
28	9/24/90	none													
	1/15/91	none													
	3/26/91	none													
	4/17/91	none													
	6/18/91	none													
	7/25/91	15.6	490	0.81	242	0.43	128	5.64	2.6	7.48	26	0.04			
	10/15/91	none													
*	9/15/92	9.35	340	0.74	203	0.23	200	5.96	2.89	7.31	30	0.05	5.9	0	0
29z	9/24/90	ND													
	1/15/91	4.5	130	0.52	50	0	9	1.88	0.02	7.55	0	0.05			
	3/26/91	4.2	153	0.61	52	0	12	1.61	0.01	7.44	0	0.12			
	4/17/91	3.1	140	0.36	45	0	11.5	1.76	0.01	7.36	0	0.16			
	6/18/91	5.2	139	0.98	58	0	8	1.87	0.02	7.81	0	0.06			
	7/25/91	6.23	135	1.04	46	0	10	1.94	0.02	7.97	0	0.08			
	10/15/91	6.5	142	0.98	49	0	12	1.88	0.03	7.83	0	0.1			
	9/17/92	6	138	0.97	47	0	9	1.65	0.02	7.77	0	0.09			

Table F-1. Analysis Results for Outfall Samples (continued)

Outfall #	Collection Dates	Flow (GPM)	Conductivity (µmhos/cm)	Fluoride (mg/L)	Hardness (mg/L) (CaCO3)	Deterg. (mg/L)	Floresc. (% scale)	K (mg/L)	NH_3 (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (% red.)	Cu (mg/L)	Phenol (mg/L)
31	9/24/90	1.6	130	1.34	56	0	23	2.49	0.01	8.04	5	0	0		
	1/15/91	5.8	207	0.98	132	1	25	1.52	0.05	7.91	0	0.03			
*	3/26/91	4.2	165	1.13	34	18	235	2.96	0.24	8.34	25	0.19			
	4/17/91	6.2	210	1.03	103	0.05	14	1.45	0.03	7.8	0	0.01			
	6/18/91	drip													
	7/25/91	-	185	1.2	75	0.11	25	4.18	0.04	7.74	10	0.02			
	10/15/91	drip													
	9/17/92	0.05	213	1	168	0.95	23	3.01	0.21	7.98	15	0.14		0.04	0
38	10/24/90	0.1	293	0.12	185	0	32	1.4	0.01	7.91	0	0	0		
	1/15/91	'0.4	301	0.09	221	0	40	1.62	0.02	7.89	0	0			
	3/26/91	0.3	295	0.15	178	0	42	1.52	0.03	7.87	0	0			
	4/17/91	0.3	320	0.3	220	0	39.5	2.3	0.02	8.02	0	0.01			
	6/18/91	1.2	307	0.21	219	0	34.5	1.4	0.01	7.91	0	0.02			
	7/25/91	1.6	310	0.2	188	0	37	3.7	0.03	7.82	0	0			
	10/15/91	0.3	313	0.14	197	0	36	1.69	0.02	7.87	0	0			
	9/17/92	0.2	299	0.17	214	0	39	1.97	0.01	7.93	0	0			
39	10/24/90	0.05	255	0.33	188	0	20.5	0.99	0.02	8.1	40	0.01	0		
	1/15/91	0.08	273	0.19	162	0	20	0.87	0.07	8.08	25	0			
	3/26/91	0.02	340	0.18	177	0	18.5	0.98	0.03	8.14	20	0.01			
	4/17/91	none													
	6/18/91	none													
	7/25/91	none													
	10/15/91	none													
	9/17/92	none													
40	10/24/90	none													
	1/15/91	none													
	3/26/91	none													
	4/17/91	16.6	326	0.21	158	0	59.5	1.76	0.2	7.96	10	0.01			
	6/18/91	4.1	299	0.32	163	0.2	87.5	3.98	0.39	7.74	40	0.01			
	7/25/91	4.7	345	0.34	167	0.23	102.4	4.07	0.47	7.76	46	0.01			
	10/15/91	none													
	9/17/92	4.6	370	0.12	220	0.35	86	2.91	0.15	7.81	45	0.01		0	0

Table F-1. Analysis Results for Outfall Samples (continued)

Outfall #	Collection Dates	Flow (GPM)	Conductivity (µmhos/cm)	Fluoride (mg/L)	Hardness (mg/L) (CaCO3)	Deterg. (mg/L)	Floresc. (%scale)	K (mg/L)	NH$_3$ (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (% red.)	Cu (mg/L)	Phenol (mg/L)
40z	10/24/90	none													
	1/15/91	none													
	3/26/91	none													
	4/17/91	none													
*	6/18/91	1	340	0.12	184	0.2	26.5	0.94	0.87	7.42	20	0			
	7/25/91	none													
	10/15/91	none													
	9/17/92	none													
42	10/24/90	149.6	390	0.22	220	0	14	1.6	0.01	7.9	10	0.01	0		
	1/15/91	149.6	387	0.16	217	0	12	1.59	0	7.87	0	0			
	3/26/91	74.8	365	0.14	205	0	9	1.65	0	7.82	0	0			
	4/17/91	74.8	380	0.14	195	0	10	1.46	0	7.87	0	0.01			
	6/18/91	149.6	372	0.13	211	0	10	1.49	0	7.85	0	0			
	7/25/91	56.1	395	0.15	226	0	11	1.47	0	7.79	0	0			
	10/15/91	-	352	0.1	233	0	11	0.9	0	7.71	0	0	0		
	9/17/92	49.9	375	0.06	230	0	8	0.73	0	7.68	0	0.01		0	0
*	3/5/93	60.2	361	0.07	228	0	6	0.81	0	7.72	0	0			
45	10/24/90	none													
	1/15/91	none													
	3/26/91	0.2	312	0.12	184	0	6.8	1	0	7.72	0	0			
	4/17/91	2.1	300	0.13	176	0	5.5	1.07	0.01	7.56	0	0			
	6/18/91	2.9	220	0.07	98	0	18	0.82	0.04	7.24	0	0			
	7/25/91	2.3	330	0.13	186	0	7.1	1.19	0	7.8	0	0			
	10/15/91	none													
	9/17/92	none													

Table F-1. Analysis Results for Outfall Samples (continued)

Outfall #	Collection Dates	Flow (GPM)	Conductivity (µmhos/cm)	Fluoride (mg/L)	Hardness (mg/L) (CaCO3)	Deterg. (mg/L)	Floresc. (%scale)	K (mg/L)	NH_3 (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (% red.)	Cu (mg/L)	Phenol (mg/L)
48	10/24/90	146.8	340	0.12	192	0	12	1.07	0.01	8	12	0	0		
	1/15/91	152	345	0.08	193	0	11	0.99	0	7.83	0	0			
	3/26/91	146.4	348	0.07	187	0	9	0.86	0	7.91	0	0			
	4/17/91	168.3	345	0.01	173	0	7.2	0.84	0	7.82	0	0			
	6/18/91	146.4	351	0.09	189	0	9	0.98	0	7.87	0	0			
	7/25/91	280.5	410	0.53	161	3.2	163.5	4.4	5.62	7.54	15	0.01			
*	8/2/91	301	482	0.53	162	5	245		10.46	7.33	32	0			
	10/15/91	320	469	0.48	158	3.6	225		5.27	7.27	27	0.01			
	9/17/92	146.4	339	0.08	196	0	10	0.98	0	7.8	0	0	0	0	0
52	10/31/90	62.3	355	0.16	216	0.3	25	1.9	1.1	7.63	0	0.01	0		
	1/15/91	37.4	368	0.18	210	0.4	28	1.68	0.31	7.78	0	0			
	3/26/91	37.4	362	0.16	213	0.2	21	1.62	0.3	7.82	0	0			
	4/17/91	28.1	400	0.15	209	0.3	17.5	1.58	0.35	7.96	0	0.01			
	6/18/91	37.4	372	0.16	217	0.33	27.5	1.66	0.37	7.81	0	0			
	7/25/91	112.2	420	0.06	233	0.18	lost	lost	lost	7.84	5	0			
	10/15/91	37.4	358	0,07	221	0	21	1.64	0.32	7.78	0	0			
	9/21/92	56.1	335	0.1	233	0	25	1.59	0.28	7.83	5	0.01		0	0
53	10/31/90	sub	230	0.84	115	0.1	25	2.04	0.73	7.79	0	0.51	93.6		
	1/15/91	sub													
	3/26/91	sub													
	4/17/91	sub	301	0.18	1.39	0.1	21.5	1.54	0.32	8.05	0	0.15			
	6/18/91	sub													
	7/25/91	28.1	330	0.23	167	2		1.57	0.19	7.94	5	0.02			
	10/15/91	sub													
	9/21/92	sub													
60	10/31/90	18.7	497	0.28	327	0	72.5	1.9	0.01	8.16	0	0.01	0		
	1/15/91	12.2	352	0.1	278	0	43	0.93	0.01	7.89	0	0			
	3/26/91	37.4	360	0.07	282	0	46	0.86	0.01	7.86	0	0			
	4/17/91	56.1	415	1.13	188	1.3	51.5	0.89	0.02	7.91	0	0.01			
	6/18/91	78.6	382	0.67	182	0.8	53	0.91	0.01	7.69	0	0			
	7/25/91	34	359	0.14	211	0.5	58	1.35	0	8.3	0	0.02			
	10/15/91	15.6	361	0.09	247	0	48	0.81	0	7.72	0	0			
	9/21/92	19.8	305	0.12	211	0	67	0.84	0	7.85	15	0		0.02	0

Table F-1. Analysis Results for Outfall Samples (continued)

Outfall #	Collection Dates	Flow (GPM)	Conductivity (µmhos/cm)	Fluoride (mg/L)	Hardness (mg/L) (CaCO3)	Deterg. (mg/L)	Floresc. (% scale)	K (mg/L)	NH_3 (mg/L)	pH (units)	Color (units)	Chlorine (mg/L)	Toxicity (% red.)	Cu (mg/L)	Phenol (mg/L)
60a	10/31/90	ND													
	1/15/91	none													
	3/26/91	none													
*	4/17/91	2.7	197	0.86	52	0	128	3.84	0.29	7.48	0	0.01	0	0	0
	6/18/91	none													
	7/25/91	none													
	10/15/91	none													
	9/21/92	1.5	280	0.61	175	0	97	2.99	0.31	7.28	10	0	0	0.03	0
64	11/14/90	84.2	335	0.16	234	0	41	1.62	0.01	7.86	20	0.01	0		
	1/15/91	58	310	0.09	210	0	15	0.99	0	7.35	0	0			
	3/26/91	168.3	295	0.1	172	0	37	1.35	0	7.28	0	0			
	4/17/91	326.6	210	0.16	192	0	22	1.4	0.01	7.2	0	0.01			
	6/18/91	450	250	0.04	101	0	41	1.03	0.08	7.01	5	0			
	7/25/91	74.8	350	0.07	228	0	9	0.87	0	7.22	5	0.01			
	10/15/91	35	298	0.05	239	0	11	0.76	0.01	7.12	0	0			
	9/21/92	30	312	0.11	213	0	17	0.89	0.02	7.25	5	0		0	0
65	11/14/90	62.3	225	0.87	137	0	52	2.26	0.01	7.74	30	0.01	22		
	1/15/91	60		0.39	121	0	62	2.69	0	7.98	20	0.01			
	3/26/91	187	290	0.42	118	0	59	1.71	0	8.23	25	0.02			
	4/17/91	598.4	330	0.34	122	0	53	1.5	0.01	8.25	5	0.02			
	6/18/91	620		0.28	138	0	43	1.3	0	7.92	0	0.01			
	7/25/91	124.7	375	0.37	174	0	61	1.63	0	8.12	20	0.02			
	10/15/91	65		0.38	110	0	72	1.81	0.02	8.28	25	0.02			
	9/21/92	60	330	0.18	119	0	68	1.72	0.01	8.31	25	0.02		0	0

Notes: * in outfall column marks sample collected when source of flow was confirmed
ND in flow column mean not detected at that time
"sub" refers to a submerged outfall

Examination of All Village Creek, Birmingham, AL, Outfall Data Using Alternative Evaluation Tools

Introduction

An evaluation of all of the Birmingham Village Creek data was conducted by Kimberly Brown, a UAB graduate student, and summarized in the following discussion. The purpose of the work described here was to (1) determine the consistency of the three main methods in identifying non-stormwater pollutants at outfalls, (2) determine the variability of flow among outfalls and the variability of non-stormwater pollutants indicated by the three methods among outfalls, (3) examine the relationship of rainfall history to non-stormwater pollutants indicated at outfalls, and (4) determine the sampling frequency needed for an adequate inappropriate discharge screening program.

A data analysis of dry-weather storm drainage outfalls was done to identify problem outfalls (outfalls affected by non-stormwater entries) and correlate them with potential sources and to identify which outfalls need further analyses and investigations. Several methods of data analyses were used, such as, physical indicators of contamination, detergents as indicators of contamination, a simple checklist for major flow component identification, a flow chart method for most significant flow component identification, flow-weighted mixing calculations, matrix algebra solutions of simultaneous equations, and matrix algebra solutions considering uncertainty using Monte Carlo simulation, alldescribed in Section 7 of this report.

During the Birmingham demonstration project, samples were collected from potential dry-weather flow sources to establish background data. The background data contained measured parameters specific to certain potential dry-weather sources. It was determined that the background data collected was sufficient to allow contaminated source types to be distinguished from non-contaminated source types and that the measured parameters identified would be sufficient to distinguish among all of the potential commercial/residential sources of dry-weather flows.

A 3-mile section of Village Creek was selected for the field investigation to test the methods of analyses for identifying problem outfalls and potential sources of contamination. Stormwater outfalls and direct discharges were identified by walking the creek. A total of 73 outfalls were located. These outfalls were described in Appendix D of this report.

Dry-weather outfall data was obtained from September 1990 to March 1993. Each outfall was visited 8 or 9 times during this 30 month period. Visits were conducted during different months of the year, wet seasons (i.e., spring and summer) and dry seasons (i.e., fall and winter) in Birmingham. This appendix earlier presented the complete analysis results from all outfall samples collected during this demonstration project.

Lalor (1993) selected 10 outfalls (14, 20, 21, 26, 28, 31, 40z, 42, 48, and 60a) from the 73 in the study area for confirmation of the problem prediction methods. She used five evaluation methods: physical indicators of contamination, detergents as indicators of contamination, a flow chart method to identify the most significant flow components, matrix algebra solutions of simultaneous equations, and matrix algebra solutions considering uncertainty using Monte Carlo simulation. Section 11 of this report presents the results of problem outfall identification and flow source confirmation for the 10 outfalls.

Evaluation of Three Methods for Identifying Problem Outfalls and Outfall Variability

The three simple methods were further evaluated for each outfall visit and presented in this appendix, in order to evaluate the consitency of the methods over an extended period of time:

(1) physical indicators of contamination,
(2) detergents as indicators of contamination, and
(3) a flow chart method for most significant flow component identification.

Twenty-four of the 73 outfalls had observed dry-weather flows during at least one of the field visits. A total of 124 occurrences of dry-weather flows were observed during the 8 or 9 visits to these outfalls.

Variability of Flow Among Outfalls

Even though the outfalls were visited for sample collection 8 or 9 times over a 30-month period during the demonstration project, flows were not consistently found during each visit at each outfall. The percentage of flowing outfalls that were sampled during outfall visits is shown in Table F-2 and Figure F-1. Most of the outfalls (49 of the 73) never had any observed dry-weather flows, and 9 had flows at every visit. Fifteen outfalls had flows from about 10 to 90 percent of the time.

Consistency of the Three Methods in Identifying Problem Outfalls

Application of the outfall data to the physical indicators of contamination method resulted in 18 observations of problems during 54 visits to the 24 outfalls that had observed dry-weather flow at least once during all visits. Field sheets were filled out for each outfall and the presence of odor, color, turbidity, floatables, deposits/stains, vegetation growth at the outfall, and structural damage were noted. If any of the above physical indicators was noted as being present on the field sheet, the outfall was termed a problem outfall. The results of the evaluation of outfalls using physical indicators of contamination are shown in Table F-3.

Table F-2. Variability of Flow Among Outfalls

Outfall Number	Number of Collection Dates	Percentage of Samples Collected with Flow Present
14	9	44
14z	8	12.5
16	8	12.5
20	9	100
21	8	62.5
22	8	50
24	8	12.5
26	9	100
28	8	25
29z	8	87.5
31	8	75
38	8	100
39	8	37.5
40	8	50
40z	8	12.5
42	9	100
45	8	50
48	9	100
52	8	100
53	8	37.5
60	8	100
60a	8	25
64	8	100
65	8	100

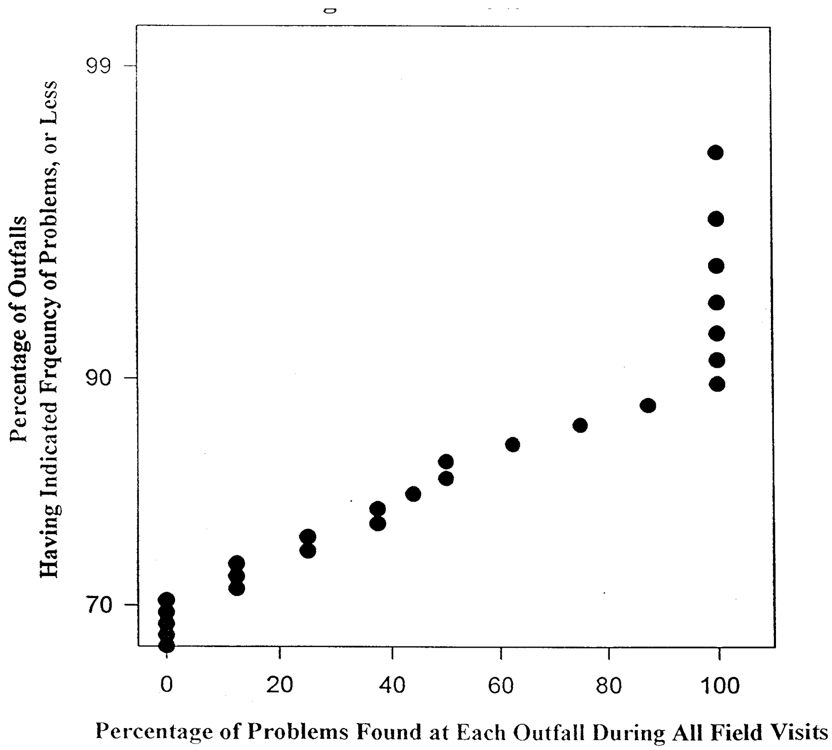


Figure F-1. Percentage of problem outfalls identified during all visits.

The outfall data was applied to the detergent method as an indicator of contamination and resulted in 10 problem outfalls that periodically had problems. These problems were found during 34 of the 124 total visits to the 24 outfalls that had observed dry-weather flow at least once. An outfall was termed a problem outfall if detergent was present at a concentration greater than 0.06 mg/L. The 0.06 mg/L concentration limit translates to the lower limit of detection (3 times the standard deviation from replicate analysis) for the HACH detergent test kit. Table F-4 summarizes the results of the application of the detergent method.

The flow chart method to identify the most significant flow component was also evaluated. This method also resulted in 10 outfalls that had periodic problems. These problems were also found during 34 of the 124 visits to the 24 outfalls that had observed dry-weather flow at least once. An outfall was termed a problem outfall by the flow chart method if the resulting source was likely washwater or sanitary wastewater. The results of the evaluation using the flow chart method are summarized in Table F-5.

Table F-6 summarizes the consistency of the three methods for determining problem outfalls. All three methods consistently identified the same occurence of problems at 15 of the 24 outfalls (63%) (outfalls 14z, 16, 20, 21, 22, 24, 26, 29z, 38, 39, 40, 42, 45, 53, and 60a). However, the three methods were not consistent in identifying problems at 9 of the 24 outfalls (outfalls 14, 28, 31, 40z, 48, 52, 60, 64, and 65). Fifteen outfall visits (at the 9 outfalls) out of the 124 total outfall visits resulted in inconsistent conclusions. Thirteen of these (at 8 outfalls) were associated with problems with the physical indicator method (7 false positives and 6 false negatives). Two visits at outfall number 31 resulted in opposite evaluations using the other two methods. However, 123 of the 125 evaluations were identical using the detergent and flow chart methods. The results of variability among problems indicated by the three methods are summarized in Table F-7 and Figure F-2.

Table F-3. Physical Indicators of Contamination

Outfall Number	Collection Date	Odor	Color	Turbidity	Floatables	Deposits/ Stains	Vegetation	Structural Damage	Problem Indicated?
14	9/18/90	No	No	No	No	Yes (white chalky)	Normal	No	Yes
14	3/26/91	No	Yes (grey)	No	No	Yes (grey sediment)	Normal	No	Yes
14z	6/18/91	No	No	No	No	No	Normal	No	No
20	9/24/90	No	No	No	No	No	Normal	No	No
20	3/26/91	No	No	No	No	No	Normal	No	No
20	4/17/91	No	No	No	No	No	Normal	No	No
20	7/25/91	No	No	No	No	No	Normal	No	No
21	9/24/90	Yes (oil)	Yes (grey)	Yes (cloudy)	No	No	Normal	No	Yes
21	3/26/91	Yes (sewage)	Yes (grey)	Yes (cloudy)	No	No	Normal	No	Yes
22	9/24/90	Yes (oil)	Yes (grey)	Yes (cloudy)	No	No	Normal	No	Yes
22	3/26/91	Yes (oil)	Yes (grey)	Yes (opaque)	No	No	Normal	No	Yes
26	9/24/90	No	No	No	No	No	Normal	No	No
26	3/26/91	No	No	No	No	No	Normal	No	No
26	4/17/91	No	No	No	No	No	Normal	No	No
26	7/25/91	No	No	No	No	No	Normal	No	No
28	7/25/91	No	No	No	No	No	Normal	No	No
29z	4/17/91	No	No	No	No	No	Normal	No	No
29z	7/25/91	No	No	No	No	No	Normal	No	No
31	9/24/90	No	No	No	No	No	Normal	No	No
31	7/25/91	No	Yes (grey)	Yes (opaque)	No	No	Normal	No	Yes
38	10/24/90	No	No	No	No	No	Normal	No	No
38	3/26/91	No	No	No	No	No	Normal	No	No
38	4/17/91	No	No	No	No	No	Normal	No	No
38	7/25/91	No	No	No	No	No	Normal	No	No

Outfall Number	Collection Date	Odor	Color	Turbidity	Floatables	Deposits/ Stains	Vegetation	Structural Damage	Problem Indicated?
39	10/24/90	No	No	No	No	No	Normal	No	No
40z	4/17/91	No	No	No	No	No	Normal	No	No

(continued)

Table F-3. Physical Indicators of Contamination (continued)

Outfall Number	Collection Date	Odor	Color	Turbidity	Floatables	Deposits/ Stains	Vegetation	Structural Damage	Problem Indicated?
42	10/24/90	No	No	No	No	No	Normal	No	No
42	3/26/91	No	No	No	No	No	Normal	No	No
42	7/25/91	No	No	No	No	No	Normal	No	No
45	3/26/91	No	No	No	No	No	Normal	No	No
45	7/25/91	No	No	No	No	No	Normal	No	No
48	10/24/91	No	No	No	No	No	Normal	No	No
48	4/17/91	No	No	No	No	No	Normal	No	No
48	7/25/91	Yes (sewage)	Yes (grey)	Yes (cloudy)	No	Yes (sediment)	Normal	No	Yes
52	10/31/90	Yes (sewage)	No	No	No	No	Excessive Growth (algae)	No	Yes
52	3/26/91	No	No	No	No	No	Normal	No	No
52	4/17/91	Yes (sewage)	No	No	No	No	Normal	No	Yes
52	7/25/91	No	No	No	No	No	Normal	No	No
53	10/31/90	Yes (dead fish)	No	No	Yes (oil sheen)	Yes (clayey)	Normal	No	Yes
53	4/17/91	Yes (sewage)	No	No	No	No	Normal	No	Yes
53	7/25/91	Yes	Yes (grey)	Yes (cloudy)	No	Yes (sediment)	Normal	No	Yes
60	10/31/90	No	No	No	No	No	Normal	No	No
60	3/26/91	No	No	No	No	No	Normal	No	No

Outfall Number	Collection Date	Odor	Color	Turbidity	Floatables	Deposits/ Stains	Vegetation	Structural Damage	Problem Indicated?
60	4/17/91	Yes (oil)	No	No	Yes (oil sheen)	No	Normal	No	Yes
60	7/25/91	No	No	No	No	No	Normal	No	No

(continued)

Table F-3. Physical Indicators of Contamination (continued)

Outfall Number	Collection Date	Odor	Color	Turbidity	Floatables	Deposits/ Stains	Vegetation	Structural Damage	Problem Indicated?
60a	4/17/91	No	No	No	No	No	Normal	No	No
64	11/14/90	No	No	No	Yes (methane bubble)	No	Normal	No	Yes
64	3/26/91	No	No	No	No	No	Normal	No	No
64	4/17/91	No	No	No	No	No	Normal	No	No
64	7/25/91	No	No	No	No	No	Normal	No	No
65	11/14/90	No	Yes (grey)	Yes (opaque)	No	No	Normal	No	Yes
65	3/26/91	No	Yes (grey)	Yes (opaque)	No	No	Normal	No	Yes
65	4/17/91	No	No	No	No	No	Normal	No	No
65	7/25/91	Yes (oil)	Yes (grey)	Yes (cloudy)	No	No	Normal	No	Yes

Table F-4. Detergent Method as an Indicator of Contamination

Outfall Number	Collection Date	Detergent Concentration (mg/L)	Detergent Concentration > 0.06 mg/L	Problem Indicated?
14	9/18/90	0	No	No
14	1/15/91	0	No	No
14	3/26/91	0	No	No
14	3/3/93	0	No	No
14z	6/18/91	0	No	No
16	6/18/91	0	No	No
20	9/24/90	0	No	No
20	1/15/91	0.02	No	No
20	3/26/91	0	No	No
20	4/17/91	0	No	No
20	6/18/91	0	No	No
20	7/25/91	0	No	No
20	10/15/91	0	No	No
20	9/15/92	0	No	No
20	3/3/93	0	No	No
21	9/24/90	9.5	Yes	Yes
21	1/15/91	10.1	Yes	Yes
21	3/26/91	9.7	Yes	Yes
21	10/15/91	15.7	Yes	Yes
21	9/15/92	20	Yes	Yes
22	9/24/90	9.5	Yes	Yes
22	1/15/91	10	Yes	Yes
22	3/26/91	9.7	Yes	Yes
22	9/15/92	14	Yes	Yes
24	9/15/92	0	No	No
26	9/24/90	0	No	No
26	1/15/91	0	No	No
26	3/26/91	0	No	No
26	4/17/91	0	No	No
26	6/18/91	0	No	No
26	7/25/91	0	No	No

Outfall Number	Collection Date	Detergent Concentration (mg/L)	Detergent Concentration > 0.06 mg/L	Problem Indicated?
26	10/15/91	0	No	No
26	9/15/92	0	No	No
26	3/3/93	0	No	No

Table F-4. Detergent Method as an Indicator of Contamination (continued)

Outfall Number	Collection Date	Detergent Concentration (mg/L)	Detergent Concentration > 0.06 mg/L	Problem Indicated?
28	7/25/91	0.43	Yes	Yes
28	9/15/92	0.23	Yes	Yes
29z	1/15/91	0	No	No
29z	3/26/91	0	No	No
29z	4/17/91	0	No	No
29z	6/18/91	0	No	No
29z	7/25/91	0	No	No
29z	10/15/91	0	No	No
29z	9/17/92	0	No	No
31	9/24/90	0	No	No
31	1/15/91	1	Yes	Yes
31	3/26/91	18	Yes	Yes
31	4/17/91	0.05	No	No
31	7/25/91	0.11	Yes	Yes
31	9/17/92	0.95	Yes	Yes
38	10/24/90	0	No	No
38	1/15/91	0	No	No
38	3/26/91	0	No	No
38	4/17/91	0	No	No
38	6/18/91	0	No	No
38	7/25/91	0	No	No
38	10/15/91	0	No	No
38	9/17/92	0	No	No
39	10/24/90	0	No	No
39	1/15/91	0	No	No

Outfall Number	Collection Date	Detergent Concentration (mg/L)	Detergent Concentration > 0.06 mg/L	Problem Indicated?
39	3/26/91	0	No	No
40	4/17/91	0	No	No
40	6/18/91	0.2	Yes	Yes
40	7/25/91	0.23	Yes	Yes
40	9/17/92	0.35	Yes	Yes
40z	6/18/91	0.2	Yes	Yes

(continued)

Table F-4. Detergent Method as an Indicator of Contamination (continued)

Outfall Number	Collection Date	Detergent Concentration (mg/L)	Detergent Concentration > 0.06 mg/L	Problem Indicated?
42	10/24/90	0	No	No
42	1/15/91	0	No	No
42	3/26/91	0	No	No
42	4/17/91	0	No	No
42	6/18/91	0	No	No
42	7/25/91	0	No	No
42	10/15/91	0	No	No
42	9/17/92	0	No	No
42	3/5/93	0	No	No
45	3/26/91	0	No	No
45	4/17/91	0	No	No
45	6/18/91	0	No	No
45	7/25/91	0	No	No
48	10/24/90	0	No	No
48	1/15/91	0	No	No
48	3/26/91	0	No	No
48	4/17/91	0	No	No
48	6/18/91	0	No	No
48	7/25/91	3.2	Yes	Yes
48	8/2/91	5	Yes	Yes

Outfall Number	Collection Date	Detergent Concentration (mg/L)	Detergent Concentration > 0.06 mg/L	Problem Indicated?
48	10/15/91	3.6	Yes	Yes
48	9/17/92	0	No	No
52	10/31/90	0.3	Yes	Yes
52	1/15/91	0.4	Yes	Yes
52	3/26/91	0.2	Yes	Yes
52	4/17/91	0.3	Yes	Yes
52	6/18/91	0.33	Yes	Yes
52	7/25/91	0.18	Yes	Yes
52	10/15/91	0	No	No
52	9/21/92	0	No	No
53	10/31/90	0.1	Yes	Yes
53	4/17/91	0.1	Yes	Yes
53	7/25/91	2	Yes	Yes

(continued)

Table F-4. Detergent Method as an Indicator of Contamination (continued)

Outfall Number	Collection Date	Detergent Concentration (mg/L)	Detergent Concentration > 0.06 mg/L	Problem Indicated?
60	10/31/90	0	No	No
60	1/15/91	0	No	No
60	3/26/91	0	No	No
60	4/17/91	1.3	Yes	Yes
60	6/18/91	0.8	Yes	Yes
60	7/25/91	0.5	Yes	Yes
60	10/15/91	0	No	No
60	9/21/92	0	No	No
60a	4/17/91	0	No	No
60a	9/21/92	0	No	No
64	11/14/90	0	No	No
64	1/15/91	0	No	No
64	3/26/91	0	No	No
64	4/17/91	0	No	No
64	6/18/91	0	No	No

Outfall Number	Collection Date	Detergent Concentration (mg/L)	Detergent Concentration > 0.06 mg/L	Problem Indicated?
64	7/25/91	0	No	No
64	10/15/91	0	No	No
64	9/21/92	0	No	No
65	11/14/90	0	No	No
65	1/15/91	0	No	No
65	3/26/91	0	No	No
65	4/17/91	0	No	No
65	6/18/91	0	No	No
65	7/25/91	0	No	No
65	10/15/91	0	No	No
65	7/25/91	0	No	No

Table F-5. Flow Chart Method for Identifying Most Significant Flow Component

Outfall Number	Collection Date(s)	Flow Present	Detergent >0.06 mg/L	Flourides >0.13 mg/L	Ammonia/Potassium >0.6 mg/L	Resulting Source	Problem Indicated?
14	9/18/90, 1/15/91, 3/26/91, 3/3/93	Yes	No	No	NA	Natural Water	No
14z	6/18/91	Yes	No	Yes	NA	Tap Water	No
16	6/18/91	Yes	No	No	NA	Natural Water	No
20	9/24/90, 1/15/91, 3/26/91, 4/17/91, 6/18/91, 7/25/91, 10/15/91, 9/15/92, 3/3/93	Yes	No	Yes	NA	Tap Water	No
21	9/24/90, 1/15/91, 3/26/91, 10/15/91, 9/15/92	Yes	Yes	NA	No	Washwater	Yes
22	9/24/90, 1/15/91, 3/26/91, 9/15/92	Yes	Yes	NA	No	Washwater	Yes
24	9/15/92	Yes	No	No	NA	Natural Water	No
26	9/24/90, 1/15/91, 3/26/91, 4/17/91, 6/18/91, 7/25/91, 10/15/91, 9/15/92, 3/3/93	Yes	No	No	NA	Natural Water	No
28	7/25/91, 9/15/92	Yes	Yes	NA	No	Washwater	Yes
29z	1/15/91, 3/26/91, 4/17/91, 6/18/91, 7/25/91, 10/15/91, 9/17/92	Yes	No	Yes	Yes	Tap Water	No
31	1/15/91, 3/26/91, 7/25/91, 9/17/92	Yes	Yes	NA	No	Washwater	Yes
31	9/24/90, 4/17/91	Yes	No	Yes	NA	Tap Water	No
38	3/26/91, 6/18/91, 4/17/91, 7/25/91, 10/15/91, 9/17/92	Yes	No	Yes	NA	Tap Water	No
38	10/24/90, 1/15/91	Yes	No	No	NA	Natural Water	No
39	10/24/90, 1/15/91, 3/26/91	Yes	No	Yes	NA	Tap Water	No
40	6/18/91, 7/25/91, 9/17/92	Yes	Yes	NA	No	Washwater	Yes

Outfall Number	Collection Date(s)	Flow Present	Detergent >0.06 mg/L	Flourides >0.13 mg/L	Ammonia/Potassium >0.6 mg/L	Resulting Source	Problem Indicated?
40	4/17/91	Yes	No	No	NA	Natural Water	No

(continued)

Table F-5. Flow Chart Method for Identifying Most Significant Flow Component

Outfall Number	Collection Date(s)	Flow Present	Detergent >0.06 mg/L	Flourides >0.13 mg/L	Ammonia/Potassium >0.6 mg/L	Resulting Source	Problem Indicated?
40z	6/18/91	Yes	Yes	NA	Yes	Sanitary Wastewater	Yes
42	10/24/90, 1/15/91, 3/26/91, 4/17/91, 7/25/91	Yes	No	Yes	NA	Tap Water	No
42	6/18/91, 10/15/91, 9/17/92, 3/5/93	Yes	No	No	NA	Natural Water	No
45	3/26/91, 4/17/91, 6/18/91, 7/25/91	Yes	No	No	NA	Natural Water	No
48	10/24/90, 1/15/91, 3/26/91, 4/17/91, 6/18/91, 9/17/92	Yes	No	No	NA	Natural Water	No
48	8/2/91, 10/15/91	Yes	Yes	NA	No	Washwater	Yes
48	7/25/91	Yes	Yes	NA	Yes	Sanitary Wastewater	Yes
52	10/31/90, 1/15/91, 3/26/91, 4/17/91, 6/18/91, 7/25/91	Yes	Yes	NA	No	Washwater	Yes
52	10/15/91, 9/21/92	Yes	No	No	NA	Natural Water	No
53	10/31/90, 4/17/91, 7/25/91	Yes	Yes	NA	No	Washwater	Yes
60	10/31/90	Yes	No	Yes	NA	Tap Water	No
60	1/15/91, 3/26/91, 10/15/91, 9/21/91	Yes	No	No	NA	Natural Water	No
60	4/17/91, 6/18/91, 7/25/91	Yes	Yes	NA	No	Washwater	Yes

Outfall Number	Collection Date(s)	Flow Present	Detergent >0.06 mg/L	Flourides >0.13 mg/L	Ammonia/Potassium >0.6 mg/L	Resulting Source	Problem Indicated?
60a	4/17/91, 9/21/92	Yes	No	Yes	NA	Tap Water	No
64	11/14/90, 4/17/91	Yes	No	Yes	NA	Tap Water	No
64	1/15/91, 3/26/91, 6/18/91, 7/25/91, 10/15/91, 9/21/92	Yes	No	No	NA	Natural Water	No
65	11/14/90, 1/15/91, 3/26/91, 4/17/91, 6/15/91, 7/25/91, 10/15/91, 9/21/92	Yes	No	Yes	NA	Tap Water	No

Table F-6. Consistency of the Three Methods for Determining Problem Outfalls and Identifying Significant Flow Components

Outfall Number	Collection Date	Flow Present	Physical Indicators	Detergent Method	Flow Chart Method
14	9/18/90	Yes	X	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	X	O	O
	4/17/91	Yes	NS	NS	NS
	6/18/91	Yes	NS	NS	NS
	7/25/91	Yes	NS	NS	NS
	10/15/91	Yes	NS	NS	NS
	9/15/92	Yes	NS	NS	NS
	3/3/93	Yes	NA	O	O
14z	9/18/90	No	NS	NS	NS
	1/15/91	No	NS	NS	NS
	3/26/91	No	NS	NS	NS
	4/17/91	No	NS	NS	NS
	6/18/91	Yes	O	O	O
	7/25/91	No	NS	NS	NS
	10/15/91	No	NS	NS	NS
	9/15/92	No	NS	NS	NS
16	9/18/90	No	NS	NS	NS
	1/15/91	No	NS	NS	NS
	3/26/91	No	NS	NS	NS
	4/17/91	No	NS	NS	NS
	6/18/91	Yes	NA	O	O
	7/25/91	No	NS	NS	NS
	10/15/91	No	NS	NS	NS
	9/15/92	No	NS	NS	NS
20	9/24/90	Yes	O	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	O	O	O
	4/17/91	Yes	O	O	O
	6/18/91	Yes	NA	O	O
	7/25/91	Yes	O	O	O

	10/15/91	Yes	NA	O	O
	9/15/92	Yes	NA	O	O
	3/3/93	Yes	NA	O	O

Table F-6. Consistency of the Three Methods for Determining Problem Outfalls and Identifying Significant Flow Components (continued)

Outfall Number	Collection Date	Flow Present	Physical Indicators	Detergent Method	Flow Chart Method
21	9/24/90	Yes	X	X	X
	1/15/91	Yes	NA	X	X
	3/26/91	Yes	X	X	X
	4/17/91	Yes	NS	NS	NS
	6/18/91	No	NS	NS	NS
	7/25/91	No	NS	NS	NS
	10/15/91	Yes	NA	X	X
	9/15/92	Yes	NA	X	X
22	9/24/90	Yes	X	X	X
	1/15/91	Yes	NA	X	X
	3/26/91	Yes	X	X	X
	4/17/91	Yes	NS	NS	NS
	6/18/91	No	NS	NS	NS
	7/25/91	No	NS	NS	NS
	10/15/91	No	NS	NS	NS
	9/15/92	Yes	NA	X	X
24	9/24/90	No	NS	NS	NS
	1/15/91	No	NS	NS	NS
	3/26/91	No	NS	NS	NS
	4/17/91	No	NS	NS	NS
	6/18/91	No	NS	NS	NS
	7/25/91	No	NS	NS	NS
	10/15/91	No	NS	NS	NS
	9/15/92	Yes	NA	O	O
26	9/24/90	Yes	O	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	O	O	O
	4/17/91	Yes	O	O	O

	6/18/91	Yes	O	O	O
	7/25/91	Yes	NA	O	O
	10/15/91	Yes	NA	O	O
	9/15/92	Yes	NA	O	O
	3/3/93	Yes	NA	O	O

(continued)

Table F-6. Consistency of the Three Methods for Determining Problem Outfalls and Identifying Significant Flow Components (continued)

Outfall Number	Collection Date	Flow Present	Physical Indicators	Detergent Method	Flow Chart Method
28	9/24/90	No	NS	NS	NS
	1/15/90	No	NS	NS	NS
	3/26/91	No	NS	NS	NS
	4/17/91	No	NS	NS	NS
	6/18/91	No	NS	NS	NS
	7/25/91	Yes	O	X	X
	10/15/91	No	NS	NS	NS
	9/15/92	Yes	NA	X	X
29z	9/24/90	No	NS	NS	NS
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	NA	O	O
	4/17/91	Yes	O	O	O
	6/18/91	Yes	NA	O	O
	7/25/91	Yes	O	O	O
	10/15/91	Yes	NA	O	O
	9/17/92	Yes	NA	O	O
31	9/24/90	Yes	O	O	O
	1/15/91	Yes	NA	X	X
	3/26/91	Yes	NA	X	X
	4/17/91	Yes	NA	X	O
	6/18/91	No	NS	NS	NS
	7/25/91	Yes	X	O	X
	10/15/91	No	NS	NS	NS
	9/17/92	Yes	NA	X	X
38	10/24/90	Yes	O	O	O

	1/15/91	Yes	NA	O	O
	3/26/91	Yes	O	O	O
	4/17/91	Yes	O	O	O
	6/18/91	Yes	NA	O	O
	7/25/91	Yes	O	O	O
	10/15/91	Yes	NA	O	O
	9/17/92	Yes	NA	O	O

(continued)

Table F-6. Consistency of the Three Methods for Determining Problem Outfalls and Identifying Significant Flow Components (continued)

Outfall Number	Collection Date	Flow Present	Physical Indicators	Detergent Method	Flow Chart Method
39	10/24/90	Yes	O	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	NA	O	O
	4/17/91	No	NS	NS	NS
	6/18/91	No	NS	NS	NS
	7/25/91	No	NS	NS	NS
	10/15/91	No	NS	NS	NS
	9/17/92	No	NS	NS	NS
40	10/24/90	No	NS	NS	NS
	1/15/91	No	NS	NS	NS
	3/26/91	No	NS	NS	NS
	4/17/91	Yes	NA	O	O
	6/18/91	Yes	NA	X	X
	7/25/91	Yes	NA	X	X
	10/15/91	No	NS	NS	NS
	9/17/92	Yes	NA	X	X
40z	10/24/90	No	NS	NS	NS
	1/15/91	No	NS	NS	NS
	3/26/91	No	NS	NS	NS
	4/17/91	No	NS	NS	NS
	6/18/91	Yes	O	X	X
	7/25/91	No	NS	NS	NS

	10/15/91	No	NS	NS	NS
	9/17/92	No	NS	NS	NS
42	10/24/90	Yes	O	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	O	O	O
	4/17/91	Yes	NA	O	O
	6/18/91	Yes	NA	O	O
	7/25/91	Yes	O	O	O
	10/15/91	Yes	NA	O	O
	9/17/92	Yes	NA	O	O
	3/5/93	Yes	NA	O	O

(continued)

Table F-6. Consistency of the Three Methods for Determining Problem Outfalls and Identifying Significant Flow Components (continued)

Outfall Number	Collection Date	Flow Present	Physical Indicators	Detergent Method	Flow Chart Method
45	10/24/90	No	NS	NS	NS
	1/15/91	No	NS	NS	NS
	3/26/91	Yes	O	O	O
	4/17/91	Yes	NA	O	O
	6/18/91	Yes	NA	O	O
	7/25/91	Yes	O	O	O
	10/15/91	No	NS	NS	NS
	9/17/92	No	NS	NS	NS
48	10/24/90	Yes	O	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	NA	O	O
	4/17/91	Yes	O	O	O
	6/18/91	Yes	NA	O	O
	7/25/91	Yes	O	X	X
	8/2/91	Yes	NA	X	X
	10/15/91	Yes	NA	X	X
	9/17/92	Yes	NA	O	O
52	10/31/90	Yes	X	X	X
	1/15/91	Yes	NA	X	X

	3/26/91	Yes	O	X	X
	4/17/91	Yes	X	X	X
	6/18/91	Yes	NA	X	X
	7/25/91	Yes	O	X	X
	10/15/91	Yes	NA	O	O
	9/21/92	Yes	NA	O	O
53	10/31/90	Yes	X	X	X
	1/15/91	Yes	NS	NS	NS
	3/26/91	Yes	NS	NS	NS
	4/17/91	Yes	X	X	X
	6/18/91	Yes	NS	NS	NS
	7/25/91	Yes	X	X	X
	10/15/91	Yes	NS	NS	NS
	9/21/92	Yes	NS	NS	NS

(continued)

Table F-6. Consistency of the Three Methods for Determining Problem Outfalls and Identifying Significant Flow Components (continued)

Outfall Number	Collection Date	Flow Present	Physical Indicators	Detergent Method	Flow Chart Method
60	10/31/90	Yes	O	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	O	O	O
	4/17/91	Yes	X	X	X
	6/18/91	Yes	NA	X	X
	7/25/91	Yes	O	X	X
	10/15/91	Yes	NA	O	O
	9/21/92	Yes	NA	O	O
60a	10/31/90	No	NS	NS	NS
	1/15/91	No	NS	NS	NS
	3/26/91	No	NS	NS	NS
	4/17/91	Yes	O	O	O
	6/18/91	No	NS	NS	NS
	7/25/91	No	NS	NS	NS
	10/15/92	No	NS	NS	NS
	9/21/92	Yes	NA	O	O

64	11/14/90	Yes	X	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	O	O	O
	4/17/91	Yes	O	O	O
	6/18/91	Yes	NA	O	O
	7/25/91	Yes	O	O	O
	10/15/91	Yes	NA	O	O
	9/21/92	Yes	NA	O	O
65	11/14/90	Yes	X	O	O
	1/15/91	Yes	NA	O	O
	3/26/91	Yes	X	O	O
	4/17/91	Yes	O	O	O
	6/18/91	Yes	NA	O	O
	7/25/91	Yes	X	O	O
	10/15/91	Yes	NA	O	O
	7/25/91	Yes	X	O	O

X - Problem indicated at outfall
O - No problem indicated at outfall
NA - Information not avaiable
NS - No sample taken

Table F-7. Variability Among Outfalls Based on the Three Analysis Methods

Outfall Number	Number of Samples Collected (flow present)	Percentage of Outfall Visits with Problems Indicated by Physical Indicators	Percentage of Outfall Visits with Problems Indicated by the Detergent Method	Percentage of Outfall Visits with Problems Indicated by the Flow Chart Method
14	4	50	0	0
14z	1	0	0	0
16	1	NA	0	0
20	9	0	0	0
21	5	40	100	100
22	4	50	100	100
24	1	NA	0	0
26	9	0	0	0
28	2	0	100	100
29z	7	0	0	0
31	6	16.6	80	66
38	8	0	0	0
39	3	0	0	0
40	4	NA	75	75
40z	1	0	100	100
42	9	0	0	0
45	4	0	0	0
48	9	0	33	33
52	8	25	75	75
53	3	100	100	100
60	8	12.5	37.5	37.5
60a	2	0	0	0
64	8	12.5	0	0
65	8	50	0	0

NA - Information not available

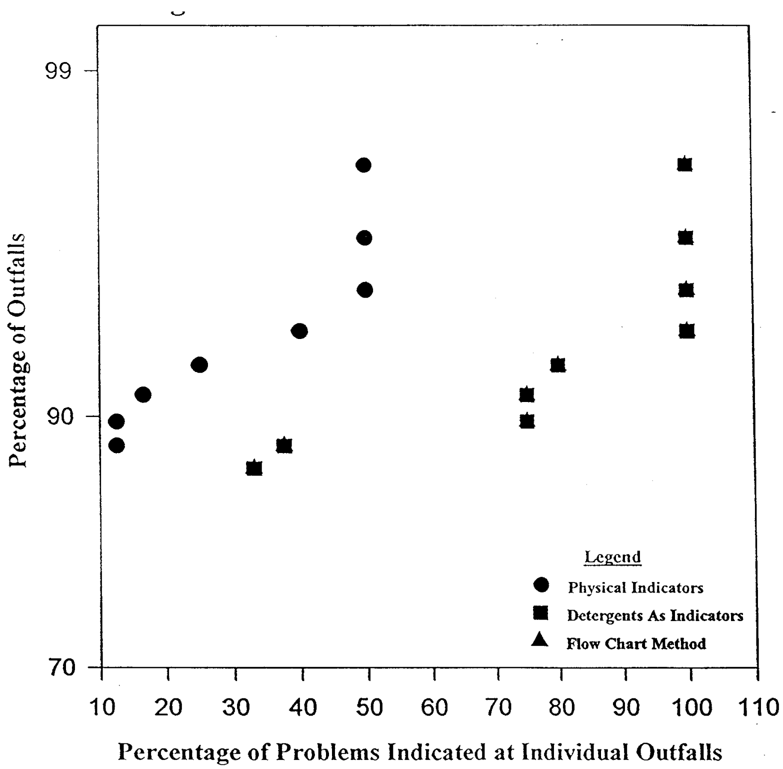


Figure F-2. Problem outfalls found using different methods.

Relationship of Rainfall History to the Presence of Problems Indicated at Outfalls

The presence of flow at outfalls with respect to rainfall amounts occurring prior to outfall collection visits was investigated. It is commonly assumed that recent rains increase the likelihood of dry-weather flows. Monthly summaries of climatological data for Birmingham, AL, from the National Oceanic and Atmospheric Administration (NOAA) were used to determine rainfall amounts 2, 7, and 30 days before each outfall collection date. The percentage of outfalls flowing on each sampling date was compared to these rainfall amount totals and is summarized in Table F-8.

The amount of rainfall 2, 7, and 30 days prior to collection date with respect to the total number of problems indicated by the three methods is illustrated on scatter plots (Figures F-3 through F-5). The Pearson Product Moment Correlation statistical test was used to determine if any significant relationships existed between the total number of problems indicated by the three methods and rainfall amounts 2, 7, and 30 days before outfall collection dates. This statistical test is designed to determine if a relationship exists between variables and the strength of that relationship. The Pearson Correlation determined that there were no significant relationships between number of problems indicated and rainfall amounts.

Seasonal Variability with Respect to the Number of Problem Outfalls Indicated

Figure F-6 illustrates the relationship between outfalls with problems indicated by the detergent and flow chart methods and month of the year. The detergent method and the flow chart method were consistent in identifying problem outfalls so the monthly variation of problems indicated is applicable to both methods. The Pearson Product Moment Correlation was used to determine the relationship between the total number of problems indicated by the detergent and flow chart methods and month. The Pearson Correlation found no relationship between these variables.

Table F-8. Variability of Flow Among Outfalls with Respect to Collection Date and Rainfall Amounts

Collection Date	Rainfall Amount 2 Days Before Sampling (in.)	Rainfall Amount 7 Days Before Sampling (in.)	Rainfall Amount 30 Days Before Sampling (in.)	Outfall(s) Flowing on Specified Date	Number of Outfalls Visited on Each Date	Percentage of All Outfalls Evaluated That Had Flow on Date (%)
9/18/90	0.00	1.62	2.00	14	18	5.6
9/24/90	0.00	0.07	2.04	20,21,22,26,31	17	29
10/24/90	1.10	2.08	2.95	38,39,42,48	15	27
10/31/90	0.00	0.03	2.98	52,53,60	8	37.5
11/14/90	0.00	2.30	4.85	64,65	7	28.6
1/15/91	0.00	0.58	6.08	14,20,21,22,26,29z,31,38,39,42,52 60,64,65	73	19.2
3/26/91	0.00	0.05	0.05	14,20,21,22,26,29z,31,38,39,42,45 48,52,60,64,65	73	21.9
4/17/91	0.01	0.24	6.91	20,26,29z,31,38,40,42,45,48,52, 53,60,60a,64,65	73	20.5
6/18/91	1.51	2.26	6.63	14z,16,20,26,29z,38,40,40z,42,45, 48,52,60,54,65	73	20.5
7/25/91	0.67	0.67	4.24	20,26,28,29z,31,38,40,42,45,48, 52,53,60,64,65	73	20.5
10/15/91	0.03	0.03	2.76	20,21,26,29z,42,48,52,53,64,65	73	13.7
9/15/92	0.00	0.23	9.52	20,21,22,24,26,29z	32	18.8
9/17/92	0.00	0.23	9.52	29z,31,40,42,48	17	29.4
9/21/92	0.00	0.41	7.24	52,60,60a,65	24	16.7

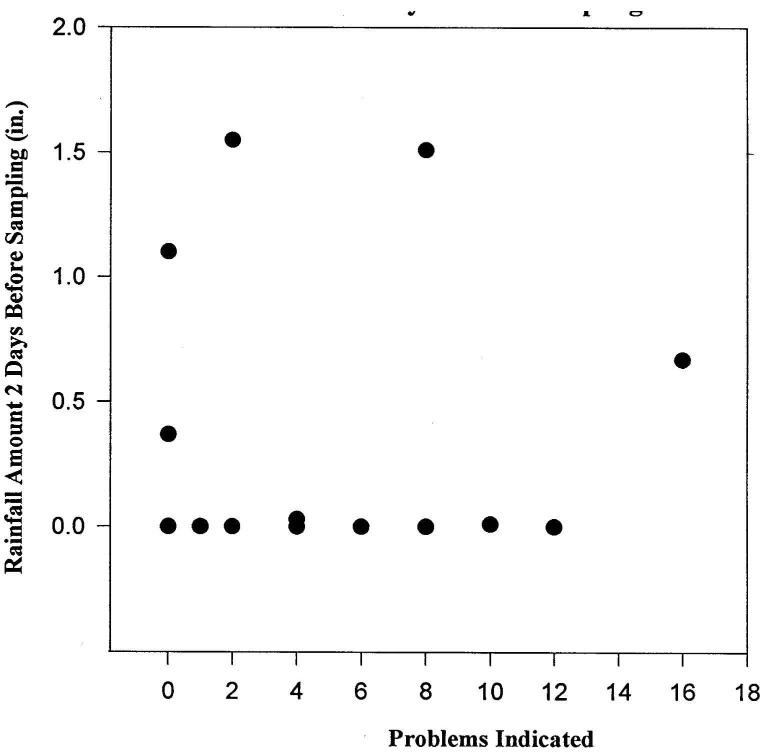


Figure F-3. Rainfall amounts within two days of sampling and numbers of problem outfalls identified.

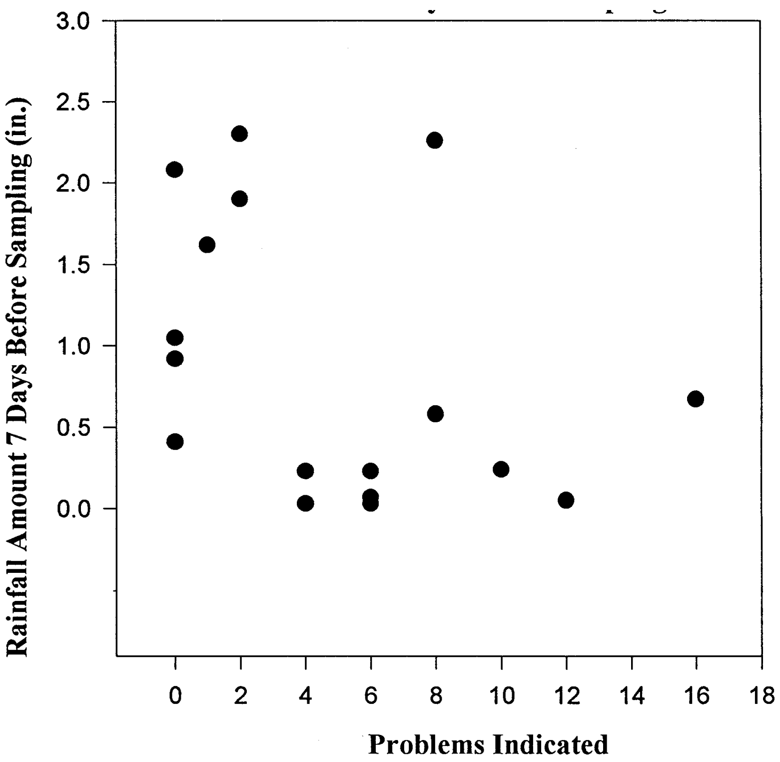


Figure F-4. Rainfall amounts within seven days of sampling and numbers of problem outfalls identified.

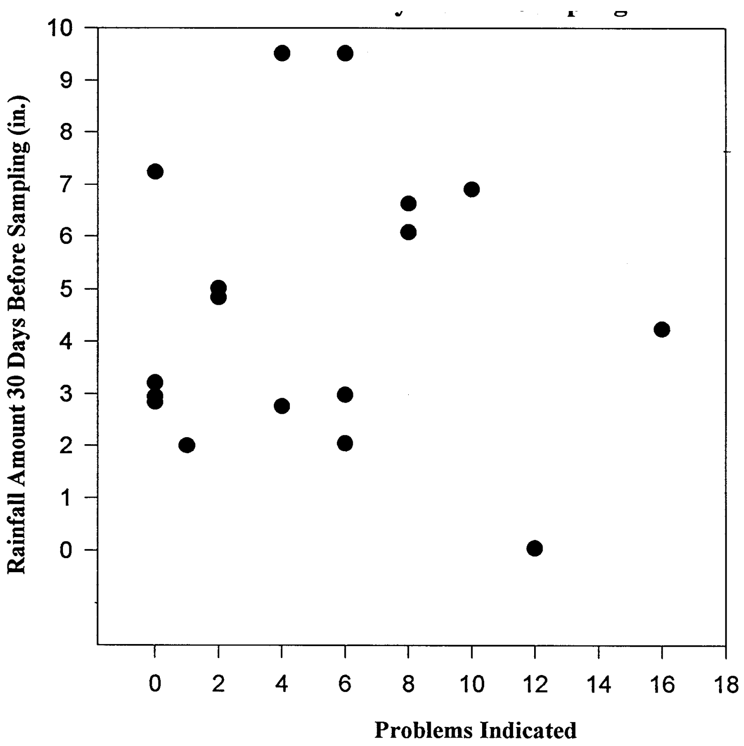


Figure F-5. Rainfall amounts within 30 days of sampling and numbers of problem outfalls identified.

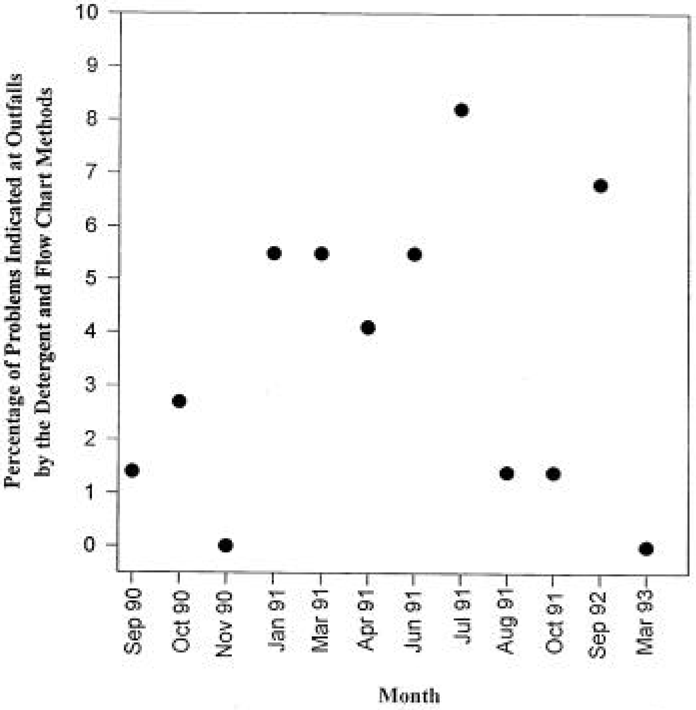


Figure F-6. Percentage of problems found during each month of sampling.

Sampling Requirements to Achieve an Adequate Screening Program for Problem Outfalls

In order to have a successful screening program for problem outfalls, an adequate number of collection visits to the outfalls over a specified time period is required. However, to determine the number of outfall visits needed, a preliminary estimate of the frequency of occurrence of problems at the outfalls and the desired error is needed.

This assessment was made by reviewing the presence of a problem at each outfall, for each outfall visit. A problem was defined using the detergent and flow chart methods for each of the 24 outfalls that ever had observed dry-weather flows during this study. Figure F-7 presents several example plots that were used in this analysis. These examples show that if consistent conditions exist at an outfall where the frequency of problem occurrence is either 0% (outfall# 65) or 100% (outfall # 21), few outfall visits are obviously needed. However, for intermediate levels of occurrence, many more visits are needed. It is quite easy to miss a problem outfall at most locations if only 1 or 2 visits are made.

Table F-9 presents the observed data relating the number of visits to an outfall (within a 1-½ year time period) to the errors associated in identifying the outfall as a problem. At least 4 outfall visits are likely needed for many intermittent conditions. If the outfall has a problem most of the time (say at least 60% of the time), four visits should result in less than a 25% error in identifying this problem. In contrast, if the outfall only has a problem infrequently (such as 20% of the time), the possible error could be much larger. In most cases, more than 5 observations seldom resulted in additional useful information.

Table F-9. Errors Associated with Number of Outfall Sampling Visits and Occurrence of Problems

	Occurrence of Problems:					
# of Observations	0%	20%	40%	60%	80%	100%
1	0	100 to 400%	100 to 150	67 to 100	25 to 100	0
2	0	100 to 150	25 to 150	17 to 100	25 to 38	0
3	0	65 to 100	18 to 100	12 to 67	16 to 25	0
4	0	25 to 100	25 to 38	17 to 25	6 to 25	0
5	0	0	0	0	0	0

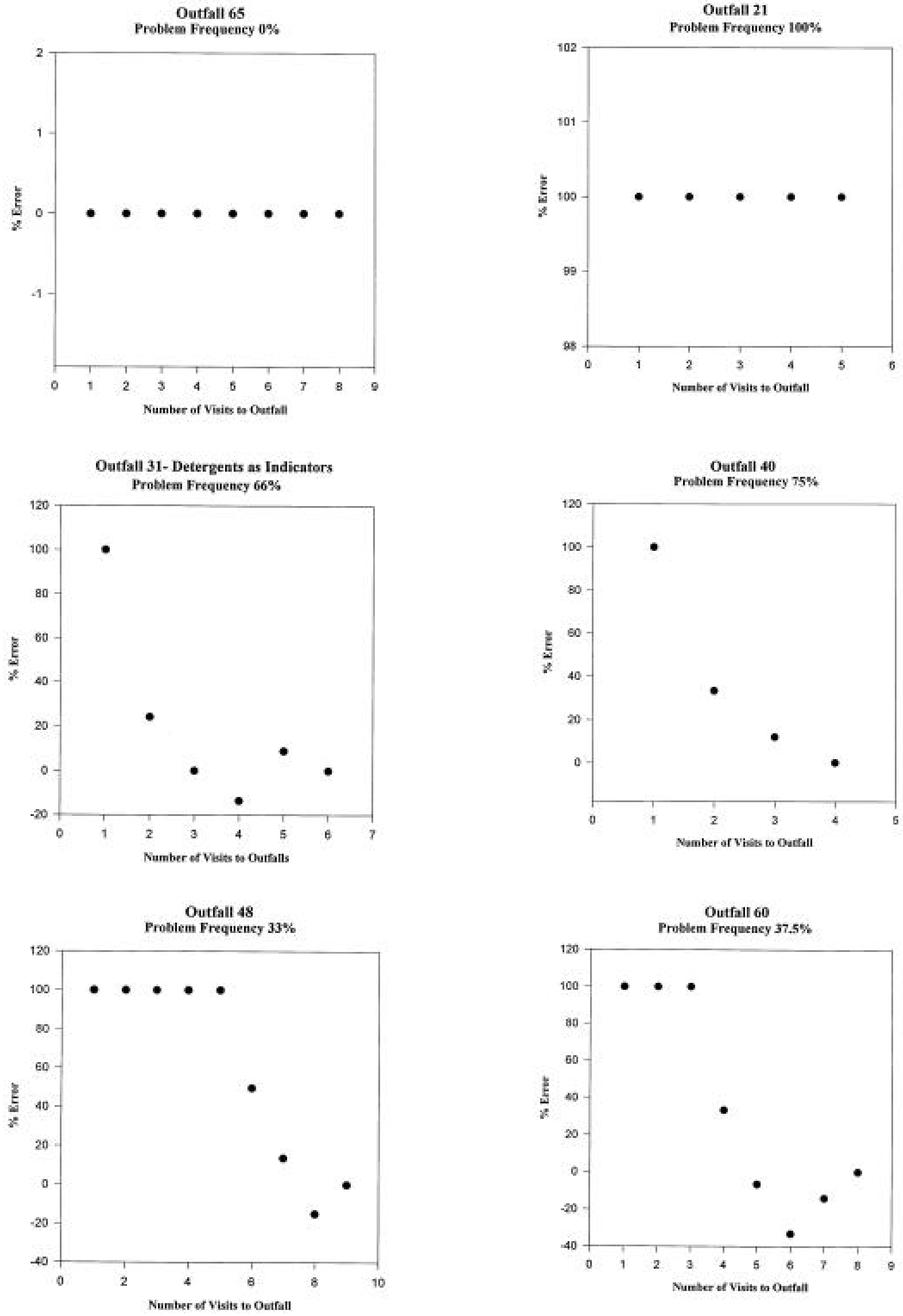


Figure F-7. Observed errors associated with different sampling efforts.

Summary of Evaluation of all Field Data

The presence of detergent method and the flow chart method are both very effective in identifying non-stormwater entry problems in storm drainage systems. Detergents as indicators and the flow chart method gave very consistent results in identifying problem outfalls. The detergent method is recommended for identifying non-stormwater entries because it is simple in technique and has minimal associated error. Unfortunately, the analytical method uses hazardous materials and care must be taken during the analysis and to ensure proper disposal of the wastes. The flow chart method (which also uses detergent data) is capable of also identifying the likely problem flow source. Based on the available data from the field sheets, the physical indicators method to identify contamination at outfalls is of limited use. The physical indicators method resulted in numerous false negative and false positive indications of problem outfalls.

Dry-weather flows at the outfalls in this study were variable. About 50 of the 73 outfalls never had any observed dry-weather flow. Only 9 outfalls (20, 26, 38, 42, 48, 52, 60, 64 and 65) of the 24 outfalls that ever had dry-weather flows were flowing for every outfall visit. The detergent and flow chart methods indicated identical frequencies of problems for 23 out of the 24 outfalls for every visit. The frequencies of problems indicated using the physical indicators of contamination method when flow was present were variable and revealed numerous false positive (33%) and false negative (66%) results.

The amount of rainfall occurring before an outfall visit is not related to non-stormwater pollutant entries to storm drainage systems. A wide range of indicated frequencies of problems at outfalls were associated with varying antecedent rainfall amounts. Also, the indicated frequencies of problems at outfalls varied widely with respect to month of the year.

An estimate of the expected frequency of problems and the desired error rate must be known to determine the number of outfall collection visits needed to adequately determine the magnitude of problems indicated at outfalls. For example, referencing Table F-9, if the expected frequency of problems is 40% and the desired error is 20%, or less, approximately 4 visits to the outfall would be required. In contrast, if the expected frequency of problems is 100% and the desired error is 0%, 1 visit to the outfall would obviously be required.

Appendix G
Chemical Mass Balance Model with Monte Carlo Simulation

This appendix contains an example for the computer program developed to help solve simultaneous equations using matrix algebra (Lalor 1993). The code was prepared by Ed Kujawski, a UAB Honors' Student. This example lists the program input and output. Also included in this appendix is the Pascal source code for the program.

In this example, eight possible source water types and eight tracer parameters were selected and is based on sample data from outfall #20, collected on March 3, 1993. Based on this analysis, the following lists the likely sources of the water affecting this outfall, as determined using 10,000 runs of the Monte Carlo model:

	Calculated Likelihood of Occurrence of Source Water		
Potential Source Water	10th percentile	median	90th percentile
Spring water	0.28	0.33	0.39
Tap water	0.46	0.60	0.75
Sewage wastewater	-0.06	0.001	0.05
Carwash wastewater	-0.004	0.0002	0.006
Landscape irrigation water	0.03	0.08	0.15
Infiltrating groundwater	-0.23	0.006	0.31
Septic tank discharge wastewater	-0.005	0.004	0.03
Commercial laundry wash wastewater	-0.01	-0.007	-0.003

The water collected at this outfall is therefore not likely a problem as it is comprised of approximately 60% tap water, 33% spring water, and 8% landscaped irrigation water. The maximum contribution of any of the wastewaters (at the 90th percentile) is less than 5%, and more likely much less.

Example Input and Output from Chemical Mass Balance Program with Monte Carlo Simulation

MAIN.LIB

```
 [Sources]
Irrigation Runoff, Tap Water, Spring Water, Commercial Car Wash, Commercial Laundry, Septic, Shallow
Ground Water, Sewage

[Parameters]
Conductivity = µmhos/cm
Fluoride = mg/L
Hardness = mg/L CaC03
Detergent = mg/L
Floresc. = % scale
Potassium = mg/L
```

Ammonia = mg/L
Color = units

[Sample]
Conductivity = 188
Fluoride = 0.61
Hardness = 127
Detergent = 0
Floresc. = 13
Potassium = 1.98
Ammonia = 0.03
Color = 0

[Irrigation Runoff]	**Median conc.**	**COV**	**Distribution**
Conductivity =	104.93	0.07	N
Fluoride =	0.90	0.11	N
Hardness =	40.15	0.04	N
Detergent =	0	0	
Floresc. =	214.40	0.16	N
Potassium =	6.08	0.26	N
Ammonia =	0.37	0.25	N
Color =	10.00	0.36	N

[Plating Bath]	**Median conc.**	**COV**	**Distribution**
Conductivity =	10352	0.45	N
Fluoride =	5.13	0.47	N
Hardness =	1430	0.32	N
Detergent =	6.81	0.68	N
Floresc. =	293	0.70	N
Potassium =	1008.8	1.24	L
Ammonia =	65.65	0.66	N
Color =	103.8	0.91	N

[Tap Water]	**Median conc.**	**COV**	**Distribution**
Conductivity =	111.6	0.01	N
Fluoride =	0.97	0.01	N
Hardness =	49.3	0.03	N
Detergent =	0	0	
Floresc. =	4.63	0.08	N
Potassium =	1.55	0.04	N
Ammonia =	0.03	0.23	N
Color =	0	0	

[Spring Water]	**Median conc.**	**COV**	**Distribution**
Conductivity =	301.2	0.04	N
Fluoride =	0.03	0.87	N
Hardness =	239.8	0.03	N
Detergent =	0	0	
Floresc. =	6.80	0.43	N
Potassium =	0.73	0.10	N
Ammonia =	0.01	0.70	L
Color =	0	0	

[Commercial Car Wash]	**Median conc.**	**COV**	**Distribution**
Conductivity =	485.3	0.06	N
Fluoride =	12.3	0.19	N
Hardness =	156.5	0.05	N
Detergent =	48.96	0.10	N
Floresc. =	1190	0.11	N
Potassium =	42.69	0.37	N
Ammonia =	0.239	0.28	N
Color =	221.5	0.35	N

[Radiator]	**Median conc.**	**COV**	**Distribution**
Conductivity =	3280	0.21	N
Fluoride =	149.32	0.16	N
Hardness =	5.60	1.88	N
Detergent =	15.0	0.11	N
Floresc. =	22046	0.04	N
Potassium =	2801.8	0.13	N
Ammonia =	26.23	0.89	N
Color =	2999	0.01	N

[Commercial Laundry]	**Median conc.**	**COV**	**Distribution**
Conductivity =	562.9	0.21	N
Fluoride =	32.82	0.38	N
Hardness =	36.15	0.08	N
Detergent =	26.90	0.25	N
Floresc. =	1024.6	0.12	N
Potassium =	3.48	0.11	N
Ammonia =	0.82	0.14	N
Color =	46.7	0.27	N

[Septic]	**Median conc.**	**COV**	**Distribution**
Conductivity =	501.74	0.42	N
Fluoride =	0.93	0.39	N
Hardness =	56.84	0.36	L
Detergent =	3.27	1.33	L
Floresc. =	381.88	0.22	N
Potassium =	18.82	0.42	N
Ammonia =	87.21	0.40	N
Color =	70.60	0.39	N

[Shallow Ground Water]	**Median conc.**	**COV**	**Distribution**
Conductivity =	51.4	0.84	N
Fluoride =	0.06	0.50	L
Hardness =	27.30	0.39	N
Detergent =	0	0	
Floresc. =	29.90	1.55	L
Potassium =	1.19	0.44	N
Ammonia =	0.24	1.26	N
Color =	8.00	1.42	L

[Sewage]	**Median conc.**	**COV**	**Distribution**
Conductivity =	419.86	0.13	N
Fluoride =	0.76	0.23	N
Hardness =	142.92	0.11	N
Detergent =	1.5	0.82	N
Floresc. =	250.89	0.20	N
Potassium =	5.97	0.23	N
Ammonia =	9.92	0.34	L
Color =	37.89	0.55	N

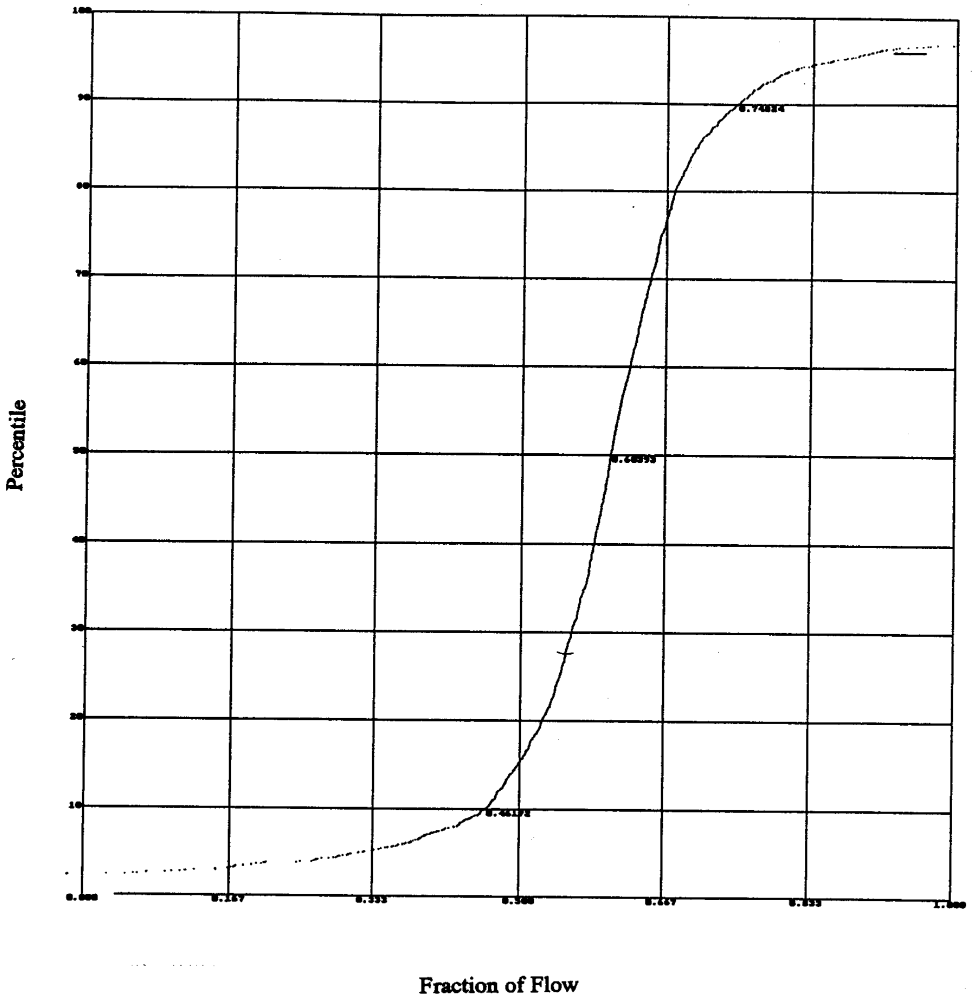


Figure G-1. Probability distribution for tap water source in mixed outfall sample.

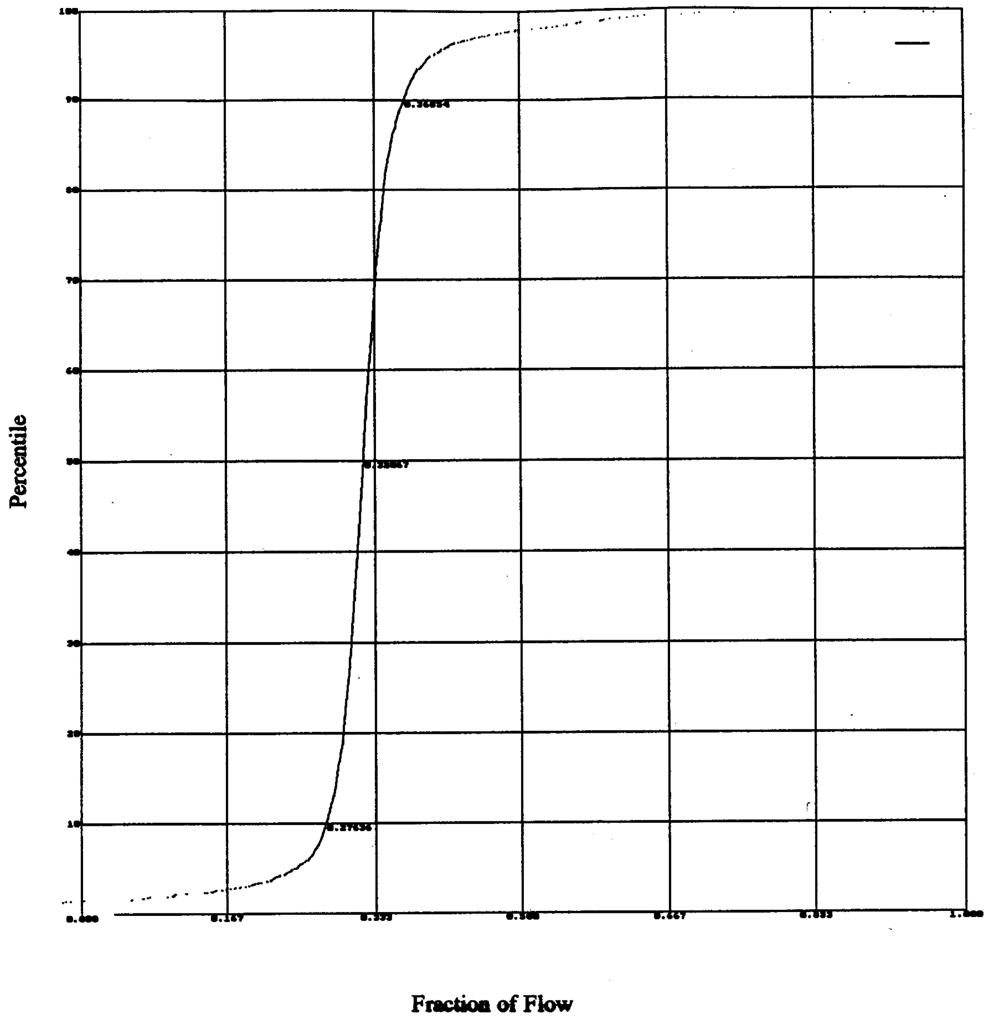


Figure G-2. Probability distribution for spring water source in mixed outfall sample.

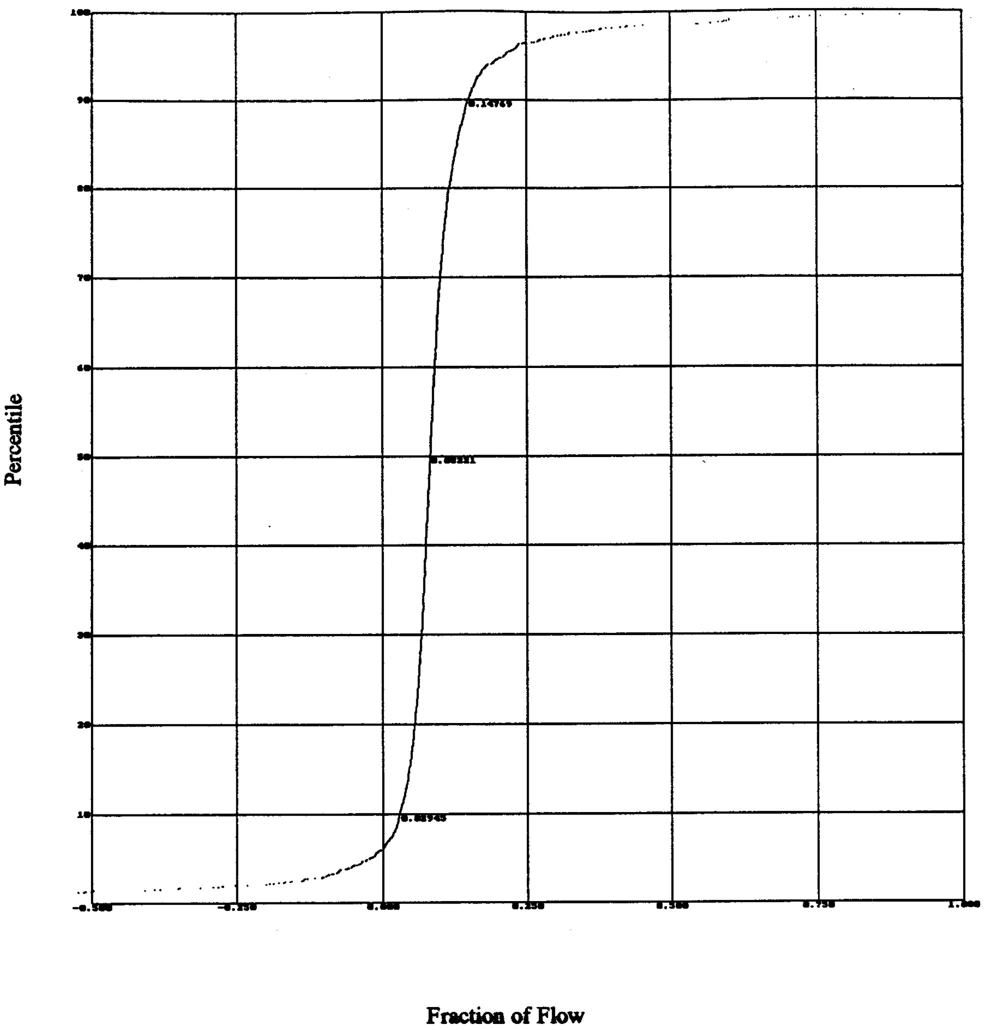


Figure G-3. Probability distribution for landscape irrigation runoff water source in mixed outfall sample.

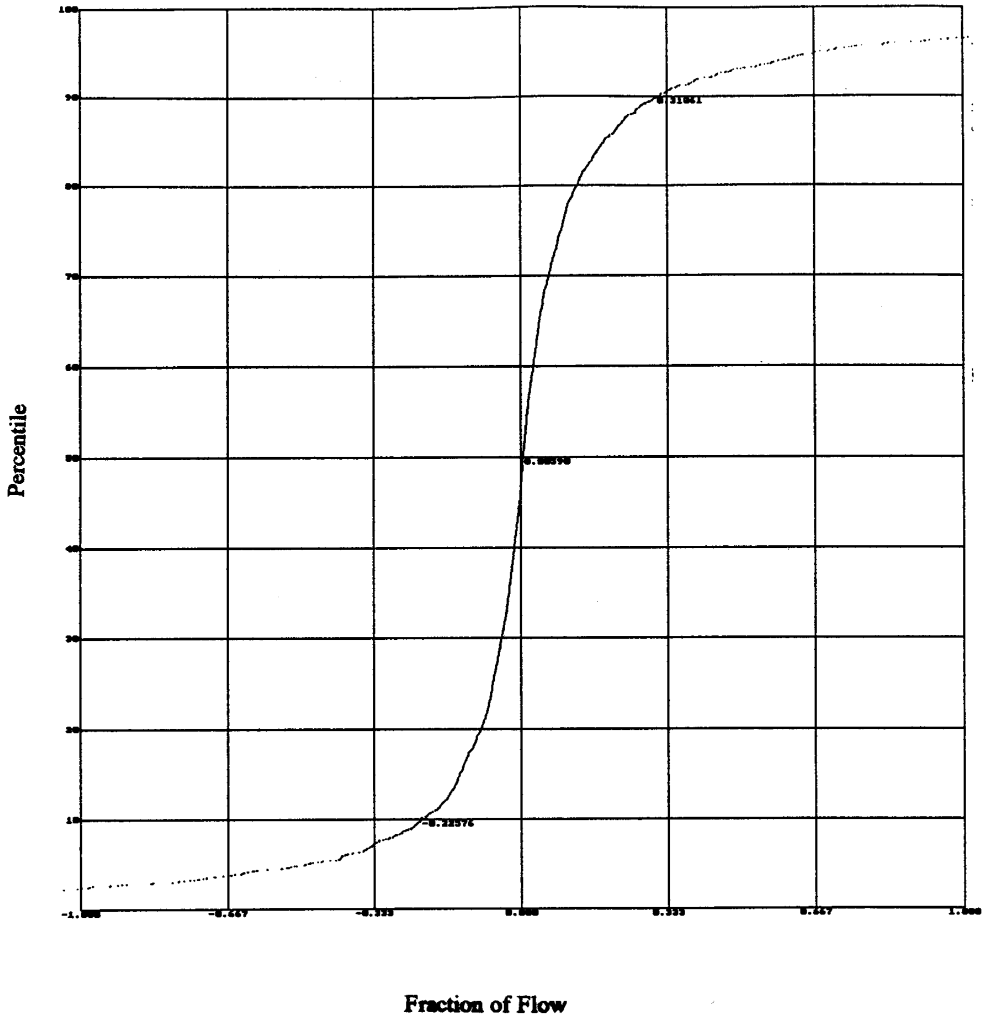


Figure G-4. Probability distribution for infiltrating groundwater source in mixed outfall sample.

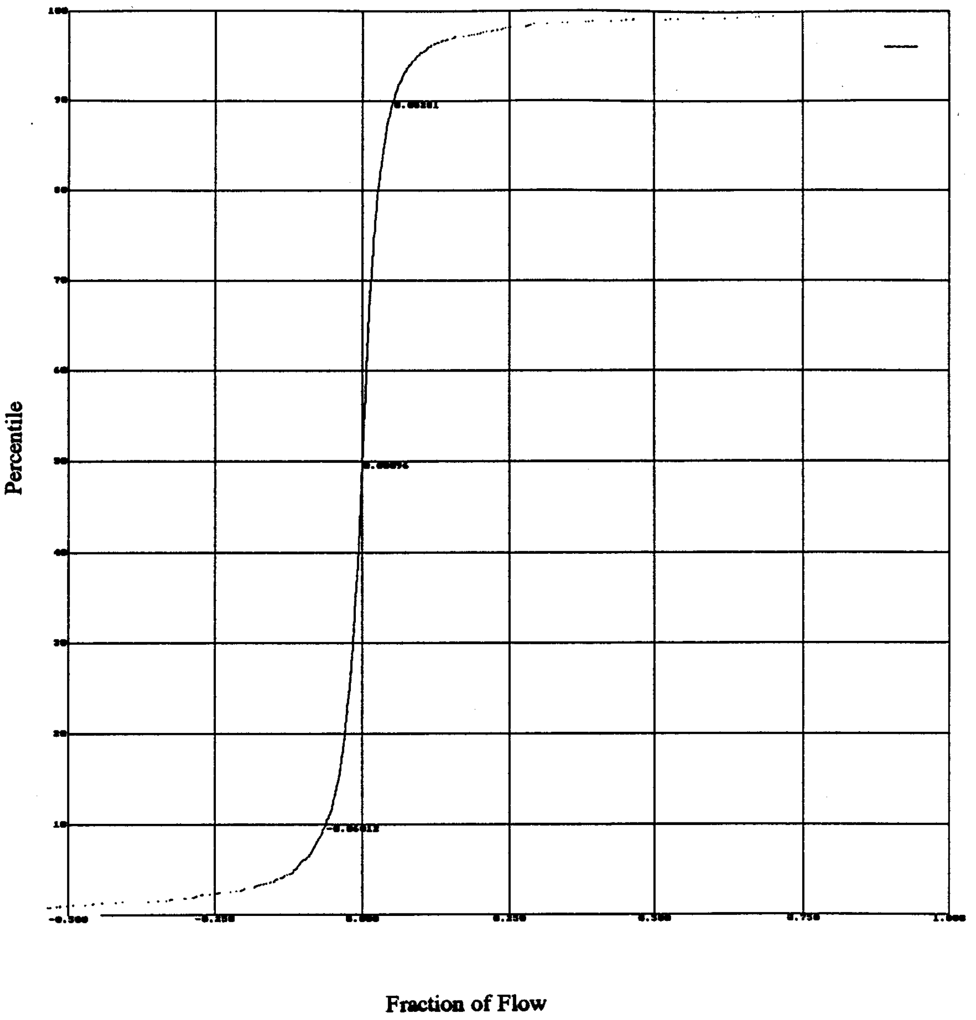


Figure G-5. Probability distribution for sanitary sewage wastewater source in mixed outfall sample.

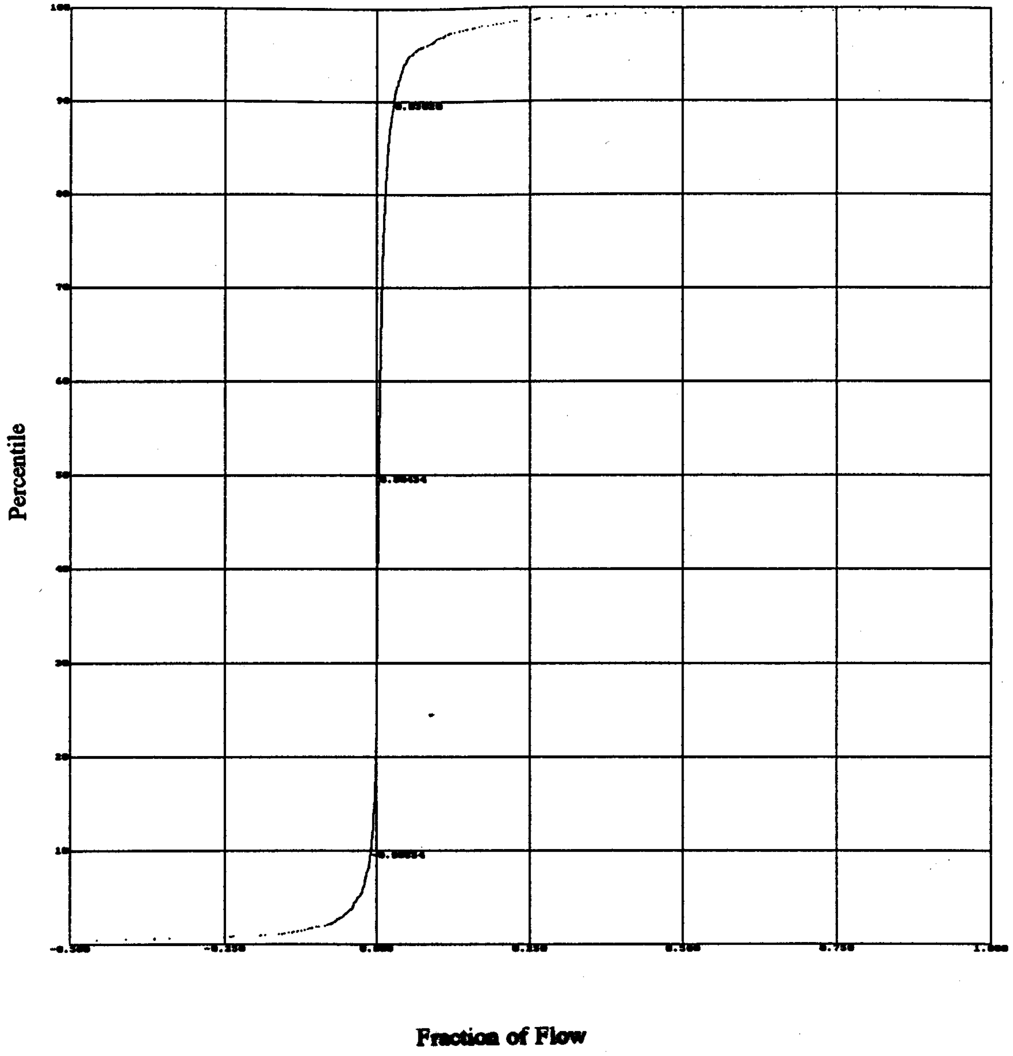


Figure G-6. Probability distribution for septic tank discharge water source in mixed outfall sample.

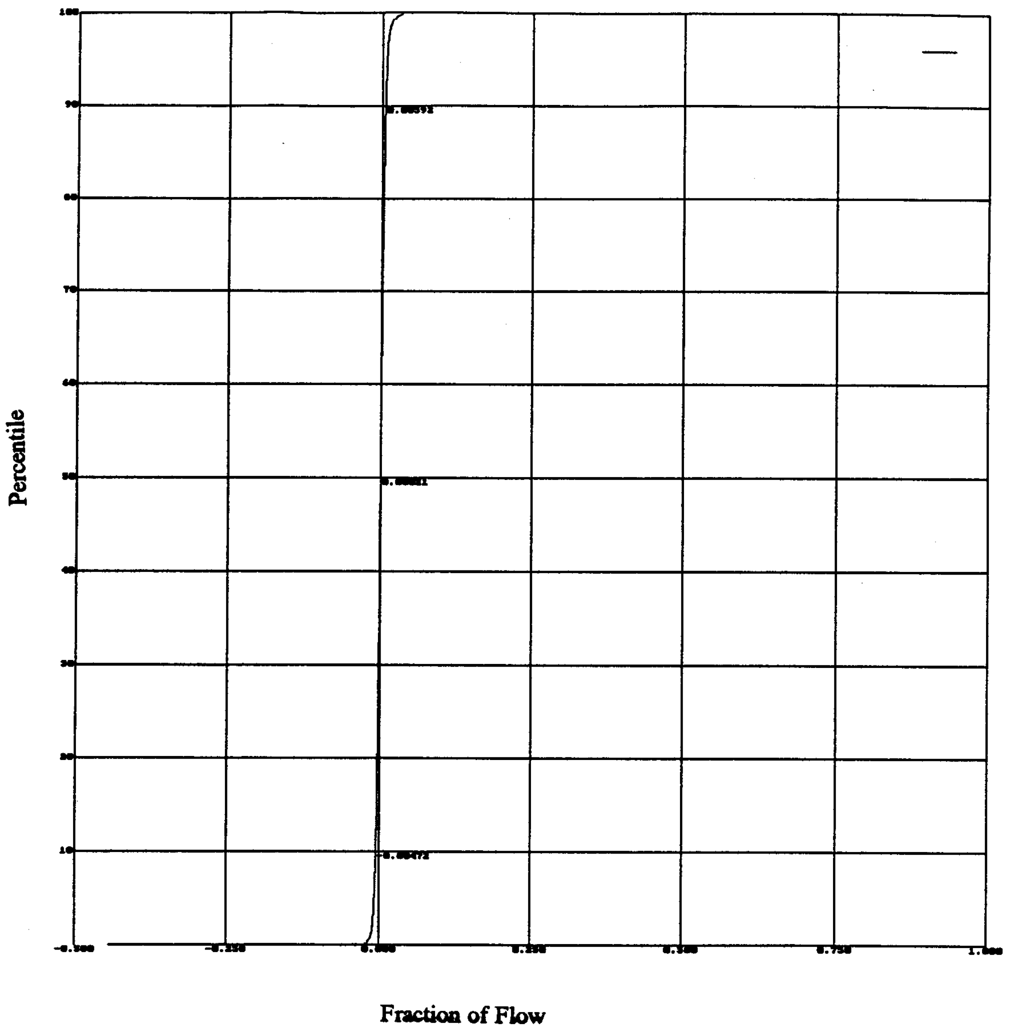


Figure G-7. Probability distribution for commercial car wash wastewater source in mixed outfall sample.

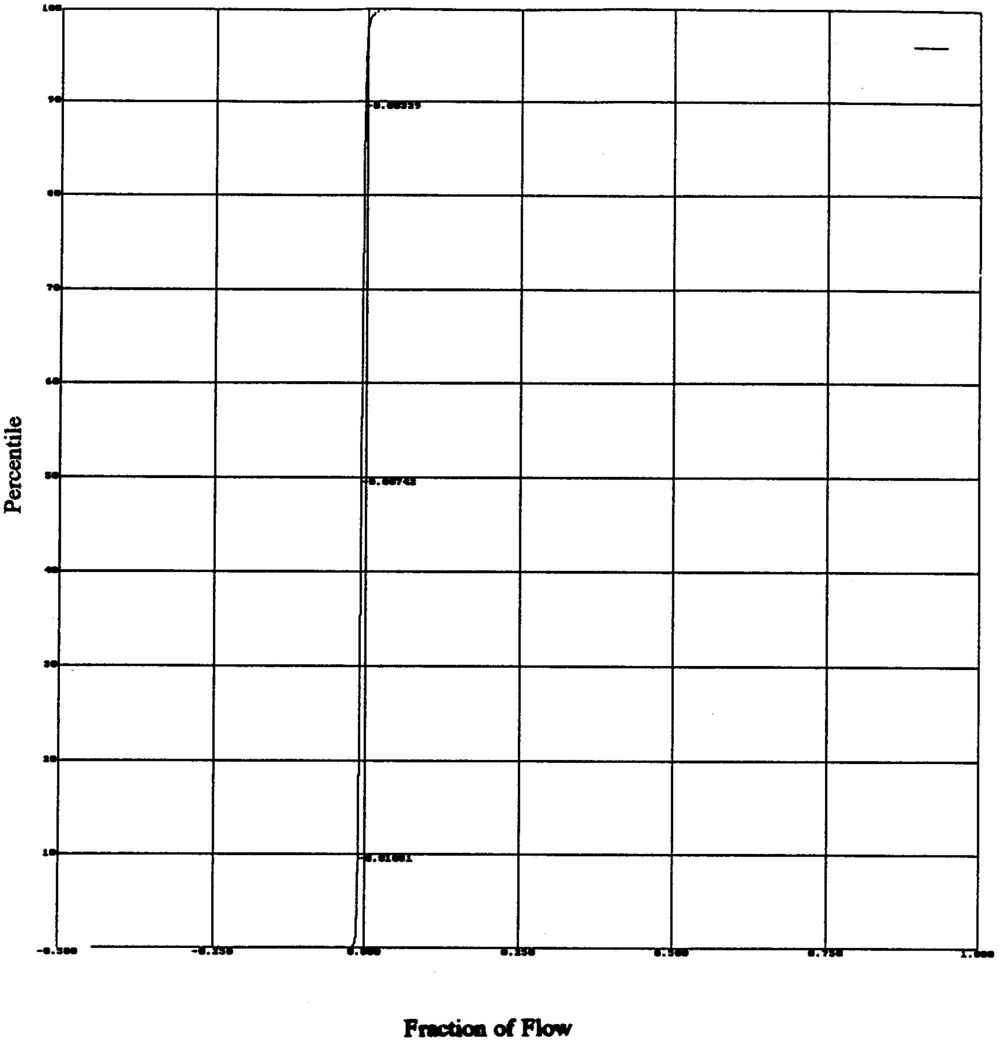


Figure G-8. Probability distribution for commercial laundry wastewater source in mixed outfall sample.

User Guide for Pol-Sit, the Monte Carlo Model to Determine the Most Likely Source Components

Introduction

Pol-Sit uses Monte Carlo simulation techniques to predict the most likely source area components in a mixed outfall sample. The files necessary to run POL-SIT include: POL-SIT.EXE the executable program, and MAINLIB a library file. To run a Monte-Carlo simulation, type:

```
POL-SIT {library filename}
```

For example, if the library filename is MAIN.LIB (the default name) then the following command will run the program:

```
POL-SITE
```

If MAIN.LIB is not the name of the library file, then type POL-SIT followed by the library filename. As an example, if the library filename is TEST.LIB, then the following command will run the program:

```
POL-SIT TEST.LIB
```

Library File

The library file consists of four main parts. Each part is separated by a header surrounded by left bracket ([) and right bracket (]) characters. The first part is identified by a header of available sources, the second part by parameters, and the third part by the sample characteristics. The fourth part of the library consists of many entries under each of the source's name. The following lists an example of these file parts:

Sources

Under the header for sources is a list of all the sources in the library. The list can be comma delimited, for example:

```
[Sources]
Irrigation Runoff, Plating Bath, Tap Water,
Spring Water, Commercial Car Wash,
Radiator, Commercial Laundry, Septic,
Shallow Ground Water, Sewage
```

Parameters

Under this header are all of the parameters that will be used in the Monte Carlo simulation. After each parameter, the units are listed. The units are used only in the output to make it more readable. An example parameters section looks like:

```
[Parameters]
Conductivity = µmhos/cm
Fluoride = mg/L
Hardness = mg/L CaC03
Detergent = mg/L
Fluorescence = % scale
Potassium = mg/L
Ammonia = mg/L
pH = units
Color = units
```

Toxicity = I_{25} % light reduction, Microtox

Sample

Under this header are the mixed outfall sample data. Each of the parameters given in the parameters section must be given a numerical value. An example sample section looks like:

```
[Sample]
Conductivity = 486.3
Fluoride = 12.3
Hardness = 156.5
Detergent = 48.96
Fluorescence = 1190
Potassium = 42.69
Ammonia = .239
pH = 6.72
Color = 221.5
Toxicity = 99.0
```

Site Parameters

Under this header are the characterization data for all of the parameters for each potential source component. The header text is the source component name. After the parameter title, the mean, coefficient of variation, and the distribution type are listed. The data distribution can be labeled as either log-normal (L) or normal (N). An example source parameter section for one component looks like:

```
[Irrigation Runoff]
Conductivity=     105.12      10.34       N
Fluoride=           0.86       0.13       N
Hardness=          39.64       1.31       N
Detergent=          0          0
Floresc.=         231.94      25.38       N
Potassium=          6.22       2.24       N
Ammonia=            0.39       0.11       N
pH=                 6.99       0.09       N
Color=             12.60       2.51       N
Chloride=           0.04       0.03       N
Toxicity=           0          0
Copper=             0          0
Phenols=            0          0
```

* Note that the value of 0 was given for the coefficient of variation for several parameters. POL-SIT interpolates this by assuming the concentration distribution is a constant and it will then use the mean in all calculations, instead of determining a random sample based upon the mean and coefficient of variation.

Editing the Library File

Any text processor can be used to edit the library file. For example, use Windows Notebook or the MS-DOS Edit command. Do not use word processors such as Microsoft Word or Word Perfect, unless the text is saved as a text-only file.

Mathematical Model

The model used for calculating the pollution concentrations in POL-SIT are linear equations that express the concentration of a pollutant in a sample based on the concentration of the pollutant in the potential source components and the amount of each source component in the sample (the unknown). Equation 1 shows the relationship between the mixed pollutant concentration, the source component, and the source component pollution concentrations.

$$\sum_{a=0}^{b} Aa,cBa = Cc$$

(1)

b is the number of pollutants that are included in the matrix for evaluation, *c* is the pollutant concentration in the mixed sample at the outfall. During each run, there are as many simultaneous equations as pollutants in the library. Matrix *A* holds the data for the concentrations of pollutants at the sources. Matrix *B* holds the amount of the source components in the sample. Matrix *C* is the mixed sample pollutant data for the outfall sample. For each iteration, the matrix in equation 2 is solved.

$$AB=C$$

(2)

During the Monte Carlo simulation, the values used in the *A* matrix are determined by the library file. In the library file, each source has the pollutant mean, coefficient of variation, and distribution type. Only two sampling types are available, normal and log-normal distribution. If the normal distribution is selected, then the value placed in the *A* matrix is determined by the following routine.

```
S:=0:
for I:=1 to 12 do
  S:=S+Random(10000)/10000:
S:=S-6.0:
FindNormal:=Mean+SD*S:
```

Where *SD* is the standard deviation, *Mean* is the mean of the data, and *FindNormal* is the resulting value with a mean of *Mean* and a standard deviation of *SD.* When the log-normal distribution is requested, the following routine is used.

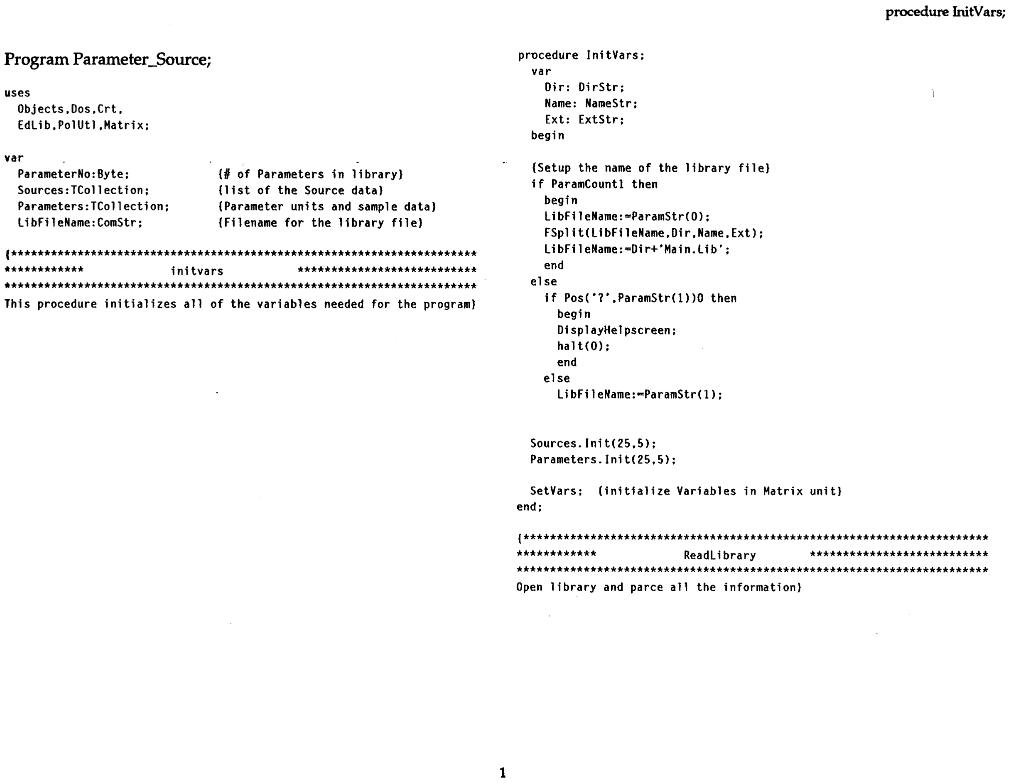
```
MeanY:=ln(Mean)-(0.5*ln(CV*CV+1));
VarianceY:=ln(CV*CV+1):
repeat
  A:=Random(10000)/10000.0:
  B:=Random(10000)/10000.0:

S:=exp(Sqrt(-2*ln(A))*cos(2*Pi*B)*VarianceY*VarianceY+MeanY)
:
until (S>0) and (S<Mean*2):
FindLogNormal:=S:
```

Where *CV* is the coefficient of variation, *Mean* is the mean value of the library data and *FindLogNormal* is the resulting value with a mean of *Mean* and log-normal distribution with a coefficient of variation of *CV*.

Simulation Run

During the simulation, there is a loop which executes many times (typically 10,000 trials) to make up the Mont Carlo simulation. The steps in the simulation include: Initialization, Solving Matrix, and Saving the data. Data in the library file for the pollutants include mean and variation data. Matrix *A* is filled with randomly selected data based on the library file. Once Matrix *A* is filled, Matrix *B* is evaluated using equation 2. Finally, Matrix *B* is saved in memory.

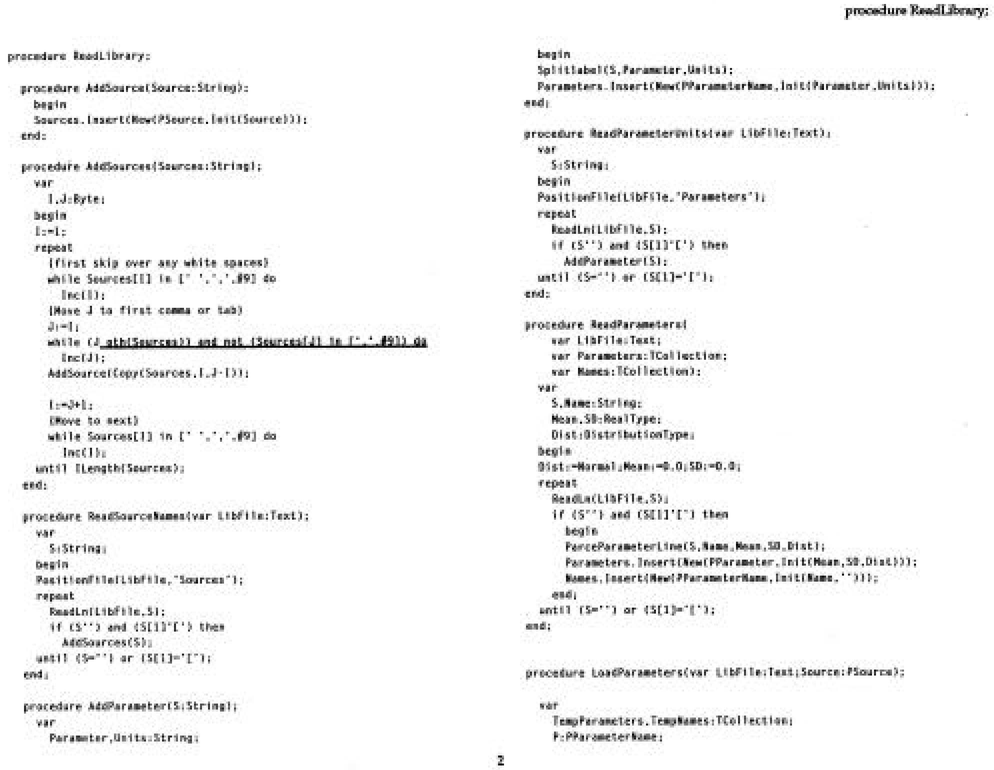
Once all of the Monte Carlo simulations have been run, the Matrix *B* values are saved in memory and are sorted and plotted on the screen. From these probability plots, the most likely source components of the sample are displayed.



Program Parameter_Source;

```
uses
  Objects,Dos,Crt,
  EdLib,PolUtl,Matrix;

var
  ParameterNo:Byte;             {# of Parameters in library}
  Sources:TCollection;          {list of the Source data}
  Parameters:TCollection;       {Parameter units and sample data}
  LibFileName:ComStr;           {Filename for the library file}

{************************************************************************
************              initvars           ****************************
*************************************************************************
This procedure initializes all of the variables needed for the program}
```

```
procedure InitVars;
  var
    Dir: DirStr;
    Name: NameStr;
    Ext: ExtStr;
  begin

  {Setup the name of the library file}
  if ParamCount1 then
    begin
    LibFileName:=ParamStr(0);
    FSplit(LibFileName,Dir,Name,Ext);
    LibFileName:=Dir+'Main.Lib';
    end
  else
    if Pos('?',ParamStr(1))0 then
      begin
      DisplayHelpscreen;
      halt(0);
      end
    else
      LibFileName:=ParamStr(1);


  Sources.Init(25,5);
  Parameters.Init(25,5);

  SetVars;  {initialize Variables in Matrix unit}
end;

{************************************************************************
************              ReadLibrary        ****************************
*************************************************************************
Open library and parce all the information}
```



```
procedure ReadLibrary:

  procedure AddSource(Source:String):
    begin
    Sources.Insert(New(PSource.Init(Source))):
  end:

  procedure AddSources(Sources:String);
    var
      I.J:Byte:
    begin
    I:=1:
    repeat
      {first skip over any white spaces}
      while Sources[I] in [' ',',',#9] do
        Inc(I):
      {Move J to first comma or tab}
      J:=I;
      while (J gth(Sources)) and not (Sources[J] in [',',#9]) do
        Inc(J):
      AddSource(Copy(Sources,I,J-I)):

      I:=J+1:
      {Move to next}
      while Sources[I] in [' ',',',#9] do
        Inc(I);
    until ILength(Sources):
  end:

  procedure ReadSourceNames(var LibFile:Text);
    var
      S:String;
    begin
    PositionFile(LibFile,'Sources');
    repeat
      ReadLn(LibFile,S):
      if (S'') and (S[1]'[') then
        AddSources(S);
    until (S='') or (S[1]='[');
  end;

  procedure AddParameter(S:String);
    var
      Parameter,Units:String;
```

```
    begin
    SplitLabel(S,Parameter,Units):
    Parameters.Insert(New(PParameterName,Init(Parameter,Units))):
  end;

  procedure ReadParameterUnits(var LibFile:Text);
    var
      S:String:
    begin
    PositionFile(LibFile,'Parameters');
    repeat
      ReadLn(LibFile,S):
      if (S'') and (S[1]'[') then
        AddParameter(S):
    until (S='') or (S[1]='[');
  end:

  procedure ReadParameters(
      var LibFile:Text;
      var Parameters:TCollection;
      var Names:TCollection):
    var
      S,Name:String:
      Mean,SD:RealType:
      Dist:DistributionType;
    begin
    Dist:=Normal;Mean:=0.0;SD:=0.0;
    repeat
      ReadLn(LibFile,S);
      if (S'') and (S[1]'[') then
        begin
        ParceParameterLine(S,Name,Mean,SD,Dist);
        Parameters.Insert(New(PParameter,Init(Mean,SD,Dist)));
        Names.Insert(New(PParameterName,Init(Name,'')));
      end;
    until (S='') or (S[1]='[');
  end;


  procedure LoadParameters(var LibFile:Text;Source:PSource);

    var
      TempParameters,TempNames:TCollection;
      P:PParameterName;
```

```
    I:Word;
    S:String;

  Function SearchComp(P:PParameterName):Boolean; far;
    begin
    SearchComp:=UpStr(P^.GetName)=S;
  end;

  begin
  TempParameters.Init(20,5);
  TempNames.Init(20,5);
  PositionFile(LibFile,Source^.GetName);
  ReadParameters(libFile,TempParameters,TempNames);
  for I:=0 to Parameters.Count-1 do
    begin
    P:=Parameters.At(I);
    S:=UpStr(P^.GetName);
    if TempNames.FirstThat(@SearchComp)nil then
      Source^.Parameters.Insert(
          TempParameters.At(
          TempNames.IndexOf(
          TempNames.FirstThat(@SearchComp))))
    else
      begin
      Writeln(output,'Could not find '+S+' Parameter in ');
      Writeln(output,'the Source data for '+UpStr(Source^.Get-
                    Name)+'.');
      Halt(1);
    end;
  end;
end;

procedure ReadSourceData(var LibFile:Text);
  var
    I:Word;
    CurrentSource:PSource;
  begin
  for I:=0 to Sources.Count-1 do
    begin
    CurrentSource:=Sources.At(I);
    LoadParameters(LibFile,CurrentSource);
  end;
end;
```

```
procedure ReadSourceSample(var LibFile:Text);
  var
    S,Name:String;
    Sample:RealType;

  Function SearchPol(P:PParameterName):Boolean; far;
    begin
    if UpStr(P^.GetName)=UpStr(Name) then
      begin
      P^.SetSample(Sample);
      SearchPol:=True;
      end
    else
      SearchPol:=False;
  end;

  Function SearchError(P:PParameterName):Boolean; far;
    begin
    SearchError:=P^.SampleTouched;
  end;

  begin
  PositionFile(LibFile,'Sample');
  repeat
    ReadLn(LibFile,S);
    if (S'') and (S[1]'[') then
      begin
      ParceSampleLine(S,Name,Sample);
      if Parameters.FirstThat(@SearchPol)=nil then
        begin
        Writeln(output,'Error: Sample include the Parameter '+Name);
        Writeln(output,'       that is not in the Parameter table');
        Halt(1);
      end;
    end;
  until (S='') or (S[1]='[');
  if Parameters.FirstThat(@SearchError)=nil then
    begin
    Writeln(output,'Error: Not all Parameters were found in the sam-
                  ple');
    Halt(1);
  end;
end;
```

```
  var
    LibFile:Text;
  begin
  Writeln(output,'Reading Data from library file');
  Assign(LibFile,LibFileName);
  ReSet(LibFile);
  CheckIOResult;
  ReadSourceNames(LibFile);
  ReadParameterUnits(libFile);
  ReadSourceData(LibFile);
  ReadSourceSample(LibFile);
  Close(LibFile);
  Writeln(output,'Finished reading data from library file');
end;
```

```
procedure SelectPoints;
  var
    I,J:Word;
  begin
  for I:=1 to MaterialNo do
    for J:=1 to SourceNo do
      IterLib[I,J]:=PSource(Sources.At(J-1))^.GetSample(I-1);
end;


const
  SampleNo=200;
  Abbrev:Array[0..9] of char=('I','P','T','G','E','R','W','L','Z','S');
var
  I,J,K:Byte;
  S:PSource;
  St:String;
  P:PParameterName;
  F:Text;
  CurrentIterations:Word;
  X,Y:Byte;
begin
Randomize;
RandSeed:=2;
DirectVideo:=False;
Writeln(output,'Pol-Sit - A program by Edward T. Kujawski (11/7/92)');
MaterialNo:=MaxMaterialNo;
SourceNo:=MaxSourceNo;
InitVars;
ReadLibrary;

(*
Assign(F,'200');
{AssignCrt(F);}
ReWrite(F);

Write(F,'Group$,Sample$');
for I:=0 to Parameters.Count-1 do
  Write(F,',',PParameterName(Parameters.At(I))^.GetName);
Writeln(F);
for I:=0 to Sources.Count-1 do
  begin
  S:=Sources.At(I);
```

```
  for J:=1 to SampleNo do
    begin
    Write(F,Abbrev[I],',',J);
    for K:=0 to Parameters.Count-1 do
      begin
      Str(S^.GetSample(K):8:2,St);
      RemoveSpace(St);
      Write(F,',',St);
      end;
    WRiteln(F);
  end;
end;
Close(F);
end.
*)


MaterialNo:=Parameters.Count;
SourceNo:=Sources.Count;
for I:=1 to MaterialNo do
  Sample[I]:=PParameterName(Parameters.At(I-1))^.Sample;

CurrentIterations:=0;
Writeln(output);
Writeln(output);
Writeln(output,'Press any key to abort additional calculations.');
Write(output,'On iteration #');
X:=WhereX;
Y:=WhereY;
repeat
  Inc(CurrentIterations);
  repeat
    SelectPoints;
    CalculateConcentration;
  until SampleOK(X,Y,CurrentIterations) or KeyPressed;
  if SampleOK(X,Y,CurrentIterations) then
    StoreResults(CurrentIterations);
  if (CurrentIterations and 7) = 7 then
    begin
    GotoXY(X,Y);
    Write(output,CurrentIterations);
  end;
until KeyPressed or (CurrentIterations=Iterations);
```

```
GotoXY(X,Y);
Writeln(output,CurrentIterations);
SortIterations(CurrentIterations);
if KeyPressed then
  ScanKBD(InputScan);
PrintResults(CurrentIterations,Sources,Parameters);
PlotResults(CurrentIterations,Sources);
end.

{Assign(F,'E:\200');}
AssignCrt(F);
ReWrite(F);

Write(F,'Group#,Sample#');
for I:=0 to Parameters.Count-1 do
  Write(F,',',PParameterName(Parameters.At(I))^.GetName);
Writeln(F);
for I:=0 to Sources.Count-1 do
  begin
  S:=Sources.At(I);
  for J:=1 to SampleNo do
    begin
    Write(F,Abbrev[I],',',J);
    for K:=0 to Parameters.Count-1 do
      begin
      Str(S^.GetSample(K):8:2,St);
      RemoveSpace(St);
      Write(F,',',St);
    end;
    WRiteln(F);
  end;
end;
Close(F);
end.

{Just Display Data}
for I:=1 to Sources.Count do
  begin
  S:=Sources.At(I-1);
  Writeln(S^.GetName);
end;

for I:=1 to Parameters.Count do
  begin
```

```
  P:=Parameters.At(I-1);
  Writeln(P^.GetName);
end;
end.
```

Unit PolUtl;

```
{This unit includes utility procedured for pol-sit}

INTERFACE

{$define Test1}             {Test for positive samples}
{ $define Test3}             {Test if  then =0}

uses
  Objects,
  EdLib;

type
  RealType=Single;
  DistributionType=(Normal,LogNormal);
  PSource=^TSource;
  TSource=Object(TObject)
      Name:PString;
      Parameters:TCollection;
      constructor Init(SourceName:String);
      function GetName:String;
      function GetSample(ParameterNo:Word):RealType;
    end;
  PParameterName=^TParameterName;
  TParameterName=Object(TObject)
      Name:PString;
      Units:PString;
      Sample:RealType;
      SampleTouched:Boolean;
      constructor Init(ParameterName,UnitName:String);
      function GetName:String;
      procedure SetSample(A:RealType);
  end;
  PParameter=^TParameter;
  TParameter=Object(TObject)
      Mean,SD:RealType;
      Dist:DistributionType;
      constructor Init(NewMean,NewCoV:RealType;NewDist:DistributionType);
      function GetSample:RealType;
  end;
```

```
procedure DisplayHelpScreen;
procedure PositionFile(var F:Text;FindStr:String);
procedure RemoveSpace(var S:String);
procedure AbortOnEOF(var F:Text;ErrMsg:String);
procedure SplitLabel(S:String;var Lab:String;var Equat:String);
procedure ParceParameterLine(S:String;var ParameterName:String;
    var Mean,SD:RealType;Dist:DistributionType);
procedure ParceSampleLine(S:String;var Name:String;var Sample:RealType);
function FindLogNormal(Mean,SD:RealType):RealType;
function FindNormal(Mean,SD:RealType):RealType;
procedure CheckIOResult;

IMPLEMENTATION
```

```
procedure DisplayHelpScreen;
  begin
  Writeln(Output,'This is the help screen for the command line - not com-
                      plete yet');
end;
```

```
procedure PositionFile(var F:Text;FindStr:String);
  var
    S:String;
  begin
  Reset(F);
  FindStr:='['+UpStr(FindStr)+']';
{  RemoveSpace(FindStr);}
  repeat
    ReadLn(F,S);
  until EOF(F) or (UpStr(S)=FindStr);
  AbortOnEOF(F,'Searching for '+FindStr);
end;
```

```
procedure RemoveSpace(var S:String);
  var
    I:Byte;
  begin
  I:=1;
  while I gth(S) do
    if S[I]=' ' then
      Delete(S,I,1)
    else
      I:=I+1;
end;
```

```
procedure AbortOnEOF(var F:Text;ErrMsg:String);
  begin
  if EOF(F) then
    begin
    Close(F);
    writeln(output,'Unexpected EOF.  ',ErrMsg);
    Halt(1);
  end;
end;
```

```
procedure ParceParameterLine(S:String;var ParameterName:String;
    var Mean,SD:RealType;Dist:DistributionType);

  procedure CheckErr(Err:integer;I:Byte);
    begin
    if (Err0) or (I>Length(S)) then
      begin
      Writeln(output,'Error in library.  Something is wrong with the');
      Writeln(output,'                   number(s) on the following
                      line:');
      Writeln(output,S);
      Halt(1);
    end;
  end;

  var
    I,J:Byte;
    Err:integer;
  begin
  ParameterName:=Copy(S,1,Pos('=',S)-1);
  I:=Pos('=',S)+1;

    while S[I] in [' ',',',#9] do
      Inc(I);
    J:=I;
    while not (S[J] in [' ',',',#9]) do
      Inc(J);
    Val(Copy(S,I,J-I),Mean,Err);
    CheckErr(Err,I);

    I:=J+1;
    while S[I] in [' ',',',#9] do
      Inc(I);
    J:=I;
    while not (S[J] in [' ',',',#9]) do
      Inc(J);
    Val(Copy(S,I,J-I),SD,Err);
    CheckErr(Err,I-1);

    if SD=0 then
      Dist:=Normal
    else
      begin
      I:=J+1;
```

```
      while S[I] in [' ',',',#9] do
        Inc(I);
      case UpCase(S[I]) of
        'L':  Dist:=LogNormal;
        'N':  Dist:=Normal;
      else
        begin
        Writeln(output,'Error in Library.  The following line has an in-
                        valid');
        Writeln(output,'                   distribution token.');
        Writeln(output,S);
        Halt(1);
        end
      end;
    end;
end;
```

```
procedure ParceSampleLine(S:String;var Name:String;var Sample:RealType);
  var
    I,J:Byte;
    Err:integer;
  begin
  Name:=Copy(S,1,Pos('=',S)-1);
  I:=Pos('=',S)+1;

  while S[I] in [' ',',',#9] do
    Inc(I);
  J:=I;
  while not (S[J] in [' ',',',#9]) do
    Inc(J);
  Val(Copy(S,I,J-I),Sample,Err);

  if Err0 then
    begin
    Writeln(output,'Error in library.  Something is wrong with the');
    Writeln(output,'                   number(s) on the following
                  line:');
    Writeln(output,S);
    Halt(1);
   end;
end;


{**********************************************************************
************            SplitLabel        ***************************
***********************************************************************}
{Split the line
  Ammonia=mg/l
into
  Ammonia
  mg/l                    }
```

```
procedure SplitLabel(
        S:String;
    var Lab:String;
    var Equat:String);
  begin
  Lab:=Copy(S,1,Pos('=',S)-1);
  Equat:=Copy(S,Pos('=',S)+1,Length(S)-Pos('=',S));
  while (Equat[Length(Equat)] in [' ',',',#9]) and (Length(Equat)0) do
    Delete(Equat,Length(Equat),1);
  if Equat='' then
    Equat:='-';
end;

{**********************************************************************
************            TSource Definition   ***************************
***********************************************************************}
```

```
constructor TSource.Init(SourceName:String);
  begin
  Name:=NewStr(SourceName);
  Parameters.Init(20,5);
end;
```

```
function TSource.GetName:String;
  begin
  GetName:=Name^;
end;
```

```
function TSource.GetSample(ParameterNo:Word):RealType;
  var
    P:PParameter;
  begin
  P:=Parameters.At(ParameterNo);
  GetSample:=PParameter(P)^.GetSample;
end;

{*********************************************************************
************            TParameterName Definition**********************
**********************************************************************}
```

```
constructor TParameterName.Init(ParameterName,UnitName:String);
  begin
  Name:=NewStr(ParameterName);
  Units:=NewStr(UnitName);
  SampleTouched:=False;
end;
```

```
function TParameterName.GetName:String;
  begin
  GetName:=Name^{+':'+Units^};
end;
```

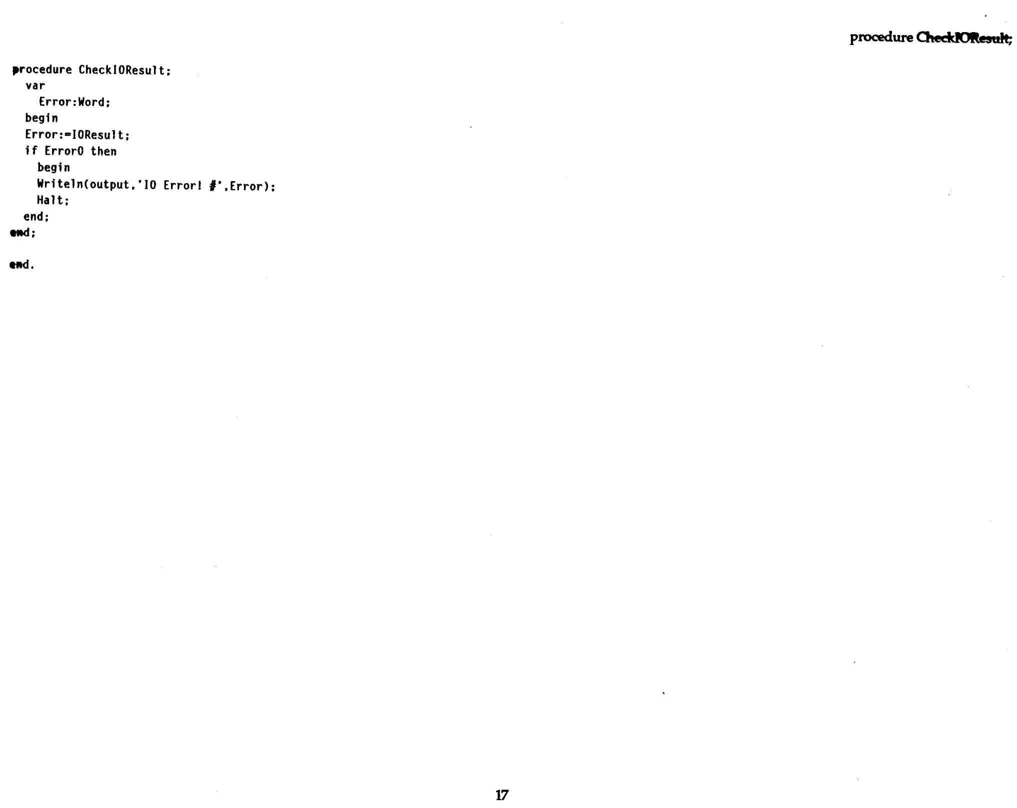
```
procedure TParameterName.SetSample(A:RealType);
  begin
  Sample:=A;
  SampleTouched:=True;
end;

{********************************************************************
************            TParameter Definition**************************
**********************************************************************}
```

```
constructor TParameter.Init(NewMean,NewCoV:RealType;NewDist:Distribution-
Type);
  begin
  case NewDist of
    LogNormal: begin
      if NewMean0 then
        Mean:=ln(NewMean)
      else
        Mean:=NewMean;
      if NewCoV0 then
        SD:=ln(NewCoV*Mean)
      else
        SD:=NewCoV*Mean;
      end;
    Normal: begin
      Mean:=NewMean;
      SD:=NewCoV*Mean;
    end;
  end;
  Dist:=NewDist;
end;
```

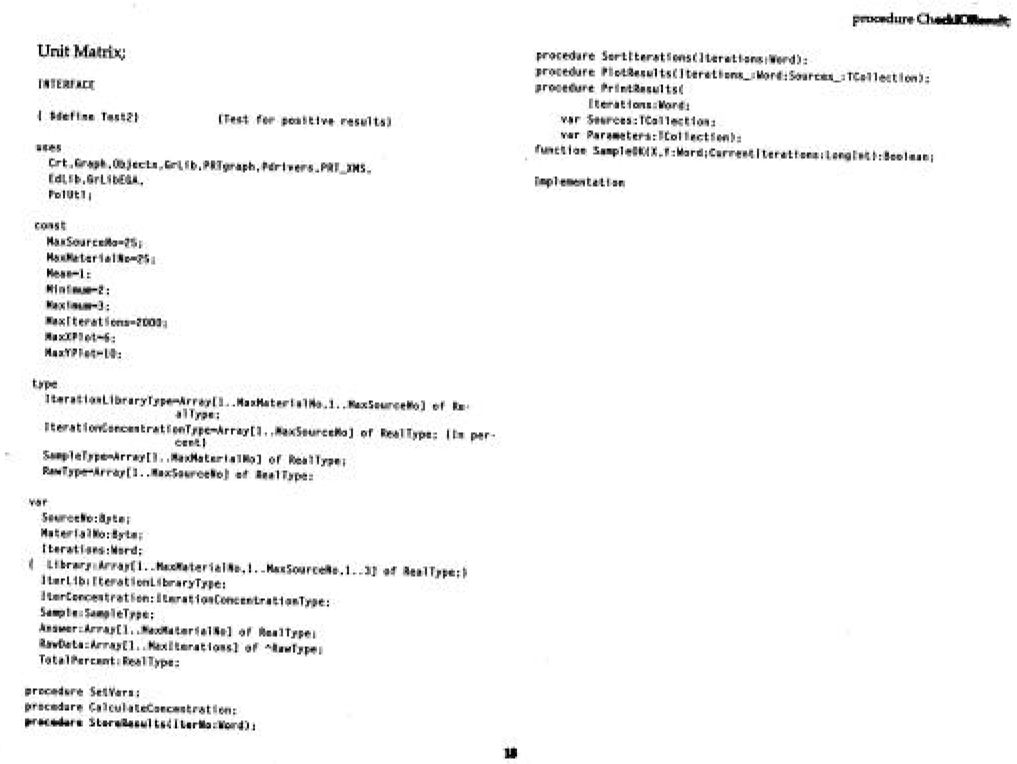
```
function TParameter.GetSample:RealType;
  begin
  if SD=0 then
    GetSample:=Mean
  else
  if Dist=Normal then
    GetSample:=FindNormal(Mean,Sd)
  else
    GetSample:=FindLogNormal(Mean,Sd);
end;
```

```
function FindLogNormal(Mean,SD:RealType):RealType;
  var
    CV,A,B,VarianceY,MeanY,S:RealType;
    I:Byte;
  begin
  CV:=SD/Mean;
  MeanY:=ln(Mean)-(0.5*ln(CV*CV+1));
  VarianceY:=ln(CV*CV+1);
  {$ifdef test1}
    repeat
      A:=Random(10000)/10000.0;
      B:=Random(10000)/10000.0;
      S:=exp(Sqrt(-2*ln(A))*cos(2*Pi*B)*VarianceY*VarianceY+MeanY);
    until (S0){ and (San*2)};
    FindLogNormal:=S;
  {$else}
    {$ifdef Test3}
      A:=Random(10000)/10000.0;
      B:=Random(10000)/10000.0;
      S:=exp(Sqrt(-2*ln(A))*cos(2*Pi*B)*VarianceY*VarianceY+MeanY);
      if S then
        FindLogNormal:=0
      else
        FindLogNormal:=S;
    {$else}
      A:=Random(10000)/10000.0;
      B:=Random(10000)/10000.0;
      FindLogNormal:=exp(Sqrt(-2*ln(A))*cos(2*Pi*B)*VarianceY*Vari-
                       anceY+MeanY);
    {$endif}
  {$endif}
end;
```

```
function FindNormal(Mean,SD:RealType):RealType;
  function DoIt:RealType;
    var
      S:RealType;
      I:Byte;
    begin
    S:=0;
    for I:=1 to 12 do
      S:=S+Random(10000)/10000;
    S:=S-6.0;
    DoIt:=Mean+SD*S;
  end;

  var
    S:RealType;
  begin
  {$ifdef test1}
    repeat
      S:=DoIt;
    until (S0){ and (San*2)};
  {$else}
    {$ifdef test3}
      S:=DoIt;
      if S then
        S:=0;
    {$else}
      S:=DoIt;
    {$endif}
  {$endif}
  FindNormal:=S;
end;
```



```
procedure CheckIOResult;
  var
    Error:Word;
  begin
  Error:=IOResult;
  if Error0 then
    begin
    Writeln(output,'IO Error! #',Error);
    Halt;
  end;
end;

end.
```



Unit Matrix;

```
INTERFACE

{ $define Test2}          {Test for positive results}

 uses
   Crt,Graph,Objects,GrLib,PRTgraph,Pdrivers,PRT_XMS,
   EdLib,GrLibEGA,
   PolUtl;

 const
   MaxSourceNo=25;
   MaxMaterialNo=25;
   Mean=1;
   Minimum=2;
   Maximum=3;
   MaxIterations=2000;
   MaxXPlot=6;
   MaxYPlot=10;

type
  IterationLibraryType=Array[1..MaxMaterialNo,1..MaxSourceNo] of Re-
                       alType;
  IterationConcentrationType=Array[1..MaxSourceNo] of RealType; {In per-
                       cent}
  SampleType=Array[1..MaxMaterialNo] of RealType;
  RawType=Array[1..MaxSourceNo] of RealType;

var
  SourceNo:Byte;
  MaterialNo:Byte;
  Iterations:Word;
{  Library:Array[1..MaxMaterialNo,1..MaxSourceNo,1..3] of RealType;}
  IterLib:IterationLibraryType;
  IterConcentration:IterationConcentrationType;
  Sample:SampleType;
  Answer:Array[1..MaxMaterialNo] of RealType;
  RawData:Array[1..MaxIterations] of ^RawType;
  TotalPercent:RealType;

procedure SetVars;
procedure CalculateConcentration;
procedure StoreResults(IterNo:Word);
```

```
procedure SortIterations(Iterations:Word);
procedure PlotResults(Iterations_:Word:Sources_:TCollection);
procedure PrintResults(
          Iterations:Word;
     var Sources:TCollection;
     var Parameters:TCollection);
function SampleOK(X,Y:Word;CurrentIterations:LongInt):Boolean;

Implementation
```

```
procedure SetVars;
  var
    I,J:Word;
    Total:RealType;
    TestLib:IterationLibraryType; {define!!}
    TestSample:SampleType;        {define!!}
  begin
  I:=0;
  repeat
    Inc(I);
    New(RawData[I]);
{    Write(MemAvail,',');}
  until (I=MaxIterations) or (MaxAvailP);
  Iterations:=I;
  Writeln(output,'Using a maximum of ',I,' itterations.');

  (*
  for I:=1 to MaterialNo do
    for J:=1 to SourceNo do
      begin
{      Library[I,J,Mean]:=Random(300)/30;}
      Library[I,J,Mean]:=TestLib[I,J];
      Library[I,J,Minimum]:=Library[I,J,Mean]*0.9;
      Library[I,J,Maximum]:=Library[I,J,Mean]*1.1;
    end;
  for I:=1 to MaterialNo do
    Answer[I]:=Random(300)/300;
  for I:=1 to MaterialNo do
    begin
    Sample[I]:=0;
    for J:=1 to SourceNo do
      Sample[I]:=Sample[I]+Answer[I]*Library[I,J,Mean];
  end;
  Sample:=TestSample;
  *)
end;
```

```
procedure CalculateConcentration;
  procedure GaussianElimination(
      var A:IterationLibraryType;
      var B:IterationconcentrationType;
          C:SampleType);
      {Solve for B in AB=C}
{    const
      TrialA:IterationLibraryType=(
          (10,-7,0),
          (0,2.5,5),
          (0,0,6.2));
      TrialC:SampleType=(7,2.5,6.2);}
    var
      I,J,K:Word;
      Scale,Sum:RealType;
    begin
{    A:=TrialA;
    C:=TrialC;}
    {Triangalize matrix}
    for I:=2 to MaterialNo do
      for J:=I to MaterialNo do
        if A[J,I-1]0 then
          begin
          Scale:=-A[J,I-1]/A[I-1,I-1];
          A[J,I-1]:=0;
          for K:=I to MaterialNo do
            A[J,K]:=A[J,K]+A[I-1,K]*Scale;
          C[J]:=C[J]+C[I-1]*Scale;
        end;

{    Writeln;
    for I:=1 to MaterialNo do
      begin
      for J:=1 to MaterialNo do
        Write(A[I,J]:10:6);
      Writeln;
    end;
    Writeln;

    {Solve for B by reverse substitution}
    B[MaterialNo]:=C[MaterialNo]/A[MaterialNo,SourceNo];
    for I:=MaterialNo-1 downto 1 do
      begin
      Sum:=0;
```

```
      for J:=I+1 to SourceNo do
        Sum:=Sum+A[I,J]*B[J];
      B[I]:=(C[I]-Sum)/A[I,I];
    end;

  end;


    {This assums a square matrix!}
  var
    I,J:Word;
    Total:RealType;
  begin
  if SourceNoMaterialNo then
    writeln(output,'SourceNoMaterialNo !!');
  GaussianElimination(IterLib,IterConcentration,Sample);
end;
```

```
procedure StoreResults(IterNo:Word);
  var
    I:Word;
  begin
  for I:=1 to SourceNo do
    RawData[IterNo]^[I]:=IterConcentration[I];
end;
```

```
procedure SortIterations(Iterations:Word);
  procedure SortSource(Source:Word);
    procedure sort(l,r: integer);
      var
        i,j: integer;
        X,Y: RealType;
      begin
      i:=l; j:=r; x:=RawData[(l+r) DIV 2]^[Source];
      repeat
        while RawData[i]^[Source]~~do i:=i+1;~~
        while x
                        awData[j]^[Source] do j:=j-1;
        if i then
          begin
          y:=RawData[i]^[Source];
                        RawData[i]^[Source]:=RawData[j]^[Source];
                        RawData[j]^[Source]:=y;
          i:=i+1; j:=j-1;
        end;
      until ij;
      if l then sort(l,j);
      if i
                        then sort(i,r);
    end;

    begin
    sort(1,Iterations);
  end;

  var
    I:Word;
  begin
  Write(output,'Sorting Source #1');
  for I:=1 to SourceNo do
    begin
    if I1 then
      Write(output,',',I);
    SortSource(I);
  end;
  Writeln;
end;
```

```
procedure ShowData(Var OutFile:Text);
  type
    SourceRec=Record
      Mean,Median,SD,Coef:RealType;
    end;
  var
    Data:Array[1..MaxSourceNo] of SourceRec;
  begin

end;
```

```
procedure PrintResults(
        Iterations:Word;
    var Sources:TCollection;
    var Parameters:TCollection);

  procedure ShowData(Var OutFile:Text);
    type
      SourceRec=Record
        Mean,Median,SD,Coef:RealType;
        SourceNo:Byte;
      end;
    var
      Data:Array[0..MaxSourceNo] of SourceRec;
      I:Byte;
      J:Word;

    procedure SortData;
      procedure sort(l,r: integer);
        var
          i,j: integer;
          X,Y: SourceRec;
        begin
        i:=l; j:=r; x:=Data[(l+r) DIV 2];
        repeat
          while Data[i].Mean~~.Mean do i:=i+1;~~
          while x.Meanata[j].Mean do j:=j-1;
          if i then
            begin
            y:=Data[i]; Data[i]:=Data[j]; Data[j]:=y;
            i:=i+1; j:=j-1;
          end;
        until ij;
        if l then sort(l,j);
        if i
                        then sort(i,r);
      end;

      begin
      sort(1,Sources.Count);
    end;

    begin
    for I:=1 to Sources.Count do
      begin
      Data[I].Mean:=0;
      for J:=1 to Iterations do
        Data[I].Mean:=Data[I].Mean+RawData[J]^[I];
      Data[I].Mean:=Data[I].Mean/Iterations;
      Data[I].Median:=RawData[Iterations div 2]^[I];

      Data[I].SD:=0;
      for J:=1 to Iterations do
        Data[I].SD:=Data[I].SD+Sqr(RawData[J]^[I]-Data[I].Mean);
      Data[I].SD:=Sqrt(Data[I].SD/Iterations);

      Data[I].Coef:=Data[I].SD/Data[I].Mean;
      Data[I].SourceNo:=I;
    end;

    SortData;

    Writeln(OutFile,'Result Summary:');
    Writeln(OutFile,'Source:,Mean,Median,Std Dev.,Co. Var.,"10%","90%"');
    for I:=Sources.Count downto 1 do
      Writeln(OutFile,PSource(Sources.At(Data[I].SourceNo-1))^.Get-
                      Name,',',
          Data[I].Mean,',',
          Data[I].Median,',',
          Data[I].SD,',',
          Data[I].Coef,',',
          RawData[Iterations div 10]^[Data[I].SourceNo],',',
          RawData[9*Iterations div 10]^[Data[I].SourceNo]);

  end;

  procedure ShowData_SCR;
    type
      SourceRec=Record
        Mean,Median,SD,Coef:RealType;
        SourceNo:Byte;
      end;
    var
      Data:Array[0..MaxSourceNo] of SourceRec;
      I:Byte;
      J:Word;

    procedure SortData;
      procedure sort(l,r: integer);
```

```
      var
        i,j: integer;
        X,Y: SourceRec;
      begin
      i:=l; j:=r; x:=Data[(l+r) DIV 2];
      repeat
        while Data[i].Mean~~.Mean do i:=i+1;~~
        while x.Meanata[j].Mean do j:=j-1;
        if i then
          begin
          y:=Data[i]; Data[i]:=Data[j]; Data[j]:=y;
          i:=i+1; j:=j-1;
        end;
      until ij;
      if l then sort(l,j);
      if i
                        then sort(i,r);
    end;

    begin
    sort(1,Sources.Count);
  end;

  begin
  for I:=1 to Sources.Count do
    begin
    Data[I].Mean:=0;
    for J:=1 to Iterations do
      Data[I].Mean:=Data[I].Mean+RawData[J]^[I];
    Data[I].Mean:=Data[I].Mean/Iterations;
    Data[I].Median:=RawData[Iterations div 2]^[I];

    Data[I].SD:=0;
    for J:=1 to Iterations do
      Data[I].SD:=Data[I].SD+Sqr(RawData[J]^[I]-Data[I].Mean);
    Data[I].SD:=Sqrt(Data[I].SD/Iterations);

    Data[I].Coef:=Data[I].SD/Data[I].Mean;
    Data[I].SourceNo:=I;
  end;

  SortData;

  Writeln('Result Summary:');
```

```
    Writeln('Source:                            Mean    Median    Std Dev.
                       Co. Var.');
    for I:=Sources.Count downto 1 do
      Writeln(PSource(Sources.At(Data[I].SourceNo-1))^.GetName:20,
          Data[I].Mean:10:5,
          Data[I].Median:9:5,
          Data[I].SD:12:5,
          Data[I].Coef:13:5);

  end;

  var
    I,J:Word;
    OutFile:Text;
    X,Y:Byte;
  begin
  ShowData_SCR;
  Assign(OutFile,'Data.txt');
  Rewrite(OutFile);
  WRiteln(output,'Press any key to stop creating DATA.TXT.');
  Write(output,'Creating DATA.TXT progress: ');
  X:=WhereX;
  Y:=WhereY;

  Writeln(OutFile,'Sample tested:');
  Writeln(OutFile,'Name:,Sample:,Units:');
  for I:=0 to Parameters.Count-1 do
    Writeln(Outfile,
        PParameterName(Parameters.At(I))^.GetName,',',
        PParameterName(Parameters.At(I))^.Sample:8:7,',',
        PParameterName(Parameters.At(I))^.Units^);
  Writeln(OutFile);
  Writeln(OutFile,'Most Likely: (in percent)');
  for I:=0 to Sources.Count-1 do
    Writeln(Outfile,
        PParameterName(Sources.At(I))^.GetName,',',
            RawData[Iterations div 2]^[I+1]*100:8:5);
  Writeln(OutFile);
  ShowData(OutFile);
  Writeln(OutFile);
  Writeln(OutFile,'RawData:');
  Writeln(OutFile,'position#,Parameter#1,Parameter#2...');
  Write(OutFile,'Sample#,,');
  for I:=0 to Parameters.Count-2 do
```

```
      Write(Outfile,PParameterName(Parameters.At(I))^.GetName,',');
    Writeln(OutFile,PParameterName(Parameters.At(Parameters.Count-1))^.Get-
                        Name);
    I:=0;
    repeat
      Inc(I);
      Write(OutFile,I,',',100.0*I/Iterations,',');
      for J:=1 to SourceNo-1 do
        Write(OutFile,RawData[I]^[J]:8:7,',');
      Writeln(OutFile,RawData[I]^[SourceNo]:8:7);
      if (I and 63) = 63 then
        begin
        GotoXY(X,Y);
        Write(output,I/Iterations*100:4:1,'%   ');
      end;
    until (I=Iterations) or Keypressed;

    if KeyPressed then
      ScanKBD(InputScan);
    Close(OutFile);
  end;
```

```
  function Trim(X:RealType):Integer;
    begin
    if X32767 then
      Trim:=32767
    else if X32768 then
      Trim:=-32768
    else Trim:=Trunc(X);
  end;




  type
    PByte=^Byte;

  var
   DS_Iterations:Word;
   Sources:PCollection;
   PRTdrv,PRTmode,rc: integer;

    procedure ShowData_SCR;
      type
        SourceRec=Record
          Mean,Median,SD,Coef:RealType;
          SourceNo:Byte;
        end;
      var
        Data:Array[0..MaxSourceNo] of SourceRec;
        I:Byte;
        J:Word;

      procedure SortData;
        procedure sort(l,r: integer);
          var
            i,j: integer;
            X,Y: SourceRec;
          begin
          i:=l; j:=r; x:=Data[(l+r) DIV 2];
          repeat
            while Data[i].Mean~~.Mean do i:=i+1;~~
            while x.Meanata[j].Mean do j:=j-1;
            if i then
              begin
              y:=Data[i]; Data[i]:=Data[j]; Data[j]:=y;
```

```
        i:=i+1; j:=j-1;
      end;
    until ij;
    if l then sort(l,j);
    if i
                   then sort(i,r);
  end;

  begin
  sort(1,Sources^.Count);
end;

begin
GotoXY(1,1);
ClearViewPort;
for I:=1 to Sources^.Count do
  begin
  Data[I].Mean:=0;
  for J:=1 to DS_Iterations do
    Data[I].Mean:=Data[I].Mean+RawData[J]^[I];
  Data[I].Mean:=Data[I].Mean/DS_Iterations;
  Data[I].Median:=RawData[DS_Iterations div 2]^[I];

  Data[I].SD:=0;
  for J:=1 to DS_Iterations do
    Data[I].SD:=Data[I].SD+Sqr(RawData[J]^[I]-Data[I].Mean);
  Data[I].SD:=Sqrt(Data[I].SD/DS_Iterations);

  Data[I].Coef:=Data[I].SD/Data[I].Mean;
  Data[I].SourceNo:=I;
end;

SortData;

Writeln('Result Summary:');
Writeln('Source:                              Mean   Median    Std Dev.
                   Co. Var.');
for I:=Sources^.Count downto 1 do
  Writeln(PSource(Sources^.At(Data[I].SourceNo-1))^.GetName:20,
      Data[I].Mean:10:5,
      Data[I].Median:9:5,
      Data[I].SD:12:5,
      Data[I].Coef:13:5);
Writeln;
```

```
    WriteLn('Press up/down arrow to see next screen');
    Writeln('Press ESC to exit program.');
  end;
{$F+}
```

```
function DisplaySource(UserPointer:pointer): integer;
  var
    Min,Max:RealType;
    I:Word;
    MaxX,MinX,MaxY,MinY:Word;
    S:String;
    Source:Byte;
  begin
  Source:=PByte(UserPointer)^;
  if Source0 then
    begin
    MinX:=30;
    MaxX:=GetMaxX-20;
    MinY:=5;
    MaxY:=GetMaxY-10;
    Max:=0;
    Min:=0;
    for I:=1 to DS_Iterations-(DS_Iterations div 20) do
      if RawData[I]^[Source]Max then
        Max:=RawData[I]^[Source];
    Max:=Max*1.3;
    if Max then
      Max:=1;
    Max:=Round(Max/0.5)*0.5;

    for I:=DS_Iterations div 20 to DS_Iterations do
      if RawData[I]^[Source]  then
        Min:=RawData[I]^[Source];
    if Min then
      Min:=Round(Min/0.5-1)*0.5;

    ClearDevice;
    SetTextStyle(DefaultFont,HorizDir,1);

    SetColor(Blue);
    Line(MinX,MaxY,MaxX,MaxY);
    Line(MinX,MinY,MinX,MaxY);
    SetTextJustify(CenterText,TopText);
    for I:=0 to MaxXPlot do
      begin
      SetColor(Cyan);
      Str((Max-Min)*I/MaxXPlot+Min:5:3,S);
      OutTextXY(Trunc((MaxX-MinX)*I/MaxXPlot+MinX),MaxY+2,S);
      SetColor(Blue);
```

```
      Line(Trunc((MaxX-MinX)*I/MaxXPlot+MinX),MaxY,
           Trunc((MaxX-MinX)*I/MaxXPlot+MinX),MinY);
    end;
    SetColor(Yellow);
    Line(Trunc((MaxX-MinX)*(-Min)/(Max-Min)+MinX),MaxY,
         Trunc((MaxX-MinX)*(-Min)/(Max-Min)+MinX),MinY);

    SetTextJustify(RightText,CenterText);
    for I:=1 to MaxYPlot do
      begin
      SetColor(Cyan);
      Str(100*I/MaxYPlot:3:0,S);
      OutTextXY(MinX-1,MaxY-Trunc((MaxY-MinY)*I/MaxYPlot),S);
      SetColor(Blue);
      Line(MinX,MaxY-Trunc((MaxY-MinY)*I/MaxYPlot),
           MaxX,MaxY-Trunc((MaxY-MinY)*I/MaxYPlot));
    end;

    SetColor(Cyan);
    SetTextJustify(RightText,TopText);
    SetTextStyle(DefaultFont,VertDir,1);
    Str(Source,S);
{    OutTextXY(GetMaxX,0,
        '(C) Edward T. Kujawski 7/2/92 Press ESC to quit Source #'+S);}
    OutTextXY(GetMaxX,0,
        '(C) Edward T. Kujawski 7/2/92  Source:
                      '+PSource(Sources^.At(Source-1))^.GetName);

    for I:=1 to DS_Iterations do
      PutPixel(Trim((MaxX-MinX)*(RawData[I]^[Source]-Min)/(Max-
                      Min)+MinX),
        Trim(MaxY-(MaxY-MinY)*(-0.5+I)/DS_Iterations),Cyan);

    SetColor(Cyan);
    SetTextJustify(LeftText,TopText);
    SetTextStyle(DefaultFont,HorizDir,1);
    Str(RawData[DS_Iterations div 2]^[Source]:7:5,S);
    OutTextXY(Trunc((MaxX-MinX)*(RawData[DS_Iterations div 2]^[Source]-
                      Min)/(Max-Min)+MinX)+2,
        MaxY-((MaxY-MinY) div 2)+2,S);
    Str(RawData[DS_Iterations div 10]^[Source]:7:5,S);
    OutTextXY(Trunc((MaxX-MinX)*(RawData[DS_Iterations div 10]^[Source]-
                      Min)/(Max-Min)+MinX)+2,
        MaxY-((MaxY-MinY) div 10)+2,S);
```

```
    Str(RawData[9*DS_Iterations div 10]^[Source]:7:5,S);
    OutTextXY(Trunc((MaxX-MinX)*(RawData[9*DS_Iterations div
                       10]^[Source]-Min)/(Max-Min)+MinX)+2,
        MaxY-(9*(MaxY-MinY) div 10)+2,S);
    DisplaySource:=0;
    end
  else
    begin
    ShowData_SCR;
  end;
end;

{$F-}
```

```
procedure PlotResults(Iterations_:Word;Sources_:TCollection);

  procedure PrintScreen(Funct:DrawFunct;Source:PByte);
    var
      PRTmode,rc, Mode: integer;
    begin
    writeln(MemAvail,',',MaxAvail);
    rc := PRT_SetDriver ( LaserJet, LaserJet_150x150, 7500,7500, PRT_IN-
                      VERSE );
{    Writeln(RC);}
{    PRTdrv := PRT_installuserdriver ( 'BitImage', NIL );
    Writeln(RC);
    rc := PRT_registerbgidriver ( @BitImage );
    Writeln(RC);}

{    rc := PRT_SetOutName('c:\temp\file.tst');
    Writeln(RC);}
{    PRTdrv:=Detect;}
    PRTmode := 0;
    rc := PRT_PrintBGI ( PRTdrv, PRTmode, '', Funct, Source );
{    Writeln(RC);
    writeln(MemAvail,',',MaxAvail);}
    mode := getgraphmode;
    restorecrtmode;
    rc:=PRT_Send(#$0C);    (*Form Feed*)
    setgraphmode(mode);
    rc:=graphresult;
  end;

  var
    I:Word;
    CurrentSource:ShortInt;
  begin
  Sources:=@Sources_;
  DS_Iterations:=Iterations_;
  DirectVideo:=False;
  Graphics(HiMode);
  CurrentSource:=0;
  InputScan.Scan:=Key_A;
  repeat
    DisplaySource(@CurrentSource);
    ScanKBD(InputScan);
    case InputScan.Scan of
      Key_up:   Inc (CurrentSource);
```

```
      Key_Down: Dec (CurrentSource);
      Key_P:    if CurrentSource0 then
                  PrintScreen(DisplaySource,@CurrentSource);
    end;
    if CurrentSource then
      CurrentSource:=SourceNo;
    if CurrentSourceSourceNo then
      CurrentSource:=0;
  until InputScan.Scan=Key_ESC;

  CloseGraph;
  DirectVideo:=True;
end;

var
  FailedNo:LongInt;
```

```
function SampleOK(X,Y:Word;CurrentIterations:LongInt):Boolean;
  var
    T:Boolean;
    I:Byte;
  begin
  {$ifdef test2}
    T:=True;
    for I:=1 to SourceNo do
      if (IterConcentration[I]0.1) or (IterConcentration[I]1.1) then
        T:=False;
    SampleOK:=T;
    inc(FailedNo);
    if (FailedNo mod 27) =0 then
      begin
      GotoXY(X,Y);
      Write(CurrentIterations,'/',FailedNo);
    end;
  {$endif}
end;

begin
    PRTdrv := PRT_installuserdriver ( 'BitImage', NIL );
    rc := PRT_registerbgidriver ( @BitImage );
    FailedNo:=0;

    DirectVideo:=False;
end.
```

unit edlib;

```
{Edward's personal library of procedures}

interface

uses
  {$ifdef OpCrt}
    Opcrt,
  {$else}
    Crt,
  {$endif}
  dos,graph,Printer;

const {Scan code values}

  mode_r_shf=1;  mode_l_shf=2;  mode_ctrl=4;    mode_alt=8;
  mode_scroll=16;mode_num=32;   mode_caps=64;   mode_ins=128;

  key_1=2;       key_q=16;      key_a=30;       key_z=44;
  key_2=3;       key_w=17;      key_s=31;       key_x=45;
  key_3=4;       key_e=18;      key_d=32;       key_c=46;
  key_4=5;       key_r=19;      key_f=33;       key_v=47;
  key_5=6;       key_t=20;      key_g=34;       key_b=48;
  key_6=7;       key_y=21;      key_h=35;       key_n=49;
  key_7=8;       key_u=22;      key_j=36;       key_m=50;
  key_8=9;       key_i=23;      key_k=37;       key_comma=51;
  key_9=10;      key_o=24;      key_l=38;       key_period=52;
  key_0=11;      key_p=25;      key_semi=39;    key_slash=53;
  key_dash=12;   key_l_br=26;   key_quote=40;
  key_equ=13;    key_r_br=27;

  key_esc=1;     key_bs=14;     key_tab=15;    key_ret=28;
  key_tilda=41;  key_b_slash=43;key_space=57;  key_prtscr=55;
  key_break=0;

  key_f1=59;    key_shift_f1=84;   key_ctrl_f1=94;   key_alt_f1=104;
  key_f2=60;    key_shift_f2=85;   key_ctrl_f2=95;   key_alt_f2=105;
  key_f3=61;    key_shift_f3=86;   key_ctrl_f3=96;   key_alt_f3=106;
  key_f4=62;    key_shift_f4=87;   key_ctrl_f4=97;   key_alt_f4=107;
  key_f5=63;    key_shift_f5=88;   key_ctrl_f5=98;   key_alt_f5=108;
  key_f6=64;    key_shift_f6=89;   key_ctrl_f6=99;   key_alt_f6=109;
  key_f7=65;    key_shift_f7=90;   key_ctrl_f7=100;  key_alt_f7=110;
```

```
  key_f8=66;    key_shift_f8=91;   key_ctrl_f8=101;  key_alt_f8=111;
  key_f9=67;    key_shift_f9=92;   key_ctrl_f9=102;  key_alt_f9=112;
  key_f10=68;   key_shift_f10=93;  key_ctrl_f10=103; key_alt_f10=113;

  key_home=71;  key_ctrl_home=119;
  key_up=72;
  key_pgup=73;  key_ctrl_pgup=132;
  key_minus=74;
  key_left=75;  key_ctrl_left=115;
  key_right=77; key_ctrl_right=116;
  key_plus=78;
  key_end=79;   key_ctrl_end=117;
  key_down=80;
  key_pgdn=81;  key_ctrl_pgdn=118;
  key_ins=82;
  key_del=83;

{not used: 29,42,54,56,58,69,70,76,114,120-131,133-}

type
  scantype=record
    modify,ascii,scan:byte
  end;
  graphicscreentype=array[1..16512] of byte;
  textscreentype=array[1..25,1..80] of integer;
{  MessageSendType=Array[1..5] of String;}

Const
  KeySense:Boolean=True;

Var
  EdgeColor:        Byte;    {Back ground and forground}
  BodyColor:        Byte;
  PromptColor:      Byte;
  EntryColor:       Byte;

  Scr:graphicscreentype absolute $b800:0;
  TextScr:textscreentype absolute $b800:0;
  TextScr0:TextScreenType absolute $b800:0;
  TextScr1:TextScreenType absolute $b8F9:$70;
  TextScr2:TextScreenType absolute $b9F2:$E0;
  TextScr3:TextScreenType absolute $bAfb:$50;
  Reg:Registers;
  InputScan:ScanType;
```

```
  PauseAbort:Boolean;


procedure scankbd(var input:scantype);
function GetVideoMode:Byte;
function GetVideoPage:Byte;
procedure erasecurser;
procedure normalcurser;
Function UpStr(S : String) : String;
procedure PutXY(x,y,v:integer);
function power(number,exponent:real):real;

{Procedure SetMessageColor(EColor,BColor,PColor:Byte);
Procedure Message(Str:MessageSendType);}

function VideoModeStr(Mode:Byte):String;
procedure SetTextPage(NewPage:Byte);

procedure ClearScr(var Scr:TextScreenType);
procedure SetPageCurser(PageNo,X,Y:Byte);

procedure Center(S:String);

procedure Pause(Length:Word);

implementation
```

```
procedure scankbd(var Input:ScanType);
  begin
  reg.ah:=0;
  intr(22,reg);
  input.ascii:=reg.al;
  input.scan:=reg.ah;
  reg.ah:=2;
  intr(22,reg);
  input.modify:=reg.al;
end;
```

Function GetVideoMode:Byte;

```
Function GetVideoMode:Byte;
  var
    Reg:Registers;
  begin
  Reg.ah:=$F;
  Intr($10,Reg);
  GetVideoMode:=Reg.al;
{ Reg.ah is columns number
  Reg.bh is current display page}
end;
```

```
Function GetVideoPage:Byte;
  var
    Reg:Registers;
  begin
  Reg.ah:=$F;
  Intr($10,Reg);
  GetVideoPage:=Reg.bh;
end;
```

procedure erasecurser;

```
procedure erasecurser;
  begin
  reg.ah:=1;  reg.ch:=32;  reg.cl:=0;
  intr(16,reg);
end;
```

```
procedure normalcurser;
  begin
  if GetVideoMode=$7 then
    begin
    reg.ah:=1;
    reg.ch:=11;
    reg.cl:=12;
    end
  else
    begin
    reg.ah:=1;
    reg.ch:=6;
    reg.cl:=7;
  end;
  intr(16,reg);
end;
```

```
function LoCase(C : Char) : Char ;
  begin
  if C in ['A'..'Z'] then
    LoCase:=Chr(Ord(C)+32)
  else
    LoCase:=C;
end;
```

```
Function UpStr(S : String) : String;
{ Converts all chars in string to upper case }

  var
    I : Word;
    T : String;
  begin
  T := S;
  I := Length(T);
  While I  0 do begin
    T[I] := UpCase(T[I]);
    dec(I);
  end;   { While I  0 }
  UpStr := T;
end;
```

```
procedure PutXY(x,y,v:integer);
  begin
  textscr[y,x]:=v;
end;
```

```
function power(number,exponent:real):real;
  begin
  if number0.0 then
    power:=exp(exponent*ln(number))
  else
    power:=0.0;
end;

{Procedure SetMessageColor(EColor,BColor,PColor:Byte);
  begin
  EdgeColor:=EColor;
  BodyColor:=BColor;
  PromptColor:=PColor;
end;
```

```
Procedure Message(Str:MessageSendType);
  Const
    Press='Press Any Key To Continue';
  Type
    ScreenType=Array[1..2000] of Integer;
    RowType=Array[1..80] of Integer;
  Var
    ScreenA:ScreenType absolute $b800:0;
    Screen:^ScreenType;
    RowA:RowType absolute $b800:0;
    Row:^RowType;
    X,Y,I,J:Integer;

  begin
  EraseCurser;
  X:=WhereX;
  Y:=WhereY;
  if MemAvailá then
    begin
    New(Row);
    Row^:=RowA;
    GotoXY(1,1);
    Write(Str[1]);
    GotoXY(70,1);
    Write('Any Key');
    Repeat Until KeyPressed;
    RowA:=Row^;
    end
  else
    begin
    New(Screen);
    Screen^:=ScreenA;
    GotoXY(20,10);
    TextColor(EdgeColor);
    Write(#218);
    for I:=21 to 60 do
      Write(#196);
    Write(#191);
    for I:=1 to 5 do
      begin
      GotoXY(20,10+I);
      TextColor(EdgeColor);
      Write(#179);
      TextColor(BodyColor);
      for J:=1 to (40-Length(Str[i])) div 2 do
        Write(' ');
      Write(Str[i]);
      for J:=1 to Trunc(Round((40-Length(Str[i]))/2)) do
        Write(' ');
      TextColor(EdgeColor);
      Write(#179);
      end;

      GotoXY(20,16);
      TextColor(EdgeColor);
      Write(#179);
      TextColor(PromptColor);
      for J:=1 to (40-Length(Press)) div 2 do
        Write(' ');
      Write(Press);
      for J:=1 to Trunc(Round((40-Length(Press))/2)) do
        Write(' ');
      TextColor(EdgeColor);
      Write(#179);

    GotoXY(20,17);
    TextColor(EdgeColor);
    Write(#192);
    for I:=21 to 60 do
      Write(#196);
    Write(#217);
    Repeat Until KeyPressed;
    ScreenA:=Screen^;
  end;
  GotoXY(X,Y);
  NormalCurser;
end;}
```

```
function VideoModeStr(Mode:Byte):String;
  begin
  case Mode of
    $00: VideoModeStr:='40x25 black and white text';
    $01: VideoModeStr:='40x25 color text';
    $02: VideoModeStr:='80x25 black and white text';
    $03: VideoModeStr:='80x25 color text';
    $04: VideoModeStr:='320x200 4 color graphics';
    $05: VideoModeStr:='320x200 4 color graphics (color burst off)';
    $06: VideoModeStr:='640x200 2 color graphics';
    $07: VideoModeStr:='Monochrome Adapter text display';
    $08: VideoModeStr:='160x200 16 color graphics (PCjr)';
    $09: VideoModeStr:='320x200 16 color graphics (PCjr)';
    $0A: VideoModeStr:='640x200 4 color graphics (PCjr)';
    $0D: VideoModeStr:='320x200 16 color graphics (EGA)';
    $0E: VideoModeStr:='640x200 16 color graphics (EGA)';
    $0F: VideoModeStr:='640x350 monochrome graphics (EGA)';
    $10: VideoModeStr:='640x350 4 color or 16 color graphics (EGA)';
  else
    VideoModeStr:='Reserved Mode.';
  end;
end;
```

```
procedure SetTextPage(NewPage:Byte);
     {InsLind and some other procedures work on the view page}
  var
    Reg:Registers;
  begin
  Reg.ah:=$5;
  Reg.al:=NewPage;
  Intr($10,Reg);
end;
```

```
procedure ClearScr(var Scr:TextScreenType);
  var
    I:Byte;
  begin
  for I:=1 to 80 do
    Scr[1,I]:=TextAttr shl 8;
  for I:=2 to 25 do
    Scr[I]:=Scr[1];
end;
```

```
procedure SetPageCurser(PageNo,X,Y:Byte);
  var
    Reg:Registers;
  begin
  Reg.ah:=2;
  Reg.bh:=PageNo;
  Reg.dh:=Y-1;
  Reg.dl:=X-1;
  Intr($10,Reg);
end;
```

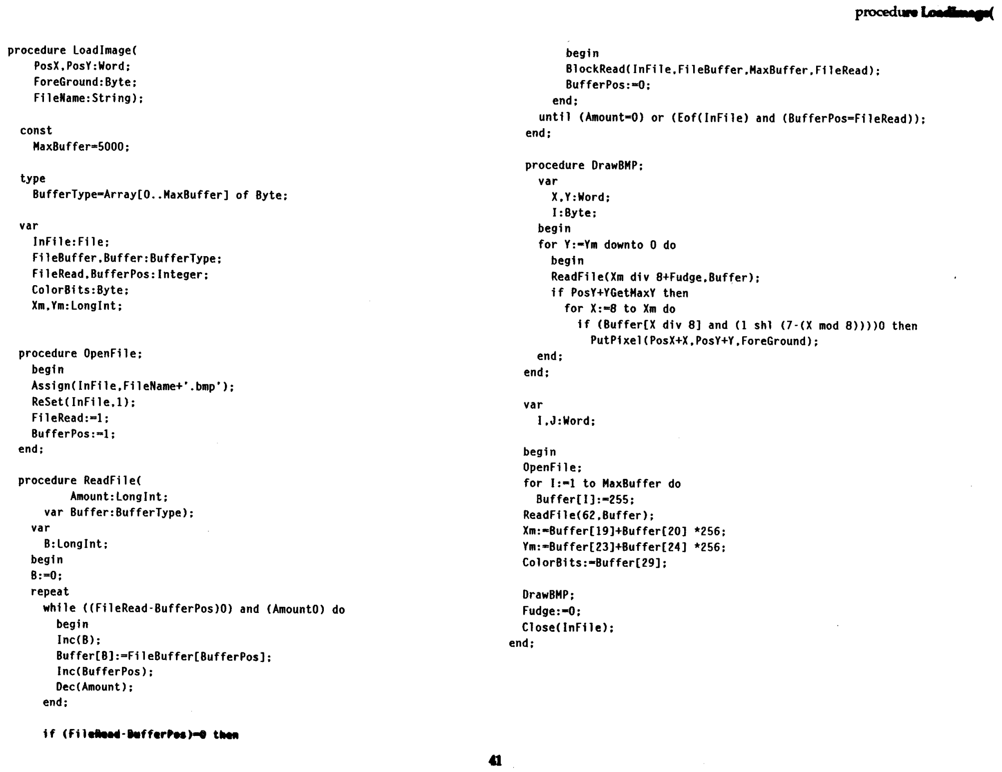
```
procedure Center(S:String);
  begin
  GotoXY(40-Length(S) shr 1,WhereY);
  Writeln(S);
end;
```

```
procedure Pause;
  var
    I:Word;
  begin
  I:=0;
  while KeyPressed do
    ScanKBD(InputScan);
  repeat
    Inc(I);
    Delay(5);
  until KeyPressed or (ILength);
  InputScan.Scan:=29;
  if KeyPressed then
    ScanKBD(InputScan);
  PauseAbort:=InputScan.Scan=Key_ESC;
end;

End.
```

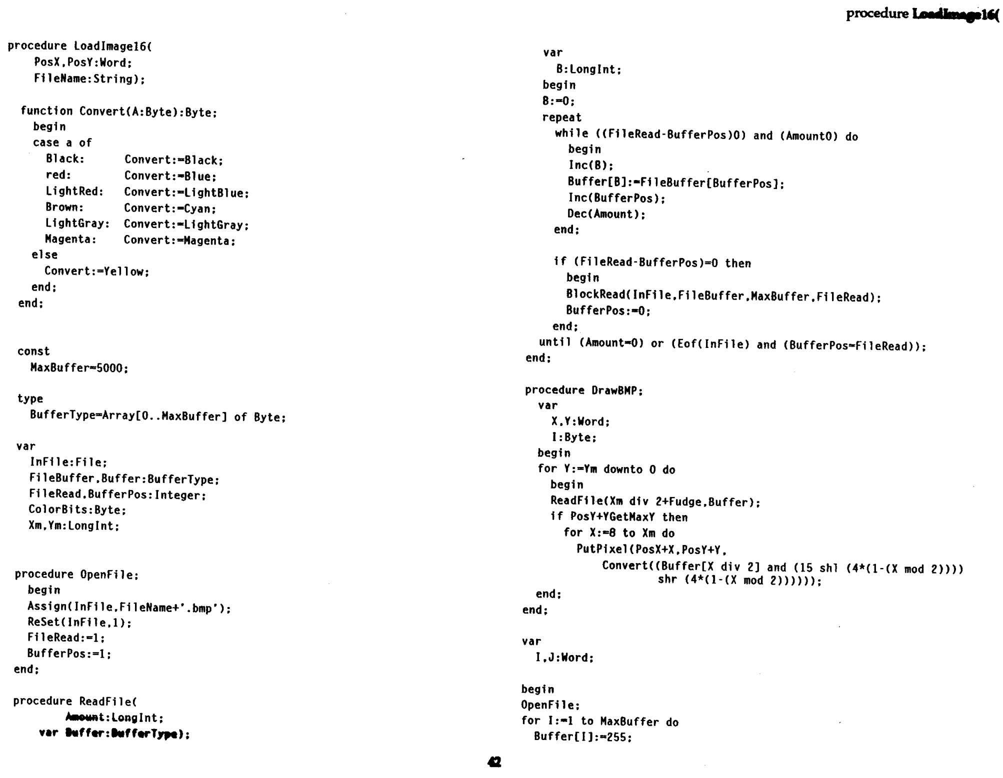
```
unit GrLibEGA;

{Limited graphics - linked library for EGA and VGA ONLY}

interface

uses
  Graph,MouseLib;

const
  HiMode=-1;
  MedMode=-2;
  LowMode=-3;
  CgaHiMode=-4;
  CgaLowMode=-5;
  _640x350VEga=-6;

var
  Fudge:ShortInt;


procedure Graphics(Mode:Integer);

procedure LoadImage(
    PosX,PosY:Word;
    ForeGround:Byte;
    FileName:String);
procedure LoadImage16(
    PosX,PosY:Word;
    FileName:String);
procedure DisplayText(
    MinX,MinY,MaxX,MaxY:Word;
    FileName:String);

procedure DrawBox(X,Y:Word);
procedure EraseBox(X,Y:Word);

implementation
```

```
procedure EgaVgaDriverProc: external;
{$L EgaVga.OBJ }
```

```
procedure Graphics(Mode:Integer);
  var
    Gd,I:Integer;
    Error:Integer;
  begin
  DetectGraph(Gd,I);
  if Mode then
    begin
    case Mode of
      LowMode:
        case Gd of
          CGA:      Mode:=CGAC0;
          MCGA:     Mode:=MCGAC0;
          EGA:      Mode:=EGALo;
          EGA64:    Mode:=EGA64Lo;
          EGAMono:  Mode:=EGAMonoHi;
          HercMono: Mode:=HercMonoHi;
          ATT400:   Mode:=ATT400C0;
          VGA:      Mode:=VGALo;
          Pc3270:   Mode:=Pc3270Hi;
        end;
      MedMode:
        case Gd of
          CGA:      Mode:=CGAC1;
          MCGA:     Mode:=MCGAMed;
          EGA:      Mode:=EGALo;
          EGA64:    Mode:=EGA64Lo;
          EGAMono:  Mode:=EGAMonoHi;
          HercMono: Mode:=HercMonoHi;
          ATT400:   Mode:=ATT400Med;
          VGA:      Mode:=VGAMed;
          Pc3270:   Mode:=Pc3270Hi;
        end;
      HiMode:
        case Gd of
          CGA:      Mode:=CGAHi;
          MCGA:     Mode:=MCGAHi;
          EGA:      Mode:=EGAHi;
          EGA64:    Mode:=EGA64Hi;
          EGAMono:  Mode:=EGAMonoHi;
          HercMono: Mode:=HercMonoHi;
          ATT400:   Mode:=ATT400Hi;
          VGA:      Mode:=VGAHi;
          Pc3270:   Mode:=Pc3270Hi;
        end;
      _640x350VEga:
          case Gd of
            EGA:      Mode:=EGAHi;
            VGA:      Mode:=VGAMed;
        end;
      CgaHiMode:
          begin
          Gd:=Cga;
          Mode:=CgaHi;
        end;
      CgaLowMode:
          begin
          Gd:=Cga;
          mode:=CgaC1;
      end;
    end;
  end;
  InitGraph(Gd,Mode,'');
  if (Gd=Cga) and (Mode=CgaHi) then
    SetPalette(0,Magenta);
  Error:=GraphResult;
  if Error then
    begin
    Write(GraphErrorMsg(Error));
    Halt;
  end;
  SetMouseLimit(0,0,GetMaxX,GetMaxY);
end;
```



```
procedure LoadImage(
    PosX,PosY:Word;
    ForeGround:Byte;
    FileName:String);

  const
    MaxBuffer=5000;

  type
    BufferType=Array[0..MaxBuffer] of Byte;

  var
    InFile:File;
    FileBuffer,Buffer:BufferType;
    FileRead,BufferPos:Integer;
    ColorBits:Byte;
    Xm,Ym:LongInt;


  procedure OpenFile;
    begin
    Assign(InFile,FileName+'.bmp');
    ReSet(InFile,1);
    FileRead:=1;
    BufferPos:=1;
  end;

  procedure ReadFile(
          Amount:LongInt;
      var Buffer:BufferType);
    var
      B:LongInt;
    begin
    B:=0;
    repeat
      while ((FileRead-BufferPos)0) and (Amount0) do
        begin
        Inc(B);
        Buffer[B]:=FileBuffer[BufferPos];
        Inc(BufferPos);
        Dec(Amount);
      end;

      if (FileRead-BufferPos)=0 then
        begin
        BlockRead(InFile,FileBuffer,MaxBuffer,FileRead);
        BufferPos:=0;
      end;
    until (Amount=0) or (Eof(InFile) and (BufferPos=FileRead));
  end;

  procedure DrawBMP;
    var
      X,Y:Word;
      I:Byte;
    begin
    for Y:=Ym downto 0 do
      begin
      ReadFile(Xm div 8+Fudge,Buffer);
      if PosY+YGetMaxY then
        for X:=8 to Xm do
          if (Buffer[X div 8] and (1 shl (7-(X mod 8))))0 then
            PutPixel(PosX+X,PosY+Y,ForeGround);
    end;
  end;

  var
    I,J:Word;

  begin
  OpenFile;
  for I:=1 to MaxBuffer do
    Buffer[I]:=255;
  ReadFile(62,Buffer);
  Xm:=Buffer[19]+Buffer[20] *256;
  Ym:=Buffer[23]+Buffer[24] *256;
  ColorBits:=Buffer[29];

  DrawBMP;
  Fudge:=0;
  Close(InFile);
end;
```



```
procedure LoadImage16(
    PosX,PosY:Word;
    FileName:String);

  function Convert(A:Byte):Byte;
    begin
    case a of
      Black:     Convert:=Black;
      red:       Convert:=Blue;
      LightRed:  Convert:=LightBlue;
      Brown:     Convert:=Cyan;
      LightGray: Convert:=LightGray;
      Magenta:   Convert:=Magenta;
    else
      Convert:=Yellow;
    end;
  end;


  const
    MaxBuffer=5000;

  type
    BufferType=Array[0..MaxBuffer] of Byte;

  var
    InFile:File;
    FileBuffer,Buffer:BufferType;
    FileRead,BufferPos:Integer;
    ColorBits:Byte;
    Xm,Ym:LongInt;


  procedure OpenFile;
    begin
    Assign(InFile,FileName+'.bmp');
    ReSet(InFile,1);
    FileRead:=1;
    BufferPos:=1;
  end;

  procedure ReadFile(
          Amount:LongInt;
      var Buffer:BufferType);
    var
      B:LongInt;
    begin
    B:=0;
    repeat
      while ((FileRead-BufferPos)0) and (Amount0) do
        begin
        Inc(B);
        Buffer[B]:=FileBuffer[BufferPos];
        Inc(BufferPos);
        Dec(Amount);
      end;

      if (FileRead-BufferPos)=0 then
        begin
        BlockRead(InFile,FileBuffer,MaxBuffer,FileRead);
        BufferPos:=0;
      end;
    until (Amount=0) or (Eof(InFile) and (BufferPos=FileRead));
  end;

  procedure DrawBMP;
    var
      X,Y:Word;
      I:Byte;
    begin
    for Y:=Ym downto 0 do
      begin
      ReadFile(Xm div 2+Fudge,Buffer);
      if PosY+YGetMaxY then
        for X:=8 to Xm do
          PutPixel(PosX+X,PosY+Y,
              Convert((Buffer[X div 2] and (15 shl (4*(1-(X mod 2))))
                      shr (4*(1-(X mod 2))))));
    end;
  end;

  var
    I,J:Word;

  begin
  OpenFile;
  for I:=1 to MaxBuffer do
    Buffer[I]:=255;
```

```
  ReadFile(62+16*3+8,Buffer);
  Xm:=Buffer[19]+Buffer[20] *256;
  Ym:=Buffer[23]+Buffer[24] *256;
  ColorBits:=Buffer[29];

  DrawBMP;
  Fudge:=0;
  Close(InFile);
end;
```

```
procedure DisplayText(
    MinX,MinY,MaxX,MaxY:Word;
    FileName:String);

  var
    LineHeight:Byte;
    InFile:Text;
    S,S2:String;
    Width:Word;
    Line:Word;
  begin
  Assign(InFile,FileName+'.Txt');
  ReSet(InFile);
  SetTextJustify(Lefttext,TopText);
  LineHeight:=(TextHeight('Text')*5) div 4;
  S:='';
  S2:='';
  Line:=0;
  ReadLn(InFile,S);
  repeat
    Width:=1;
    repeat
      S2:=S2+S;
      while (TextWidth(Copy(S2,1,Width))axX-MinX) and (Width gth(S2)) do
        Inc(Width);
      ReadLn(InFile,S);
    until (TextWidth(Copy(S2,1,Width))MaxX-MinX) or Eof(InFile);
    while (S2[Width]' ') and (Width0) do
      Dec(Width);
    OutTextXY(MinX,MinY+Line*LineHeight,Copy(S2,1,Width));
    Inc(Line);
    Delete(S2,1,Width);
  until Eof(InFile);

  while Length(S2)0 do
    begin
    Width:=1;
    while (TextWidth(Copy(S2,1,Width))axX-MinX) and (Width gth(S2)) do
      Inc(Width);
    while S2[Width]' ' do
      Dec(Width);
    OutTextXY(MinX,MinY+Line*LineHeight,Copy(S2,1,Width));
    Inc(Line);
    Delete(S2,1,Width);
```

```
  end;
  Close(InFile);
end;
```

```
procedure DrawBox(X,Y:Word);
  var
    I,J:Word;
  begin
  for I:=1 to 20 do
    for J:=0 to I*2-1 do
      begin
      PutPixel(X+I,Y-J+I,GetPixel(X+I,Y-J+I)+1);
      PutPixel(X-J+I,Y-I,GetPixel(X-J+I,Y-I)+1);
      PutPixel(X-I,Y+J-I,GetPixel(X-I,Y+J-I)+1);
      PutPixel(X+J-I,Y+I,GetPixel(X+J-I,Y+I)+1);
    end;
end;
```

```
procedure EraseBox(X,Y:Word);
  var
    I,J:Word;
  begin
  for I:=1 to 20 do
    for J:=0 to I*2-1 do
      begin
      PutPixel(X+I,Y-J+I,GetPixel(X+I,Y-J+I)-1);
      PutPixel(X-J+I,Y-I,GetPixel(X-J+I,Y-I)-1);
      PutPixel(X-I,Y+J-I,GetPixel(X-I,Y+J-I)-1);
      PutPixel(X+J-I,Y+I,GetPixel(X+J-I,Y+I)-1);
    end;
end;



var
  I:Integer;

begin
I:=RegisterBGIdriver(@EgaVgaDriverProc);
Fudge:=0;
end.
```

Appendix H
Glossary

Accuracy - The combination of bias and precision of an analytical procedure which reflects the closeness of a measured value to a true value.

Baseflow - The dry-weather flow occurring in a drainage system, with no apparent source. Likely to be mostly infiltrating groundwaters in a sanitary or storm drainage system, but can also be contaminated with illicit wastewaters. See constant (or continual) dry-weather flow.

Batch dump - The disposal of a large volume of waste material during a short period of time. Usually an industrial waste.
Bias - A consistent deviation of measured values from the true value, caused by systematic errors in a procedure.

Coefficient of Variation (COV) - A measure of the spread of data (ratio of the standard deviation to the mean).

Combined Sewer - A sewer designed for receiving intercepted surface (dry- and wet-weather) runoff, municipal (sanitary and industrial) wastewater and subsurface waters from infiltration. It is designed as both a sanitary sewer and as a storm sewer [40 CFR 35.2005 (b) (11)]. During dry weather, it acts as a sanitary sewer, but it also carries stormwater during periods of rain. Untreated combined sewer overflows (CSO) to receiving waters occur during wet weather when the stormwater plus sanitary wastewater flow rate exceeds the sewer capacity.

Combined sewer overflow (CSO) - Flow from an outfall (discharge conduit) of a combined sewer collection system, in excess of the interceptor capacity, that is discharged into a receiving water and/or an auxiliary CSO control storage-treatment system.
Constant (or continual) dry-weather flow - Uninterrupted flow in a storm sewer or drainage ditch occurring in the absence of rain. See baseflow.
Deposits and stains - Any type of coating that remains at an outfall after a dry-weather discharge has occurred.
Detection limit - A number of different detection limits have been defined: IDL (instrument detection limit), is the constituent concentration that produces a signal greater than five times the signal to noise ratio of the instrument; MDL (method detection limit) is the constituent concentration that, when processed through a complete method, produces a signal with a 99% probability that it is different from a blank; PQL (practical quantification limit) is the lowest constituent concentration achievable among laboratories within specified limits during routine laboratory operations. The ratios of these limits are approximately: IDL:MDL:PQL = 1:4:20 (APHA, *et al*. 1989).
Direct (dry-weather) entries into the storm drainage system - Sources which enter a storm drainage system directly, usually by direct piping connections between the wastewater piping and the storm drain.
Domestic sanitary wastewater - Sewage derived principally from residential buildings.

Dry-weather flow - Flow in a storm sewer or drainage ditch occurring in the absence of rain. See baseflow.

Entries to storm drainage - water (clean or polluted) discharged into a stormwater drain from sources such as, but not limited to, direct industrial or sanitary wastewater connections, roof leaders, yard and area drains, cooling water connections, manhole covers, etc.

Floatables - Large coarse floating materials, which are either part of the waste streams discharged to a stormwater system, or collected by flows which enters a stormwater drainage system.

Geographic Information System (GIS) - Computer software that maps land areas and shows information relating to the land area, e.g., topography, drainage, public utilities, roads, buildings, industry, land use, etc.

Groundwater infiltration - Seepage of groundwater into stormwater or sanitary wastewater drainage systems, through such means as defective pipes, pipe joints, connections, or manhole walls.

Hardness - Caused by the presence of divalent cations in water, especially calcium and magnesium. Causes an increased amount of soap usage before producing a lather and causes scale to form in hot water pipes, cooling systems, kettles, etc.

Indirect dry-weather entries into the storm drainage system - Non-stormwater sources which enter a storm drainage system indirectly, usually by floor drains or inlets.

Industrial dry-weather entries into the storm drainage system - Any solid or liquid waste coming from industrial sources which enter storm drainage systems during periods of dry weather.

Infiltration - The process whereby water enters a drainage system underground through such means as defective pipes, pipe joints, connections, manhole walls, etc.

Inflow - The process whereby water enters a sanitary wastewater drainage system from surface locations, such as through manhole covers.

Intercepted stormwater/groundwater - The portion of surface runoff or groundwater moving through the soil that enters a storm drainage, combined sewer, or sanitary sewer system.

Interceptor - A sewer that receives flows from a number of transverse wastewater trunk lines.

Intermittent dry-weather flow - Irregular flow in a storm drainage system occurring in the absence of rain.

Lateral - A drain or sewer that has no other drains or sewers discharging into it, except for service connections.

Leaching field - A system of underground perforated pipes which distribute the effluent from a septic tank to the soil. This is typically done by a pipe and infiltrating trench system which takes the partially treated effluent from the septic tank and distributes it through the leaching field where further treatment occurs before discharge to the ground.

Monte Carlo probabilistic simulation - A statistical modeling approach used to determine the expected frequency and magnitude of an output by running repetitive simulations using statistically selected inputs for the model parameters.

Municipal sewage/wastewater - Sewage/wastewater from a community which may be composed of domestic sewage/wastewater, industrial wastewater and/or commercial wastewater, together with any infiltration.

National Pollution Discharge Elimination System (NPDES) - A national system of permits issued to industrial, commercial, and municipal dischargers to limit the amount of pollutants that can be discharged to waters of the USA.

Non-contact cooling water - Water that decreases the temperature of an object, without ever physically touching the object.

Nonpoint pollution source- Any unconfined and nondiscrete conveyance from which pollutants are discharged.

Outfall - In this User's Guide, an outfall refers to a point at which a stormwater drainage system discharges to a receiving water. There is often a concrete structure or retaining wall at this location to protect the end of the discharge pipe and prevent local erosion of the receiving water bank.

Pathogen - A disease-causing microorganism.

Point source - Any discernible, confined, and discrete conveyance from which pollutants are, or may be, discharged.

Pollutant - Any material in water or wastewater interfering with designated beneficial uses.

Potable domestic water - Water that has been treated, or is naturally fit, for drinking, i.e., the water has no harmful contents to make it unsuitable for human consumption.

Precision - The measure of the degree of agreement among replicate analyses of a sample, usually expressed as the standard deviation.

Pretreatment - The removal of material such as, gross solids, grit, grease, metals, toxicants. etc. or treatment such as aeration, pH adjustment, etc. to improve the quality of a wastewater prior to discharge to a municipal wastewater system. This is usually done by the industrial user of the water, but can also refer to the initial treatment processes of a sewage treatment plant.

Process line discharge - The disposal of anything used in, or resulting from, a manufacturing process.

Process water - Water used in industry to perform a variety of functions, or as an actual product ingredient.

Receiving waters - Natural or man-made water systems into which stormwaters, or other wastewaters, are discharged for disposal.

Rinse water - Water that cleans or reduces the temperature of an object through actual physical contact with the object.

Sanitary sewer - A sanitary wastewater drainage system intended to carry wastewaters from residences, commercial buildings, industrial plants, and institutions together with minor quantities of groundwater, stormwater and surface water that are not admitted intentionally [40 CFR 35.2005 (b) (37)].
Sanitary wastewater - Wastewater of human origin.

Septic Tank - A rectangular tank divided into two compartments for the treatment of residential (most common) wastewaters by anaerobic digestion, floatation, and sedimentation. Partially treated septic tank effluent is then discharged to a leaching field for additional treatment in the soil system and for final disposal.

Sewage - Sanitary wastewater.

Sewer - A pipe or conduit generally closed, but normally not flowing full, for carrying wastewater.

Sewerage - System of piping, with appurtenances, for collecting and conveying wastewaters from source to discharge.

Specific Conductivity - Expressed in microSiemens/cm (or micromhos/cm). It is an indication of the amount of dissolved solids in a liquid.

Storm drainage discharge - Flow from a storm drain that is discharged to a receiving water.

Storm drain - A pipe, or natural or man-made channel, or ditch, that is designed to carry only stormwater, surface runoff, street washwaters, and drainage from source to point of discharge [40 CFR 35.2005 (b) (47)].
Stormwater - Water resulting from precipitation which does not percolate into the soil; it runs freely from the surface, or is captured by storm drainage, combined sewer, and to a limited degree, by sanitary sewer facilities.

Surfactants - Surface-active agent and common component in detergents which affects the surface tension of water and can cause foaming.

SIC - Standard Industrial Classification, a code used to describe an industry.

Total solids - The entire quantity of solids in the liquid flow or volume including the dissolved and particulate (suspended, floatable and settleable) fractions.

Toxicity - The degree to which a pollutant causes physiological harm to the health of an organism.

Tracer - In this User's Guide, a tracer is a distinct component, or combination of components ("fingerprint"), of a polluting source which is identified in order to confirm the entry of the polluting source to a storm drainage system.

Trace Metals - Metals present in small concentrations. From a regulatory standpoint, this usually refers to metal concentrations that can cause toxicity at trace concentrations.

Turbidity - A measure of the lack of clarity in the water usually caused by suspended particulate matter.

Urban runoff - Any discharge from a stormwater drainage system. During wet weather, it is comprised of surface runoff from an urban drainage area. During dry weather, it may be comprised of many baseflow components, both uncontaminated and contaminated.

Urban stormwater runoff - A discharge from a stormwater drainage system occurring during wet weather, comprised of surface runoff from an urban drainage area. See stormwater and urban runoff.

Wet-weather flow - Surface runoff due to precipitation (rain and snow) which may introduce contaminants into storm drainage systems.