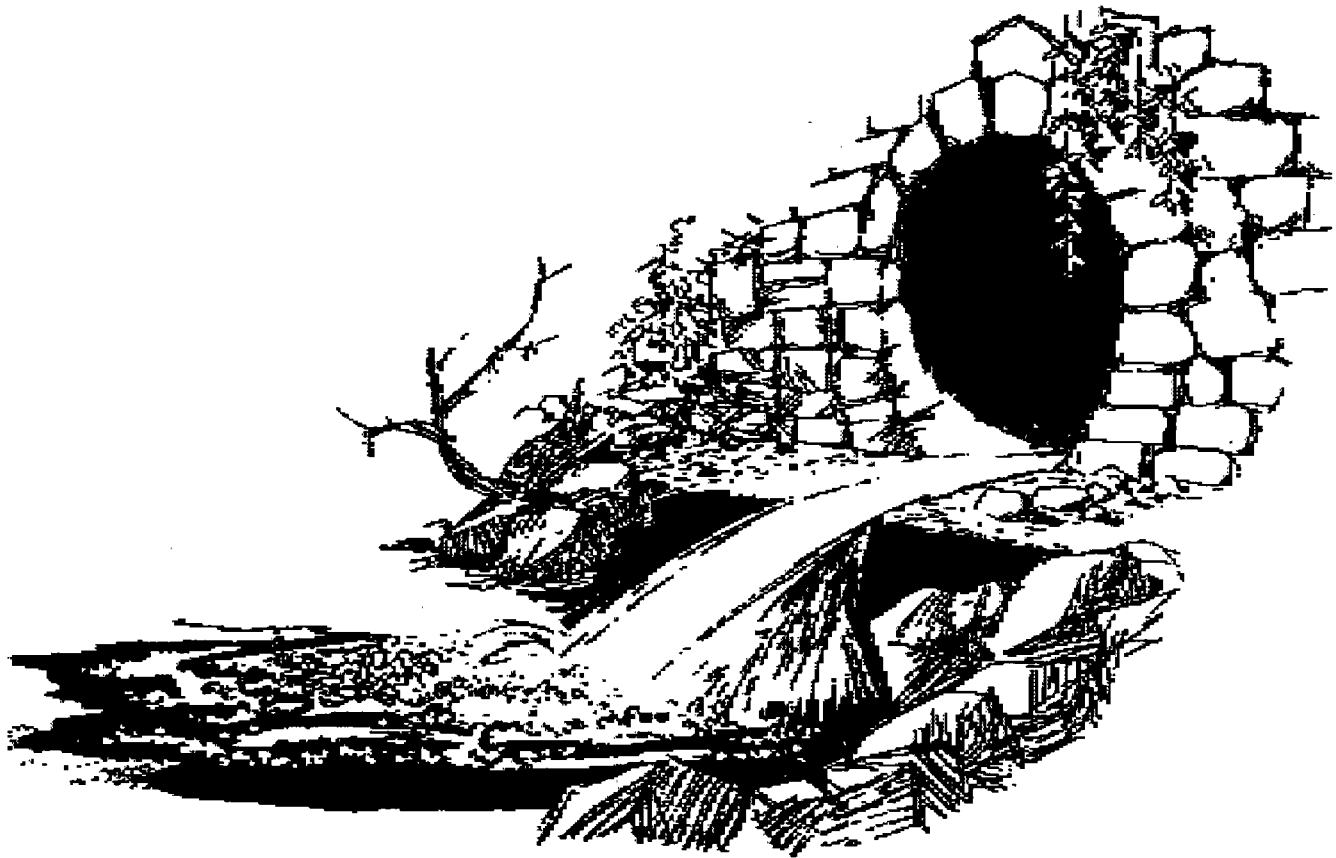




Stormwater Treatment at Critical Areas: The Multi-Chambered Treatment Train (MCTT)



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Notice

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Foreword

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E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Abstract

This is the first volume for this report series and describes the work conducted during the early years of this project through recent full-scale tests. Other volumes in this report series describe the results of field investigations of storm drain inlet devices and the use of filter media for stormwater treatment.

The first project phase investigated typical toxicant concentrations in stormwater, the origins of these toxicants, and storm and land-use factors that influenced these toxicant concentrations. Nine percent of the 87 stormwater source area samples analyzed were considered extremely toxic (using the Microtox™ toxicity screening procedure). Thirty-two percent of the samples exhibited moderate toxicity, while fifty-nine percent of the samples had no evidence of toxicity. Only a small fraction of the organic toxicants analyzed were frequently detected, with 1,3-dichlorobenzene and fluoranthene the most commonly detected organics investigated (present in 23 percent of the samples). Vehicle service and parking area runoff samples had many of the highest observed concentrations of organic toxicants. All metallic toxicants analyzed were commonly found in all samples analyzed.

The second project phase investigated the control of stormwater toxicants using a variety of conventional bench-scale treatment processes. Toxicity changes were monitored using the Azur Environmental Microtox™ bioassay screening test. The most beneficial treatment tests included settling for at least 24 h (up to 90 percent reductions), screening and filtering through at least 40 μm screens (up to 70 percent reductions), and aeration and/or photo-degradation for at least 24 h (up to 80 percent reductions). Because many samples exhibited uneven toxicity reductions for the different treatment tests, a treatment train approach was selected for testing during the third project phase.

The third project phase included testing of a prototype treatment device (the multi-chambered treatment train, or MCTT). However, the information provided in this report can also be used to develop other stormwater treatment devices. This device, through pilot and initial full-scale testing, has been shown to remove more than 90% of many of the stormwater toxicants, in both particulate and filtered forms. The MCTT is most suitable for use at relatively small and isolated paved critical source areas, from about 0.1 to 1 ha (0.25 to 2.5 acre) in area. These areas would include vehicle service facilities (gas stations, car washes, oil change stores, etc.), convenience store parking areas and areas used for equipment storage, along with salvage yards. The MCTT is an underground device that has three main chambers: an initial grit chamber for trapping of the largest sediment and release of most volatile materials; a main settling chamber (providing initial aeration and sorbent pillows) for the trapping of fine sediment and associated toxicants and floating hydrocarbons; and a sand and peat mixed media “filter” (sorption-ion exchange) unit for the reduction of filterable toxicants. A typical MCTT requires between 0.5 and 1.5 percent of the paved drainage area, which is about 1/3 of the area required for a well-designed wet detention pond.

A pilot-scale MCTT was constructed in Birmingham, AL, and tested over a six month monitoring period. Two additional full-scale MCTT units have recently been constructed and are currently being monitored as part of Wisconsin’s 319 grant from the U.S. EPA. During monitoring of 13 storms at a parking facility, the pilot-scale MCTT was found to have the following overall median reduction rates: 96% for total toxicity, 98% for filtered toxicity, 83% for SS, 60% for COD, 40% for turbidity, 100% for lead, 91% for zinc, 100% for n-Nitro-di-n-proplamine, 100% for pyrene, and 99% for bis (2-ethyl hexyl) phthalate. The color was increased by about 50% due to staining from the peat and the pH decreased by about one-half pH unit, also from the peat media. Ammonia nitrogen was increased by several times, and nitrate nitrogen had low reductions (about 14%). The MCTT therefore operated as intended: it had very effective reduction rates for both filtered and particulate stormwater toxicants and SS. Increased filterable toxicant reductions were obtained in the peat/sand mixed media sorption-ion exchange chamber, at the expense of increased color, lowered pH, and depressed COD and nitrate reduction rates. The preliminary full-scale test results substantiate the excellent reductions found during the pilot-scale tests, while showing better control of COD, filterable heavy metals, and nutrients, and less detrimental effects on pH and color.

Contents

Notice	ii
Foreword	iii
Abstract	iv
Contents	v
Tables	viii
Figures	x
Acknowledgments	xiii
 Chapter 1 - Introduction and Conclusions	 1
Conclusions	1
Organization of report	3
 Chapter 2 - Sources of Urban Stormwater Pollutants	 4
Sources and characteristics of urban runoff pollutants	5
Chemical quality of rocks and soils	6
Street dust and dirt pollutant sources	8
Characteristics	8
Street dirt accumulation	9
Washoff of street dirt	12
Observed particle size distributions in stormwater	21
Atmospheric sources of urban runoff pollutants	21
Source area sheetflow and particulate quality	26
Source area particulate quality	26
Warm weather sheetflow quality	27
Other pollutant contributions to the storm drainage system	39
Phase 1 project activities - Sources of stormwater toxicants	39
Phase 1 - analyses and sampling	39
Phase 1 - potential sources	42
Phase 1 - results	42
 Chapter 3 - Laboratory-Scale Toxicant Reduction Tests	 49
Phase 2 - analysis and sampling	49
Phase 2 - experimental error	49
Phase 2 - treatability tests	50
Phase 2 - results	50
 Chapter 4 - The Development of the MCTT	 60
Oil and water separators	62
Factors relevant to oil/water separator performance	62
Oil droplet size and critical rise rate	62
Design flow rate	64
Effective horizontal separation area	64

Other considerations	64
Gravity separation	64
Conventional American Petroleum Institute (API) oil/water separator	65
Separation vaults	67
Coalescing plate interceptor oil/water separators	68
Impingement coalescers and filtration devices	69
Maintenance of oil/water separators	70
Performance of oil/water separators for treating stormwater	71
The multi-chambered treatment train (MCTT)	72
Phase 3 - field demonstrations of the multi-chambered treatment train	72
Development of the MCTT	73
Catchbasin/grit chamber	74
Main settling chamber	74
Upflow velocity	74
Toxicity reductions associated with particle settling	77
Filter/ion exchange chamber	79
Sand	79
Peat moss	79
Combined sand and peat moss filters	80
Preliminary filtration tests with stormwater	80
Site specific design requirements of the MCTT main settling chamber	81
Toxicity reduction through settling	81
Storage/treatment trade-offs in MCTT design	82
Additional considerations in MCTT design and construction	90
Chapter 5 - Pilot-Scale and Preliminary Full-Scale Test Results of the MCTT	91
Pilot-scale MCTT design	91
Leaching of materials used for the construction of treatability test equipment	91
Pilot-scale MCTT operation	92
Pilot-scale MCTT sampling and analytical techniques	96
Results of the pilot-scale MCTT evaluation tests	98
Preliminary full-scale MCTT test results	113
Chapter 6 - General Design Procedures for the MCTT	122
Design procedure	122
Pollutant removal goal	122
Catchbasin inlet chamber design	124
Main settling chamber design	127
Drainage of main settling chamber	128
Final filtrations-sorption-ion exchange chamber	129
Selection of filtration media for pollutant reduction capabilities	129
Design of filters for specified filtration durations	130
Example design of full-scale MCTT	133
Determine the pollutant removal goal.	133
Main settling and filtration chamber designs.	133
Rainfall for Detroit and expected performance of MCTT	134
Site surveys	134
MCTT sizing options	135
Catchbasin/grit chamber design.	137
Maintenance activities.	137
Preliminary material specifications:	138

References	159
Appendix A - Plotted MCTT Performance Data	A-1
Appendix B - Tabular MCTT Performance Data	B-1
Appendix C - Source Area Pollutant Observations	C-1
Appendix D - Receiving Water Impacts	D-1
Toxicological effects of stormwater	D-2
Ecological effects of stormwater	D-2
Fates of stormwater pollutants in surface waters	D-5
Human health effects of stormwater	D-6
Groundwater impacts from stormwater infiltration	D-6
Constituents of concern	D-7
Nutrients	D-7
Pesticides	D-7
Other organics	D-7
Pathogenic microorganisms	D-8
Heavy metals and other inorganic compounds	D-8
Salts	D-9
Recommendations to protect groundwater during stormwater infiltration	D-9
Appendix E - Laboratory Procedures Used For MCTT Pilot-Scale Evaluations	E-1
.....	

Tables

	Page
2.1 Uses and sources for organic compounds found in stormwater.....	6
2.2 Common elements in the lithosphere	7
2.3 Common elements in soils	7
2.4 Street dirt loadings and deposition rates	11
2.5 Suspended solids washoff coefficients	21
2.6 Summary of reported rain quality	23
2.7 Atmosphere dustfall quality	24
2.8 Bulk precipitation quality	25
2.9 Urban bulk precipitation deposition rates	25
2.10 Summary of observed street dirt chemical quality	28
2.11 Summary of observed particulate quality for other source areas	29
2.12 Sheetflow quality summary for other source areas	30
2.13 Sheetflow quality summary for undeveloped landscaped and freeway pavement areas	36
2.14 Source area bacteria sheetflow quality summary	37
2.15 Source area filterable pollutant concentration summary	38
2.16 Numbers of samples collected from each source area type.....	39
2.17 List of toxic pollutants analyzed in samples	40
2.18 Fraction of samples rated as toxic	41
2.19 Stormwater toxicants detected in at least 10% of the source area sheetflow samples	44
2.20 Relative toxicity of samples using Microtox™	45
3.1 Phase 2 treatability sample descriptions	50
3.2 Two-sided probabilities comparing different treatment tests	51
4.1 Example oil droplet size distribution	64
4.2 Short-circuiting factor	67
4.3 Characteristics of coalescing plate interceptor separators	69
4.4 Reported filtration media performance for stormwater control	79
4.5 Median toxicity reduction for different holding times	82
4.6 Excel® spreadsheet model used to develop MCTT design curves	83
4.7 Risk assessment and design evaluation of an MCTT for Birmingham, AL, conditions	84
5.1 Potential sample contamination from sampler material	92
5.2 Potential sample contamination from materials that may be used in treatability test apparatus	95
5.3 Pilot-scale MCTT construction material leach test	96
5.4 Compounds analyzed during MCTT tests	97
5.5 Analytes and volumes collected	98
5.6 MCTT catchbasin chamber performance summary	99
5.7 MCTT settling chamber performance summary	101
5.8 MCTT sand-peat chamber performance summary	103
5.9 Overall MCTT performance summary	105
5.10 Median percent reductions by chamber	107
5.11 Significant (1-sided p value < 0.05) concentration changes for MCTT	108
5.12 Preliminary performance information for full-scale MCTT tests, compared to Birmingham pilot-scale MCTT results	114

	Page
6.1 Full MCTT pollutant removals compared to design toxicity reductions	123
6.2 Approximate suspended solids accumulations in catchbasin sump	127
6.3 MCTT main settling chamber required sizes	127
6.4 Filtration capacity as a function of suspended solids loadings	130
6.5 Filtration capacity as a function of pretreated water loading	130
6.6 Filter media categories and filtration capacities	131
6.7 Typical volumetric runoff coefficients for different land use areas	131
6.8 Likely suspended solids concentrations for different source areas	132
6.9 Example pollutant removals for example design alternatives	133

Figures

	Page
2.1 Deposition and accumulation of street dirt	10
2.2 Particle size distribution of HDS test	16
2.3 Particle size distribution for LCR test	16
2.4 Washoff plots for HCR test	17
2.5 Washoff plots for LCR test	17
2.6 Washoff plots for HDR test	18
2.7 Washoff plots for LDR test	18
2.8 Washoff plots for HCS test	19
2.9 Washoff plots for LCS test	19
2.10 Washoff plots for HDS test	20
2.11 Washoff plots for LCS test	20
2.12 Tenth percentile particle sizes for stormwater inlet flows	22
2.13 Fiftieth percentile particle sizes for stormwater inlet flows	22
2.14 Ninetieth percentile particle sizes for stormwater inlet flows	22
3.1 Toxicity reduction on control samples - industrial loading and parking areas	52
3.2 Toxicity reduction on control samples - automobile service facilities	52
3.3 Toxicity reduction on control samples - automobile salvage yards	52
3.4 Toxicity reduction from settling treatment - industrial loading and parking areas	53
3.5 Toxicity reduction from settling treatment - automobile service facilities	53
3.6 Toxicity reduction from settling treatment - automobile salvage yards	53
3.7 Toxicity reduction from aeration treatment - industrial loading and parking areas	54
3.8 Toxicity reduction from aeration treatment - automobile service facilities	54
3.9 Toxicity reduction from aeration treatment - automobile salvage yards	54
3.10 Toxicity reduction from sieve treatment - industrial loading and parking areas	55
3.11 Toxicity reduction from sieve treatment - automobile service facilities	55
3.12 Toxicity reduction from sieve treatment - automobile salvage yards	55
3.13 Toxicity reduction from photo-degradation treatment - industrial loading and parking areas	56
3.14 Toxicity reduction from photo-degradation treatment - automobile service facilities	56
3.15 Toxicity reduction from photo-degradation treatment - automobile salvage yards	56
3.16 Toxicity reduction from aeration and photo-degradation treatment - industrial loading and parking areas	57
3.17 Toxicity reduction from aeration and photo-degradation treatment - automobile service facilities ..	57
3.18 Toxicity reduction from aeration and photo-degradation treatment - automobile salvage yards	57
3.19 Toxicity reduction from floatation treatment (top layer samples) - industrial loading and parking areas	58
3.20 Toxicity reduction from floatation treatment (top layer samples) - automobile service facilities	58
3.21 Toxicity reduction from floatation treatment (top layer samples) - automobile salvage yards	58
3.22 Toxicity reduction from floatation treatment (middle layer samples) - industrial loading and parking areas	59
3.23 Toxicity reduction from floatation treatment (middle layer samples) - automobile service facilities	59
3.24 Toxicity reduction from floatation treatment (middle layer samples) - automobile salvage yards ...	59

	Page
4.1 MCTT cross section	61
4.2 Performance of API oil/water separators	63
4.3 API oil/water separator	65
4.4 Downflow parallel plate separator	69
4.5 Monthly changes in sediment in 17 oil/water separators	71
4.6 Critical Velocity and Settling Tank Dimensions	75
4.7 Effects of hydraulic loading on toxicity reduction	78
4.8 Effects of storage volume and treatment time on annual toxicity reduction, 2.1 m settling depth ...	90
5.1 Pilot-scale MCTT under construction	93
5.2 Pilot-scale MCTT in place at the UAB parking facility	93
5.3 Automatic samplers installed on the pilot-scale MCTT	94
5.4 Pilot-scale MCTT during a storm event	94
5.5 MCTT performance for suspended solids	109
5.6 MCTT performance for relative toxicity, by Microtox™, - unfiltered sample	110
5.7 MCTT performance for zinc - unfiltered sample	111
5.8 MCTT performance for bis(2-ethylhexyl)phthalate - unfiltered sample	112
5.9 Ruby Garage, Milwaukee, drainage area	115
5.10 Ruby Garage, Milwaukee, MCTT installation	115
5.11 Ruby Garage, Milwaukee, MCTT installation	116
5.12 Ruby Garage, Milwaukee, MCTT installation	116
5.13 Ruby Garage, Milwaukee, MCTT catchbasin inlet and piping	117
5.14 Ruby Garage, Milwaukee, MCTT main settling chamber inclined tube settlers and sorbent pillows	117
5.15 Minocqua, WI, MCTT, drainage area	118
5.16 Minocqua, WI, MCTT, installation of box culverts	118
5.17 Minocqua, WI, MCTT, installation of box culverts	119
5.18 Minocqua, WI, MCTT, placement of tube settlers	119
5.19 Minocqua, WI, MCTT, filter fabric being prepared for installation	120
5.20 Minocqua, WI, MCTT, grit chamber	120
5.21 Minocqua, WI, MCTT, interior of final filtration chamber	121
5.22 Minocqua, WI, MCTT, site after installation	121
6.1 Conventional catchbasin with inverted sump	125
6.2 Suspended solids capture vs. flowrate	126
6.3 Amount of rainfall treated before sumps are 60% full	126
6.4 MCTT design curves for Atlanta, GA	139
6.5 MCTT design curves for Austin, TX	140
6.6 MCTT design curves for Birmingham, AL	141
6.7 MCTT design curves for Bozeman, MT	142
6.8 MCTT design curves for Buffalo, NY	143
6.9 MCTT design curves for Dallas, TX	144
6.10 MCTT design curves for Detroit, MI	145
6.11 MCTT design curves for Little Rock, AR	146
6.12 MCTT design curves for Los Angeles, CA	147
6.13 MCTT design curves for Madison, WI	148
6.14 MCTT design curves for Miami, FL	149
6.15 MCTT design curves for Milwaukee, WI	150

	Page
6.16 MCTT design curves for Minneapolis, MN	151
6.17 MCTT design curves for Newark, NJ	152
6.18 MCTT design curves for New Orleans, LA	153
6.19 MCTT design curves for Phoenix, AZ	154
6.20 MCTT design curves for Portland, ME	155
6.21 MCTT design curves for Rapid City, SD	156
6.22 MCTT design curves for Reno, NV	157
6.23 MCTT design curves for Seattle, WA	158
6.24 MCTT design curves for St. Louis, MO	159

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- Shirley Clark's *Evaluation of Filtration Media for the Treatment of Stormwater* (1996),
- Brian Robertson's *Evaluation of a Multi-Chambered Treatment Train for Treatment of Stormwater Runoff from Critical Pollutant Source Areas* (1995).
- Ali Ayyoubi's *Physical Treatment of Urban Storm Water Runoff Toxicants* (1993), and
- Patricia Barron's *Characterization of Polynuclear Aromatic Hydrocarbons in Urban Runoff* (1990).

Much of the material in this report was previously presented in these theses, which also contain considerable additional supporting information.

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Chapter 1

Introduction and Conclusions

Past studies have identified urban runoff as a major contributor to the degradation of many urban streams and rivers (Field and Turkeltaub 1981; Pitt and Bozeman 1982; Pitt and Bissonnette 1984, and Pitt 1994, which includes an extensive literature review). Previous studies also found organic and metallic toxicants in urban storm induced discharges (EPA 1983a; Hoffman, *et al.* 1984; Fram, *et al.* 1987) which can contribute to receiving water degradation. Appendix D contains a summary of basic receiving water problems associated with urban stormwater, stressing recent research that supplements the above referenced studies and reviews.

The Nationwide Urban Runoff Program (NURP) monitored stormwater toxicant discharges from 28 cities and concluded that urban areas were responsible for substantial discharges of toxicants (EPA 1983a). The NURP data were collected mostly from residential areas and did not consider snowmelt. Furthermore, only a few commercial and light industrial areas were represented. NURP did not identify any significant regional differences in toxicants found, or in their concentrations. However, other information indicates that industrial stormwater, snowmelt runoff, and dry weather discharges (including illegal discharges into storm drainage) can all contribute significant amounts of toxicants to receiving waters (Pitt and McLean 1986).

The objective of this research was to further characterize stormwater toxicants, confirm the source areas of concern, and investigate the effectiveness of treatment processes to control the toxicants. A parallel EPA sponsored research project resulted in a user's guide for the investigation of inappropriate discharges into storm drainage systems (Pitt, *et al.* 1993) and a comprehensive review of groundwater impacts from stormwater infiltration (Pitt, *et al.* 1994 and 1996). Clearly, an effective urban runoff control program must consider all seasonal flow phases and sources of critical pollutants. If warm weather stormwater runoff was the only source considered, storm drainage control programs in many areas would be disappointingly deficient. A complete control program must consider dry weather flows, plus snow melt in northern areas, in addition to stormwater runoff. The results of the research reported here is only one component of this complete control program approach.

Conclusions

Previous studies have indicated that urban stormwater runoff contains a variety of conventional and potentially toxic pollutants that can degrade receiving waters and impair beneficial uses. Receiving water impacts are due to many variables, including: the magnitude of the dry and wet weather discharges; the transport and fate mechanisms of the toxicants; and effects from other discharges and receiving water conditions. These factors, and the unknown and site specific relationships between them, make the prediction of receiving water effects difficult, if not impossible, especially if one only relies on water column quality measurements. *In situ* biological community structure studies can give an indication of the receiving water effects, especially if pre-development or control conditions are known for comparison purposes. However it will generally be difficult to relate any identified impacts to any specific pollutant, but an in-stream biological community structure and habitat study will indicate whether the receiving water is being adversely effected.

Phase 1 of this research detected only a small fraction of the organic toxicants analyzed (as is typical for stormwater evaluations), but detected heavy metals in the majority of the samples analyzed. The study also confirmed that many toxicants are associated with particulate matter in the runoff. Industrial/commercial areas are likely to be the most significant pollutant source areas, with the highest toxicant concentrations and most frequent occurrences found at vehicle service and parking/storage areas. The duration of the antecedent dry period before a storm and the intensity of the storm event were found to be significant factors influencing the concentrations of most of the toxicants detected. These critical areas were sampled for the phase 2 treatability tests.

The treatability study (phase 2) found that settling, screening, and aeration and/or photo-degradation treatments showed the greatest potential for toxicant reductions, as measured by the reduction in toxicity of the samples, using the Microtox™ toxicity screening test. Studies to measure the actual toxicant reductions in full-scale applications are needed to confirm the real benefit of the potential treatment processes. The results from the second study phase, in conjunction with results from the first project phase, will enable the modification of treatment devices and system designs (for new installations and for retrofitting existing installations) to optimize toxicant reductions from critical stormwater runoff source areas. The third project phase examined the toxicant reduction benefits of large-scale applications of the most suitable treatment unit processes investigated.

The third phase of this research examined the use of a multi-chambered treatment tank (MCTT) to collect and treat runoff from critical stormwater source areas, including gas stations, oil change facilities, transmission repair shops, and other auto repair facilities. The collected runoff is first treated in a catchbasin chamber where larger particles are removed by settling. The water then flows into a main settling chamber containing oil sorbent material where it undergoes a much longer treatment period (24 to 72 h) to remove finer particles and associated pollutants. The final chamber contains a mixed media filter material comprising equal amounts of sand and peat. This final chamber acts as a polishing “filter” to remove some of the filterable toxicants from the runoff by other processes, such as ion exchange and sorption.

The pilot- and full-scale test results show that the MCTT is providing substantial reductions in stormwater toxicants (both in particulate and filtered phases) and suspended solids. Increases in color and a slight decrease in pH also occurred during the final treatment step when using peat as part of the filtering/ion-exchange media.

The main settling chamber provided substantial reductions in total and dissolved toxicity, lead, zinc, certain organic toxicants, SS, COD, turbidity, and color. The sand-peat chamber also provided additional filterable toxicant reductions. However, the catchbasin/grit chamber did not provide any significant improvements in water quality, although it is an important element in reducing maintenance problems by trapping bulk material.

Zinc and toxicity are examples where the use of the final chamber was needed to provide high levels of control. Otherwise, it may be tempting to simplify the MCTT by removing the last chamber. Another option would be to remove the main settling chamber and only use the pre-treating capabilities of the catchbasin as a grit chamber before the peat “filtration” chamber (similar to many stormwater filter designs). This option is not recommended because of the short life that the filter would have before it would clog (Clark and Pitt 1997). In addition, the bench-scale tests showed that a treatment train was needed to provide some redundancy because of frequent variability in sample treatability storm to storm, even for a single sampling site.

It is important not to confuse the MCTT with an oil/water separator or a grit chamber. Oil/water separators are mainly industrial wastewater treatment devices that work well for removing high concentrations of relatively large droplets of oil from wastewater. Stormwaters rarely have such levels of hydrocarbon contamination. If an area did produce stormwater having these hydrocarbon contamination conditions, then oil/water separators should be used, but further treatment may also be needed to remove other pollutants. Unfortunately, the available literature does not contain many examples of successful applications of oil/water separators for stormwater control. Common problems include lack of maintenance and under-sized separators for the flows encountered. Scouring of previously captured material is also common.

Several proprietary stormwater treatment devices have recently been marketed throughout North America. These devices can also be located underground. Unfortunately, comprehensive testing with actual stormwater is not available for most of these devices. The designs and demonstrations are mostly based on reduction of relatively large particles that rarely occur in stormwater. As indicated in this report, the suspended solids in stormwater is mostly in the range of 1 to 100 µm, with only a small fraction of the mass (usually <10%) associated with particles greater than 100 µm. These devices are designed to capture particle sizes that have typically been found on streets, not in the runoff water (Pitt 1987). These devices are excellent grit chambers (and can probably capture floating oils) and can be used to prevent sand-sized particles from accumulating in sewerage. Very little scour of the captured grit material is also likely with these devices. However, they are not likely to provide important reductions of most stormwater pollutants, especially the toxicants. The MCTT was designed to remove pollutants of a specific class of

concern in stormwater: particulates as small as a few μm and associated particulate bound toxicants, plus filterable toxicants. If a site is grossly contaminated with oils or grit, then a proprietary oil/water separator or grit chamber is needed, but further treatment will also likely be necessary.

The MCTT is capable of reducing a broad range of stormwater pollutants that cause substantial receiving-water problems (Pitt 1995). The MCTT has a high potential for cost-effective use as an integrated component in watershed management programs designed to protect and enhance receiving waters.

Organization of Report

This report includes discussions pertaining to the major issues that must be addressed when developing a stormwater management plan. These issues include a knowledge of the receiving water problems caused by stormwater (Appendix D), a knowledge of the problem pollutants and where they originate in the watershed (Chapter 2), and a knowledge of the control of these critical pollutants (Chapters 3, 4, 5 and 6). This EPA sponsored cooperative agreement with UAB included three research phases reported in this report covering these basic elements. The first phase included investigating sources of critical stormwater pollutants, the second phase included conducting bench-scale treatability tests to identify the effectiveness of many unit processes, while the third project phase included testing of a pilot-scale treatment device containing many of the most promising unit processes. These project phases are all presented in this report, along with preliminary information from full-scale testing conducted by the state of Wisconsin. The project research information is also substantially supported by information from the literature, especially on effects of stormwater (Appendix D) and sources of pollutants (Chapter 2).

Chapter 1 contains a brief discussion of the conclusions from the research, while Chapter 2 includes much literature information, plus the results of source area characterization studies conducted during this research project. Chapter 3 presents the results of the bench-scale treatability tests. Chapter 4 begins with a discussion of oil/water separators for stormwater control, and then discusses the development of the MCTT. Chapter 5 presents the results of the pilot-scale tests of the MCTT conducted in Birmingham and the preliminary test results from the full-scale tests being conducted in Wisconsin. Chapter 6 includes the general design procedure for the MCTT, including an example design for a Detroit site. Appendices A, B, and C include detailed observations obtained during this research. Appendix D reviews receiving effects from stormwater, while Appendix E is an excerpt from the project Quality Assurance Project Plan (QAPP) describing the laboratory analytical methods used during this project.

This is one of three project reports prepared for this cooperative agreement. The other two volumes describe tests of stormwater inlets and stormwater filtering media for their ability to reduce concentrations of stormwater pollutants. Previous reporting efforts of this cooperative agreement included an earlier report (and a book published by Ann Arbor Press) on groundwater effects of stormwater infiltration, a soon-to-be published book (CRC/Lewis) on conducting receiving water studies, and numerous technical conference presentations and published articles, many through the Engineering Foundation/ASCE series of stormwater conferences.

Chapter 2

Sources of Urban Stormwater Pollutants

Urban runoff is comprised of many separate source area flow components that are combined within the drainage area and at the outfall before entering the receiving water. It may be adequate to consider the combined outfall conditions alone when evaluating the long term, areawide effects of many separate outfall discharges to a receiving water. However, if better predictions of outfall characteristics (or the effects of source area controls) are needed, then the separate source area components must be characterized. The discharge at the outfall is made up of a mixture of contributions from different source areas. The “mix” depends on the characteristics of the drainage area and the specific rain event. The effectiveness of source area controls is therefore highly site and storm specific.

Various urban source areas all contribute different quantities of runoff and pollutants, depending on their specific characteristics. Impervious source areas may contribute most of the runoff during small rain events. Examples of these source areas include paved parking lots, streets, driveways, roofs, and sidewalks. Pervious source areas become important contributors for larger rain events. These pervious source areas include gardens, lawns, bare ground, unpaved parking areas and driveways, and undeveloped areas. The relative importance of the individual sources is a function of their areas, their pollutant washoff potentials, and the rain characteristics.

The washoff of debris and soil during a rain is dependent on the energy of the rain and the properties of the material. Pollutants are also removed from source areas by winds, litter pickup, or other cleanup activities. The runoff and pollutants from the source areas flow directly into the drainage system, onto impervious areas that are directly connected to the drainage system, or onto pervious areas that will attenuate some of the flows and pollutants, before they discharge to the drainage system .

Sources of pollutants on paved areas include on-site particulate storage that cannot be removed by usual processes e.g., rain, wind, street cleaning, etc. Atmospheric deposition, deposition from activities on these paved surfaces (auto traffic, material storage, etc.) and the erosion of material from upland areas that directly discharge flows onto these areas, are the major sources of pollutants to the paved areas. Pervious areas contribute pollutants mainly through erosion processes where the rain energy dislodges soil from between plants. The runoff from these source areas enter the storm drainage system where sedimentation in catchbasins or in the sewerage may affect their ultimate discharge to the outfall. In-stream physical, biological, and chemical processes affect the pollutants after they are discharged to the ultimate receiving water.

It is important to know when the different source areas become “active” (when runoff initiates from the area, carrying pollutants to the drainage system). If pervious source areas are not contributing runoff or pollutants, then the prediction of urban runoff quality is much simplified. The mechanisms of washoff, and delivery yields of runoff and pollutants from paved areas, is much better known than from pervious urban areas (Novotny and Chesters 1981). In many cases, pervious areas are not active except during rain events greater than at least five or ten mm. For smaller rain depths, almost all of the runoff and pollutants originate from impervious surfaces (Pitt 1987). However, in many urban areas, pervious areas may contribute the majority of the runoff, and some pollutants, when rain depths are greater than about 20 mm. The actual importance of the different source areas is highly dependent on the specific land use and rainfall patterns. Obviously, in areas having relatively low density development, especially where moderate and large sized rains occur frequently (such as in the Southeast), pervious areas typically dominate outfall discharges. In contrast, in areas having significant paved areas, especially where most rains are relatively small (such as in the arid west), the impervious areas would dominate outfall discharges. The effectiveness of different source controls would therefore be quite different for different land uses and climatic patterns.

If the number of events exceeding a water quality objective are important, then the small rain events are of most concern. Stormwater runoff typically exceeds some water quality standards for practically every rain event (especially for bacteria and some heavy metals). In the upper Midwest, the median rain depth is about 6 mm, while in the Southeast, the median rain depth is about twice this depth. For these small rain depths and for most urban land uses, directly connected paved areas usually contribute most of the runoff and pollutants. However, if annual mass discharges are more important, e.g. for long-term effects, then the moderate rains are more important. Rains from about 10 to 50 mm produce most of the annual runoff volume in many areas of the U.S. Runoff from both impervious and pervious areas can be very important for these rains. The largest rains (greater than 100 mm) are relatively rare and do not contribute significant amounts of runoff pollutants during normal years, but are very important for drainage design. The specific source areas that are most important (and controllable) for these different conditions vary widely.

The remaining portions of this chapter describe sources of urban runoff flows and pollutants as reported from many past studies as found in the literature. This chapter also reports on the specific source area sampling activities conducted as part of this EPA funded research.

Sources and Characteristics of Urban Runoff Pollutants

It has been known for many years that the vast majority of stormwater toxicants and much of the conventional pollutants are associated with automobile use and maintenance activities and that these pollutants are strongly associated with the particulates suspended in the stormwater (the non-filterable components, or suspended solids). It has been difficult to reduce or modify automobile use to reduce the use of these compounds, with the notable exception of the phasing out of leaded gasoline. Current activities, concentrated in the San Francisco area, are trying to encourage brake pad manufactures to reduce the use of copper. The effectiveness of most stormwater control practices is therefore dependent on their ability to remove these particles from the water, or possibly from intermediate accumulating locations (such as streets or other surfaces) and not through source reduction. The removal of these particles from stormwater is dependent on various characteristics of these particles, especially their size and settling rates. Some source area controls (most notably street cleaning) affect the particles before they are washed-off and transported by the runoff, while others remove the particles from the flowing water. This discussion therefore summarizes the accumulation and washoff of these particulates and the particle size distribution of the suspended solids in stormwater runoff to better understand the effectiveness of source area control practices.

Table 2.1 shows that most of the organic compounds found in stormwater are associated with various human-related activities, especially automobile and pesticide use, or are associated with plastics (Verschuere 1983). Heavy metals found in stormwater also mostly originate from automobile use activities, including gasoline combustion, brake lining, fluids (brake fluid, transmission oil, anti-freeze, grease, etc.), undercoatings, and tire wear (Durum 1974, Koeppe 1977, Rubin 1976, Shaheen 1975, Solomon and Natusch 1977, and Wilbur and Hunter 1980). Auto repair, pavement wear, and deicing compound use also contribute heavy metals to stormwater (Field, *et al.* 1973, and Shaheen 1975). Shaheen (1975) found that eroding area soils are the major source of the particulates in stormwater. The eroding area soil particles, and the particles associated with road surface wear, become contaminated with exhaust emissions and runoff containing the polluting compounds. Most of these compounds become tightly bound to these particles and are then transported through the urban area and drainage system (or removed) with the particulates. Stormwater concentrations of zinc, fluoranthene, 1,3-dichlorobenzene, and pyrene are unique in that substantial fractions of these compounds remain in the water and are less associated with the particulates.

All areas are affected by atmospheric deposition, while other sources of pollutants are specific to the activities conducted on the areas. As examples, the ground surfaces of unpaved equipment or material storage areas can become contaminated by spills and debris, while undeveloped land remaining relatively unspoiled by activities can still contribute runoff solids, organics, and nutrients, if eroded. Atmospheric deposition, deposition from activities on paved surfaces, and the erosion of material from upland unconnected areas are the major sources of pollutants in urban areas.

Table 2.1. Uses and Sources for Organic Compounds found in Stormwater (Source: Verschueren 1983)

COMPOUND	EXAMPLE USE/SOURCE
Phenol	gasoline, exhaust
N-Nitroso-di-n-propylamine	contaminant of herbicide Treflan
Hexachloroethane	plasticizer in cellulose esters, minor use in rubber and insecticide
Nitrobenzene	solvent, rubber, lubricants
2,4-Dimethylphenol	asphalt, fuel, plastics, pesticides
Hexachlorobutadiene	rubber and polymer solvent, transformer and hydraulic oil
4-Chloro-3-methylphenol	germicide; preservative for glues, gums, inks, textile, and leather
Pentachlorophenol	insecticide, algacide, herbicide, & fungicide mfg., wood preservative
Fluoranthene	gasoline, motor and lubricating oil, wood preservative
Pyrene	gasoline, asphalt, wood preservative, motor oil
Di-n-octylphthalate	general use of plastics

There have been many studies in the past that have examined different sources of urban runoff pollutants. These references have been reviewed as part of this study and the results are summarized in this section. These significant pollutants have been shown to have a potential for creating various receiving water impact problems, as described in Appendix D of this report. Most of these potential problem pollutants typically have significant concentration increases in the urban feeder creeks and sediments, as compared to areas not affected by urban runoff.

The important sources of these pollutants are related to various uses and processes. Automobile related potential sources usually affect road dust and dirt quality more importantly than other particulate components of the runoff system. The road dust and dirt quality is affected by vehicle fluid drips and spills (gasoline, oils, etc.) and vehicle exhaust, along with various vehicle wear, local soil erosion, and pavement wear products. Urban landscaping practices potentially affecting urban runoff include vegetation litter, fertilizer and pesticide. Miscellaneous sources of urban runoff pollutants include firework debris, wildlife and domestic pet wastes and possibly industrial and sanitary wastewaters. Wet and dry atmospheric contributions both affect runoff quality. Pesticide use in an urban area can contribute significant quantities of various toxic materials to urban runoff. Many manufacturing and industrial activities, including the combustion of fuels, also affects urban runoff quality.

Natural weathering and erosion products of rocks contribute the majority of the hardness and iron in urban runoff pollutants. Road dust and associated automobile use activities (gasoline exhaust products) historically contributed most of the lead in urban runoff. However, the decrease of lead in gasoline has resulted in current stormwater lead concentrations being about 1/10 of the levels found in stormwater in the early 1970s (Bannerman, *et al.* 1993). In certain situations, paint chipping can also be a major source of lead in urban areas. Road dust contaminated by tire wear products, and zinc plated metal erosion material, contribute most of the zinc to urban runoff. Urban landscaping activities can be a major source of cadmium (Phillips and Russo 1978). Electroplating and ore processing activities can also contribute chromium and cadmium.

Many pollutant sources are specific to a particular area and on-going activities. For example, iron oxides are associated with welding operations and strontium, used in the production of flares and fireworks, would probably be found on the streets in greater quantities around holidays, or at the scenes of traffic accidents. The relative contribution of each of these potential urban runoff sources, is, therefore, highly variable, depending upon specific site conditions and seasons.

Specific information is presented in the following subsections concerning the qualities of various rocks and soils, urban and rural dustfall, and precipitation. This information is presented to assist in the interpretation of the source area runoff samples collected as part of this project.

Chemical Quality of Rocks and Soils

The abundance of common elements in the lithosphere (the earth's crust) is shown in Table 2.2 (Lindsay 1979). Almost half of the lithosphere is oxygen and about 25 percent is silica. Approximately 8 percent is aluminum and 5 percent is iron. Elements comprising between 2 percent and 4 percent of the lithosphere include calcium, sodium, potassium and magnesium. Because of the great abundance of these materials in the lithosphere, urban runoff transports only a relatively small portion of these elements to receiving waters, compared to natural processes. Iron

and aluminum can both cause detrimental effects in receiving waters, if in their dissolved forms. A reduction of the pH substantially increases the abundance of dissolved metals. Table 2.3, also from Lindsay (1979), shows the rankings for common elements in soils. These rankings are quite similar to the values shown previously for the lithosphere. Natural soils can contribute pollutants to urban runoff through local erosion. Again, iron and aluminum are very high on this list and receiving water concentrations of these metals are not expected to be significantly affected by urban activities alone.

Table 2.2 Common Elements in the Lithosphere
(Source: Lindsay 1979)

Abundance Rank	Element	Concentration in Lithosphere (mg/kg)
1	O	465,000
2	Si	276,000
3	Al	81,000
4	Fe	51,000
5	Ca	36,000
6	Na	28,000
7	K	26,000
8	Mg	21,000
9	P	1,200
10	C	950
11	Mn	900
12	F	625
13	S	600
14	Cl	500
15	Ba	430
16	Rb	280
17	Zr	220
18	Cr	200
19	Sr	150
20	V	150
21	Ni	100

Table 2.3 Common Elements in Soils (Source: Lindsay 1979)

Abundance Rank	Element	Typical Minimum (mg/kg)	Typical Maximum (mg/kg)	Typical Average (mg/kg)
1	O			490,000
2	Si	230,000	350,000	320,000
3	Al	10,000	300,000	71,000
4	Fe	7,000	550,000	38,000
5	C			20,000
6	Ca	7,000	500,000	13,700
7	K	400	30,000	8,300
8	Na	750	7,500	6,300
9	Mg	600	6,000	5,000
10	Ti	1,000	10,000	4,000
11	N	200	4,000	1,400
12	S	30	10,000	700
13	Mn	20	3,000	600
14	P	200	5,000	600
15	Ba	100	3,000	430
16	Zr	60	2,000	300
17	F	10	4,000	200
18	Sr	50	1,000	200
19	Cl	20	900	100
20	Cr	1	1,000	100
21	V	20	500	100

The values shown on these tables are expected to vary substantially, depending upon the specific mineral types. Arsenic is mainly concentrated in iron and manganese oxides, shales, clays, sedimentary rocks and phosphorites. Mercury is concentrated mostly in sulfide ores, shales and clays. Lead is fairly uniformly distributed, but can be concentrated in clayey sediments and sulfide deposits. Cadmium can also be concentrated in shales, clays and phosphorites (Durum 1974).

Street Dust and Dirt Pollutant Sources

Characteristics

Most of the street surface dust and dirt material (by weight) are local soil erosion products, while some materials are contributed by motor vehicle emissions and wear (Shaheen 1975). Minor contributions are made by erosion of street surfaces in good condition. The specific makeup of street surface contaminants is a function of many conditions and varies widely (Pitt 1979).

Automobile tire wear is a major source of zinc in urban runoff and is mostly deposited on street surfaces and nearby adjacent areas. About half of the airborne particulates lost due to tire wear settle out on the street and the majority of the remaining particulates settle within about 6 meters of the roadway. Exhaust particulates, fluid losses, drips, spills and mechanical wear products can all contribute lead to street dirt. Many heavy metals are important pollutants associated with automobile activity. Most of these automobile pollutants affect parking lots and street surfaces. However, some of the automobile related materials also affect areas adjacent to the streets after being transported by wind after being resuspended from the road surface by traffic-induced turbulence.

Automobile exhaust particulates contribute many important heavy metals to street surface particulates and to urban runoff and receiving waters. The most notable of these heavy metals has been lead. However, since the late 1980s, the concentrations of lead in stormwater has decreased substantially (by about ten times) compared to early 1970 observations. This decrease, of course, is associated with significantly decreased consumption of leaded gasoline. Solomon and Natusch (1977) studied automobile exhaust particulates in conjunction with a comprehensive study of lead in the Champaign-Urbana, Illinois area. They found that the exhaust particulates existed in two distinct morphological forms. The smallest particulates were almost perfectly spherical, having diameters in the range of 0.1 to 0.5 μm . These small particles consisted almost entirely of PbBrCl at the time of emission. Because they are small, they are expected to remain airborne for considerable distances and can be captured in the lungs when inhaled. They concluded that the small particles are formed by condensation of PbBrCl vapor onto small nucleating centers, which are probably introduced into the engine with the filtered engine air.

Solomon and Natusch (1977) also found that the second major form of automobile exhaust particulates were rather large, being roughly 10 to 20 μm in diameter. These had typically irregular shapes, with somewhat smooth surfaces. They found that the elemental compositions of these irregular particles were quite variable, being predominantly iron, calcium, lead, chlorine and bromine. They found that individual particles did contain aluminum, zinc, sulfur, phosphorus and some carbon, chromium, potassium, sodium, nickel and thallium. Many of these elements (bromine, carbon, chlorine, chromium, potassium, sodium, nickel, phosphorus, lead, sulfur, and thallium) are most likely condensed, or adsorbed, onto the surfaces of these larger particles during passage through the exhaust system. They believed that these large particles originate in the engine or exhaust system because of their very high iron content. They found that 50 to 70 percent of the emitted lead was associated with these large particles, which would be deposited within a few meters of the emission point onto the roadway, because of their aerodynamic properties.

Solomon and Natusch (1977) also examined urban particulates near roadways and homes in urban areas. They found that lead concentrations in soils were higher near roads and houses. This indicated the capability of road dust and peeling house paint to contaminate nearby soils. The lead content of the soils ranged from 130 to about 1,200 mg/kg. Koeppe (1977), during another element of the Champaign-Urbana lead study, found that lead was tightly bound to various soil components. However, the lead did not remain in one location, but it was transported both downward in the soil profile and to adjacent areas through both natural and man-assisted processes.

Street Dirt Accumulation

The washoff of street dirt and the effectiveness of street cleaning as a stormwater control practice are highly dependent on the available street dirt loading. Street dirt loadings are the result of deposition and removal rates, plus "permanent storage." The permanent storage component is a function of street texture and condition and is the quantity of street dust and dirt that cannot be removed naturally or by street cleaning equipment. It is literally trapped in the texture, or cracks, of the street. The street dirt loading at any time is this initial permanent loading plus the accumulation amount corresponding to the exposure period, minus the re-suspended material removal by wind and traffic-induced turbulence. Removal of street dirt can occur naturally by winds and rain, or by human activity (by the turbulence of traffic or by street cleaning equipment). Very little removal occurs by any process when the street dirt loadings are small, but wind removal may be very large with larger loadings, especially for smooth streets (Pitt 1979).

Figure 2.1 shows very different street dirt loadings for two San Jose, CA, residential study areas (Pitt 1979). The accumulation and deposition rates (and therefore the amounts lost to air) are quite similar, but the initial loading values (the permanent storage values) are very different. The loading differences were almost solely caused by the different street textures. Table 2.4 summarizes many accumulation rate measurements obtained from throughout North America. In the earliest studies (APWA 1969; Sartor and Boyd 1972; and Shaheen 1975) it was assumed that the initial street dirt loading values after a major rain or street cleaning were zero. Calculated accumulation rates for rough streets were therefore very large. Later tests measured the initial loading values close to the end of major rains and street cleaning and found that they could be very high, depending on the street texture. When these starting loadings were considered, the calculated accumulation rates were therefore much lower. The early, uncorrected, Sartor and Boyd accumulation rates that ignored the initial loading values were almost ten times the correct values shown on this table. Unfortunately, most urban stormwater models used these very high early accumulation rates as default values.

The most important factors affecting the initial loading and maximum loading values shown on Table 2.4 were found to be street texture and street condition. When data from many locations are studied, it is apparent that smooth streets have substantially less loadings at any accumulation period compared to rough streets for the same land use. Very long accumulation periods relative to the rain frequency resultant in high street dirt loadings. During these conditions, the wind losses of street dirt (as fugitive dust) may approximate the deposition rate, resulting in relatively constant street dirt loadings. At Bellevue, WA, typical interevent rain periods average about 3 days. Relatively constant street dirt loadings were observed in Bellevue because the frequent rains kept the loadings low and very close to the initial storage value, with little observed increase in dirt accumulation over time (Pitt 1985). In Castro Valley, CA, the rain interevent periods were much longer (ranging from about 20 to 100 days) and steady loadings were only observed after about 30 days when the loadings became very high and fugitive dust losses caused by the winds and traffic turbulence moderated the loadings (Pitt and Shawley 1982).

An example of the type of research conducted to obtain the values shown in Table 2.4 was conducted by Pitt and McLean (1986) in Toronto. They measured street dirt accumulation rates and the effects of street cleaning as part of a comprehensive stormwater research project. An industrial street with heavy traffic and a residential street with light traffic were monitored about twice a week for three months. At the beginning of this period, intensive street cleaning (one pass per day for each of three consecutive days) was conducted to obtain reasonably clean streets. Street dirt loadings were then monitored every few days to measure the accumulation rates of street dirt. Street dirt sampling procedures developed by Pitt (1979) were used: powerful industrial vacuums (two units, each having 2 HP, combined with a "Y" connector, and using a 6 in. wide solid aluminum head) were used to clean many separate subsample strips across the roads which were then combined for physical and chemical analyses.

In Toronto, the street dirt particulate loadings were quite high before the initial intensive street cleaning period and were reduced to their lowest observed levels immediately after the last street cleaning. After street cleaning, the loadings on the industrial street increased much faster than for the residential street. Right after intensive cleaning, the street dirt particle sizes were also similar for the two land uses. However, the loadings of larger particles on the industrial street increased at a much faster rate than on the residential street, indicating more erosion or tracking materials being deposited onto the industrial street. The residential street dirt measurements did not indicate that any material was lost to the atmosphere as fugitive dust, likely due to the low street dirt accumulation rate and the short

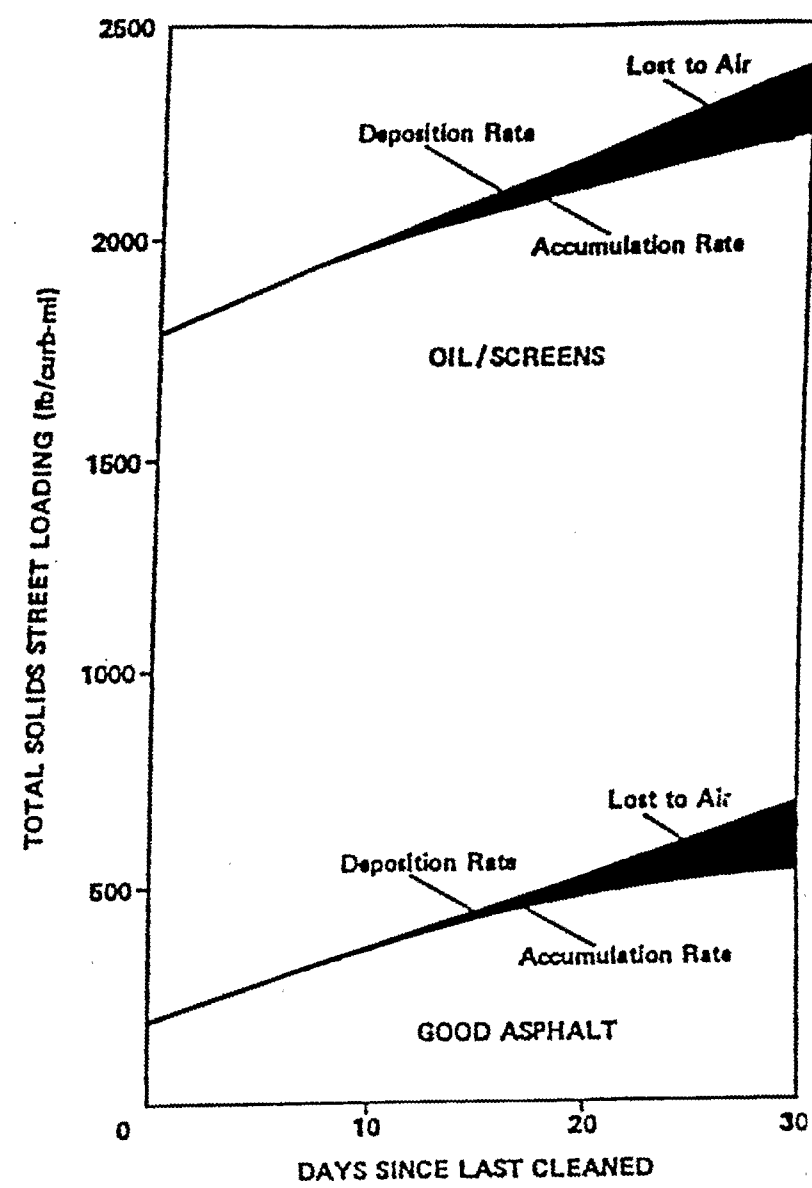


Figure 2.1 Deposition and accumulation of street dirt (Pitt 1979).

Table 2.4 Street Dirt Loadings and Deposition Rates

Street Dirt Loadings (grams/curb-meter) and Deposition Rates (grams/curb-meter-day)

	Initial Loading Value	Daily Deposition Rate	Maximum Observed Loading	Days to Observed Maximum Loading	Reference
Smooth and Intermediate Textured Streets					
Reno/Sparks, NV - good condition	80	1	85	5	Pitt and Sutherland 1982
Reno/Sparks, NV - good with smooth gutters (windy)	250	7	400	30	Pitt and Sutherland 1982
San Jose, CA - good condition	35	4	>140	>50	Pitt 1979
U.S. nationwide - residential streets, good condition	110	6	140	5	Sartor and Boyd 1972 (corrected)
U.S. nationwide - commercial streets, good condition	85	4	140	5	Sartor and Boyd 1972 (corrected)
Reno/Sparks, NV - moderate to poor condition	200	2	200	5	Pitt and Sutherland 1982
Reno/Sparks, NV - new residential area (construction)	710	17	910	15	Pitt and Sutherland 1982
Reno/Sparks, NV - poor condition, with lipped gutters	370	15	630	35	Pitt and Sutherland 1982
San Jose, CA - fair to poor condition	80	4	230	70	Pitt 1979
Castro Valley, CA - moderate condition	85	10	290	70	Pitt and Shawley 1982
Ottawa, Ontario - moderate condition	40	20	na	na	Pitt 1983
Toronto, Ontario - moderate condition, residential	40	32	100	>10	Pitt and McLean 1986
Toronto, Ontario - moderate condition, industrial	60	40	351	>10	Pitt and McLean 1986
Bellevue, WA - dry period, moderate condition	140	6	>230	20	Pitt 1984
Bellevue, WA - heavy traffic	60	1	110	30	Pitt 1984
Bellevue, WA - other residential sites	70	3	140	30	Pitt 1984
average:	150	9	>270	>25	
range:	35 - 710	1 - 40	85 - 910	5 - 70	
Rough and Very Rough Textured Streets					
San Jose, CA - oil and screens overlay	510	6	>710	>50	Pitt 1979
Ottawa, Ontario - very rough	310	20	na	na	Pitt 1983
Reno/Sparks, NV	630	10	860	35	Pitt and Sutherland 1982
Reno/Sparks, NV - windy	540	34	>1,400	>40	Pitt and Sutherland 1982
San Jose, CA - poor condition	220	6	430	30	Pitt 1979
Ottawa, Ontario - rough	200	20	na	na	Pitt 1983
U.S. nationwide - industrial streets (poor condition)	190	10	370	10	Sartor and Boyd 1972 (corrected)
average:	370	15	>750	>30	
range:	190 - 630	6 - 34	370 - >1,400	10 - >50	

periods of time between rains. The street dirt loadings never had the opportunity to reach the high loading values needed before they could be blown from the streets by winds or by traffic-induced turbulence. The industrial street, in contrast, had a much greater street dirt accumulation rate and was able to reach the critical loading values needed for fugitive losses in the relatively short periods between the rains.

Washoff of Street Dirt

The Yalin equation relates the sediment carrying capacity to runoff flow rate (Yalin 1963). Yalin stated that sediment motion begins when the lift force of flow exceeds a critical lift force. Once a particle is lifted, the drag force of the flow moves it downstream until the weight of the particle forces it back down. The Yalin equation is used to predict particle transport, for specific particle sizes, on a weight per unit flow width basis. It is used for fully turbulent channel flow conditions, typical of shallow overland flow in urban areas. The receding limb (tail) of a hydrograph may have laminar flow conditions, and the suspended sediment carried in the previously turbulent flows would settle out. The predicted constant Yalin sediment load would therefore only occur during periods of rain, and, the sediment load would decrease, due to sedimentation, after the rain stops. The critical particle bedload tractive force, the tractive force at which the particle begins to move, can be obtained from the Shield's diagram. However, Shen (1981) warned that the Shield's diagram alone cannot be used to predict "self-cleaning" velocities, as it gives only a lower limit below which deposition will occur. It defines the boundary between bed movement and stationary bed conditions. The Shield's diagram does not consider the particulate supply rate in relationship to the particulate transport rate. Reduced particulate transport occurs if the sediment supply rate is less than the transport rate. The Yalin equation by itself is therefore not sensitive to particulate supply; it only predicts the carrying capacity of flowing waters.

Besides the particulate supply rate, the Yalin equation is also very sensitive to local flow parameters (specifically gutter flow depth). Therefore, a hydraulic model that can accurately predict sheetflow across impervious surfaces and gutter flow is needed. Sutherland and McCuen (1978) statistically analyzed a modified form of the Yalin equation, in conjunction with a hydraulic model for different gutter flow conditions. Except for the largest particle sizes, the effect of rain intensity on particle washoff was found to be negligible.

The Yalin equation is based on classical sediment transport equations, and requires some assumptions concerning the micro-scale aspects of gutter flows and street dirt distributions. The Yalin equation, as typically used in urban stormwater evaluations, assumes that all particles lie within the gutter, and no significant washoff occurs by sheetflows traveling across the street towards the gutter. The early measurements of across-the-street dirt distributions made by Sartor and Boyd (1972) indicated that about 90 percent of the street dirt was within about 30 cm of the curb face (typically within the gutter area). These measurements, however, were made in areas of no parking (near fire hydrants because of the need for water for the sampling procedures that were used), and the traffic turbulence was capable of blowing most of the street dirt against the curb barrier (or over the curb onto adjacent sidewalks or landscaped areas) (Shaheen 1975). In later tests, Pitt (1979) and Pitt and Sutherland (1982) examined street dirt distributions across-the-street in many additional situations. They found distributions similar to Sartor and Boyd's observations only on smooth streets, with moderate to heavy traffic, and with no on-street parking. In many cases, most of the street dirt was actually in the driving lanes, trapped by the texture of rough streets. If extensive on-street parking was common, much of the street dirt was found on the outside edge of the parking lanes, where much of the resuspended (in air) street dirt blew against the parked cars and settled to the pavement.

Another process that may result in washoff less than predicted by Yalin is bed armoring (Sutherland, *et al.* 1982). As the smaller particulates are removed, the surface is covered by predominantly larger particulates which are not effectively washed-off by rain. Eventually, these larger particulates hinder the washoff of the trapped, under-lying, smaller particulates. Debris on the street, especially leaves, can also effectively armor the particulates, reducing the washoff of particulates to very low levels (Singer and Blackard 1978).

Observations of particulate washoff during controlled tests using actual streets and natural street dirt and debris are affected by street dirt distributions and armoring. The earliest controlled street dirt washoff experiments were conducted by Sartor and Boyd (1972) during the summer of 1970 in Bakersfield, CA. Their data was used in many stormwater models (including SWMM, Huber and Heaney 1981; STORM, COE 1975; and HSPF, Donigian and Crawford 1976) to estimate the percentage of the available particulates on the streets that would wash off during

rains of different magnitudes. Sartor and Boyd used a rain simulator having many nozzles and a drop height of 1-1/2 to 2 meters in street test areas of about 5 by 10 meters. Tests were conducted on concrete, new asphalt, and old asphalt, using simulated rain intensities of about 5 and 20 mm/hr. They collected and analyzed runoff samples every 15 minutes for about two hours for each test. Sartor and Boyd fitted their data to an exponential curve, assuming that the rate of particle removal of a given size is proportional to the street dirt loading and the constant rain intensity:

$$dN/dt = krN$$

where: dN/dt = the change in street dirt loading per unit time
 k = proportionality constant
 r = rain intensity (in/hr)
 N = street dirt loading (lb/curb-mile)

This equation, upon integration, becomes:

$$N = N_0 e^{-kr t}$$

where: N = residual street dirt load (after the rain)
 N_0 = initial street dirt load
 t = rain duration

Street dirt washoff is therefore equal to N_0 minus N . The variable combination rt , or rain intensity (in/h) times rain duration (h), is equal to total rain depth (R), in inches. This equation then further reduces to:

$$N = N_0 e^{-kR}$$

Therefore, this equation is only sensitive to the total depth of the rain that has fallen since the beginning of the rain, and not rain intensity. Because of decreasing particulate supplies, the exponential washoff curve also predicts decreasing concentrations of particulates with time since the start of a constant rain (Alley 1980 and 1981).

The proportionality constant, k , was found by Sartor and Boyd to be slightly dependent on street texture and condition, but was independent of rain intensity and particle size. The value of this constant is usually taken as 0.18/mm, assuming that 90 percent of the particulates will be washed from a paved surface in 1 h during a 13 mm/h rain. However, Alley (1981) fitted this model to watershed outfall runoff data and found that the constant varied for different storms and pollutants for a single study area. Novotny (as part of Bannerman, *et al.* 1983) also examined “before” and “after” rain event street particulate loading data from the Milwaukee Nationwide Urban Runoff Program (NURP) project and found almost a three-fold difference between the constant value of k for fine (<45 μm) and medium sized particles (100 to 250 μm). The calculated values were 0.026/mm for the fine particles and 0.01/mm for the medium sized particles, both much less than the “accepted” value of 0.18/mm. Jewell, *et al.* (1980) also found large variations in outfall “fitted” constant values for different rains compared to the typical default value. Either the assumption of the high removal of particulates during the 13 mm/hr storm was incorrect or/and the equation cannot be fitted to outfall data (most likely, as this would require that all the particulates are originating from homogeneous paved surfaces during all storm conditions).

This washoff equation has been used in many stormwater models, along with an expression for an availability factor. An availability factor is needed, as N_0 is only the portion of the total street load available for washoff. This availability factor (the fraction of the total street dirt loading available for washoff) is generally used as 1.0 for all rain intensities greater than about 18 mm/hr and reduces to about 0.10 for rains of 1 mm/hr.

The Bellevue, WA, urban runoff project (Pitt 1985) included about 50 pairs of street dirt loading observations close to the beginnings and ends of rains. These “before” and “after” loading values were compared to determine significant differences in loadings that may have been caused by the rains. The observations were affected by rains falling directly on the streets, along with flows and particulates originating from non-street areas. The net loading differences were therefore affected by street dirt washoff (by direct rains on the street surfaces and by gutter flows

augmented by “upstream” area runoff) and by erosion products that originated from non-street areas that may have settled out in the gutters. When all the data were considered together, the net loading difference was about 10 to 13 g/curb-m removed. This amounted to a street dirt load reduction of about 15 percent, which was much less than predicted using either of the two previously described washoff models. Very large reductions in street dirt loadings during rains were observed in Bellevue for the smallest particles, but the largest particles actually increased in loadings (due to deposited erosion materials originating from off-street areas). The particles were not source limited, but armor shielding may have been important. Most of the particulates in the runoff were in the fine particle sizes ($<63\ \mu\text{m}$). Very few particles greater than $1000\ \mu\text{m}$ were found in the washoff water. Care must be taken to not confuse street dirt particle size distributions with stormwater runoff particle size distributions. The stormwater particle size distributions are much more biased towards the smaller sizes, as described later.

Suspended solids washoff predictions for Bellevue conditions were made using the Sutherland and McCuen modification of the Yalin equation, and the Sartor and Boyd equation. Three particle size groups (<63 , 250-500, and $2000\text{-}6350\ \mu\text{m}$), and three rains, having depths of 5, 10, and 20 mm and 3-h durations, were considered. The gutter lengths for the Bellevue test areas averaged about 80 m, with gutter slopes of about 4.5 percent. Typical total initial street dirt loadings for the three particle sizes were: 9 g/curb-m for $<63\ \mu\text{m}$, 18 g/curb-m for 250-500 μm , and 9 g/curb-m for $2000\text{-}6350\ \mu\text{m}$. The actual Bellevue net loading removals during the storms were about 45 percent for the smallest particle size group, 17 percent for the middle particle size group, and -6 percent (6 percent loading increase) for the largest particle size group. The predicted removals were 90 to 100 percent using the Sutherland and McCuen method, 61 to 98 percent using the Sartor and Boyd equation, and 8 to 37 percent using the availability factor with the Sartor and Boyd equation. The ranges given reflect the different rain volumes and intensities only. There were no large predicted differences in removal percentages as a function of particle size. The availability factor with the Sartor and Boyd equation resulted in the closest predicted values, but the great differences in washoff as a function of particle size was not predicted.

The Bellevue street dirt washoff observations included effects of additional runoff water and particulates originating from non-street areas. The additional flows should have produced more gutter particulate washoff, but upland erosion materials may also have settled in the gutters (as noted for the large particles). However, across-the-street particulate loading measurements indicated that much of the street dirt was in the street lanes, not in the gutters, before and after rains. This particulate distribution reduces the importance of these extra flows and particulates from upland areas. The increased loadings of the largest particles after rains were obviously caused by upland erosion, but the magnitude of the settled amounts was quite small compared to the total street dirt loadings.

In order to clarify street dirt washoff, Pitt (1987) conducted numerous controlled washoff tests on city streets in Toronto. These tests were arranged as an overlapping series of 2^3 factorial tests, and were analyzed using standard factorial test procedures described by Box, *et al.* (1978). The experimental factors examined included: rain intensity, street texture, and street dirt loading. The differences between available and total street dirt loads were also related to the experimental factors. The samples were analyzed for total solids (total residue), dissolved solids (filterable residue: $<0.45\ \mu\text{m}$), and SS (particulate residue: $>0.45\ \mu\text{m}$). Runoff samples were also filtered through $0.45\ \mu\text{m}$ filters and the filters were microscopically analyzed (using low power polarized light microscopes to differentiate between inorganic and organic debris) to determine particulate size distributions from about 1 to $500\ \mu\text{m}$. The runoff flow quantities were also carefully monitored to determine the magnitude of initial and total rain water losses on impervious surfaces.

The total solids concentrations varied from about 25 to $3000\ \text{mg/L}$, with an obvious decrease in concentrations with increasing rain depths during these constant rain intensity tests. No concentrations greater than $500\ \text{mg/L}$ occurred after about 2 mm of rain, while all concentrations after about 10 mm of rain were less than $100\ \text{mg/L}$. Total solids concentrations were independent of the test conditions. A wide range in runoff concentrations was also observed for SS, with concentrations ranging from about 1 to $3000\ \text{mg/L}$. Again, a decreasing trend of concentrations was seen with increasing rain depths, but the data scatter was larger because of the experimental factors. The dissolved solids ($<0.45\ \mu\text{m}$) concentrations ranged from about 20 to $900\ \text{mg/L}$, comprising a surprisingly large percentage of the total solids loadings. For small rain depths, dissolved solids comprised up to 90 percent of the total solids. After 10 mm of rain depth, the filterable residue concentrations were all less than about $50\ \text{mg/L}$.

Manual particle size analyses were also conducted on the suspended solids washoff samples, using a microscope with a calibrated recticle. Figures 2.2 and 2.3 are examples of particle size distributions for two tests. These plots show the percentage of the particles that were less than various sizes, by measured particle volume (assumed to be similar to weight). The plots also indicate median particle sizes of about 10 to 50 μm , depending on when the sample was obtained during the washoff tests. All of the distributions showed surprisingly similar trends of particle sizes with elapsed rain depth. The median size for the sample obtained at about 1 mm of rain was much greater than for the samples taken after more rain. The median particle sizes of material remaining on the streets after the washoff tests were also much larger than for most of the runoff samples, but were quite close to the initial samples' median particle sizes. The washoff water at the very beginning of the test rains therefore contained many more larger particles than during later portions of the rains. Also, a substantial amount of larger particles remained on the streets after the test rains. Most street runoff waters during test rains in the 5 to 15 mm depth category had median suspended solids particle sizes of about 10 to 50 μm . However, dissolved solids (less than 0.45 μm) made up most of the total solids washoff for elapsed rain depths greater than about 5 mm.

These particle size distributions indicate that the smaller particles were much more important than indicated during previous tests. As an example, the Sartor and Boyd (1972) washoff tests (rain intensities of 50 mm/h for 2 h durations) found median particle sizes of about 150 μm which were typically three to five times larger than were found during these tests. They also did not find any significant particle size distribution differences for different rain depths (or rain duration), in contrast to the Toronto tests which were conducted at more likely rain intensities (3 to 12 mm/h for 2 h).

The particulate washoff values obtained during these Toronto tests were expressed in units of grams per square meter and grams per curb-meter, concentrations (mg/L), and the percent of the total initial loading washed off during the test. Plots of accumulative washoff are shown on Figures 2.4 through 2.11. These plots show the asymptotic washoff values observed in the tests, along with the measured total street dirt loadings. The maximum asymptotic values are the "available" street dirt loadings (N_0). The measured total loadings are seen to be several times larger than these "available" loading values. As an example, the asymptotic available total solids value for the HDS (high intensity rain, dirty street, smooth street) test (Figure 2.10) was about 3g/m² while the total load on the street for this test was about 14g/m², or about five times the available load. The differences between available and total loadings for the other tests were even greater, with the total loads typically about ten times greater than the available loads. The total loading and available loading values for dissolved solids were quite close, indicating almost complete washoff of the very small particles. However, the differences between the two loading values for SS were much greater. Shielding, therefore, may not have been very important during these tests, as almost all of the smallest particles were removed, even in the presence of heavy loadings of large particles.

The actual data are shown on these figures, along with the fitted Sartor and Boyd exponential washoff equations. In many cases, the fitted washoff equations greatly over-predicted suspended solids washoff during the very small rains (usually less than 1 to 3 mm in depth). In all cases, the fitted washoff equations described suspended solids washoff very well for rains greater than about 10 mm in depth.

Table 2.5 presents the equation parameters for each of the eight washoff tests for suspended solids. Pitt (1987) concluded that particulate washoff should be divided into two main categories, one for high intensity rains with dirty streets, possibly divided into categories by street texture, and the other for all other conditions. Factorial tests also found that the availability factor (the ratio of the available loading, N_0 , to the total loading) varied depending on the rain intensity and the street roughness, as indicated below:

- Low rain intensity and rough streets: 0.045
- High rain intensity and rough streets, or low rain intensity and smooth streets: 0.075
- High rain intensity and smooth streets: 0.20

Obviously, washoff was more efficient for the higher rain energy and smoother pavement tests. The worst case was for a low rain intensity and rough street, where only about 4.5% of the street dirt would be washed from the pavement. In contrast, the high rain intensities on the smooth streets were more than four times more efficient in removing the street dirt.

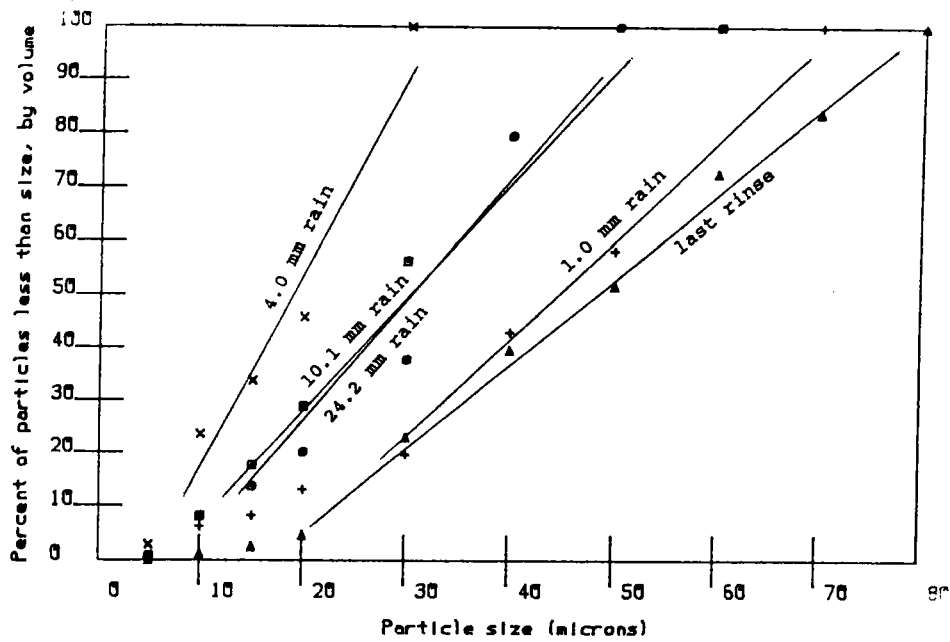


Figure 2.2 Particle size distribution of HDS test (high rain intensity, dirty, and smooth street) (Pitt 1987).

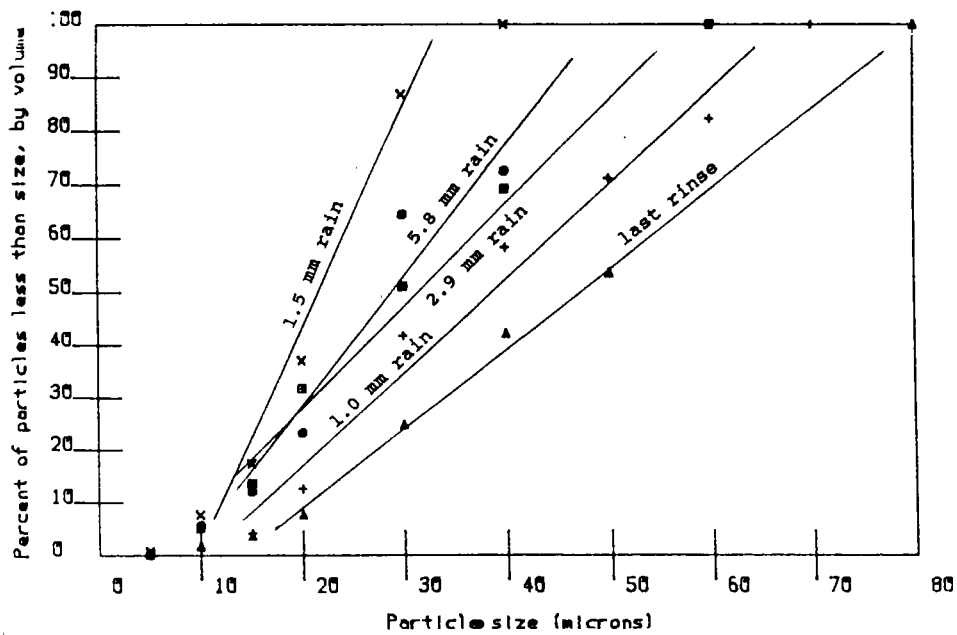


Figure 2.3 Particle size distribution for LCR test (light rain intensity, clean, and rough street) (Pitt 1987).

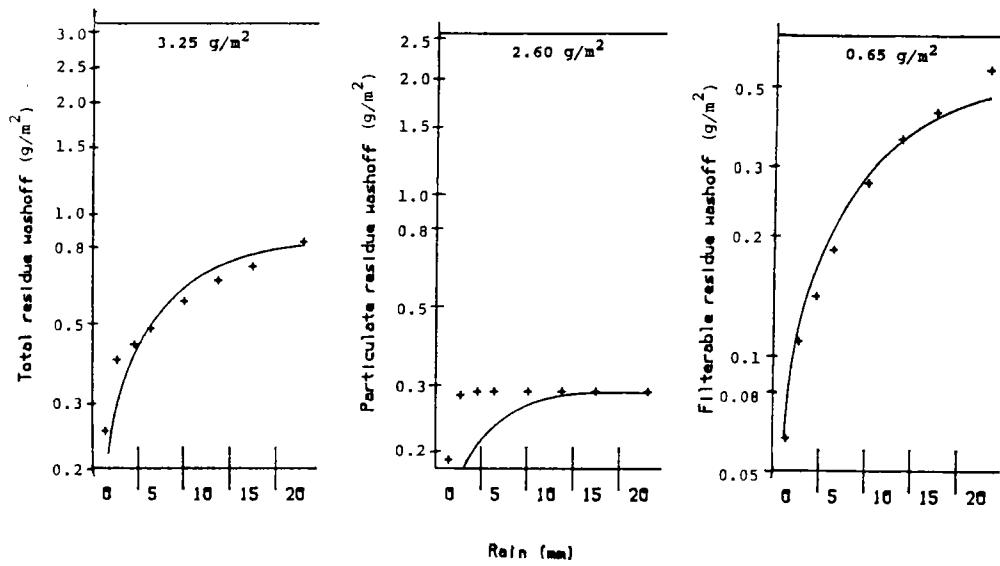


Figure 2.4 Washoff plots for HCR test (high rain intensity, clean, and rough street) (Pitt 1987).

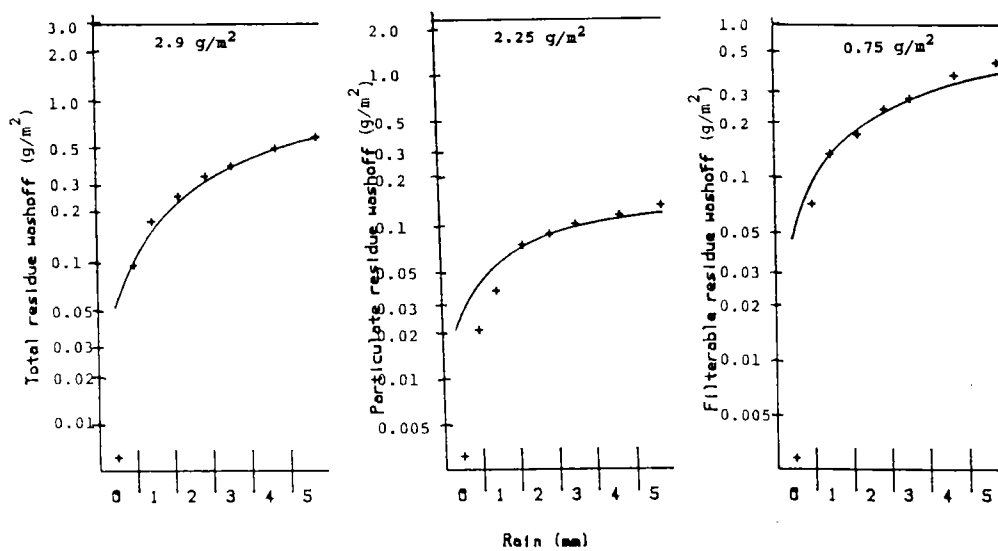


Figure 2.5 Washoff plots for LCR test (light rain intensity, clean, and rough street) (Pitt 1987).

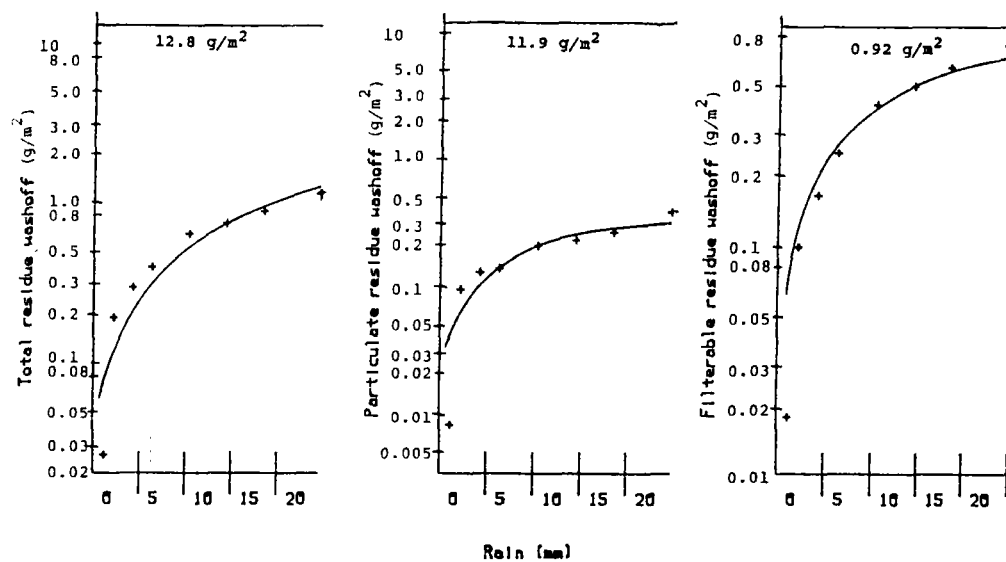


Figure 2.6 Washoff plots for HDR test (high rain intensity, dirty, and rough street) (Pitt 1987).

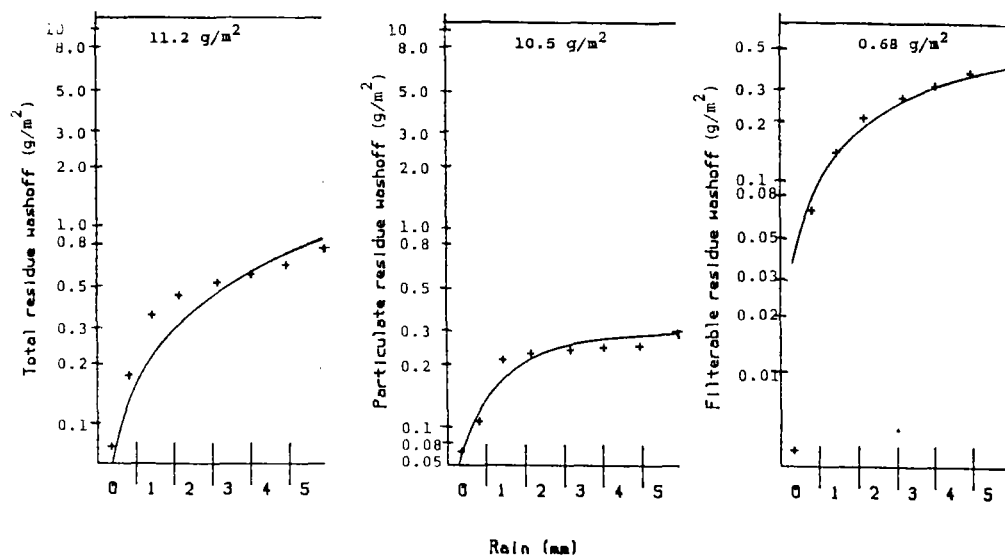


Figure 2.7 Washoff plots for LDR test (light rain intensity, dirty, and rough street) (Pitt 1987).

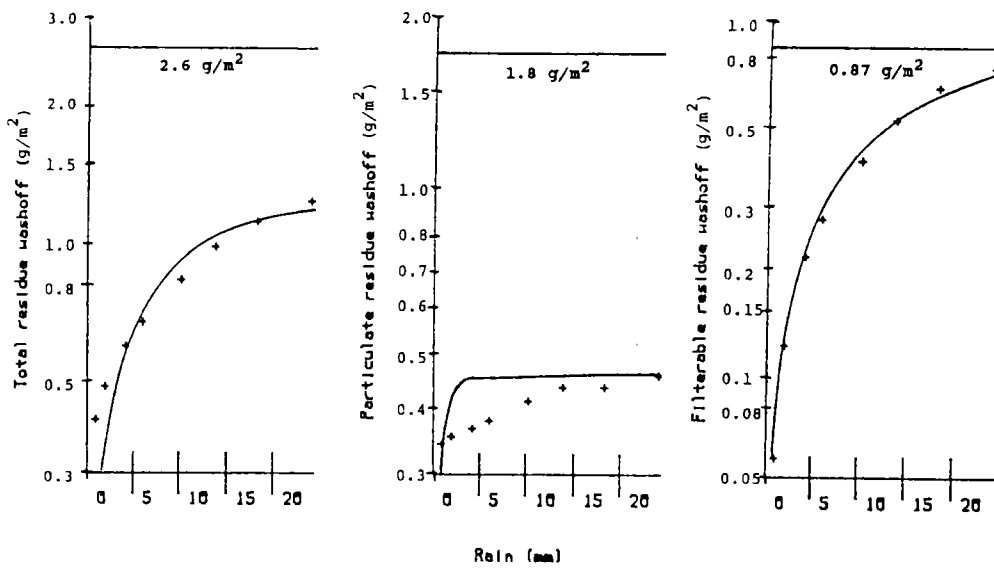


Figure 2.8 Washoff plots for HCS test (high rain intensity, clean, and smooth street) (Pitt 1987).

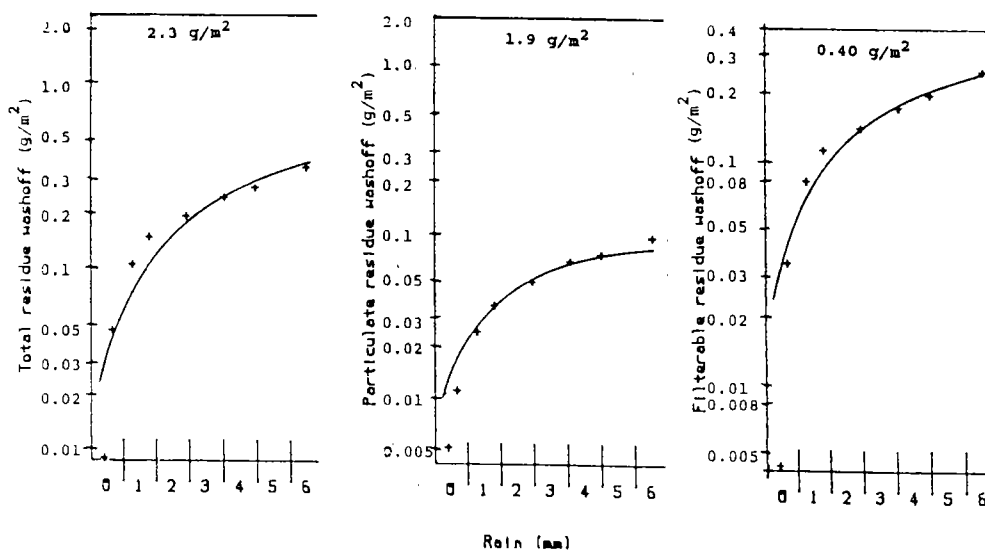


Figure 2.9 Washoff plots for LCS test (light rain intensity, clean, and smooth street) (Pitt 1987).

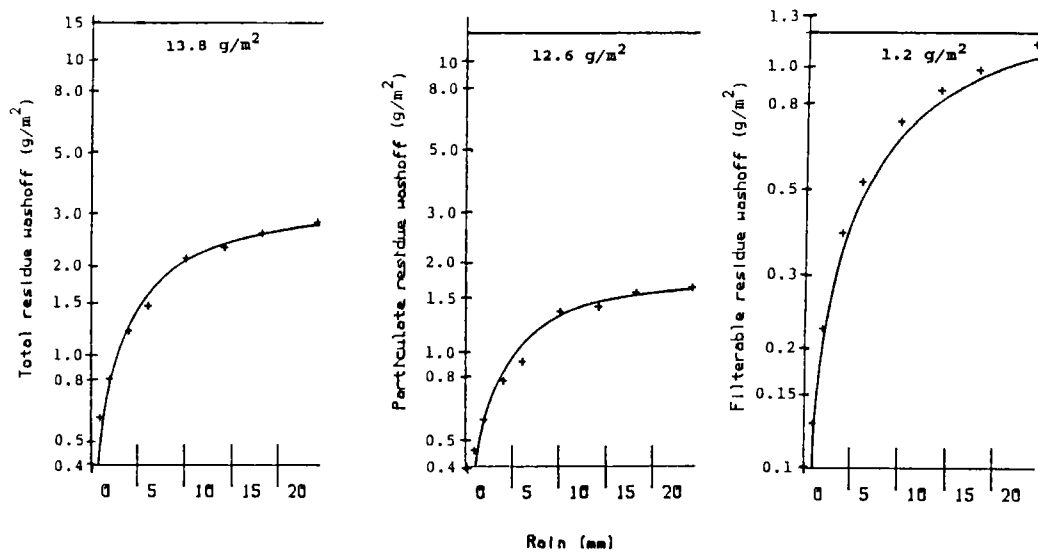


Figure 2.10 Washoff plots for HDS test (high rain intensity, dirty, and smooth street) (Pitt 1987).

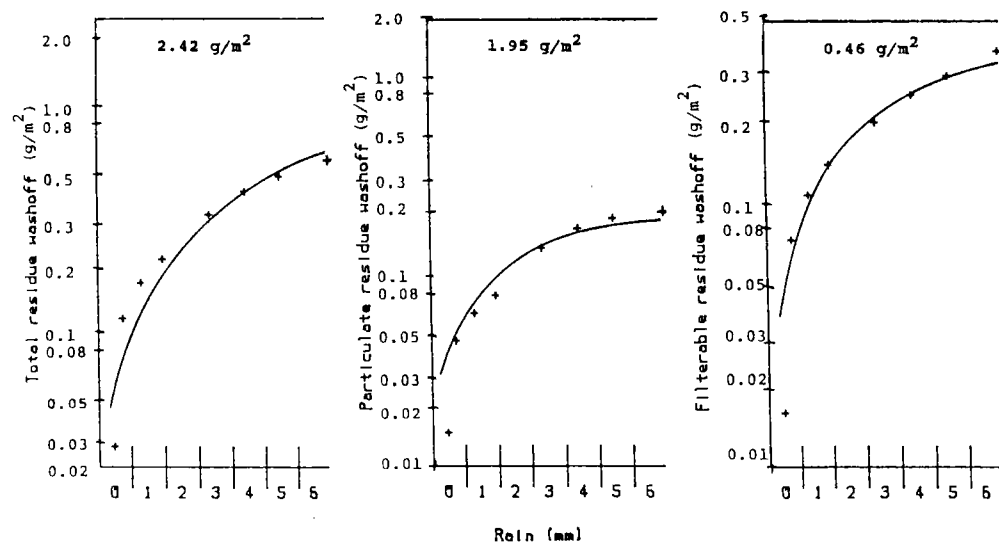


Figure 2.11 Washoff plots for LCS replicate test (light rain intensity, clean, and smooth street) (Pitt 1987).

Table 2.5 Suspended Solids Washoff Coefficients (Pitt 1987)¹

Test condition code	Rain intensity category	Street dirt loading category	Street texture category	Calculated k	Standard error for k	Ratio of available load to total initial load
HCR	high	clean	rough	0.832	0.064	0.11
LCR	low	clean	rough	0.344	0.038	0.061
HDR	high	dirty	rough	0.077	0.008	0.032
LDR	low	dirty	rough	0.619	0.052	0.028
HCS	high	clean	smooth	1.007	0.321	0.26
LCS	low	clean	smooth	0.302	0.024	0.047
HDS	high	dirty	smooth	0.167	0.015	0.13
L(D)CS	low	(actually clean)	smooth	0.335	0.031	0.11

¹Note:

$$N = N_0 e^{-kR}$$

where: N = residual street dirt load, after the rain (lb/curb-mile)
 N_0 = initial street dirt load
R = rain depth (inches)
k = proportionality constant (1/hr)

Observed Particle Size Distributions in Stormwater

The particle size distributions of stormwater greatly affect the ability of most controls in reducing pollutant discharges. This research has included particle size analyses of 121 stormwater samples from three states that were not affected by stormwater controls (southern New Jersey as part of the inlet tests; Birmingham, Alabama as part of the MCTT pilot-scale tests; and in Milwaukee and Minocqua, Wisconsin, as part of the MCTT full-scale tests). These samples represented stormwater entering the stormwater controls being tested. Particle sizes were measured using a Coulter Multi-Sizer IIe and verified with microscopic, sieve, and settling column tests. Figures 2.12 through 2.14 are grouped box and whisker plots showing the particle sizes (in μm) corresponding to the 10th, 50th (median) and 90th percentiles of the cumulative distributions. If 90 percent control of SS was desired, then the particles larger than the 90th percentile would have to be removed, for example. The median particle sizes ranged from 0.6 to 38 μm and averaged 14 μm . The 90th percentile sizes ranged from 0.5 to 11 μm and averaged 3 μm . These particle sizes are all substantially smaller than have been typically assumed for stormwater. In all cases, the New Jersey samples had the smallest particle sizes, followed by Wisconsin, and then Birmingham, AL, which had the largest particles. The New Jersey samples were obtained from gutter flows in a residential semi-xeroscaped neighborhood, the Wisconsin samples were obtained from several source areas, including parking areas and gutter flows mostly from residential, but from some commercial areas, and the Birmingham samples were collected from a long-term parking area.

Atmospheric Sources of Urban Runoff Pollutants

Atmospheric processes affecting urban runoff pollutants include dry dustfall and precipitation quality. These have been monitored in many urban and rural areas. In many instances, however, the samples were combined as a bulk precipitation sample before processing. Automatic precipitation sampling equipment can distinguish between dry periods of fallout and precipitation. These devices cover and uncover appropriate collection jars exposed to the atmosphere. Much of this information has been collected as part of the Nationwide Urban Runoff Program (NURP) and the Atmospheric Deposition Program, both sponsored by the U.S. Environmental Protection Agency (EPA 1983a).

One must be very careful in interpreting this information, however, because of the ability of many polluted dust and dirt particles to be resuspended and then redeposited within the urban area. In many cases, the measured atmospheric deposition measurements include material that was previously residing and measured in other urban runoff pollutant source areas. Also, only small amounts of the atmospheric deposition material would directly contribute to runoff. Rain is subjected to infiltration and the dry fall particulates are likely mostly incorporated with surface soils and

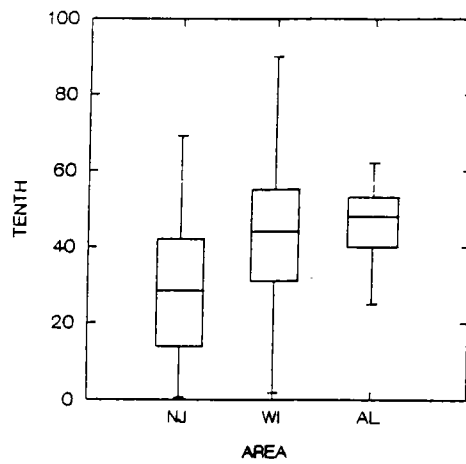


Figure 2.12 Tenth percentile particle sizes for stormwater inlet flows.

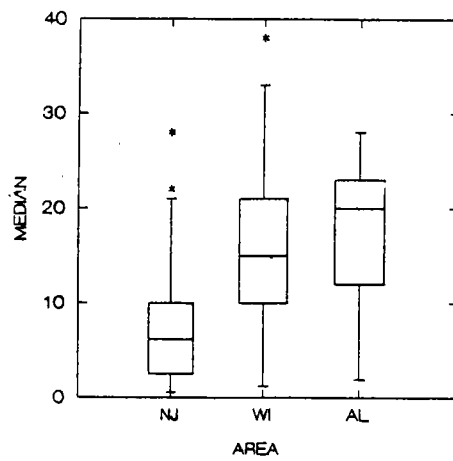


Figure 2.13 Fiftieth percentile particle sizes for stormwater inlet flows.

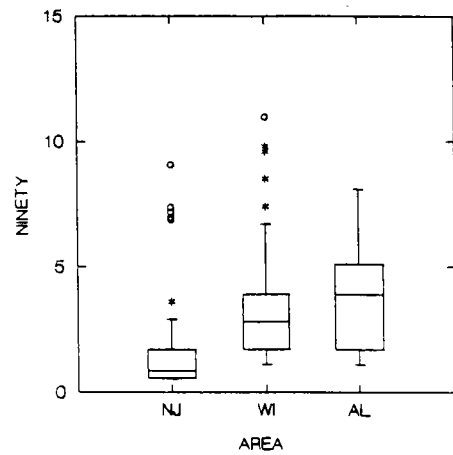


Figure 2.14 Ninetieth percentile particle sizes for stormwater inlet flows.

only small fractions are then eroded during rains. Therefore, mass balances and determinations of urban runoff deposition and accumulation from different source areas can be highly misleading, unless transfer of material between source areas and the effective yield of this material to the receiving water is considered. Depending on the land use, relatively little of the dustfall in urban areas likely contributes to stormwater discharges.

Dustfall and precipitation affect all of the major urban runoff source areas in an urban area. Dustfall, however, is typically not a major pollutant source but fugitive dust is mostly a mechanism for pollutant transport, as previously mentioned. Most of the dustfall monitored in an urban area is resuspended particulate matter from street surfaces or wind erosion products from vacant areas (Pitt 1979). Point source pollutant emissions can also significantly contribute to dustfall pollution, especially in industrial areas. Transported dust from regional agricultural activities can also significantly affect urban stormwater.

Wind transported materials are commonly called "dustfall." Dustfall includes sedimentation, coagulation with subsequent sedimentation and impaction. Dustfall is normally measured by collecting dry samples, excluding rainfall and snowfall. If rainout and washout are included, one has a measure of total atmospheric fallout. This total atmospheric fallout is sometimes called "bulk precipitation." Rainout removes contaminants from the atmosphere by condensation processes in clouds, while washout is the removal of contaminants by the falling rain. Therefore, precipitation can include natural contamination associated with condensation nuclei in addition to collecting atmospheric pollutants as the rain or snow falls. In some areas, the contaminant contribution by dry deposition is small, compared to the contribution by precipitation (Malmquist 1978). However, in heavily urbanized areas, dustfall can contribute more of an annual load than the wet precipitation, especially when dustfall includes resuspended materials.

Table 2.6 summarizes rain quality reported by several researchers. As expected, the non-urban area rain quality can be substantially better than urban rain quality. Many of the important heavy metals, however, have not been detected in rain in many areas of the country. The most important heavy metals found in rain have been lead and zinc, both being present in rain in concentrations from about 20 up to several hundred $\mu\text{g/L}$. It is expected that more recent lead rainfall concentrations would be substantially less, reflecting the decreased use of leaded gasoline since these measurements were taken. Iron is also present in relatively high concentrations in rain (about 30 to 40 $\mu\text{g/L}$).

Table 2.6. Summary of Reported Rain Quality

	Rural- Northwest (Quilayute, WA) ¹	Rural- Northeast (Lake George, NY) ¹	Urban- Northwest (Lodi, NJ) ²	Urban- Midwest (Cincinnati, OH) ³	Other Urban ³	Continental Avg. (32 locations) ¹
Suspended solids, mg/L				13		
Volatile suspended solids, mg/L				3.8		
Inorganic nitrogen, mg/L as N				0.69		
Ammonia, mg/L as N					0.7	
Nitrates, mg/L as N					0.3	
Total phosphates, mg/L as P					<0.1	
Ortho phosphate, mg/L as P				0.24		
Scandium, $\mu\text{g/L}$	<0.002	nd				nd
Titanium, $\mu\text{g/L}$	nd	nd				nd
Vanadium, $\mu\text{g/L}$	nd	nd				nd
Chromium, $\mu\text{g/L}$	<2	nd	1			nd
Manganese, $\mu\text{g/L}$	2.6	3.4				12
Iron, $\mu\text{g/L}$	32	35				
Cobalt, $\mu\text{g/L}$	0.04	nd				nd
Nickel, $\mu\text{g/L}$	nd	nd	3			43
Copper, $\mu\text{g/L}$	3.1	8.2	6			21
Zinc, $\mu\text{g/L}$	20	30	44			107
Lead, $\mu\text{g/L}$			45			

¹ Rubin 1976

² Wilbur and Hunter 1980

³ Manning, *et al.* 1976

The concentrations of various urban runoff pollutants associated with dry dustfall are summarized in Table 2.7. Urban, rural and oceanic dry dustfall samples contained more than 5,000 mg iron/kg total solids. Zinc and lead were present in high concentrations. These constituents can have concentrations of up to several thousand mg of pollutant per kg of dry dustfall. Spring, *et al.* (1978) monitored dry dustfall near a major freeway in Los Angeles. Based on a series of samples collected over several months, they found that lead concentrations on and near the freeway can be about 3,000 mg/kg, but as low as about 500 mg/kg 150 m (500 feet) away. In contrast, the chromium concentrations of the dustfall did not vary substantially between the two locations and approached oceanic dustfall chromium concentrations.

Table 2.7. Atmosphere Dustfall Quality

Constituent, (mg constituent/kg total solids)	Urban ¹	Rural/suburban ¹	Oceanic ¹	Near freeway (LA) ²	500' from freeway (LA) ²
pH				4.3	4.7
Phosphate-Phosphorous				1200	1600
Nitrate-Nitrogen, µg/L				5800	9000
Scandium, µg/L	5	3	4		
Titanium, µg/L	380	810	2700		
Vanadium, µg/L	480	140	18		
Chromium, µg/L	190	270	38	34	45
Manganese, µg/L	6700	1400	1800		
Iron, µg/L	24000	5400	21000		
Cobalt, µg/L	48	27	8		
Nickel, µg/L	950	1400			
Copper, µg/L	1900	2700	4500		
Zinc, µg/L	6700	1400	230		
Lead, µg/L				2800	550

¹ Summarized by Rubin 1976

² Spring 1978

Much of the monitored atmospheric dustfall and precipitation would not reach the urban runoff receiving waters. The percentage of dry atmospheric deposition retained in a rural watershed was extensively monitored and modeled in Oakridge, TN (Barkdoll, *et al.* 1977). They found that about 98 percent of the lead in dry atmospheric deposits was retained in the watershed, along with about 95 percent of the cadmium, 85 percent of the copper, 60 percent of the chromium and magnesium and 75 percent of the zinc and mercury. Therefore, if the dry deposition rates were added directly to the yields from other urban runoff pollutant sources, the resultant urban runoff loads would be very much overestimated.

Tables 2.8 and 2.9 report bulk precipitation (dry dustfall plus rainfall) quality and deposition rates as reported by several researchers. For the Knoxville, KY, area (Betson 1978), chemical oxygen demand (COD) was found to be the largest component in the bulk precipitation monitored, followed by filterable residue and nonfilterable residue. Table 2.9 also presents the total watershed bulk precipitation, as the percentage of the total stream flow output for the three Knoxville watersheds studies. This shows that almost all of the pollutants presented in the urban runoff streamflow outputs could easily be accounted for by bulk precipitation deposition alone. Betson concluded that bulk precipitation is an important component for some of the constituents in urban runoff, but the transport and resuspension of particulates from other areas in the watershed are overriding factors.

Rubin (1976) stated that resuspended urban particulates are returned to the earth's surface and waters in four main ways: gravitational settling, impaction, precipitation and washout. Gravitational settling, as dry deposition, returns most of the particles. This not only involves the settling of relatively large fly ash and soil particles, but also the settling of smaller particles that collide and coagulate. Rubin stated that particles that are less than 0.1 µm in diameter move randomly in the air and collide often with other particles. These small particles can grow rapidly by this coagulation process. These small particles would soon be totally depleted in the air if they were not constantly replenished. Particles in the 0.1 to 1.0 µm range are also removed primarily by coagulation. These larger particles grow more slowly than the smaller particles because they move less rapidly in the air, are somewhat less numerous and, therefore, collide less often with other particles. Particles with diameters larger than 1 µm have appreciable

Table 2.8. Bulk Precipitation Quality

Constituent (all units mg/L except pH)	Urban (average of Knoxville St. Louis & Germany) ¹	Rural (Tennessee) ¹	Urban (Guteburg, Sweden) ²
Calcium	3.4	0.4	
Magnesium	0.6	0.1	
Sodium	1.2	0.3	
Chlorine	2.5	0.2	
Sulfate	8.0	8.4	
pH	5.0	4.9	
Organic Nitrogen	2.5	1.2	
Ammonia Nitrogen	0.4	0.4	2
Nitrite plus Nitrate-N	0.5	0.4	1
Total phosphate	1.1	0.8	0.03
Potassium	1.8	0.6	
Total iron	0.8	0.7	
Manganese	0.03	0.05	
Lead	0.03	0.01	0.05
Mercury	0.01	0.0002	
Nonfilterable residue	16		
Chemical Oxygen Demand	65		10
Zinc			0.08
Copper			0.02

¹ Betson 1978

² Malmquist 1978

Table 2.9. Urban Bulk Precipitation Deposition Rates (Source: Betson 1978)^a

Rank	Constituent	Average Bulk Deposition Rate (kg/ha/yr)	Average Bulk Prec. as a % of Total Streamflow Output
1	Chemical oxygen demand	530	490
2	Filterable residue	310	60
3	Nonfilterable residue	170	120
4	Alkalinity	150	120
5	Sulfate	96	470
6	Chloride	47	360
7	Calcium	38	170
8	Potassium	21	310
9	Organic nitrogen	17	490
10	Sodium	15	270
11	Silica	11	130
12	Magnesium	9	180
13	Total Phosphate	9	130
14	Nitrite and Nitrate-N	5.7	360
15	Soluble phosphate	5.3	170
16	Ammonia Nitrogen	3.2	1,100
17	Total Iron	1.9	47
18	Fluoride	1.8	300
19	Lead	1.1	650
20	Manganese	0.54	270
21	Arsenic	0.07	720
22	Mercury	0.008	250

^a Average for 3 Knoxville, KY, watersheds.

settling velocities. Those particles about 10 μm in diameter can settle rapidly, although they can be kept airborne for extended periods of time and for long distances by atmospheric turbulence.

The second important particulate removal process from the atmosphere is impaction. Impaction of particles near the earth's surface can occur on vegetation, rocks and building surfaces. The third form of particulate removal from the atmosphere is precipitation, in the form of rain and snow. This is caused by the rainout process where the particulates are removed in the cloud-forming process. The fourth important removal process is washout of the particulates below the clouds during the precipitation event. Therefore, it is easy to see that re-entrained particles (especially from street surfaces, other paved surfaces, rooftops and from soil erosion) in urban areas can be readily redeposited through these various processes, either close to the points of origin or at some distance away.

Pitt (1979) monitored airborne concentrations of particulates near typical urban roads. He found that on a number basis, the downwind roadside particulate concentrations were about 10 percent greater than upwind conditions. About 80 percent of the concentration increases, by number, were associated with particles in the 0.5 to 1.0 μm size range. However, about 90 percent of the particle concentration increases by weight were associated with particles greater than 10 μm . He found that the rate of particulate resuspension from street surfaces increases when the streets are dirty (cleaned infrequently) and varied widely for different street and traffic conditions. The resuspension rates were calculated based upon observed long-term accumulation conditions on street surfaces for many different study area conditions, and varied from about 0.30 to 3.6 kg per curb-km (1 to 12 lb per curb-mile) of street per day.

Murphy (1975) described a Chicago study where airborne particulate material within the city was microscopically examined, along with street surface particulates. The particulates from both of these areas were found to be similar (mostly limestone and quartz) indicating that the airborne particulates were most likely resuspended street surface particulates, or were from the same source. PEDCo (1977) found that the re-entrained portion of the traffic-related particulate emissions (by weight) is an order of magnitude greater than the direct emissions accounted for by vehicle exhaust and tire wear. They also found that particulate resuspensions from a street are directly proportional to the traffic volume and that the suspended particulate concentrations near the streets are associated with relatively large particle sizes. The medium particle size found, by weight, was about 15 μm , with about 22 percent of the particulates occurring at sizes greater than 30 μm . These relatively large particle sizes resulted in substantial particulate fallout near the road. They found that about 15 percent of the resuspended particulates fall out at 10 m, 25 percent at 20 m, and 35 percent at 30 m from the street (by weight). In a similar study Cowherd, *et al.* (1977) reported a wind erosion threshold value of about 5.8 m/s (13 mph). At this wind speed, or greater, significant dust and dirt losses from the road surface could result, even in the absence of traffic-induced turbulence. Rolfe and Reinbold (1977) also found that most of the particulate lead from automobile emissions settled out within 100 m of roads. However, the automobile lead does widely disperse over a large area. They found, through multi-elemental analyses, that the settled outdoor dust collected at or near the curb was contaminated by automobile activity and originated from the streets.

Source Area Sheetflow and Particulate Quality

This chapter section summarizes the source area sheetflow and particulate quality data obtained from several studies conducted in California, Washington, Nevada, Wisconsin, Illinois, Ontario, Colorado, New Hampshire, and New York since 1979. Most of the data obtained was for street dirt chemical quality, but a relatively large amount of parking and roof runoff quality data has also been obtained. Only a few of these studies evaluated a broad range of source areas or land uses.

Source Area Particulate Quality

Particulate potency factors (usually expressed as mg pollutant/kg dry particulate residue) for many samples are summarized on Tables 2.10 and 2.11. These data can help recognize critical source areas, but care must be taken if they are used for predicting runoff quality because of likely differential effects due to washoff and erosion from the different source areas. These data show the variations in chemical quality between particles from different land uses and source areas. Typically, the potency factors increase as the use of an area becomes more intensive, but the variations are slight for different locations throughout the country. Increasing concentrations of heavy metals with decreasing particle sizes was also evident, for those studies that included particle size information. Only the quality

of the smallest particle sizes are shown on these tables because they best represent the particles that are removed during rains.

Warm Weather Sheetflow Quality

Sheetflow data, collected during actual rain, are probably more representative of runoff conditions than the previously presented dry particulate quality data because they are not further modified by washoff mechanisms. These data, in conjunction with source area flow quantity information, can be used to predict outfall conditions and the magnitude of the relative sources of critical pollutants. Tables 2.12 through 2.15 summarize warm weather sheetflow observations, separated by source area type and land use, from many locations. The major source area categories are listed below:

- roofs
- paved parking areas
- paved storage areas
- unpaved parking and storage areas
- paved driveways
- unpaved driveways
- dirt walks
- paved sidewalks
- streets
- landscaped areas
- undeveloped areas
- freeway paved lanes and shoulders

Toronto warm weather sheetflow water quality data were plotted against the rain volume that had occurred before the samples were collected to identify any possible trends of concentrations with rain volume (Pitt and McLean 1986). The street runoff data obtained during the special washoff tests reported earlier were also compared with the street sheetflow data obtained during the actual rain events (Pitt 1987). These data observations showed definite trends of solids concentrations versus rain volume for most of the source area categories. Sheetflows from all pervious areas combined had the highest total solids concentrations from any source category, for all rain events. Other paved areas (besides streets) had total solids concentrations similar to runoff from smooth industrial streets. The concentrations of total solids in roof runoff were almost constant for all rain events, being slightly lower for small rains than for large rains. No other pollutant, besides SS, had observed trends of concentrations with rain depths for the samples collected in Toronto. Lead and zinc concentrations were highest in sheetflows from paved parking areas and streets, with some high zinc concentrations also found in roof drainage samples. 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. High concentrations of dissolved chromium, dissolved copper, and dissolved zinc in a Toronto industrial outfall during both wet and dry weather could not be explained by wet weather sheetflow observations (Pitt and McLean 1986). As an example, very few detectable chromium observations were obtained in any of the more than 100 surface sheetflow samples analyzed. Similarly, 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 industrial wastes, possibly originating from metal plating operations, were the cause of these high concentrations of dissolved metals at the outfall and that some sanitary sewage was entering the storm drainage system.

Table 2.15 summarizes the very little filterable pollutant concentration data available, before this EPA project, for different source areas. Most of the available data is for residential roofs and commercial parking lots.

**Table 2.10 Summary of Observed Street Dirt Chemical Quality (means)
(mg constituent/kg solids)**

	Residential	Commercial	Industrial
P	620 (4) 540 (6) 1100 (5) 710 (1) 810 (3)	400 (6) 1500 (5) 910 (1)	670 (4)
TKN	1030 (4) 3000 (6) 290 (5) 2630 (3) 3000 (2)	1100 (6) 340 (5) 4300 (2)	560 (4)
COD	100,000 (4) 150,000 (6) 180,000 (5) 280,000 (1) 180,000 (3) 170,000 (2)	110,000 (6) 250,000 (5) 340,000 (1) 210,000 (2)	65,000 (4)
Cu	162 (4) 110 (6) 420 (2)	130 (6) 220 (2)	360 (4)
Pb	1010 (4) 1800 (6) 530 (5) 1200 (1) 1650 (3) 3500 (2)	3500 (6) 2600 (5) 2400 (1) 7500 (2)	900 (4)
Zn	460 (4) 260 (5) 325 (3) 680 (2)	750 (5) 1200 (2)	500 (4)
Cd	<3 (5) 4 (2)	5 (5) 5 (2)	
Cr	42 (4) 31 (5) 170 (2)	65 (5) 180 (2)	70 (4)

References; location; particle size described:

- (1) Bannerman, *et al.* 1983 (Milwaukee, WI) <31 μ m
- (2) Pitt 1979 (San Jose, CA) <45 μ m
- (3) Pitt 1985 (Bellevue, WA) <63 μ m
- (4) Pitt and McLean 1986 (Toronto, Ontario) <125 μ m
- (5) Pitt and Sutherland 1982 (Reno/Sparks, NV) <63 μ m
- (6) Terstrip, *et al.* 1982 (Champaign/Urbana, IL) >63 μ m

Table 2.11 Summary of Observed Particulate Quality for Other Source Areas (means for <125 µm particles) (mg constituent/kg solids)

	P	TKN	COD	Cu	Pb	Zn	Cr
Residential/Commercial Land Uses							
Roofs	1500	5700	240,000	130	980	1900	77
Paved parking	600	790	78,000	145	630	420	47
Unpaved driveways	400	850	50,000	45	160	170	20
Paved driveways	550	2750	250,000	170	900	800	70
Dirt footpath	360	760	25,000	15	38	50	25
Paved sidewalk	1100	3620	146,000	44	1200	430	32
Garden soil	1300	1950	70,000	30	50	120	35
Road shoulder	870	720	35,000	35	230	120	25
Industrial Land Uses							
Paved parking	770	1060	130,000	1110	650	930	98
Unpaved parking/storage	620	700	110,000	1120	2050	1120	62
Paved footpath	890	1900	120,000	280	460	1300	63
Bare ground	700	1700	70,000	91	135	270	38

Source: Pitt and McLean 1986 (Toronto, Ontario)

Table 2.12 Sheetflow Quality Summary for Other Source Areas (mean concentration and reference)

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
<u>Total Solids (mg/L)</u>									
Residential:	58 (5) 64 (1) 18 (4)	1790 (5)	73 (5)		510 (5)		1240 (5)	49 (5)	325 (5) 235 (4)
Commercial:	95 (1) 190 (4)	340 (2) 240 (1) 102 (7)							325 (4)
Industrial:	113 (5)	490 (5)	270 (5)	1250 (5)	506 (5)	5620 (5)		580 (5)	1800 (5)
<u>Suspended Solids (mg/L)</u>									
Residential:	22 (1) 13 (5)	1660 (5)	41 (5)		440 (5)		810 (5)	20 (5)	242 (5)
Commercial:		270 (2) 65 (1) 41 (7)							242 (5)
Industrial:	4 (5)	306 (5)	202 (5)	730 (5)	373 (5)	4670 (5)		434 (5)	1300 (5)
<u>Dissolved Solids (mg/L)</u>									
Residential:	42 (10) 5 (5)	130 (5)	32 (5)		70 (5)		430 (5)	29 (5)	83 (5) 83 (4)
Commercial:		70 (2) 175 (1) 61 (7)							83 (5)
Industrial:	109 (5)	184 (5)	68 (5)	520 (5)	133 (5)	950 (5)		146 (5)	500 (5)

Table 2.12 Sheetflow Quality Summary for Other Source Areas (mean concentration and reference) (Continued)

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
<u>BOD₅ (mg/L)</u>									
Residential:	3 (4)	22 (4)							13 (4)
Commercial:	7 (4)	11 (1) 4 (8)							
<u>COD (mg/L)</u>									
Residential:	46 (5) 27 (1) 20 (4)	173 (5)	22 (5)		178 (5)			62 (5)	174 (5) 170 (4)
Commercial:	130 (4)	190 (2) 180 (4) 53 (1) 57 (8)							174 (5)
Industrial:	55 (5)	180 (5)	82 (5)	247 (5)	138 (5)	418 (5)		98 (5)	322 (5)
<u>Total Phosphorus (mg/L)</u>									
Residential:	0.03 (5) 0.05 (1) 0.1 (4)				0.36 (5)		0.20 (5)	0.80 (5)	0.62 (5) 0.31 (4)
Commercial:	0.03 (4) 0.07 (4)	0.16 (1) 0.15 (7) 0.73 (5) 0.9 (2) 0.5 (4)							0.62 (5)
Industrial:	<0.06 (5)	2.3 (5)	0.7 (5)	1.0 (5)	0.9 (5)	3.0 (5)		0.82 (5)	1.6 (5)

Table 2.12 Sheetflow Quality Summary for Other Source Areas (mean concentration and reference) (Continued)

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
<u>Total Phosphate (mg/L)</u>									
Residential:	<0.04 (5) 0.08 (4)				<0.2 (5)		0.66 (5)	0.64 (5)	0.07 (5) 0.12 (4)
Commercial:	0.02 (4)	0.03 (5) 0.3 (2) 0.5 (4) 0.04 (7) 0.22 (8)	<0.02 (5)						0.07 (5)
Industrial:	<0.02 (5)	0.6 (5)	0.06 (5)	0.13 (5)	<0.02 (5)	0.10 (5)		0.03 (5)	0.15 (5)
<u>TKN (mg/L)</u>									
Residential:	1.1 (5) 0.71 (4)				3.1 (5)		1.3 (5)	1.1 (5)	2.4 (5) 2.4 (4)
Commercial:	4.4 (4)	3.8 (5) 4.1 (2) 1.5 (4) 1.0 (1) 0.8 (8)							2.4 (5)
Industrial:	1.7 (5)	2.9 (5)	3.5 (5)	2.7 (5)	5.7 (5)	7.5 (5)		4.7 (5)	5.7 (5)
<u>Ammonia (mg/L)</u>									
Residential:	0.1 (5) 0.9 (1) 0.5 (4)	0.1 (5)	0.3 (5)		<0.1 (5)		0.5 (5)	0.3 (5)	<0.1 (5) 0.42 (4)
Commercial:	1.1 (4)	1.4 (2) 0.35 (4) 0.38 (1)							<0.1 (5)
Industrial:	0.4 (5)	0.3 (5)	0.3 (5)	<0.1 (5)	<0.1 (5)	<0.1 (5)		<0.1 (5)	<0.1 (5)

Table 2.12 Sheetflow Quality Summary for Other Source Areas (mean concentration and reference) (Continued)

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
<u>Phenols (mg/L)</u>									
Residential:	2.4 (5)	12.2 (5)	30.0 (5)		9.7 (5)		<0.4 (5)	8.6 (5)	6.2 (5)
Industrial:	1.2 (5)	9.4 (5)	2.6 (5)	8.7 (5)	7.0 (5)	7.4 (5)		8.7 (5)	24 (7)
<u>Aluminum (µg/L)</u>									
Residential:	0.4 (5)	3.2 (5)	0.38 (5)		5.3 (5)		<0.03 (5)	0.5 (5)	1.5 (5)
Industrial:	<0.2 (5)	3.5 (5)	3.1 (5)	9.2 (5)	3.4 (5)	41 (5)		1.2 (5)	14 (5)
<u>Cadmium (µg/L)</u>									
Residential:	<4 (5) 0.6 (1)	2 (5)	<5 (5)		5 (5)		<1 (5)	<4 (5)	<5 (5)
Commercial:		5.1 (7) 0.6 (8)							<5 (5)
Industrial:	<4 (5)	<4 (5)	<4 (5)	<4 (5)	<4 (5)	<4 (5)		<4 (5)	<4 (5)
<u>Chromium (µg/L)</u>									
Residential:	<60 (5) <5 (4)	20 (5) 71 (4)	<10 (5)		<60 (5)		<10 (5)	<60 (5)	<60 (5) 49 (4)
Commercial:	<5 (4)	19 (7) 12 (8)							<60 (5)
Industrial:	<60 (5)	<60 (5)	<60 (5)	<60 (5)	<60 (5)	70 (5)		<60 (5)	<60 (5)

Table 2.12 Sheetflow Quality Summary for Other Source Areas (mean concentration and reference) (Continued)

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
<u>Copper (µg/L)</u>									
Residential:	10 (5) <5 (4)	100 (5)	20 (5)		210 (5)		20 (5)	20 (5)	40 (5) 30 (4)
Commercial:	110 (4)	40 (2) 46 (4) 110 (7)							40 (5)
Industrial:	<20 (5)	480 (5)	260 (5)	120 (5)	40 (5)	140 (5)		30 (5)	220 (5)
<u>Lead (µg/L)</u>									
Residential:	<40 (5) 30 (3) 48 (1) 17 (4)	250 (5)	760 (5)		1400 (5)		30 (5)	80 (5)	180 (5) 670 (4)
Commercial:	19 (4) 30 (1)	200 (2) 350 (3) 1090 (4) 146 (1) 255 (7) 54 (8)							180 (5)
Industrial:	<40 (5)	230 (5)	280 (5)	210 (5)	260 (5)	340 (5)		<40 (5)	560 (5)

Table 2.12 Sheetflow Quality Summary for Other Source Areas (mean concentration and reference) (Continued)

Pollutant and Land Use	Roofs	Paved Parking	Paved Storage	Unpaved Parking/Storage	Paved Driveways	Unpaved Driveways	Dirt Walks	Paved Sidewalks	Streets
<u>Zinc (µg/L)</u>									
Residential:	320 (5) 670 (1) 180 (4)	520 (5)	390 (5)		1000 (5)		40 (5)	60 (5)	180 (5) 140 (4)
Commercial:	310 (1) 80 (4)	300 (5) 230 (4) 133 (1) 490 (7)							180 (5)
Industrial:	70 (5)	640 (7)	310 (5)	410 (5)	310 (5)	690 (5)		60 (5)	910 (5)

References:

- (1) Bannerman, *et al.* 1983 (Milwaukee, WI) (NURP)
- (2) Denver Regional Council of Governments 1983 (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)

**Table 2.13 Sheetflow Quality Summary for Undeveloped Landscaped and Freeway Pavement Areas
(Mean Observed Concentrations and reference)**

Pollutants	Landscaped Areas	Undeveloped Areas	Freeway Paved Lane and Shoulder Areas
Total Solids, mg/L	388 (5)	588 (5)	340 (6)
Suspended Solids, mg/L	100 (5)	400 (2) 390 (5)	180 (6)
Dissolved Solids, mg/L	288 (5)	193 (5)	160 (6)
BOD ₅ , mg/L	3 (4)	----	10 (6)
COD, mg/L	70 (4) 26 (5)	72 (2) 54 (5)	130 (6)
Total Phosphorus, mg/L	0.42 (4) 0.56 (5)	0.40 (2) 0.68 (5)	----
Total Phosphate, mg/L	0.32 (4) 0.14 (5)	0.10 (2) 0.26 (5)	0.38 (6)
TKN, mg/L	1.32 (4) 3.6 (5)	2.9 (2) 1.8 (5)	2.5 (6)
Ammonia, mg/L	1.2 (4) 0.4 (5)	0.1 (2) <0.1 (5)	----
Phenols, µg/L	0.8 (5)	----	----
Aluminum, µg/L	1.5 (5)	11 (5)	----
Cadmium, µg/L	<3 (5)	<4 (5)	60 (6)
Chromium, µg/L	10 (4)	<60 (5)	70 (6)
Copper, µg/L	<20 (5)	40 (2) 31 (4) <20 (5)	120 (6)
Lead, µg/L	30 (3) 35 (4) <30 (5)	100 (2) 30 (3) <40 (5)	2000 (6)
Zinc, µg/L	10 (4)	100 (2) 100 (5)	460 (6)

References:

- (2) Denver Regional Council of Governments 1983 (NURP)
- (3) Pitt 1983 (Ottawa)
- (4) Pitt and Bozeman 1982 (San Jose)
- (5) Pitt and McLean 1986 (Toronto)
- (6) Shelly and Gaboury 1986 (Milwaukee)

Table 2.14 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
<u>Fecal Coliforms</u> (#/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)			
<u>Fecal Strep</u> (#/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)			
<u>Pseudo. Aerug</u> (#/100 mL)												
Residential:	30,000 (5)	1900 (5)	100 (5)		600 (5)		600 (5)		570 (5)	2100 (5)		
Industrial:	50 (5)	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) Korbringer, *et al.* 1981 and Gupta, *et al.* 1979

Table 2.15 Source Area Filterable Pollutant Concentration Summary (means)

	Residential			Commercial			Industrial		
	Total	Filterable	% Filt.	Total	Filterable	% Filt.	Total	Filterable	% Filt.
<u>Roof Runoff</u>									
Solids (mg/L)	64 58	42 45	66 (1) 77 (5)				113	110	97 (5)
Phosphorus (mg/L)	0.054	0.013	24 (1)						
Lead (µg/L)	48	4	8 (1)						
<u>Paved Parking</u>									
Solids (mg/L)				240 102 1790	175 61 138	73 (1) 60 (7) 8 (5)	490	138	28 (5)
Phosphorus (mg/L)				0.16 0.9	0.03 0.3	19 (1) 33 (2)			
TKN (mg/L)				0.77	0.48	62 (8)			
Lead (µg/L)				146 54	5 8.8	3 (1) 16 (8)			
Arsenic (µg/L)				0.38	0.095	25 (8)			
Cadmium (µg/L)				0.62	0.11	18 (8)			
Chromium (µg/L)				11.8	2.8	24 (8)			
<u>Paved Storage</u>									
Solids (mg/L)				73	32	44 (5)	270	64	24 (5)

References:

- (1) Bannerman, *et al.* 1983 (Milwaukee) (NURP)
- (2) Denver Regional Council of Governments 1983 (NURP)
- (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)

Other Pollutant Contributions to the Storm Drainage System

The detection of pentachlorophenols in the relatively few samples previously analyzed indicated important leaching from treated wood. Frequent detections of polycyclic aromatic hydrocarbons (PAHs) during the U.S. Environmental Protection Agency's Nationwide Urban Runoff Program (EPA 1983a) may possibly indicate leaching from creosote treated wood, in addition to fossil fuel combustion sources. High concentrations of copper, and some chromium and arsenic observations also indicate the potential of leaching from "CCA" (copper, chromium, and arsenic) treated wood. The significance of these leachate products in the receiving waters is currently unknown, but alternatives to these preservatives should be considered. Many cities use aluminum and concrete utility poles instead of treated wood poles. This is especially important considering that utility poles are usually located very close to the drainage system ensuring an efficient delivery of leachate products. Many homes currently use wood stains containing pentachlorophenol and other wood preservatives. Similarly, the construction of retaining walls, wood decks and playground equipment with treated wood is common. Some preservatives (especially creosote) cause direct skin irritation, besides contributing to potential problems in receiving waters. Many of these wood products are at least located some distance from the storm drainage system, allowing some improvement to surface water quality by infiltration through pervious surfaces.

Phase 1 Project Activities - Sources of Stormwater Toxicants

The first project phase of this research project included the collection and analysis of 87 urban stormwater runoff samples from a variety of source areas under different rain conditions (Table 2.16). All of the samples were analyzed in filtered (0.45 μ m filter) and non-filtered forms to enable partitioning of the toxicants into "particulate" (non-filterable) and "dissolved" (filterable) forms.

Table 2.16. Numbers of Samples Collected from each Source Area Type

Local Source Areas ^a	Residential	Commercial/ Institutional	Industrial	Mixed
Roofs	5	3	4	
Parking Areas	2	11	3	
Storage Areas	na	2	6	
Streets	1	1	4	
Loading Docks	na	na	3	
Vehicle Service Area	na	5	na	
Landscaped Areas	2	2	2	
Urban Creeks				19
Detention Ponds				12

^a All collected in Birmingham, AL.

Phase 1 - Analyses and Sampling

The samples listed in Table 2.16 were all obtained from the Birmingham, AL, area. Samples were obtained from shallow flows originating from homogeneous source areas by using several manual grab sampling procedures. For deep flows, samples were collected directly into the sample bottles. For shallow flows, a peristaltic hand operated vacuum pump created a small vacuum in the sample bottle which then gently drew the sample directly into the container through a Teflon™ tube. About one liter of sample was needed, split into two containers: one 500 mL glass bottle with Teflon™ lined lid was used for the organic and toxicity analyses, and another 500 mL polyethylene bottle was used for the metal and other analyses.

An important aspect of the first phase of this research was to evaluate the effects of different land uses and source areas, plus the effects of rain characteristics, on sample toxicant concentrations. Therefore, careful records were obtained of the amount of rain and the rain intensity that occurred before the samples were obtained. Antecedent dry period data were also obtained to compare with the chemical data in a series of statistical tests.

All samples were handled, preserved, and analyzed according to accepted protocols (EPA 1982 and 1983b). The organic pollutants were analyzed using two gas chromatographs, one with a mass selective detector (GC/MSD) and another with an electron capture detector (GC/ECD). The pesticides were analyzed according to EPA method 505, while the base neutral compounds were analyzed according to EPA method 625 (but only using 100 mL samples). The pesticides were analyzed on a Perkin Elmer Sigma 300 GC/ECD using a J&W DB-1 capillary column (30m by 0.32 mm ID with a 1 µm film thickness). The base neutrals were analyzed on a Hewlett Packard 5890 GC with a 5970 MSD using a Supelco DB-5 capillary column (30m by 0.25 mm ID with a 0.2 µm film thickness). Table 2.17 lists the organic toxicants that were analyzed.

Table 2.17. List of Toxic Pollutants Analyzed in Samples

Pesticides DL = 0.3 µg/L	Phthalate Esters DL = 0.5 µg/L	Polynuclear Aromatic Hydrocarbons DL = 0.5 µg/L		Metals DL = 1 µg/L
BHC (Benzene hexachloride)	Bis(2-ethylhexyl) Phthalate	Acenaphthene	Fluoranthene	Aluminum
Heptachlor	Butyl benzyl phthalate	Acenaphthylene	Fluorene	Cadmium
Aldrin	Di-n-butyl phthalate	Anthracene	Indeno (1,2,3-cd) pyrene	Chromium
Endosulfan	Diethyl phthalate	Benzo (a) anthracene	Naphthalene	Copper
Heptachlor epoxide	Dimethyl phthalate	Benzo (a) pyrene	Phenanthrene	Lead
DDE (Dichlorodiphenyl dichloroethylene)	Di-n-octyl phthalate	Benzo (b) fluoranthene	Pyrene	Nickel
DDD (Dichlorodiphenyl dichloroethane)		Benzo (ghi) perylene		Zinc
DDT (Dichlorodiphenyl trichloroethane)		Benzo (k) fluoranthene		
Endrin		Chrysene		
Chlordane		Dibenzo (a,h) anthracene		

D.L. = Detection Limit

Metallic toxicants, also listed in Table 2.17, were analyzed using a graphite furnace equipped atomic absorption spectrophotometer (GFAA). EPA methods 202.2 (Al), 213.2 (Cd), 218.2 (Cr), 220.2 (Cu), 239.2 (Pb), 249.2 (Ni), and 289.2 (Zn) were followed in these analyses. A Perkin Elmer 3030B atomic absorption spectrophotometer was used after nitric acid digestion of the samples. Previous research (Pitt and McLean 1986; EPA 1983a) indicated that low detection limits were necessary in order to measure the filtered sample concentrations of the metals, which would not be achieved by use of a standard flame atomic absorption spectrophotometer. Low detection limits would enable partitioning of the metals between the solid and liquid phases to be investigated, an important factor in assessing the fates of the metals in receiving waters and in treatment processes.

The Microtox™ 100% sample toxicity screening test, from Azur Environmental (previously Microbics, Inc.), was selected for this research after comparisons with other laboratory bioassay tests. During the first research phase, twenty source area stormwater samples and combined sewer samples (obtained during a cooperative study being conducted in New York City) were split and sent to four laboratories for analyses using 14 different bioassay tests. Conventional bioassay tests were conducted using freshwater organisms at the EPA's Duluth, MN, laboratory and using marine organisms at the EPA's Narragansett Bay, RI, laboratory. In addition, other bioassay tests, using bacteria, were also conducted at the Environmental Health Sciences Laboratory at Wright State University, Dayton, Ohio. The tests represented a range of organisms that included fish, invertebrates, plants, and microorganisms.

The conventional bioassay tests conducted simultaneously with the Microtox™ screening test for the 20 stormwater sheetflow and combined sewer overflow (CSO) samples were all short-term tests. However, some of the tests were indicative of chronic toxicity (life cycle tests and the marine organism sexual reproduction tests, for example), whereas the others would be classically considered as indicative of acute toxicity (Microtox™ and the fathead minnow tests, for example). The following list shows the major tests that were conducted by each participating laboratory:

- University of Alabama at Birmingham, Environmental Engineering Laboratory
Microtox™ bacterial luminescence tests (10-, 20-, and 35-minute exposures) using the marine *Photobacterium phosphoreum*.
- Wright State University, Biological Sciences Department
Macrofaunal toxicity tests:
Daphnia magna (water flea) survival; *Lemna minor* (duckweed) growth; and *Selenastrum capricornutum* (green alga) growth.
Microbial activity tests (bacterial respiration):
Indigenous microbial electron transport activity;
Indigenous microbial inhibition of β -galactosidase activity;
Alkaline phosphatase for indigenous microbial activity;
Inhibition of β -galactosidase for indigenous microbial activity; and
Bacterial surrogate assay using *O*-nitrophenol- β -D-galactopyranside activity and *Escherichia coli*.
- EPA Environmental Research Laboratory, Duluth, Minnesota
Ceriodaphnia dubia (water flea) 48-h survival; and
Pimephales promelas (fathead minnow) 96-h survival.
- EPA Environmental Research Laboratory, Narragansett Bay, Rhode Island
Champia parvula (marine red alga) sexual reproduction (formation of cystocarps after 5 to 7 d exposure); and
Arbacia punctulata (sea urchin) fertilization by sperm cells.

Table 2.18 summarizes the results of the toxicity tests. The *C. dubia*, *P. promelas*, and *C. parvula* tests experienced problems with the control samples, and those results are therefore uncertain. The *A. punctulata* tests on the stormwater samples also had a potential problem with the control samples. The CSO test results (excluding the fathead minnow tests) indicated that from 50% to 100% of the samples were toxic, with most tests identifying the same few samples as the most toxic. The toxicity tests for the stormwater samples indicated that 0% to 40% of the samples were toxic. The Microtox™ screening procedure gave similar rankings for the samples as the other toxicity tests.

Table 2.18. Fraction of Samples Rated as Toxic

Sample series	Combined sewer overflows, %	Stormwater, %
Microtox™ marine bacteria	100	20
<i>C. Dubia</i>	60	0 ^a
<i>P. promelas</i>	0 ^a	0 ^a
<i>C. parvula</i>	100	0 ^a
<i>A. punctulata</i>	100	0 ^a
<i>D. magna</i>	63	40
<i>L. minor</i>	50 ^a	0

^a Results uncertain, see text

Laboratory toxicity tests can result in important information on the effects of stormwater in receiving waters, but actual in-stream taxonomic studies should also be conducted. A recently published proceedings of a conference on stormwater impacts on receiving streams (Herrick 1995) contains many examples of actual receiving water impacts and toxicity test protocols for stormwater.

All of the Birmingham samples represented separate stormwater. However, as part of the Microtox™ evaluation, several CSO samples from New York City were also tested to compare the different toxicity tests. These samples were collected from six CSO discharge locations having the following land uses:

- 290 acres, 90% residential and 10% institutional;
- 50 acres, 100% commercial;
- 620 acres, 20% institutional, 6% commercial, 5% warehousing, 5% heavy industrial, and 64% residential;
- 225 acres, 13% institutional, 4% commercial, 2% heavy industrial, and 81% residential;
- 400 acres, 1% institutional and 99% residential; and
- 250 acres, 88% commercial, 6% warehousing, and 6% residential.

Therefore, there was a chance that some of the CSO samples may have had some industrial process waters. However, none of the Birmingham sheetflow samples could have contained any process waters because of how and where they were collected.

The Microtox™ screening procedure gave similar toxicity rankings for the twenty samples as the conventional bioassay tests. It is also a rapid procedure (requiring about one hour) and only requires small (<1 mL) sample volumes. The Microtox™ toxicity test uses marine bioluminescence bacteria and monitors the light output for different sample concentrations. About one million bacteria organisms are used per sample, resulting in highly repeatable results. The more toxic samples produce greater stress on the bacteria test organisms that results in a greater light attenuation compared to the control sample. It should be emphasized that the Microtox™ procedure was not used during this research to determine the absolute toxicities of the samples, or to predict the toxic effects of stormwater runoff on receiving waters, but to compare the relative toxicities of different samples that may indicate efficient source area treatment locations, and to examine changes in toxicity during different treatment procedures.

Phase 1 - Potential Sources

A drainage system captures runoff and pollutants from many source areas, all with individual characteristics influencing the quantity of runoff and pollutant load. Impervious source areas may contribute most of the runoff during small storm events (e.g., paved parking lots, streets, driveways, roofs, sidewalks, etc.). Pervious source areas can have higher material washoff potentials and become important contributors for larger storm events when their infiltration rate capacity is exceeded (e.g., gardens, bare ground, unpaved parking areas, construction sites, undeveloped areas, etc.). Many other factors also affect the pollutant contributions from source areas, including: surface roughness, vegetative cover, gradient, and hydraulic connections to a drainage system; rainfall intensity, duration, and antecedent dry period; and pollutant availability due to direct contamination from local activities, cleaning frequency/efficiency, and natural and regional sources of pollutants. The relative importance of the different source areas is therefore a function of the area characteristics, pollutant washoff potential, and the rainfall characteristics (Pitt 1987).

Important sources of toxicants are often related to the land use (e.g., high traffic capacity roads, industrial processes, and storage area) that are unique to specific land uses activities. Automobile related sources affect the quality and quantity of road dust particles through gasoline and oil drips/spills; deposition of exhaust products; and wear of tire, brake, and pavement materials (Shaheen 1975). Urban landscaping practices potentially produce vegetation cuttings and fertilizer and pesticide washoff. Miscellaneous sources include holiday firework debris, wildlife and domestic pet wastes, and possible sanitary wastewater infiltration. In addition, resuspension and deposition of pollutants/particles via the atmosphere can increase or decrease the contribution potential of a source area (Pitt and Bozeman 1982; Bannerman, *et al.* 1993).

Phase 1 - Results

Table 2.19 summarizes the source area sample data for the most frequently detected organic toxicants and for all of the metallic toxicants analyzed. The organic toxicants analyzed, but not reported, were generally detected in 5, or

less, of the non-filtered samples and in none of the filtered samples. Table 2.19 shows the mean, maximum, and minimum concentrations for the detected toxicants. It is important to note that these values are only based on the observed concentrations only. They do not consider the non-detectable conditions. Mean values based on total sample numbers for each source area category would therefore result in much lower concentrations. The frequency of detection is therefore an important consideration when evaluating organic toxicants. High detection frequencies for the organics may indicate greater potential problems than infrequent high concentrations.

Table 2.19 also summarizes the measured pH and SS concentrations. Most pH values were in the range of 7.0 to 8.5 with a low of 4.4 and a high of 11.6 for a roof and concrete plant storage area runoff sample, respectively. This range of pH can have dramatic effects on the speciation of the metals analyzed. The SS concentrations were generally less than 100 mg/L, with impervious area runoff (e.g., roofs and parking areas) having much lower SS concentrations and turbidities compared to samples obtained from pervious areas (e.g., landscaped areas).

Thirteen organic compounds, out of more than thirty-five targeted compounds analyzed, were detected in more than 10 percent of all samples, as shown in Table 2.19. The greatest detection frequencies were for 1,3-dichlorobenzene and fluoranthene, which were each detected in 23 percent of the samples. The organics most frequently found in these source area samples (i.e., polycyclic aromatic hydrocarbons (PAH), especially fluoranthene and pyrene) were similar to the organics most frequently detected at outfalls in prior studies (EPA 1983a).

Roof runoff, parking area and vehicle service area samples had the greatest detection frequencies for the organic toxicants. Vehicle service areas and urban creeks had several of the observed maximum organic compound concentrations. Most of the organics were associated with the non-filtered sample portions, indicating an association with the particulate sample fractions. The compound 1,3-dichlorobenzene was an exception, having a significant dissolved fraction.

In contrast to the organics, the heavy metals analyzed were detected in almost all samples, including the filtered sample portions. The non-filtered samples generally had much higher concentrations, with the exception of zinc which was mostly associated with the dissolved sample portion (i.e., not associated with the SS). Roof runoff generally had the highest concentrations of zinc, probably from galvanized roof drainage components, as previously reported by Bannerman, *et al.* (1983). Parking and storage areas had the highest nickel concentrations, while vehicle service areas and street runoff had the highest concentrations of cadmium and lead. Urban creek samples had the highest copper concentrations, which were probably due to illicit industrial connections or other non-stormwater discharges.

Table 2.20 shows the relative toxicities of the collected stormwaters. A wide range of toxicities were found. About 9% of the non-filtered samples were considered highly toxic using the Microtox™ toxicity screening procedure. About 32% of the samples were moderately toxic and about 59% were considered non-toxic. The greatest percentage of samples considered the most toxic were from industrial storage and parking areas. Landscaped areas also had a high incidence of highly toxic samples (presumably due to landscaping chemicals), and roof runoff had some highly toxic samples (presumably due to high zinc concentrations). The phase 2 treatability study activities indicated that filtering the samples through a range of fine sieves and finally a 0.45µm filter consistently reduced sample toxicities. The chemical analyses also generally found much higher toxicant concentrations in the non-filtered sample portions, compared to the filtered sample portions.

Replicate samples were collected from several source areas at three land uses during four different storm events to statistically examine toxicity and pollutant concentration differences due to storm and site conditions. These data indicated that variations in Microtox™ toxicities and organic toxicant concentrations may be partially explained by rain characteristics. As an example, high concentrations of many of the PAHs were associated with long antecedent dry periods and large rains (Barron 1990).

Table 2.19. Stormwater toxicants detected in at least 10% of the source area sheetflow samples ($\mu\text{g/L}$, unless otherwise noted).

	Roof areas		Parking areas		Storage areas		Street runoff		Loading docks		Vehicle service areas		Landscaped areas		Urban creeks		Detention ponds	
	N.F. ^a	F. ^b	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.
Total samples	12	12	16	16	8	8	6	6	3	3	5	5	6	6	19	19	12	12
Base neutrals (detection limit = 0.5 $\mu\text{g/L}$)																		
1,3-Dichlorobenzene detection frequency = 20% N.F. and 13% F.																		
No. detected ^c	3	2	3	2	1	1	1	1	0	0	3	2	3	2	2	0	1	1
Mean ^d	52	20	34	13	16	14	5.4	3.3			48	26	29	5.6	93		27	21
Max.	88	23	103	26							72	47	54	7.5	120			
Min. ^e	14	17	3.0	2.0							6.0	4.9	4.5	3.8	65			
Fluoranthene detection frequency = 20% N.F. and 12% F.																		
No. detected	3	2	3	2	1	0	1	1	0	0	3	2	3	2	1	0	2	1
Mean	23	9.3	37	2.7	4.5		0.6	0.5			39	3.6	13	1.0	130		10	6.6
Max.	45	14	110	5.4							53	6.8	38	1.3			14	
Min.	7.6	4.8	3.0	2.0							0.4	0.4	0.7	0.7			6.6	
Pyrene detection frequency = 17% N.F. and 7% F.																		
No. detected	1	0	3	2	1	0	1	1	0	0	3	2	2	0	1	0	2	1
Mean	28		40	9.8	8		1.0	0.7			44	4.1	5.3		100		31	5.8
Max.			120	20							51	7.4	8.2				57	
Min.			3.0	2.0							0.7	0.7	2.3				6.0	
Benzo(b)fluoranthene detection frequency = 15% N.F. and 0% F.																		
No. detected	4	0	3	0	0	0	1	0	0	0	2	0	1	0	2	0	0	0
Mean	76		53				14				98		30		36			
Max.	260		160								110				64			
Min.	6.4		3.0								90				8.0			
Benzo(k)fluoranthene detection frequency = 11% N.F. and 0% F.																		
No. detected	0	0	3	0	0	0	1	0	0	0	2	0	1	0	2	0	0	0
Mean			20				15				59		61		55			
Max.			1								103				78			
Min.			3.0								15				31			
Benzo(a)pyrene detection frequency = 15% N.F. and 0% F.																		
No. detected	4	0	3	0	0	0	1	0	0	0	2	0	1	0	2	0	0	0
Mean	99		40				19				90		54		73			
Max.	300		120								120				130			
Min.	34		3.0								60				19			

Table 2.19. Continued).

	Roof areas		Parking areas		Storage areas		Street runoff		Loading docks		Vehicle service areas		Landscaped areas		Urban creeks		Detention ponds	
	N.F. ^a	F. ^b	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.
Total samples	12	12	16	16	8	8	6	6	3	3	5	5	6	6	19	19	12	12
Bis(2-chloroethyl) ether detection frequency = 12% N.F. and 2% F.																		
No. detected	3	1	2	0	0	0	1	0	0	0	1	1	1	0	1	0	1	0
Mean	42	17	20				15				45	23	56		200		15	
Max.	87	2	39															
Min.	20		2.0															
Bis(chloroisopropyl) ether detection frequency = 13% N.F. and 0% F.																		
No. detected	3	0	3	0	0	0	0	0	0	0	2	0	1	0	2	0	0	0
Mean	99		130								120		85		59			
Max.	150		400								160				78			
Min.	68		3.0								74				40			
Naphthalene detection frequency = 11% N.F. and 6% F.																		
No. detected	2	0	1	1	0	0	0	0	0	0	2	1	1	0	1	1	2	2
Mean	17		72	6.6							70	82	49		300	6.7	43	12
Max.	21										100						68	17
Min.	13										37						18	6.6
Benzo(a)anthracene detection frequency = 10% N.F. and 0% F.																		
No. detected	1	0	3	0	0	0	0	0	0	0	2	0	1	0	1	0	0	0
Mean	16		24								35		54		61			
Max.			73								39							
Min.			3.0								31							
Butylbenzyl phthalate detection frequency = 10% N.F. and 4% F.																		
No. detected	1	0	2	1	0	0	0	0	0	0	2	2	1	0	1	0	1	0
Mean	100		12	3.3							26	9.8	130		59		13	
Max.			21								48	16						
Min.			3.3								3.8	3						
Pesticides (detection limit = 0.3 µg/L)																		
Chlordane detection frequency = 11% N.F. and 0% F.																		
No. detected	2	0	2	0	3	0	1	0	0	0	1	0	0	0	0	0	0	0
Mean	1.6		1.0		1.7		0.8				0.8							
Max.	2.2		1.2		2.9													
Min.	0.9		0.8		1.0													

Table 2.19. Continued).

	Roof areas N.F. ^a F. ^b		Parking areas N.F. F.		Storage areas N.F. F.		Street runoff N.F. F.		Loading docks N.F. F.		Vehicle service areas N.F. F.		Landscaped areas N.F. F.		Urban creeks N.F. F.		Detention ponds N.F. F.	
Total samples	12	12	16	16	8	8	6	6	3	3	5	5	6	6	19	19	12	12
Metals (detection limit = 1 µg/L)																		
Lead detection frequency = 100% N.F. and 54% F.																		
No. detected	12	1	16	8	8	7	6	4	3	1	5	2	6	1	19	15	12	8
Mean	41	1.1	46	2.1	105	2.6	43	2.0	55	2.3	63	2.4	24	1.7	20	1.4	19	1.0
Max.	170		130	5.2	330	5.7	150	3.9	80		110	3.4	70		100	1.6	55	1.0
Min.	1.3		1.0	1.2	3.6	1.6	1.5	1.1	25		27	1.4	1.4		1.4	<1	1	<1
Zinc detection frequency = 99% N.F. and 98% F.																		
No. detected	12	12	16	16	8	7	6	6	2	2	5	5	6	6	19	19	12	12
Mean	250	220	110	86	1730	22	58	31	55	33	105	73	230	140	10	10	13	14
Max.	1580	1550	650	560	13100	100	130	76	79	62	230	230	1160	670	32	23	25	25
Min.	11	9	12	6	12	3.0	4.0	4.0	31	4.0	30	11	18	18	<1	<1	<1	<1
Copper detection frequency = 98% N.F. and 78% F.																		
No. detected	11	7	15	13	8	6	6	5	3	2	5	4	6	6	19	17	12	8
Mean	110	2.9	116	11	290	250	280	3.8	22	8.7	135	8.4	81	4.2	50	1.4	43	20
Max.	900	8.7	770	61	1830	1520	1250	11	30	15	580	24	300	8.8	440	1.7	210	35
Min.	1.5	1.1	10	1.1	10	1.0	10	1.0	15	2.6	1.5	1.1	1.9	0.9	<1	<1	0.2	<1
Aluminum detection frequency = 97% N.F. and 92% F.																		
No. detected	12	12	15	15	7	6	6	6	3	1	5	4	5	5	19	19	12	12
Mean	6850	230	3210	430	2320	180	3080	880	780	18	700	170	2310	1210	620	190	700	210
Max.	71300	1550	6480	2890	6990	740	10040	4380	930		1370	410	4610	1860	3250	500	1570	360
Min.	25	6.4	130	5.0	180	10	70	18	590		93	0.3	180	120	<5	<5	<5	<5
Cadmium detection frequency = 95% N.F. and 69% F.																		
No. detected	11	7	15	9	8	7	6	5	3	3	5	3	4	2	19	15	12	9
Mean	3.4	0.4	6.3	0.6	5.9	2.1	37	0.3	1.4	0.4	9.2	0.3	0.5	0.6	8.3	0.2	2	0.5
Max.	30	0.7	70	1.8	17	10	220	0.6	2.4	0.6	30	0.5	1	1	30	0.3	11	0.7
Min.	0.2	0.1	0.1	0.1	0.9	0.3	0.4	0.1	0.7	0.3	1.7	0.2	0.1	0.1	<0.1	<0.1	0.1	0.4
Chromium detection frequency = 91% N.F. and 55% F.																		
No. detected	7	2	15	8	8	5	5	4	3	0	5	1	6	5	19	15	11	8
Mean	85	1.8	56	2.3	75	11	9.9	1.8	17		74	2.5	79	2.0	62	1.6	37	2.0
Max.	510	2.3	310	5.0	340	32	30	2.7	40		320		250	4.1	710	4.3	230	3.0
Min.	5.0	1.4	2.4	1.1	3.7	1.1	2.8	1.3	2.4		2.4		2.2	1.4	<0.1	<0.1	<0.1	<0.1

Table 2.19. Continued).

	Roof areas		Parking areas		Storage areas		Street runoff		Loading docks		Vehicle service areas		Landscaped areas		Urban creeks		Detention ponds	
	N.F. ^a	F. ^b	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.	N.F.	F.
Total samples	12	12	16	16	8	8	6	6	3	3	5	5	6	6	19	19	12	12
Nickel detection frequency = 90% N.F. and 37% F.																		
No. detected	10	0	14	4	8	1	5	0	3	1	5	1	4	1	18	16	11	8
Mean	16		45	5.1	55	87	17		6.7	1.3	42	31	53	2.1	29	2.3	24	3.0
Max.	70		130	13	170		70		8.1		70		130		74	3.6	70	6.0
Min	2.6		4.2	1.6	1.9		1.2		4.2		7.9		21		<1	<1	1.5	<1
Other constituents (always detected, analyzed only for non-filtered samples)																		
pH																		
Mean	6.9		7.3		8.5		7.6		7.8		7.2		6.7		7.7		8.0	
Max.	8.4		8.7		12		8.4		8.3		8.1		7.2		8.6		9.0	
Min	4.4		5.6		6.5		6.9		7.1		5.3		6.2		6.9		7.0	
Suspended solids																		
Mean	14		110		100		49		40		24		33		26		17	
Max.	92		750		450		110		47		38		81		140		60	
Min.	0.5		9.0		5.0		7.0		34		17		8.0		5.0		3.0	

^aN.F.: concentration associated with a nonfiltered sample.^bF.: concentration after the sample was filtered through a 0.45 µm membrane filter.^cNumber detected refers to the number of samples in which the toxicant was detected.^dMean values based only on the number of samples with a definite concentration of toxicant reported (not on the total number of samples analyzed).^eThe minimum values shown are the lowest concentration detected, they are not necessarily the detection limit.

Table 2.20. Relative Toxicity of Samples Using Microtox™ (Non-filtered)

Local Source Areas	Highly Toxic (%)	Moderately Toxic (%)	Not Toxic (%)	Number of Samples
Roofs	8	58	33	12
Parking Areas	19	31	50	16
Storage Areas	25	50	25	8
Streets	0	67	33	6
Loading Docks	0	67	33	3
Vehicle Service Areas	0	40	60	5
Landscaped Areas	17	17	66	6
Urban Creeks	0	11	89	19
Detention Ponds	8	8	84	12
All Areas	9%	32%	59%	87

Microbics suggested toxicity definitions for 35 minute exposures:

Highly Toxic - light decrease >60%

Moderately Toxic - light decrease <60% & >20%

Not Toxic - light decrease <20%

Chapter 3

Laboratory-Scale Toxicant Reduction Tests

The phase 2 activities of this project examined methods to reduce stormwater toxicity from critical source areas using a variety of conventional bench-scale treatment processes. The data from phase 1 identified the critical source areas which generally had the highest toxicant concentrations for study during this research phase. The critical source areas targeted for this additional study were storage/parking and vehicle service areas.

Phase 2 - Analysis and Sampling

The objective of this second research phase was to quantify improvements in stormwater toxicity using different stages of several bench-scale treatment methods. These data were used to indicate the relative effectiveness of different treatment efforts and processes. To meet this objective and the resource restraints of cost and time, the Azur Environmental (previously Microbics, Inc.) Microtox™ screening toxicity test was chosen to indicate the relative changes in toxicity.

The efficiency of many pollution control devices is affected by the particle sizes and settling velocity distributions of the pollutants in the wastewater. Therefore, settling column tests were conducted to determine the pollutant settling velocities. Standard gravimetric solids analyses (EPA 1983b) were conducted on the settling column samples to calculate the settling velocities and specific gravities of the particulates. Nephelometric turbidity analyses were also conducted (EPA 1983b) for all subsamples during the treatability tests.

Samples were collected in the same manner from the critical source areas selected for testing as described in phase 1, but a larger volume of sample (10 to 20 liters) was collected from each location.

Phase 2 - Experimental Error

The second phase included intensive analyses of samples from twelve sampling locations in the Birmingham, AL, area. Table 3.1 lists the sampling dates, source area categories, and relative toxicity category prior to treatment. These sampled storms represent practically all of the rains that occurred during the field portion of the second project phase (July-November, 1990). Independent replicates (obtained during separate analysis runs) were used to determine the measurement errors associated with the Microtox™ procedure. The total number of Microtox™ analyses that were conducted for all of the treatability tests for each sample is also noted, as are the means, standard deviations, and coefficients of variation of the replicate toxicity values.

The initial toxicity values (before treatability tests) were plotted on normal-probability paper to indicate their probability distribution characteristics. Almost all of the samples had initial toxicity values that were shown to be normally distributed. Therefore, the coefficient of variation (COV = standard deviation/mean) values shown on Table 3.1 can be used as an indication of the confidence intervals of the Microtox™ measurements. The COVs ranged from 2.3 to 9.8 percent, with an average value of 5.1 percent. Therefore, the 95 percent confidence interval (two times the COV values include 95.4 percent of the data, if normally distributed) for the Microtox™ procedure ranged between 5 and 20 percent of the mean values. These confidence intervals are quite narrow for a bioassay test and indicate the good repeatability of the Microtox™ procedure. In all cases, statistical tests were performed on the test results to indicate the significance of the different treatability tests.

Table 3.1 also shows that samples B and D were initially extremely toxic, while the remainder of the samples were moderately toxic. All samples were reduced to “non-toxic” levels after various degrees of treatment.

Table 3.1. Phase 2 Treatability Sample Descriptions

Sample Source	Date	Initial Toxicity ^a (%)	Number of Analyses	Standard Deviation ^b	Coefficient of Variation ^b (%)
<u>Automobile Service Area Samples</u>					
B	7/10/90	78	28	7.6	9.8
C	7/21/90	34	42	2.9	8.5
E	8/19/90	43	74	1.3	3.0
H	10/17/90	50	88	1.5	3.0
<u>Industrial Loading & Parking Area Samples</u>					
D	8/2/90	67	74	2.1	3.1
F	9/12/90	31	88	1.5	4.9
G	10/3/90	53	88	3.0	5.7
I	10/24/90	55	89	1.9	3.4
J	11/5/90	49	89	1.1	2.3
K	11/9/90	28	89	2.2	8.1
<u>Automobile Salvage Yard Samples</u>					
L	11/28/90	26	89	1.4	5.5
M	12/3/90	54	89	1.8	3.4

^a Toxicity measured as percent light reduction after 35 minute exposure.

^b Applies to replicate samples only.

Phase 2 - Treatability Tests

The selected source area runoff samples all had elevated toxicant concentrations, compared to the other urban source areas initially examined, allowing a wide range of laboratory partitioning and treatability analyses to be conducted. The treatability tests conducted were:

- Settling column (37 mm x 0.8 m Teflon™ column).
- Floatation (series of eight glass narrow neck 100 mL volumetric flasks).
- Screening and filtering (series of eleven stainless steel sieves, from 20 to 106 µm, and a 0.45 µm membrane filter).
- Photo-degradation (2 liter glass beaker with a 60 watt broad-band incandescent light placed 25 cm above the water, stirred with a magnetic stirrer with water temperature and evaporation rate also monitored).
- Aeration (the same beaker arrangement as above, without the light, but with filtered compressed air keeping the test solution supersaturated and well mixed).
- Photo-degradation and aeration combined (the same beaker arrangement as above, with compressed air, light, and stirrer).
- Undisturbed control sample (a sealed and covered glass jar at room temperature).

Because of the difficulty of obtaining large sample volumes from many of the source areas that were to be examined, these bench-scale tests were all designed to use small sample volumes (about one liter per test). Each test (except for filtration, which was an “instantaneous” test) was conducted over a duration of 3 d. Subsamples (40 mL each) were obtained for toxicity analyses at 0, 1, 2, 3, 6, 12, 24, 48, and 72 h. In addition, settling column samples were also obtained several times within the first hour, at: 1, 3, 5, 10, 15, 25, and 40 minutes.

Phase 2 - Results

The Microtox™ procedure allowed toxicity screening tests to be conducted on each sample partition during the treatment tests. This procedure enabled more than 900 toxicity tests to be made. Turbidity tests were also conducted on all samples.

Figures 3.1 to 3.24 (placed at end of chapter) are graphical data plots of the toxicity reductions observed during each treatment procedure examined, including the control measurements. These figures are grouped in threes for each treatment type. One group contains the treatment responses for the automobile service facility areas (samples B, C, E, and H), another group is for the industrial loading and parking areas (samples D, F, G, I, J, and K), and the last group is for the automobile salvage yards (samples L and M). These plots indicate the reduction in toxicity as the

level of treatment increased. As an example, Figures 3.1 through 3.3 show three separate plots for the undisturbed samples undergoing very little change, except for samples F (which increased in toxicity with time) and C (which decreased in toxicity with time). In contrast, Figures 3.4 through 3.6 show the dramatic improvements available with plain physical settling. All samples, except for B, showed dramatic reductions in toxicity with increasing settling times. Even though the data are separated into these three groups, very few consistent differences are noted in the way the different sample types responded to various treatments. As expected, there are greater apparent differences between the treatment methods than between the sample groupings.

Table 3.2 summarizes results from the non-parametric Wilcoxon signed ranks test (using SYSTAT: The System for Statistics, Version 5, SYSTAT, Inc., Evanston, Ill.) for different treatment combinations. This statistical test indicates the two-sided probabilities that the sample groups are the same. A probability of 0.05, or less, is used to indicate significant differences in the data sets (indicated by bold italics in the table). As an example, Table 3.2 indicates that there were significant differences (probabilities of 0.02) for all of the treatment tests done on sample D (an extremely toxic sample), compared to the undisturbed control sample.

Table 3.2. Two-sided Probabilities Comparing Different Treatment Tests

	Auto. Service Area				Industrial Loading & Parking Area						Auto. Salvage	
Undisturbed versus:	B	C	E	H	D	F	G	I	J	K	L	M
settling	n/a	0.25	0.02	0.41	0.02	0.12	0.09	0.07	0.01	0.01	0.02	0.02
aeration	n/a	0.31	0.25	0.07	0.02	0.05	0.06	0.04	0.01	0.01	0.02	0.03
photodegradation	n/a	0.12	0.06	0.16	0.02	0.04	0.03	0.07	0.01	0.01	0.02	0.16
aeration & photodegradation.	n/a	0.35	0.24	0.06	0.02	0.05	0.03	0.09	0.01	0.01	0.02	0.09
flotation - top layer	n/a	n/a	0.74	0.02	0.02	0.05	0.13	0.01	0.03	0.21	0.01	0.09
flotation - mid. layer	n/a	n/a	0.31	0.87	0.02	0.78	0.02	0.26	0.16	0.17	0.59	0.89

The aeration test provided the most samples that had significant probabilities of being different from the control condition. Settling, photo-degradation, and aeration and photo-degradation combined, were similar in providing the next greatest number of samples that had significant probabilities of being different from the control condition. The floatation test had six samples that had significant differences in toxicity between the top floating layer and the control sample. However, the more important contrast between the middle sample layers (below the top floating layer) and the control sample, which would indicate a reduction in toxicity of post-treated water, had only two samples that were significantly different from the control sample.

The absolute magnitudes of toxicity reductions must also be considered. As an example, it may be significant, but unimportant, if a treatment test provided many (and therefore consistent) samples having statistically significant differences compared to the control sample, if the actual toxicity reductions were very small.

As shown on Figures 3.1 to 3.24, important reductions in toxicities were found during many of the treatment tests. The highest toxicant reductions were obtained by settling for at least 24 h (providing at least 50 percent reductions for all but 2 samples), screening through at least a 40 µm screen (20-70 percent reductions), and aeration and/or photo-degradation for at least 24 h (up to 80 percent reductions). Increased settling, aeration or photo-degradation times, and screening through finer meshes, all reduced sample toxicities further. The floatation tests produced floating sample layers that generally increased in toxicity with time and lower sample layers that generally decreased in toxicity with time, as expected; however, the benefits were quite small (less than 30 percent reductions). As shown on Table 3.2, only about 40% of the floatation test toxicity changes were statistically different from the variations found in the control samples.

These tests indicate the wide ranging behavior of these related samples for the different treatment tests. Some samples responded poorly to some tests, while other samples responded well to all of the treatment tests. Any practical application of these treatment unit processes would therefore require a treatment train approach, subjecting critical source area runoff to a combination of processes in order to obtain relatively consistent overall toxicant reduction benefits. The next three chapters describe a treatment train that was evaluated to reduce critical source area stormwater toxicity.

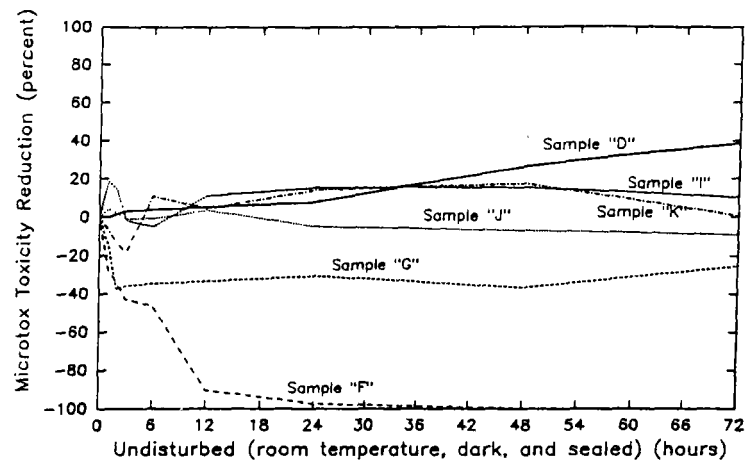


Figure 3.1 Toxicity reduction on control samples - industrial loading and parking areas.

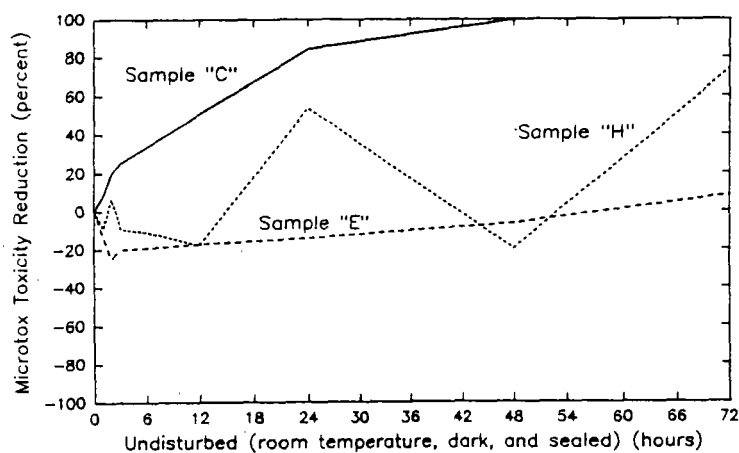


Figure 3.2 Toxicity reduction on control samples - automobile service facilities.

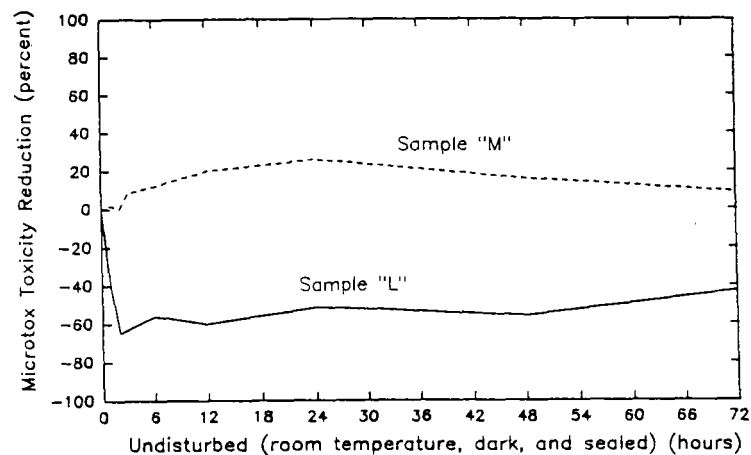


Figure 3.3 Toxicity reduction on control samples - automobile salvage yards.

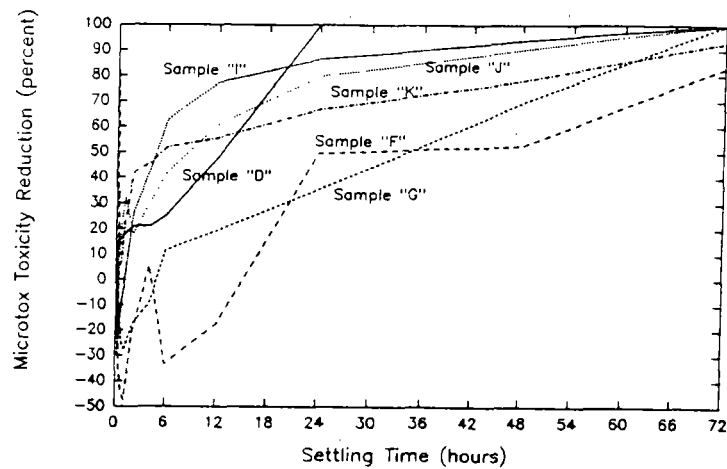


Figure 3.4 Toxicity reduction from settling treatment - industrial loading and parking areas.

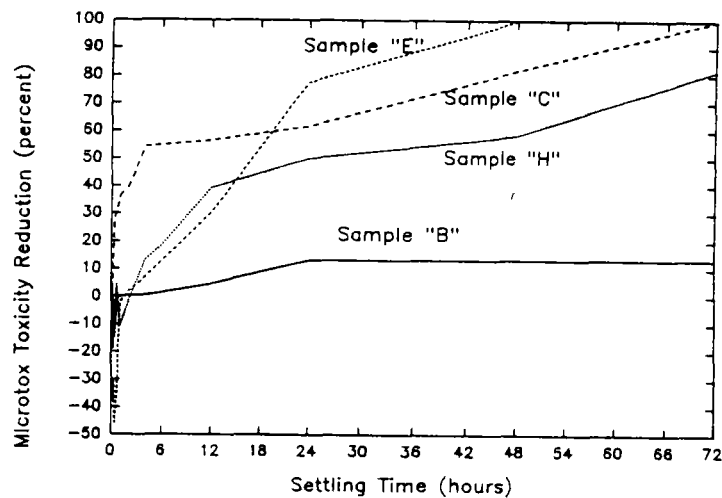


Figure 3.5 Toxicity reduction from settling treatment - automobile service facilities.

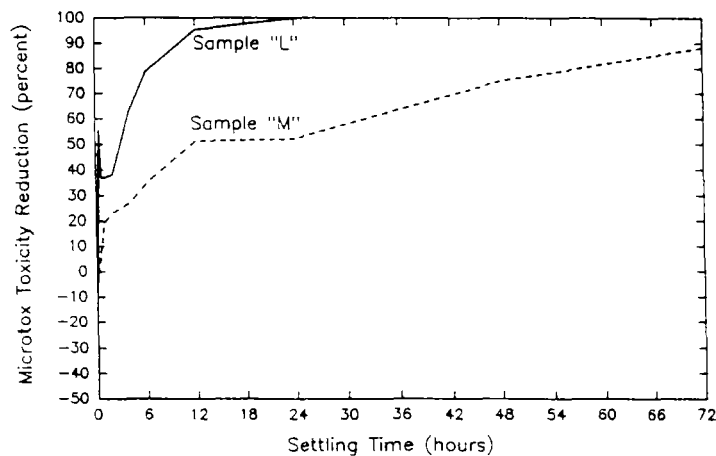


Figure 3.6 Toxicity reduction from settling treatment - automobile salvage yards.

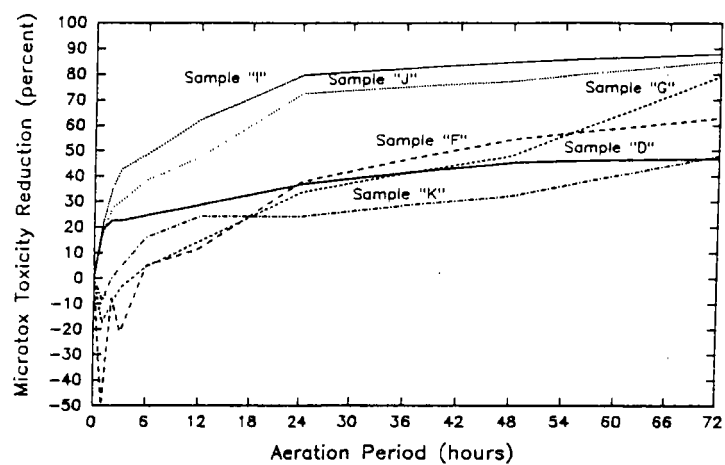


Figure 3.7 Toxicity reduction from aeration treatment - industrial loading and parking areas.

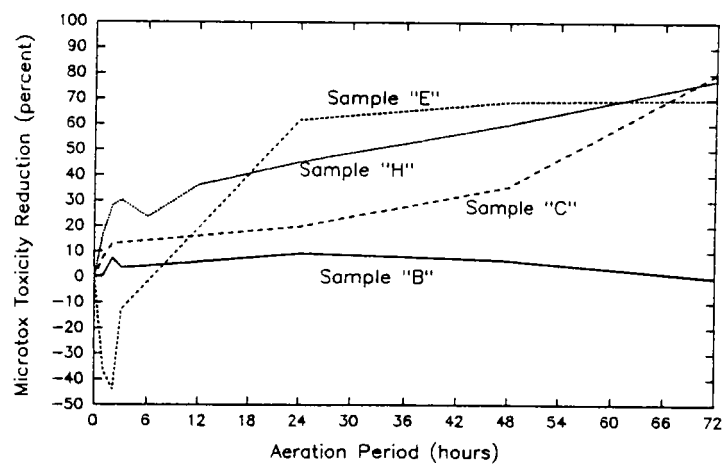


Figure 3.8 Toxicity reduction from aeration treatment - automobile service facilities.

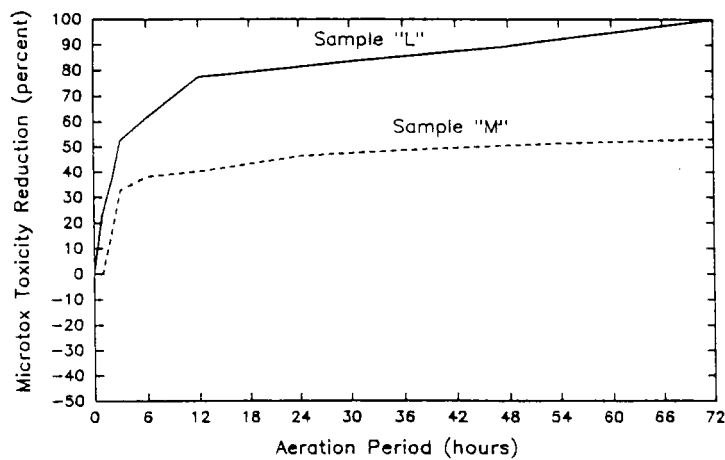


Figure 3.9 Toxicity reduction from aeration treatment - automobile salvage yards.

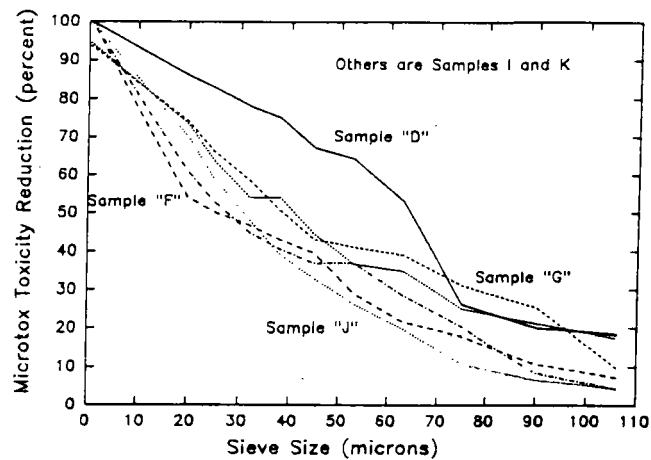


Figure 3.10 Toxicity reduction from sieve treatment - industrial loading and parking areas.

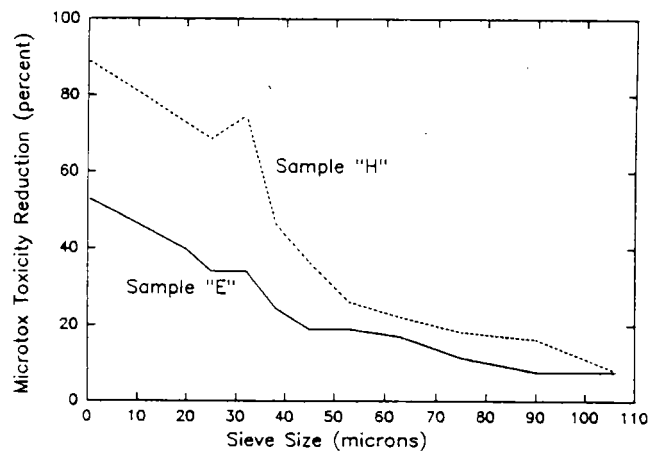


Figure 3.11 Toxicity reduction from sieve treatment - automobile service facilities.

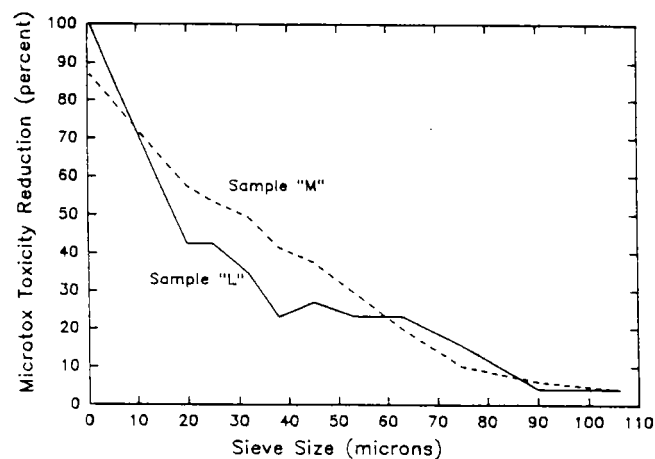


Figure 3.12 Toxicity reduction from sieve treatment - automobile salvage yards.

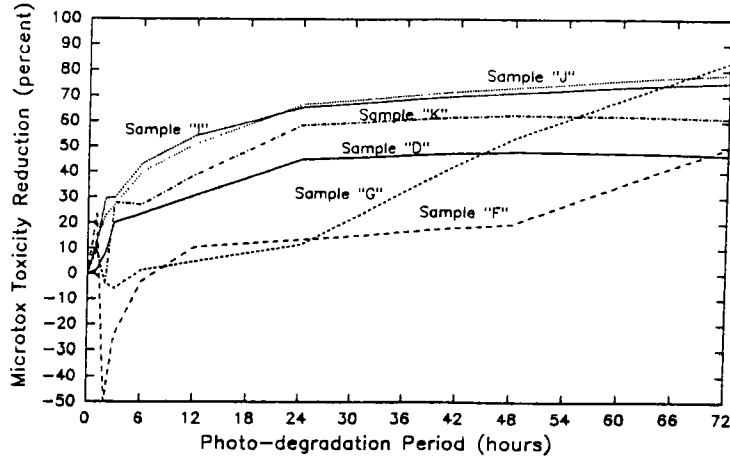


Figure 3.13 Toxicity reduction from photo-degradation treatment - industrial loading and parking areas.

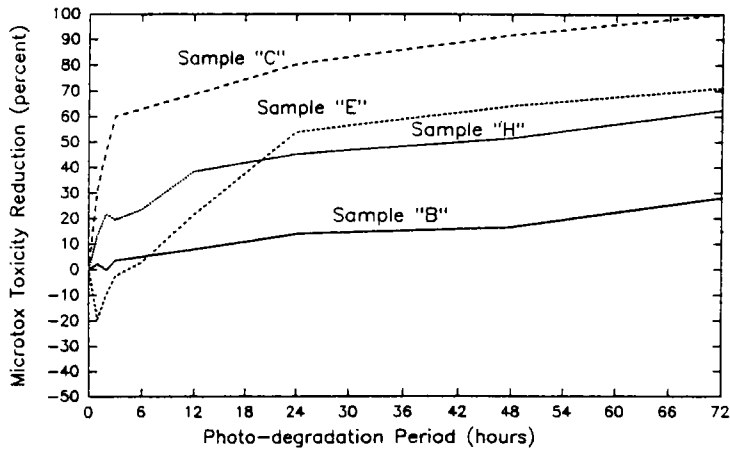


Figure 3.14 Toxicity reduction from photo-degradation treatment - automobile service facilities.

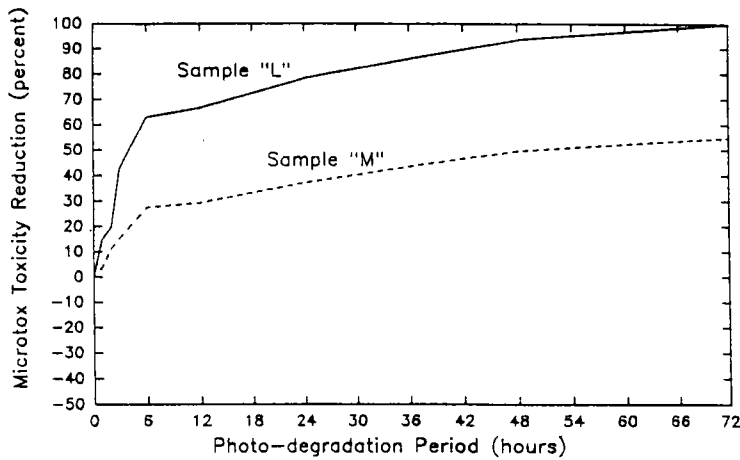


Figure 3.15 Toxicity reduction from photo-degradation treatment - automobile salvage yards.

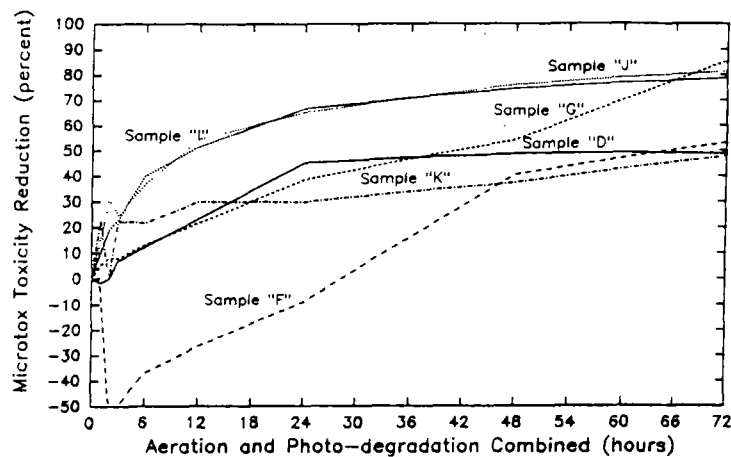


Figure 3.16 Toxicity reduction from aeration and photo-degradation treatment - industrial loading and parking areas.

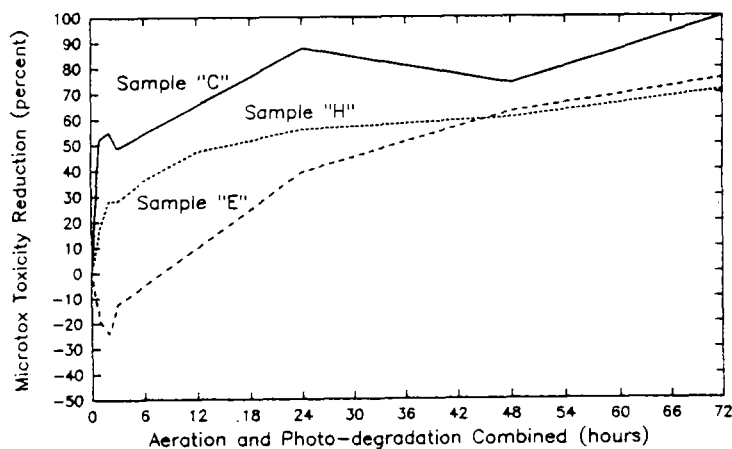


Figure 3.17 Toxicity reduction from aeration and photo-degradation treatment - automobile service facilities.

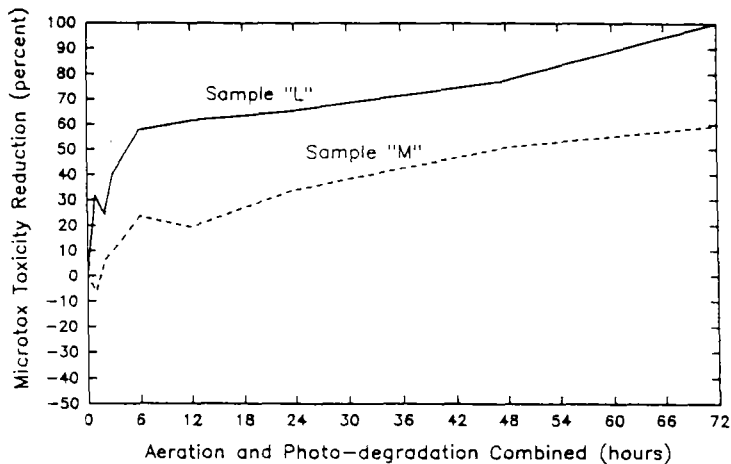


Figure 3.18 Toxicity reduction from aeration and photo-degradation treatment - automobile salvage yards.

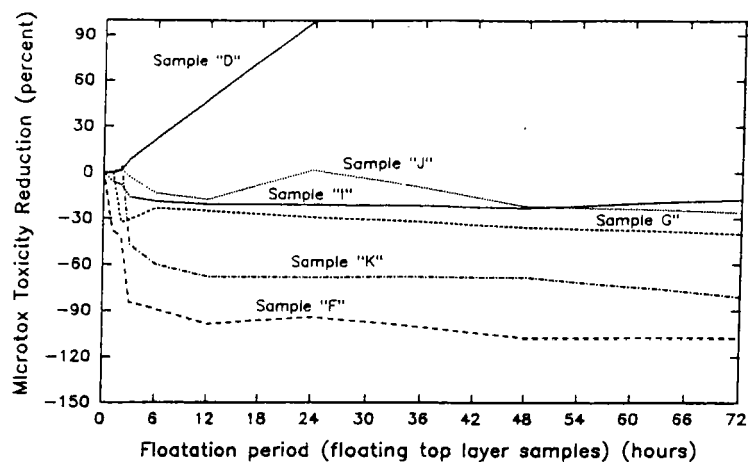


Figure 3.19 Toxicity reduction from floatation treatment (top layer samples) - Industrial loading and parking areas.

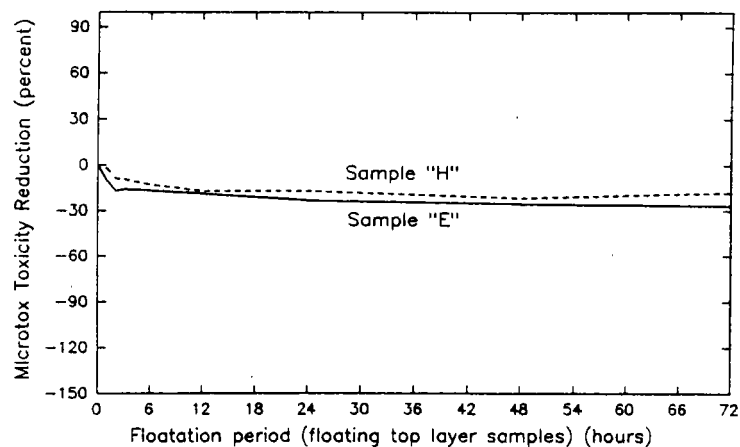


Figure 3.20 Toxicity reduction from floatation treatment (top layer samples) - automobile service facilities.

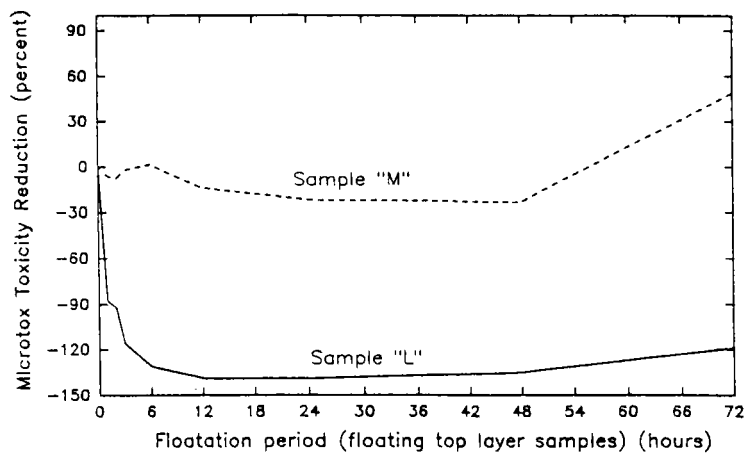


Figure 3.21 Toxicity reduction from floatation treatment (top layer samples) - automobile salvage yards.

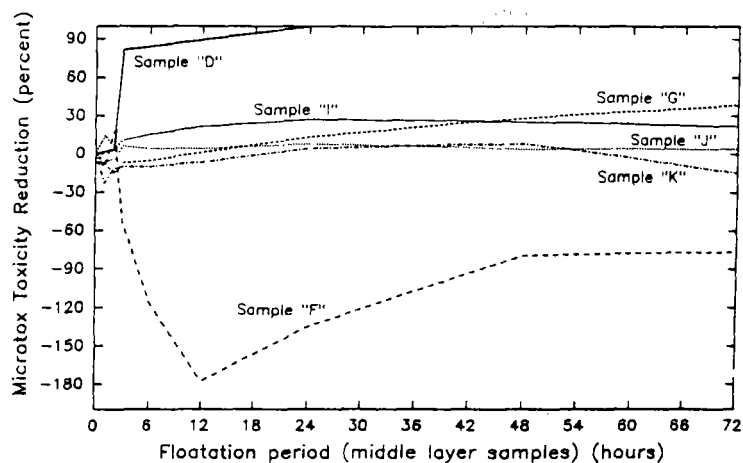


Figure 3.22 Toxicity reduction from floatation treatment (middle layer samples) - industrial loading and parking areas.

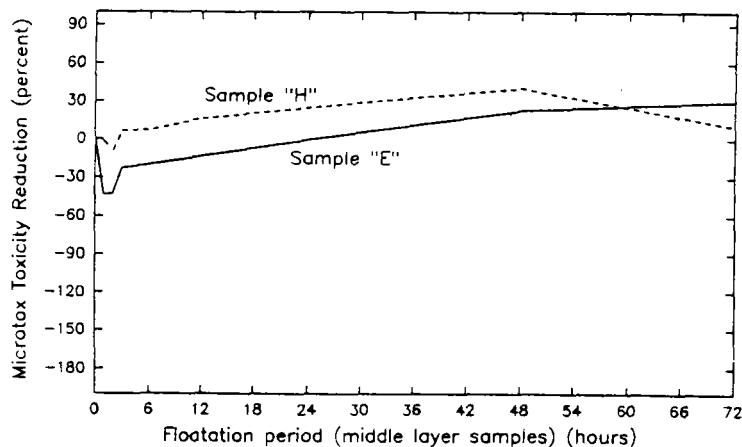


Figure 3.23 Toxicity reduction from floatation treatment (middle layer samples) - automobile service facilities.

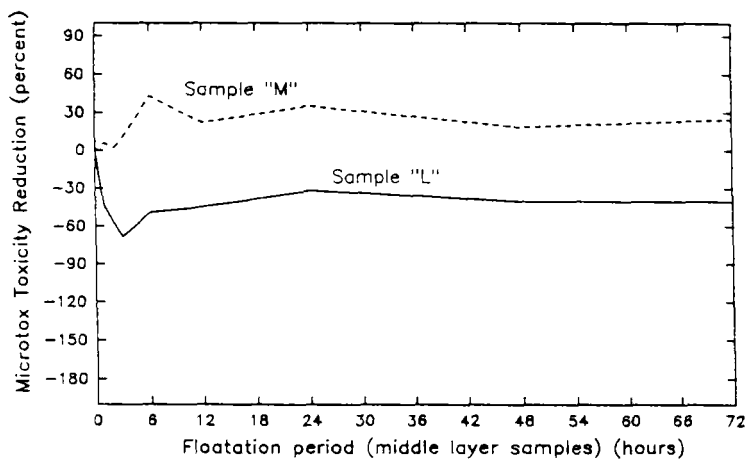


Figure 3.24 Toxicity reduction from floatation treatment (middle layer samples) - automobile salvage yards.

Chapter 4

The Development of the MCTT

The information contained in this report can be used to develop new stormwater controls by selecting the most promising unit processes described during the bench-scale tests and applying them in unique combinations, or by adding them to currently utilized stormwater controls. This chapter presents one such application of this information in the development of the Multi-Chambered Treatment Train (MCTT).

Component of a comprehensive urban runoff control program typically include structural practices such as detention ponds, grass swales, infiltration trenches, and other physical devices. The goal of this research was to add additional tools to these other technologies. This research developed and evaluated the effectiveness of the MCTT for the treatment of stormwater toxicants at critical source areas. The target area for use of this particular device includes areas such as vehicle service facilities, parking areas, paved storage areas, and fueling stations. In prior studies and during the first phase of this research project (as summarized in Chapter 2), these areas were found to have some of the highest concentrations of toxicants compared to all source areas (Barron 1990; Pitt, *et al.* 1995). The MCTT device is especially suited for these locations as it is a subterranean unit consuming no land surface area. Space is extremely limited for these typically small areas and these critical source areas are therefore left with few alternatives.

The MCTT consists of three chambers:

1. a catchbasin (or grit chamber) for removal of large particles and litter,
2. a settling chamber for quiescent settling of fine settleable solids,
3. a sand-peat moss "filter" for final polishing.

Figure 4.1 shows a cross section of the MCTT. The catchbasin functions primarily as a protector for the other two units by removing large, grit-sized material. The settling chamber is the primary treatment chamber for removing settleable solids and associated constituents. The sand-peat filter is for final polishing of the effluent, using a combination of sorption and ion exchange for the removal of soluble pollutants, for example. During this research, testing of the pilot-scale MCTT at a typical critical source area found it to significantly reduce urban stormwater pollutants.

The remaining sections of this chapter briefly review oil and water separators, and the development of the MCTT. Chapter 5 presents the results of field trials of the MCTT as a pilot-scale unit in Birmingham., AL, plus as two full-sized units located in Wisconsin. Chapter 6 describes the general procedures for designing an MCTT.

Oil/water separators are discussed in the following section because of their common use in treating stormwater at critical source areas. Information provided from manufactures and from the literature is summarized to indicate their ability to treat stormwater. Several types of commercially available oil/water separators are reviewed in this chapter. Little documentation, however, was located describing the performance of conventional oil/water separators for stormwater treatment. Documentation was also limited as to the proper design and application of these devices for stormwater. These devices are typically used for treating process wastewaters, although some authors describe their use for stormwater treatment. Their short-comings in treating stormwater were a major incentive for the development of the MCTT. The MCTT is somewhat comparable to an oil/water separator, but with enhanced settling and with the addition of a mixed media filter.

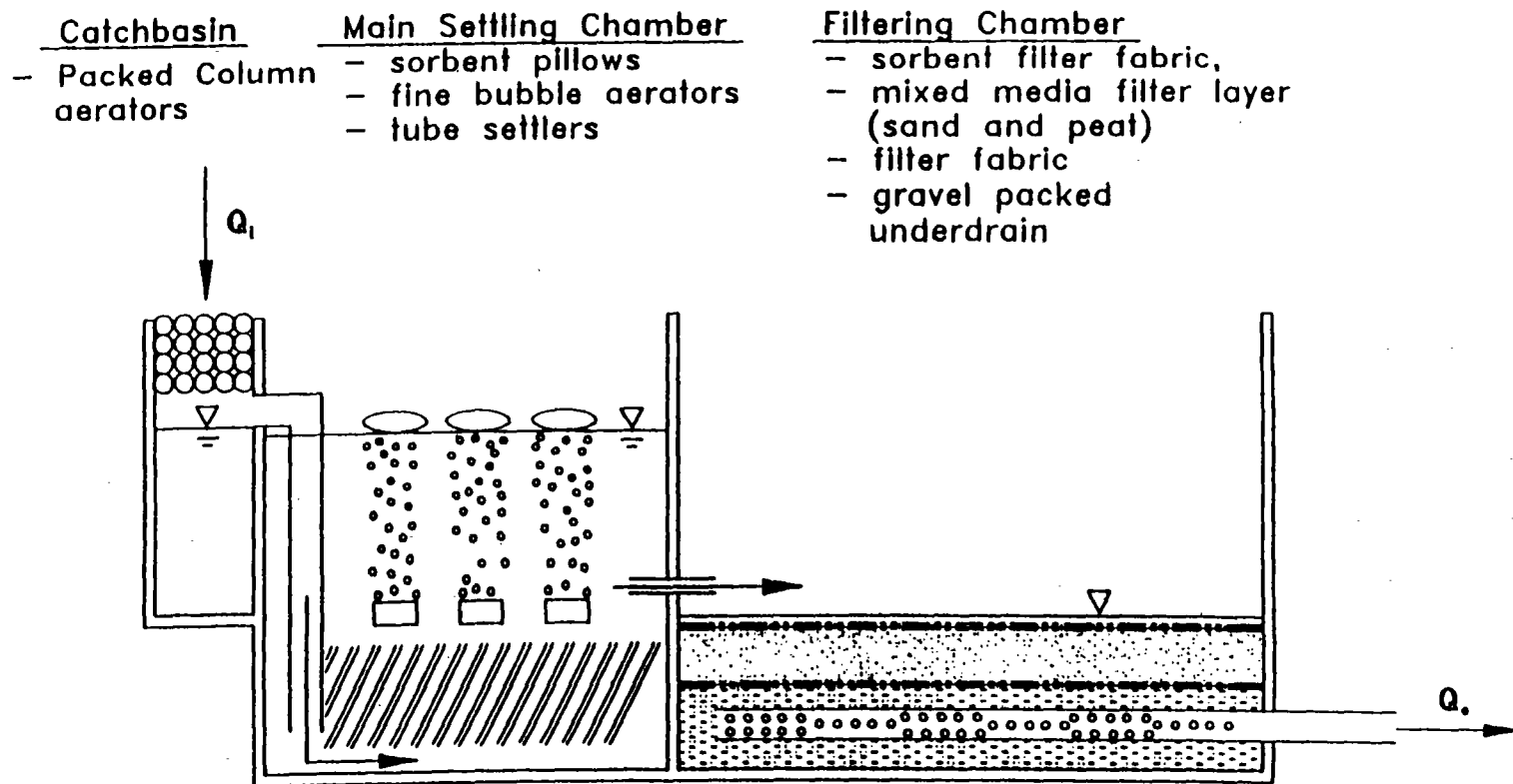


Figure 4.1 MCTT cross section.

Oil/Water Separators

This report section briefly examines the most widely available oil/water separation technologies and their expected ability to treat stormwater. These devices include gravity separators (including API separators and separation vaults), coalescing plates separators, and cartridge filters added to oil/water separators. These devices are extensively used to treat industrial wastewaters and have been shown to be effective in those applications for which they were designed. Figure 4.2 summarizes the effectiveness of gravity oil/water separators. These units perform best at very high levels of oil contamination, such as may be found at some industrial locations. This figure shows about 90% reductions in oil, if the influent oil concentrations are greater than about 10,000 mg/L. Reductions of about 50% would occur at influent oil concentrations of about 200 mg/L. Very little reduction is expected at levels less than about 100 mg/L. Little information is available demonstrating their effectiveness in treating stormwater, which usually has oil contamination levels of much less than 100 mg/L.

Other oil/water reduction technologies are used in some industrial applications, including separation tanks (typically small tanks used in shops that produce very small wastewater flows), and centrifuge separators (which require high energy demands and high maintenance, and are utilized in off-shore drilling operations). Neither of these technologies would be appropriate for the diffuse locations and highly irregular stormwater flows from critical source areas and are therefore not addressed in this report.

Factors Relevant to Oil/Water Separator Performance

Many factors affect separator performance, including: the quantity of oil, oil density, water temperature and other wastestream characteristics. The most important characteristic affecting oil removal performance is oil droplet size, from which the critical rise rate can be determined. After determining the rise rate, design flow rate, and effective horizontal separation area, the separator can be appropriately sized.

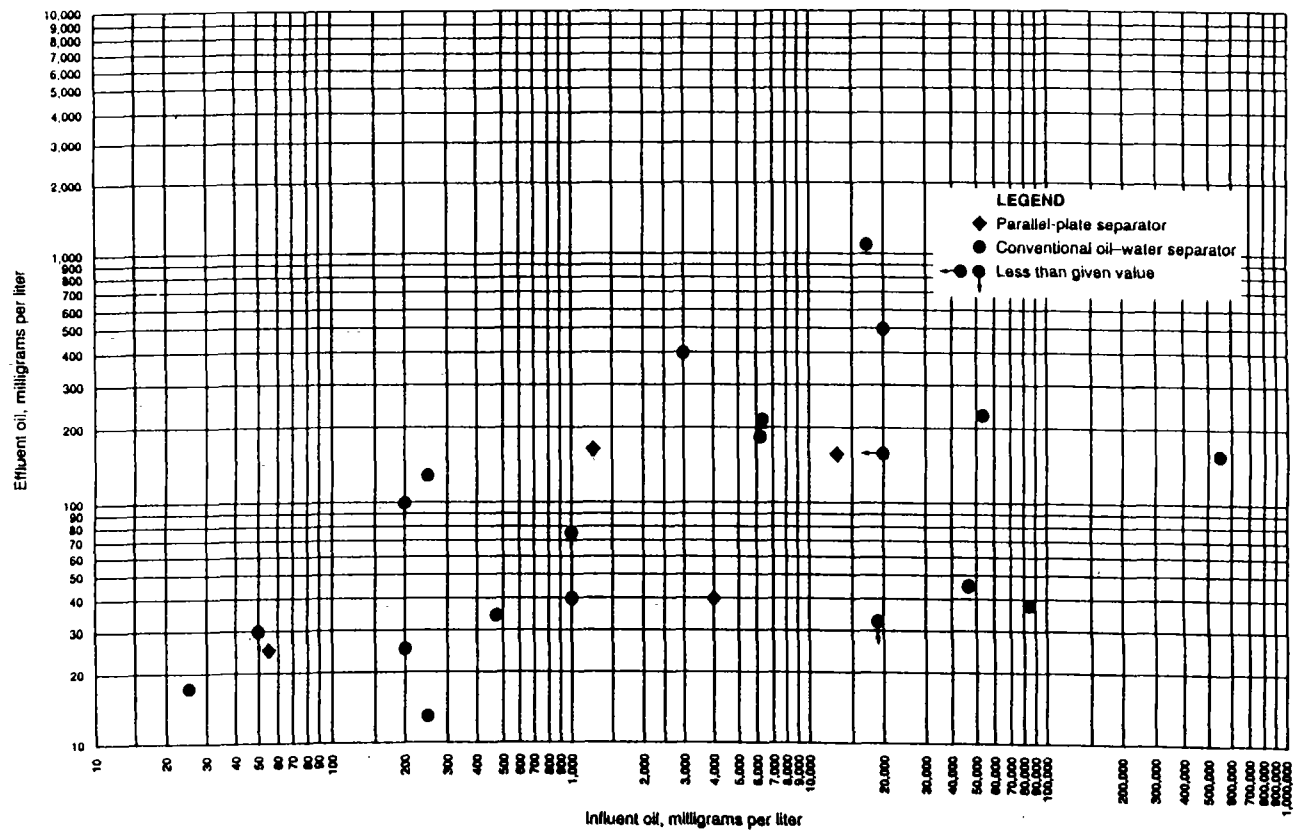
Oil Droplet Size and Critical Rise Rate

Oil/water mixtures are usually divided into four categories:

- free-floating oil, with oil droplet sizes of 250 μm or more, is evidenced by an oil slick or film on the water surface. In this case, the oil has separated from the water.
- oil droplets and globules ranging in size from 10-300 μm . This range is the most important range when dealing with oil/water separation.
- emulsions, which have sizes in the 1-30 μm range, and
- “dissolved” oil with diameters of less than 10 μm .

The largest oil droplets are easily separated from water using a basic spill trap or separation device. Smaller droplets cause wide ranging differences in performance from different separation devices. Emulsions are of two types: stable and unstable. Stable emulsions are usually the result of surfactants (i.e. soaps and detergents) which hold the droplets in solution. This type of emulsion is often present in cleaning operations and can often be very difficult to remove. Unstable emulsions are created by shearing forces present in mixing: the oil is held in suspension when the interfacial tension of the drops' surface is equal to the force acting on the drops. These will generally separate by physical methods such as extended settling times or filtration methods. Oil/water separators are not able to treat stable emulsions or dissolved oil.

The American Petroleum Institute (API) suggests that the trapping of all oil droplets greater than 60 μm is an appropriate design goal for API oil/water separators (API 1990). The following example was presented by the Local Hazardous Waste Management Program in King County, Washington. The first step is to obtain the oil droplet size distribution, by volume. Droplet size determinations can be made using several techniques, including using a Coulter Counter, manual counting, or using a laser particle counter. The Coulter LS230 is an appropriate laser particle counter, while the Coulter Multi-Sizer IIe measures the oil droplets by sensing their effects on an electrical field. Table 4.1 shows a size distribution of droplets. If the goal is 95% oil reduction, by volume, then all droplets greater than 30 μm should be removed. If the goal was only 65% control, then the critical drop size would be only 90 μm . The critical rise rate (V_T) can be calculated for the critical drop size using Stokes' law and used to select the



Note: The data in this figure are taken from the 1985 API Refinery Survey.

Figure 4.2 Performance of API oil/water separators (API 1990).

most appropriate oil/water separator design. The relationship between the number of droplets and the volume of oil is given in the following equation:

$$\text{Volume of Oil} = (\text{number of droplets}) * (\pi/6) * (\text{diameter of droplets})^3$$

Table 4.1. Example Oil Droplet Size Distribution
(Source: King Co. 1995)

Drop Diameter (μm)	% in Size Range (by count)	% in Size Range (by volume)
<30	10	<1
31 - 60	40	5
60 - 90	30	30
90 - 120	15	45
>120	5	20

Design Flow Rate

The efficiency of a separator also depends upon the flow rate: as the flow increases, the separator performance decreases. Therefore, a separator must be designed to accommodate the maximum expected flow for a given rainfall event.

Effective Horizontal Separation Area

Once the critical rise-rate and maximum flow have been determined, the effective horizontal area is calculated from the equation $A_H = Q/V_T$. This formula, also known as Hazen's principle, is commonly used in oil/water separator design. Often, large areas are required for effective separation. However, stacked coalescing plates can be used to create the necessary separator area in a limited space.

Other Considerations

Selecting the critical (or design) density of oil is another relevant factor in the design of an oil/water separator. The heaviest oil presumed to be present is used in determining the critical rise velocity. In general, densities range from 0.82-0.95. The separator will be most efficient for the lowest oil densities.

Water temperature also affects oil/water separator performance. At lower temperatures, separation becomes more difficult, and therefore, the lowest temperature routinely encountered should be used in the design. Ambient ground temperatures a few meters below the surface can be used to estimate water temperatures for an underground installation. Also, ambient air temperatures during cooler weather can be used. Highland Tank suggests a conservative value within the 5 – 15°C (40 – 60° F) range, unless actual testing indicates that another value should be used.

The solids content of the wastewater must also be considered for separator design. After the basic dimensions of the separator have been calculated, sufficient volume within the separator must be added for solids storage between cleanings. However, the exact amount of solids that may accumulate is not as important as the knowledge that they do enter the system and that one must design for their removal from the separator (Highland Tank). Therefore, a proper design should include not only the needed storage volumes for both hydrocarbons and solids, but also adequate access so that proper monitoring and cleaning may occur.

Gravity Separation

Gravity separation relies on the density differences between oil and water. Oil will rise to the water surface unless some other contributing factor such as a solvent or detergent interferes with the process. For gravity units, this density difference is the only mechanism by which separation occurs. Other technologies, such as air flotation, coalescing plates, and impingement coalescing filters, enhance the separation process by mechanical means.

Gravity separators are the most basic type of separator and are the most widely used. They have few, if any, moving parts and require little maintenance with regard to the structure or operation of the device. Usually, separators are designed to meet the criteria of the American Petroleum Institute (API), and are fitted with other devices such as coalescing plate interceptors (CPI) and filters. Even though these separators are effective in removing free and unstable oil emulsions, they are ineffective in removing most emulsions and soluble oil fractions (Ford 1978). Furthermore, it is important to remember that no gravity oil/water separation device will have a significant impact on many of the other important stormwater pollutants, requiring additional treatment (Highland Tank).

Conventional American Petroleum Institute (API) Oil/Water Separator

The conventional API oil/water separator consists of a large chamber divided by baffles into three sections. The first chamber acts as an equalization chamber where grit and larger solids settle and turbulent flow slows before entering the main separation chamber (Figure 4.3).

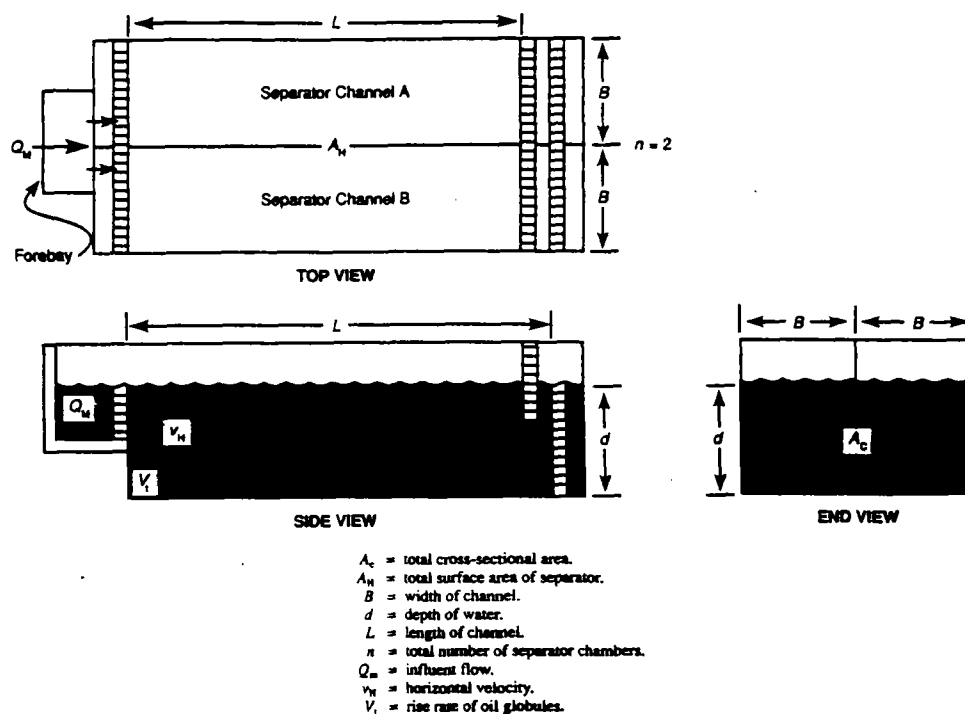


Figure 4.3 API oil/water separator (API 1990).

Often, manufacturers suggest the use of a catchbasin or interceptor tank as a pretreatment device so that coarse material will be kept from entering the oil/water separation tank. After entering the main chamber, solids settle to the bottom and oil rises to the top, according to Stokes' law. Larger API oil/water separators contain a sludge scraper which continually removes the captured settled solids into a sludge pit. The oil is also removed by an oil skimmer operating on the water surface. At the end of the separation chamber, all oil particles having a diameter of larger than the critical size have theoretically risen to the surface and have been removed by an oil skimmer. Small API units usually do not contain an oil skimmer, sludge scraper, or sludge pit. While they are less costly due to the absence of moving parts, they require more frequent cleaning and maintenance. These smaller units have been shown to be as effective as the larger more expensive units, if they receive proper maintenance at regular intervals.

The API has developed a process by which to design a separator. The following steps describe this process with Figure 4.3 used as a reference:

1. Determine the droplet rise velocity (V_T) of the critical droplet size using Stokes' Law:

$$V_T = (g/18\mu) * (\rho_w - \rho_o) * d^2$$

Where:

V_T = rising velocity (terminal velocity) of oil droplets (cm/sec or ft/s)
 g = acceleration due to gravity (cm/sec² or ft/s²)
 μ = absolute viscosity of water (g/cm·s or lb_m/ft·s)
 ρ_w = density of water (g/cm³ or lbm/ft³)
 ρ_o = density of oil (g/cm³ or lbm/ft³)
 d = droplet diameter (cm or ft)

2. Calculate the design horizontal velocity (V_H) using the following equation:

$$V_H = 15 V_T \leq 3 \text{ ft/min}$$

Where:

V_H = horizontal velocity (cm/s or ft/s)

If the calculated velocity is greater than 3 ft/min, then 3 ft/min is used as the appropriate design value.

3. Calculate the minimum vertical cross-sectional area (A_V) using the following equation while using a value for flow rate (Q) that reflects the maximum expected flow:

$$A_V = Q/V_H$$

4. Calculate the channel width (W) and height (H) using the following equation:

$$A_V = H \times W$$

The values H and W will need to conform to the following restraints:

- The depth (d) of the wastewater should be 0.9 – 2.8 m (3 – 8 ft).
- The width (B) of the chamber should be 1.8 – 6.1 m (6 – 20 ft).
- The ratio of depth (d) to width (B) should be 0.3 – 0.5.

Highland Tank notes that these values, as well as the values for horizontal velocity, have a practical basis in that they attempt to limit turbulence within the separation zone and provide a reasonable depth for maintenance while considering construction costs.

5. Calculate the main chamber length (L) using the following equation:

$$L = F * (V_H)/(V_T) * H \geq 5W$$

F is a turbulence and short-circuiting factor, and serves as a correction factor which allows for less than ideal performance. F is a function of V_H and V_T . Values of F are found in American Petroleum Institute publication number 421 (Table 4.2).

Table 4.2. Short-Circuiting Factor
(Source: API 1990)

V_H / V_T	F
20	1.74
15	1.64
10	1.52
6	1.37
3	1.28

6. Finally, the design calculations are checked to see that the actual horizontal surface area is greater than the minimum horizontal area (A_H). If A_H is greater than the actual surface area, then steps 3 through 5 are repeated with different assumptions about height and width. A_H is found by the following equation:

$$A_H = F * (Q/V_T)$$

The API (1990) stipulates that if these design criteria are met, then the separator will remove all oil droplets greater than about 150 μm in diameter. The API reports that retention times are usually greater than the actual design values since actual flows are usually smaller than design flows, hence smaller droplets are removed most of the time. This finding is confirmed by Ruperd (1993) in a study of an oil/water separator treatment device in the community of Velizy, France. Also, API tanks are known to effectively remove large amounts of oil, including slugs of pure oil, and will not be overwhelmed (Tramier 1983). Studies have also shown that these separators can produce effluents down to 30 ppm (Delaine 1995), routinely at 30-150 ppm, with occasional concentrations above 150 ppm, depending upon the flow rate, and hence the retention times (Ford 1978).

The API has stated that very few separators with ratios of surface area to flow within the API design range achieved effluent oil concentrations lower than 100 ppm (API 1990). Therefore, the API separator is a recommended system for the removal of solids and gross oil as a pretreatment device upstream of another treatment system, if additional pollutants of concern are present, or if more stringent effluent standards are to be met.

The following is a partial list of oil/water separator manufacturers in the U.S.:

- Highland Tank and Manufacturing Co., One Highland, Rd. Stoystown, PA 15563
- McTighe Industries, P.O. Box 928, Mitchell, SD 57301-0928
- Xerxes Corp., 7901 Xerxes Rd. Minneapolis, MN 55431-1253

Separation Vaults

Separation vaults are variations on the API oil/water separator design. They are usually either septic tanks or utility vaults that have been fitted with baffles in the manner of an API separator. They are usually poured in place or manufactured locally. Surveys of these vaults in King County, Washington, revealed that they had main chamber depths of 1.2 – 1.5 m (4 – 5 ft), widths of 1.2 – 1.8 m (4 – 6 ft), and lengths of about 1.8 m (6 ft). These vaults are not necessarily designed according to the previously stated API methods and therefore are termed separation vaults to differentiate them from conventional API oil/water separators (King County 1995).

These vaults can theoretically achieve removal of all oil droplets of 75 μm in size, or greater. The following example is from the Local Hazardous Waste Management Program of King County, Washington. A truck maintenance facility utilizes a separation vault with a depth of 1.2 m (4 ft), width of 1.5 m (5 ft), and an effective length of 1.5 m (5 ft), and which receives runoff at a flow of 0.6 L/s (10 gpm, or 0.02 ft^3/s) from the shop floor and washing pad. It is assumed that the runoff consists of non-emulsified oil and solids. The retention time is therefore 4,500 s (75 min). If the rising time is equal to the retention time ($T_{\text{oil}} = T_{\text{water}}$), then the critical droplet diameter is found from the following equation:

$$d_{\text{crit}} = \{[18\mu\text{H}] / [g(\rho_{\text{water}} - \rho_{\text{oil}})T_{\text{water}}]\}^{0.5}$$

This results in a critical droplet size of 75 μm under ideal conditions. This is smaller than the API standard of 150 μm ; however, the API separators have been shown to remove particles down to 30 μm under ideal conditions and the value of 150 μm represents what would normally be achieved under practical applications. Here the 75 μm represents an ideal condition; practical removal sizes would probably be in excess of 150 μm .

Coalescing Plate Interceptor Oil/Water Separators

The coalescing plate interceptor (CPI) oil/water separators are simply conventional API oil/water separators and separator vaults with sets of parallel plates added to the main separation chamber. As small droplets of oil enter the plates, they rise until they encounter the next plate. Other drops also rise and coalesce. As the drops become larger, the buoyant forces acting on them become greater, eventually forcing the drops to slide off the plates and to rise quickly to the surface.

The total horizontal separator area requirement is reduced by the use of parallel plates by compacting the effective separation area into a limited space. The total area is the sum of the area of each plate projected on the horizontal plane, along with the open surface area of the separator itself. According to vendors, the use of coalescing plates can reduce spatial requirements of separators up to two-fold on width and ten-fold on length when used in place of a conventional separator without plates. Plates also help to dampen turbulence in the system, thus helping to maintain laminar flow. Oil collected from these systems has a lower water content than from conventional separators. The overall effluent oil content has been reported to be 60% lower for parallel-plate systems, with a higher proportion of small oil droplets recovered (Brunsmann 1962).

The earliest models of CPI separators used horizontal parallel plates. Currently, two types of parallel-plate separators are marketed: the cross-flow inclined plate separator and the down-flow inclined plate separator. Figure 4.4 is a drawing of a downflow parallel plate separator. In the cross-flow separator, flow enters the plates from the side and oil and sludge accumulates above and below the current. As oil and sludge build up, the oil then breaks free and rises, while the sludge descends to the separator bottom. In a down-flow separator, the water flows downward while oil rises to the above plate, and after coalescence, rises counter to the current to the top, while sludge will descend, helped along by the current.

The plates themselves are corrugated to improve oil and sludge collection. Vertical gutters are placed along the sides of the plates themselves at the influent and effluent points to aid in the collection of oils and solids. The plates are tilted at an angle of 45° - 60°, allowing sludge and oil to slide off, preventing clogging and resulting in lower maintenance requirements. A 45° angle has been found to be most effective for oil removal (Thanh and Thipsuwan 1978), but a 60° angle would reduce maintenance requirements further by insuring less clogging. However, a greater angle would also reduce the effective surface area as the effective surface is equal to the projection of the plates onto the horizontal plane (Branion 1978).

Typical sizes for CPI oil/water separators are shown in the Table 4.3. As shown, the spacing between plates usually ranges from 20 – 40 mm (0.75 – 1.5 in.). However, Dull (1984) found that the optimum distance is 20 mm (3/4 in.), based on practical experience. Spacings 13 mm (1/2 in.) and less are prone to clogging and require intensive maintenance. Wider spacings, of up to 50 mm (2 in.) are occasionally used, but this limits the number of plates that can be placed in a separator, thereby decreasing its effectiveness.

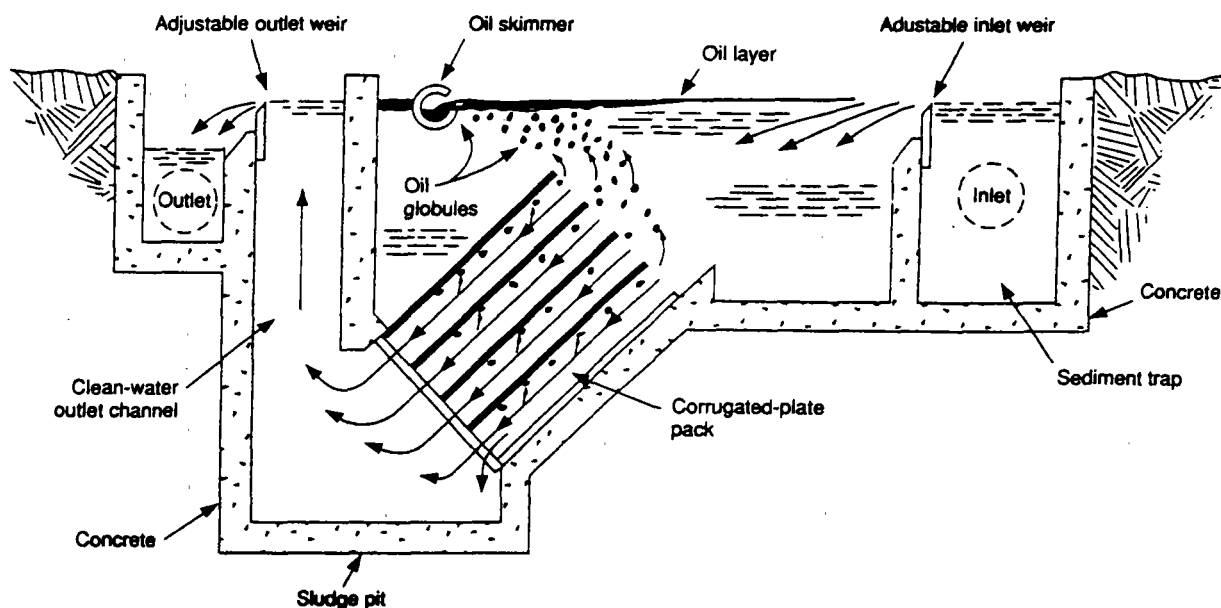


Figure 4.4 Downflow parallel plate separator (API 1990).

Table 4.3. Characteristics of coalescing plate interceptor separators (Source: API 1990)

Characteristic	Range
Perpendicular distance between plates	0.75 - 1.5 inches
Angle of plate inclination from the horizontal	45°- 60°
Types of oil removed	free oil only
Direction of wastewater flow	cross-flow, or down-flow

CPI separators have been found to remove droplets down to 30 to 60 μm size (Ryan 1986; Romano 1990), and have been found to produce effluent concentrations in the range of 10 to 20 ppm (Delaine 1995; Dull 1984; Ryan 1986). CPI separators are a good treatment choice if the wastewater contains smaller droplets and possibly some unstable emulsions with larger diameter droplet sizes. Dissolved oil, stable emulsions, or a large amount of unstable emulsions would decrease the performance of the coalescing plate interceptor separators.

The API notes that it is difficult to describe the separation process in a parallel plate separator due to the variability of plate size, spacing, and inclination. They recommend that users rely on the empirically-derived recommendations of the plate unit vendors when selecting a coalescing plate interceptor separator.

Impingement Coalescers and Filtration Devices

Filtration devices are used as post-treatment after separation in coalescing plate separators, and greatly improves the removal efficiency of a system. Many systems utilize these devices for treatment of industrial runoff; however, they are occasionally used in stormwater applications as well (Aires 1995). The most common type used is a vertical tube coalescer which has a random matrix of vertical tubes made of polypropylene fitted together in bundles. These bundles are placed towards the end of the separation tank before the outlet and after the coalescing plates; however,

some manufacturers use these devices in place of plate systems. Oleophilic (oil-loving) filters provide a maximum coalescing surface, as well as helping to create a more laminar flow. These types of devices can provide better oil removal than a tank fitted only with coalescing plates, often with effluents suitable for direct discharge into surface waters.

Solids are trapped in sharp turns or crevices while oils are removed by two mechanisms occurring within the filters. First, the small passages in the filters allow the oil droplets to come in contact with each other and coalesce together. Second, the oleophilic properties of the media attract oil droplets and hold them until they coalesce with other trapped droplets until they eventually break free and rise to the surface.

The cartridge bundles can be removed and cleaned for reuse, although disposable filters are sometimes used. Disposable cartridge filters have the benefit of having simple maintenance requirements: when filters become clogged or saturated, they are simply removed and discarded. However, this process in itself may be a drawback in that the cartridges may need to be disposed of as a hazardous waste. Further, the cost of filters may be high and quickly reduce any benefit gained from reduced maintenance. Filters are typically made from fiberglass, nylon, polypropylene, and polyurethane foam; and are normally recommended as a secondary stage of treatment after gross solids and oil have been removed (Webb 1991).

Other problems exist with filter cartridges as well. Filters are easily clogged, even when pretreatment occurs. Also, if stable emulsions are present, surfactants will poison the filter by interfering with the surface-wetting properties of the filter (Tabakin, *et al.* 1978). Despite these problems, filters are known to remove oil to concentrations as low as 10 ppm, with all droplets greater than 20 μm being removed (Xerxes Corp).

Maintenance of Oil/Water Separators

Problems with oil/water separators can be attributed largely to poor maintenance by allowing waste materials to accumulate in the system to levels that hinder performance and to levels that can be readily scoured during intermittent high flows. When excess oil accumulates, it will be forced around the oil retention baffle and make its way into the discharge stream. Also, sludge buildup is a major reason for failure. As waste builds up, the volume in the chamber above the sludge layer is reduced and therefore the retention time is also reduced, allowing oil to be discharged. Therefore, the efficiency of oil/water separators in trapping and retaining solids and hydrocarbons depends largely upon how they are maintained. They must be designed for ease of maintenance and be frequently maintained. Apparently, few oil/water separators built for stormwater control are adequately maintained.

Manufacturers of prefabricated oil/water separators, as well as the American Petroleum Institute, all recommend periodic inspection and maintenance. Some manufacturers advise that these devices be cleaned twice per year, even if the device is apparently working properly. However, it is best if the devices are inspected after every rainfall to determine the rate of hydrocarbon and sludge buildup. The most effective maintenance schedule can then be obtained for each individual device. French researchers also advocate this approach, by developing individual maintenance schedules after intensive observations for six months (Aires 1995).

Ease of maintenance must be considered when designing separators, including providing easy access. Maintenance on these devices is accomplished by using suction equipment, such as a truck mounted vacuum utilized by personnel trained to handle potentially hazardous waste. The vacuum is used to skim off the top oil layer and the device is then drained. In larger devices, the corrugated plates are left in place, but otherwise, they are lifted out along with any other filter devices that are present. The sludge is then vacuumed out or shoveled out and any remaining solids are loosened by spraying hot water at normal pressure.

Maintenance of parallel plate units and coalescing filters is similar. The separator is drained and the plates are washed by spraying. If there is inadequate space, then the plates will need to be lifted from the separator for effective cleaning. Cleaning should occur when coating of the plates is evident and before accumulations begin to clog the spaces. Cleaning of polypropylene coalescing tubes is also accomplished by lifting out the tube bundles and cleaning with a hose or high pressure water spray to remove accumulated oil and grit. Sludge is removed from

underneath the coalescer supports and the coalescers are then replaced. No soaps or detergents are used in cleaning polypropylene components as they would destroy the oleophilic nature of the material.

Performance of Oil/Water Separators for Treating Stormwater

Manufacturers state that efficiencies observed during testing of oil/water separators are on the order of 97 – 99% for the removal of oil from wastewater. The test method typically applies oil to a paved washpad, with water added via a sprinkler system to simulate rainfall. Oil is of a specified density (typically 0.72 – 0.95). These synthetic events are necessary to evaluate the performance of a separator but do not necessarily reflect the processes which occur during actual rainfall conditions where rapidly changing flows rates, unknown oil mixtures, and other pollutants are present. Published research is difficult to find on how these units actually perform once placed in operation.

Interception of solid particles through settling, and flotation of oils and other floatables are processes occurring within an oil/water separator. French studies have shown that the average SS removal efficiency of separators is about 50% (Aires 1995). Oil/water separation requires an ascending speed of about 8 m/h, while the settling velocity of solids require descending velocities on the order of 1 to 3 m/h. At rates of 20% of the design flow rate, about 80% of the solids are removed; at 30% of the design flow rate, about 50% of the solids are removed. Negative removals also occur as the result of resuspension of previously settled material (Legrand, *et al.* 1994).

In many instances, pretreatment tanks are placed before the oil/water separator to remove settleable solids before stormwater enters the separator. A study in Velizy, France, found that the SS removal efficiency of a separator, placed downstream of a settling pond, was about 13%. This low value was attributed to the fact that solids had been allowed to settle during pretreatment, and therefore influent to the device had a low content of only the most difficult to remove solids (Ruperd 1993).

When the concentration of the oil in the wastewater is high, the oil removal efficiency increases. In Velizy, France, Ruperd (1993) found that oil/water separators fitted with cross current separators had removal efficiencies ranging from zero to 90%, with an average of 47%. Low efficiencies were associated with low influent levels and greater efficiencies were associated with higher influent levels. This finding supports those of Tramier (1983), stated earlier, that separators are effective in removing large amounts of oil when the oil concentrations are elevated.

The Metropolitan Washington Council of Governments (Washington, D.C.) has conducted a survey of 109 separator vaults in suburban Maryland and subsequently examined 17 in detail to determine their long-term effectiveness (Schueler and Shepp 1993). These separators were used for controlling runoff from areas associated with automobile usage. These separators were either pre-cast or poured in place concrete structures consisting of one, two or three chambers. The results of this study revealed that the amount of trapped sediments within separators varied from month to month and that the contained waters were commonly completely displaced during even minor storms (Shepp and Cole 1992). Figure 4.5 shows the variability in average sediment depth with time for these 17 separators.

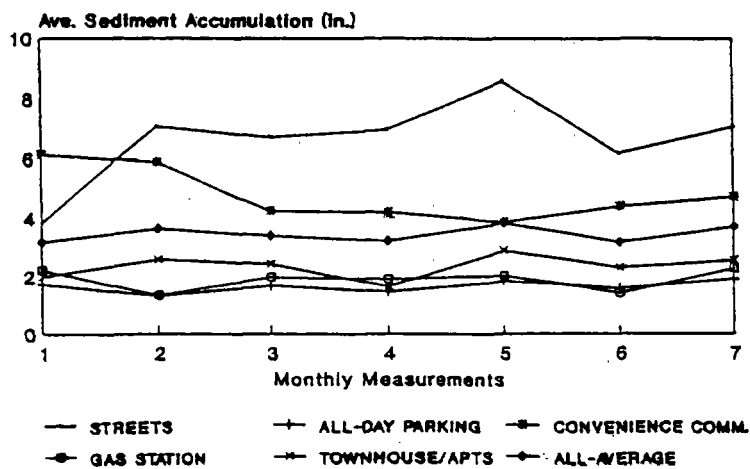


Figure 4.5 Monthly changes in sediment in 17 oil/water separators (Schueler and Shepp 1993).

Of the original 109 separators that were observed in the survey, devices less than one year old were effective in trapping sediments. Devices older than one year appeared to lose as much sediment as they retained (Shepp and Cole 1992). Not one of these separators had received maintenance since their installation. Survey observations suggested no net accumulation of sediment over time, in part because they received strong variations in flow. Of the 109 separators surveyed in this suburban Maryland study, 100% had received no maintenance, 1% needed structural repair, 6% were observed to have clogged trash racks, 84% contained high oil concentrations in the sediments trapped in their first chamber, 77% contained high oil concentrations in the sediments trapped in their second chambers, 27% contained high oil and floatables loading in their first chambers, and 23% contained high oil and floatables loading in their second chambers.

Numerous manufacturers have developed small prefabricated separators to remove oils and solids from runoff. These separators are rarely specifically designed and sized for stormwater discharges, but usually consist of modified oil/water separators. Solids are intended to settle and oils are intended to rise within these separators, either by free fall/rise or by counter-current or cross-current lamella separation. Many of these separators have been installed in France, especially along highways (Rupperd 1993). Despite the number of installations, few studies have been carried out in order to assess their efficiency (Aires and Tabuchi 1995).

The historical use of oil/water separators to treat stormwater has been shown to be ineffective for various reasons, especially lack of maintenance and poor design for the relatively low levels of oils present in most stormwaters (Schueler 1994). Stormwater treatment test results from Fourage (1992), Rupperd (1993) and Legrand, *et al.* (1994) show that these devices are usually greatly under-sized. They may possibly work reasonably well at flow rates between 20 and 30% of their published design hydraulic capacities. For higher flow rates, the flow is very turbulent (the Reynolds numbers can be higher than 6000), and improvements in settling by using lamella plates is very poor. These devices need to be cleaned very frequently. If they are not cleaned, the deposits are scoured during storm events, with negative efficiencies. However, the cleaning is usually manually conducted, and expensive. In addition, the maintenance job is not very easy because the separators are very small. Some new devices are equipped with automatic sediment extraction pumps which should be a significant improvement. Currently, these researchers have found that the cleaning frequencies are very insufficient and the stormwater quality benefits from using oil/water separators are very limited.

The Multi-Chambered Treatment Train (MCTT)

Phase 3 - Field Demonstrations of the Multi-Chambered Treatment Train

The Multi-Chambered Treatment Train (MCTT) was developed to specifically address many of the previously stated problems found for oil/water separators used for stormwater treatment at critical source areas. It was developed and tested with specific stormwater conditions in mind, plus it has been tested at several sizes for the reduction of stormwater pollutants of concern. The MCTT is intended to reduce organic and metallic toxicants, plus suspended solids, in the stormwater. Oil/water separators are intended to reduce very large concentrations of floating oils that may be present in industrial wastewaters. The extremely high concentrations of oils that the oil/water separators are most effective in removing are very rare in stormwater, even from critical source areas. If a site has these high levels, then an oil/water separator may be needed, in addition to other controls to reduce the other critical pollutants likely present. The MCTT can remove the typically highest levels of oils that may be present in stormwater from most critical source areas, plus also providing control of the trace toxicants present.

Earlier bench scale treatability studies conducted during this research (Chapter 3) found that the most beneficial treatment for the reduction of stormwater toxicants (as measured using the Microtox™ test) included quiescent settling for at least 24 h (generally 40% to 90% reductions), screening through at least 40 µm screens (20% to 70% reductions), and aeration and/or photo-degradation for at least 24 h (up to 80% reductions). These processes were combined in the MCTT. The MCTT contains aeration, sedimentation, sorption, and sand-peat (or other media) filtration and has been shown to provide excellent toxicant reductions.

The third research phase of this project included pilot- and full-scale tests of the MCTT. A pilot-scale MCTT treatment device was installed at a large parking lot and vehicle maintenance area in Birmingham, AL, on the University of Alabama at Birmingham campus. In addition, the state of Wisconsin Department of Natural Resources (WI DNR) (in conjunction with Region V of EPA, the USGS, and the affected cities) installed full-scale MCTT units at a public works yard in Milwaukee and at a city parking area in Minocqua. These full-scale tests are still in progress, with preliminary results summarized in this report.

The MCTT is most suitable for use at relatively small and isolated paved critical source areas, from about 0.1 to 1 ha (0.25 to 2.5 acre) in area. These areas include vehicle service facilities (gas stations, car washes, oil change stores, etc.), convenience store parking areas and areas used for equipment storage, along with salvage yards. The MCTT is an underground device that has three main chambers: an initial grit chamber for reduction of the largest sediment and most volatile materials; a main settling chamber (containing initial aeration and sorbent pillows) for the trapping of fine sediment and associated toxicants and floating hydrocarbons; and a sand and peat mixed media sorption/ion exchange unit for the removal of filterable toxicants. A typical MCTT requires between 0.5 and 1.5 percent of the paved drainage area, which is about 1/3 of the area required for a well designed wet detention pond.

A pilot-scale MCTT was constructed in Birmingham, AL, and tested over a six month monitoring period, from May to October, 1994. Two additional full-scale MCTT units have recently been constructed and are currently being monitored as part of Wisconsin's 319 grant from the U.S. EPA. Complete organic and metallic toxicant analyses, in addition to conventional pollutants, were included in the analysis program. During monitoring of 13 storms at a parking facility, the Birmingham pilot-scale MCTT was found to have the following overall median reduction rates: 96% for total toxicity (as measured using the Microtox™ screening test), 98% for filtered toxicity, 83% for SS, 60% for COD, 40% for turbidity, 100% for lead, 91% for zinc, 100% for n-Nitro-di-n-proplamine, 100% for pyrene, and 99% for bis (2-ethyl hexyl) phthalate. The color was increased by about 50% due to staining from the peat and the pH decreased by about one-half pH unit, also from the peat media. Ammonia nitrogen was increased by several times, and nitrate nitrogen had very low reductions (about 14%). The MCTT therefore operated as intended: it had very effective reduction rates for both filtered and particulate stormwater toxicants and SS. Increased filterable toxicant reductions were obtained in the peat/sand mixed media sorption/ion exchange chamber, at the expense of increased color, lowered pH, and depressed COD and nitrate reduction rates. The preliminary full-scale test results substantiate the excellent reductions found during the pilot-scale tests, while showing better control of COD and nutrients and less detrimental effects on pH and color. The test results are discussed later in more detail.

Development of the MCTT

The MCTT includes a catchbasin/grit chamber followed by a two chambered tank that is intended to reduce a broad range of toxicants (volatile, particulate, and dissolved). The runoff enters the catchbasin chamber by passing over a flash aerator (small column packing balls with counter-current air flow) to remove highly volatile components, if present, and to capture large debris (such as plastic bags and litter). This catchbasin also serves as a grit chamber to remove the largest (fastest settling) particles. The second chamber serves as an enhanced settling chamber to remove smaller particles and has inclined tube or plate settlers to enhance sedimentation. The tube or plate settlers are mostly used to prevent scour of deposited small particles. This chamber also contains fine bubble diffusers and sorbent pads to further enhance the removal of floatable hydrocarbons and additional volatile compounds. The water is then pumped to the final chamber at a slow rate to maximize pollutant reductions. The final chamber contains a mixed media (usually sand and peat) slow filter (sorption/ion exchange) device, with a filter fabric top layer. The MCTT is typically sized to totally contain all of the runoff from a 6 to 20 mm (0.25 to 0.8 in) rain, depending on interevent time, rain size, and rain intensity patterns for the site.

The treatability and source area information previously described in this report can be used to develop other source area or outfall stormwater controls. As an example, it would be relatively easy to enhance the performance of typical wet detention ponds by adding some of the unit processes investigated. The most important control process would be to enhance the capture of small particles. In addition, water circulation and aeration may also enhance toxicant control by better utilizing photo-degradation and aeration processes. Care obviously needs to be taken to minimize scour of the deposited sediments. Conventional aeration design usually results in a circulation and aeration system than would have about 1/10 of the energy requirements needed for bottom scour. Subsurface discharges would also be an important addition in a wet detention pond to maximize capture of floatable debris and oils. Obviously, many

other small units like the MCTT can be conceived and used for stormwater control at critical areas also. Typical goals would be to use a treatment unit having redundant processes, is easy to maintain, is robust for the changing conditions expected, and has the least cost possible for the needed level of stormwater control.

Catchbasin/Grit Chamber

Catchbasins have been found to be effective in removing coarser runoff solids. Moderate reductions in total and suspended solids (SS) (up to 45%, depending on the inflowing water rate) have been indicated by prior studies (Lager, *et al.* 1977, Aronson, *et al.* 1983, Pitt 1979, and Pitt 1985). While relatively few pollutants are associated with these coarser solids, their removal decreases maintenance problems of the other MCTT chambers.

Pitt, *et al.* (1997) (another volume in this series) recently evaluated three storm drain inlet designs in Stafford Township, New Jersey: a conventional catchbasin with a sump, and two representative designs that used filter fabric material. The inlet devices were located in a residential area. Twelve storms were evaluated for each of the three inlet units by taking grab composite samples using a dipper sampler throughout the events. Influent and effluent samples were analyzed for a broad range of conventional pollutants, metals, and organic toxicants, both in total and filtered forms. The catchbasin with the sump was the only device that showed important and significant removals for several pollutants:

- total solids (0 to 50%, average 22%).
- suspended solids (0 to 55%, average 32%).
- turbidity (0 to 65%, average 38%).
- color (0 to 50%, average 24%).

The MCTT catchbasin/grit chamber design is based upon a recommended design from previous studies of catchbasins. This design suggests using a circular catchbasin with the diameter 4 times the diameter of the circular outlet. The outlet is then placed 1.5 times its diameter from the top and 4 times its diameter from the bottom of the catchbasin, thus providing a total depth of 6.5 times the outlet diameter (Lager, *et al.* 1977 and Aronson, *et al.* 1983). The size of the MCTT catchbasin is controlled by three factors: the runoff flow rate, the SS concentration in the runoff, and the desired frequency at which the catchbasin will be cleaned so as not to sacrifice efficiency.

Main Settling Chamber

The main settling chamber mimics the completely mixed settling column bench-scale tests previously conducted and uses a hydraulic loading rate (depth to time ratio) for removal estimates. This loading rate is equivalent to the conventional surface overflow rate (SOR), or upflow velocity, for continuous-flow systems, or the ratio of water depth to detention time for static systems. The MCTT can be operated in both modes. If it uses an orifice, to control the settling chamber outflow, then it operates in a similar mode to a conventional wet detention pond and the rate is the upflow velocity (the instantaneous outflow divided by the surface area of the tank). If the outflow is controlled with a float switch and a pump, then it operates as a static system and the hydraulic loading rate is simply the tank depth divided by the settling time before the pump switches on to remove the settled water. The following discussion describes the development of the this conventional settling tank design parameter.

Upflow Velocity

Linsley and Franzini (1964) stated that in order to get a fairly high percentage removal of particulates, it is necessary that a sedimentation tank be properly designed. In an ideal system, particles that do not settle below the bottom of the tank's outlet will pass through the sedimentation tank, while particles that do settle below/before the outlet will be retained. In the MCTT, the retention of the settled material is enhanced through the use of the inclined tube settlers which prevent scouring velocities from re-suspending previously settled particles.

The path of any particle is the vector sum of the water velocity (V) passing through the tank and the particle settling velocity (v). Therefore, if the water velocity is slow, slowly falling particles can be retained. If the water velocity is fast, then only the heaviest (fastest falling) particles are likely to be retained. The critical ratio of water velocity to particle settling velocity must therefore be equal to the ratio of the sedimentation tank length (L) to depth to the bottom of the outlet (D):

$$\frac{V}{v} = \frac{L}{D}$$

as shown on Figure 4.6.

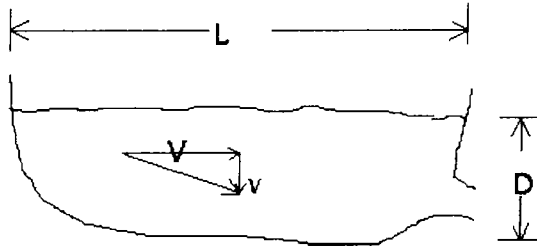


Figure 4.6. Critical Velocity and Settling Tank Dimensions

The water velocity is equal to the discharge rate (Q , such as measured by cubic feet per second) divided by the tank cross-sectional area (a , or depth times width: DW):

$$V = \frac{Q}{a}$$

or

$$V = \frac{Q}{DW}$$

The tank outflow rate equals the tank inflow rate under steady state conditions. The critical time period for steady state conditions is the time of travel from the inlet to the outlet. During critical portions of a storm, the inflow rate (Q_{in}) will be greater than the outflow rate (Q_{out}) due to freeboard storage. The outflow rate is therefore less and controls the water velocity through the tank. By substituting this definition of water velocity into the critical ratio:

$$\frac{Q_{out}}{WDv} = \frac{L}{D}$$

The water depth to the outlet bottom (D) cancels out, leaving:

$$\frac{Q_{out}}{Wv} = L$$

Or

$$\frac{Q_{out}}{v} = LW$$

However, tank length (L) times tank width (W) equals tank surface area (A). Substituting leaves:

$$\frac{Q_{out}}{v} = A$$

and the definition of upflow velocity:

$$v = \frac{Q_{out}}{A}$$

where

Q_{out} = tank outflow rate (cubic feet per second),

A = tank surface area (square feet: tank length times tank width), and

v = upflow velocity, or critical particle settling velocity (feet per second).

Therefore, for an ideal sedimentation tank, particles having settling velocities less than this upflow velocity will be removed. Only increasing the surface area, or decreasing the tank outflow rate, will increase particle settling efficiency. Increasing the tank depth lessens the possibility of bottom scour. Deeper tanks may also be needed to provide sacrificial storage volumes for sediment between sediment removal operations.

For slowly changing flow conditions (such as when quiescent settling is provided in the MCTT by a pump and float switch), the following relationships can be shown:

$$t = \frac{Volume}{Flow\ rate}$$

and

$$Flow\ rate\ (Q_{out}) = \frac{Volume}{t}$$

where t = hydraulic detention (residence) time. With

$$v = \frac{Q_{out}}{A}$$

and substituting:

$$v = \frac{Volume}{(t)(A)}$$

but

$$Volume = (A)(depth)$$

therefore,

$$v = \frac{(A)(depth)}{(t)(A)}$$

leaving:

$$v = \frac{depth}{t}$$

It is seen that the overflow rate (Q/A) is equivalent to the ratio of tank depth to detention time, not just detention time alone. Therefore, the MCTT main settling tank can be sized and evaluated using either of these methods. A continuous simulation computer model, presented later, used this relationship to develop storage/treatment design curves for many U.S. cities.

In addition to housing plate or tube settlers, the main settling chamber also contains floating sorbent “pillows” to trap floating oils and a fine bubble aerator that operates during the filling time of the MCTT. Plate settlers (or inclined tubes) increase solids removal by reducing the distance particles travel to the chamber floor and by reducing scour potential. Plate settler theory is described by Davis, *et al.* (1989). The main settling chamber operates much like a settling tank, as described above, but with the plate settlers increasing the effective surface area of the tank. The increase in performance is based on the number of plate diagonals crossing the vertical. If the plates are relatively flat and close together, the increase in performance is greater than if the plates are steeper and wider apart. The effective increase is usually about 3 to 5 fold.

The fine bubble aerator serves two functions: to support aerobic conditions in the settling chamber and to provide dissolved air flotation of particles. Aeration was used during the pilot-scale MCTT tests, but was not used during the full-scale Wisconsin MCTT tests. Flotation has been utilized in industrial applications and combined sewer overflow studies (Gupta, *et al.* 1977). The settling time in the main settling chamber typically ranges from 1 to 3 d, and the settling depth typically ranges from 0.6 to 2.7 m (2 to 9 ft). These depth to time ratios provide for excellent particulate (and associate pollutant) removals in the main settling chamber.

Toxicity Reductions Associated with Particle Settling

Figure 4.7 shows the percent toxicity reductions (compared to the initial toxicity levels) for all samples, plotted against the hydraulic loading (depth/time), for plain settling alone. This hydraulic loading rate is for batch processes which is equivalent to the surface overflow rate (ft/s) for continuous processes, as shown above. The range of possible toxicant reductions can vary greatly, depending on sample characteristics. The settling chamber is therefore supplemented by other processes, including flash aeration, extended aeration, sorbent pillows, sorption and ion exchange, and sand filtration which combine to reduce variations in overall treatment performance.

This figure indicates that depth/time ratios of at least 3×10^{-5} m/s (1×10^{-4} ft/s) are needed to obtain a median toxicity reduction of at least 70 percent in the main settling chamber. If the main settling chamber tank was one meter (3.3 ft) deep, then the required detention time would have to be at least 0.4 days to obtain this level of treatment. If the tank was twice as deep, the required detention time would be 0.8 days. The tank surface area is therefore based on the volume of runoff to be detained and the settling depth desired/available. Shallow tanks require shorter detention times than deeper tanks, but the surface areas are correspondingly larger. Since the MCTT is placed underground, a tank having a large surface area (and a shallower depth) may be much more expensive than

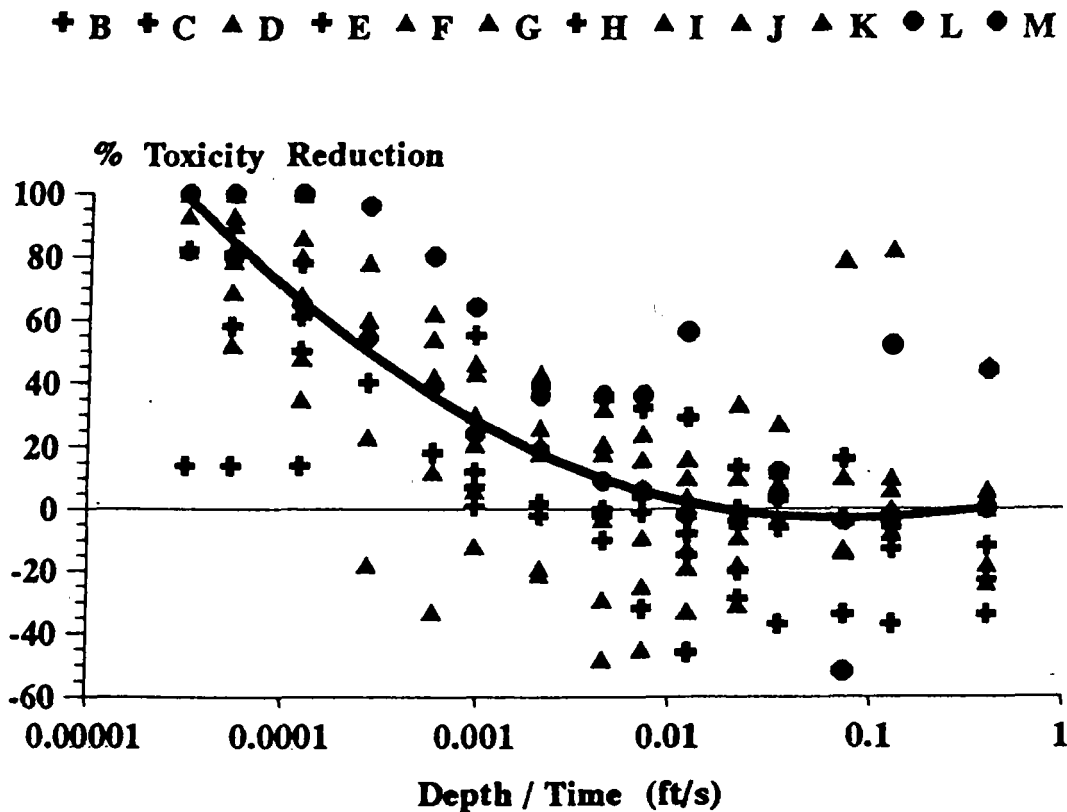


Figure 4.7 Effects of hydraulic loading on toxicity reduction.

a deeper tank requiring a longer detention time. The needed tank dimensions are therefore sensitive to specific site conditions, including:

- available depth before interferences with existing buried utilities that cannot be moved, or bedrock,
- the hydraulic grade line of the drainage system,
- costs for different sizes and shapes of tanks, including structural problems associated with having a large roofed tank in areas having heavy surface traffic, and
- the local rainfall characteristics.

If the rains are infrequent, long detention periods are easily obtained without having “left-over” water in the tank at the beginning of the next event. However, if the rains are frequent, the available holding times are shortened, requiring shallower main settling chamber tanks for the same level of treatment. The discussion of storage/treatment trade-offs later in this chapter presents a computer spreadsheet program that was used to determine the most effective tank sizes and detention periods for different areas of the US. Chapter 6 also includes an example showing how these trade-offs are evaluated for an example design for Detroit, MI.

Filter/Ion exchange Chamber

The final MCTT chamber is a mixed media filter (sorption/ion exchange) device. It receives water partially treated by the grit and the main settling chambers. The initial designs used a 50/50 mix of sand and peat moss, while the Ruby Garage full-scale MCTT in Milwaukee used a 33/33/33 mixture of sand, peat moss, and granulated activated carbon. The MCTT can be easily modified to contain any mixture of media in the last chamber. However, care must be taken to ensure an adequate hydraulic capacity. As an example, peat moss alone was not effective because it compressed quickly, preventing water from flowing through the media. However, when mixed with sand, the hydraulic capacity was much greater and didn't change rapidly with time. The following is a summary of some of the media investigated in prior stormwater treatment devices. Clark and Pitt (1997), another report in this research series, present much more detail pertaining to alternative treatment media for stormwater control. Table 4.4 is a summary of past stormwater treatment benefits from using different filtering media.

Table 4.4. Reported Filtration Media Performance for Stormwater Control

Pollutant	Sand ¹	Leaf Compost ²	Peat Moss ³
Suspended Solids	70	95	90
Turbidity	n/a	84	n/a
Total Nitrogen	21	n/a	50
Total Kjeldahl Nitrogen	46	56	n/a
Nitrate - Nitrogen	0	n/a	n/a
Total Phosphorus	33	40	70
BOD ₅	70	n/a	90
Fecal Coliform Bacteria	76	n/a	90
COD	n/a	67	n/a
Total Organic Carbon	48	n/a	n/a
Iron	45	89	n/a
Copper	n/a	67	80
Lead	45	n/a	80
Zinc	45	88	80
Petroleum Hydrocarbons	n/a	87	n/a

¹ City of Austin (1988)

² W&H Pacific (1992)

³ Galli (1990)

Sand

Sand filtration for stormwater treatment began in earnest in Austin, Texas (City of Austin 1988). Sand filters in Austin have been used for single sites and for drainage areas less than fifty acres. They are designed to hold and treat the first one-half inch of runoff with very good pollutant reductions. In Washington, D.C., sand filters are used both to improve water quality and to delay the entrance of large slug inputs of runoff into the combined sewer system. Water quality filters are designed to retain and treat 8 – 13 mm (0.3 – 0.5 in.) of runoff, with the specific filter size depending on the amount of impervious area in the watershed (Galli 1990). In the State of Delaware, sand filters are recognized as an acceptable method for achieving the 80% reduction requirements for SS, especially for sites with large impervious areas that drain directly to the filter. The purpose of the filter in many areas is to help prevent or postpone clogging of an infiltration device (Shaver 1991). According to Delaware's specifications, the sand filter should adequately remove particulates (SS reduction efficiency 75 – 85%) but not soluble compounds. Studies of a six year old sand filter in Maryland found that the filter is just now becoming clogged after use in a heavily traversed parking lot. Inspection below the surface of the sand filter shows that oil, grease, and finer sediments have migrated into the filter, but only to a depth of about two to three inches (Shaver 1991).

Peat Moss

Peat is a partially decomposed organic material that forms in water in the absence of air. Generally, the more decomposed the peat is, the lower its hydraulic conductivity (Cohen, *et al.* 1991). Peat is generally light in weight when dry, and is highly adsorptive of water. Peat has a large surface area per unit volume and has a high cation exchange capacity (Clymo 1963). Peat naturally performs an ion exchange with copper, zinc, lead, and mercury, especially at pH levels between 3.0 and 8.5. This capacity to bind and retain cations, though, is finite and reversible

and is determined mostly by the pH of the solution. Peat is an excellent substrate for microbial growth and assimilation of nutrients and organic waste materials because of its high C:N:P ratio, which often approaches 100:10:1. Peat's ability to retain phosphorus in the long-term is related to its calcium, aluminum, iron and ash content. The higher the content of each of the above constituents, the higher the retention capability. Peat is also polar and has a high specific adsorption for dissolved solids such as transition metals and polar organic compounds (Galli 1990). Sorption of organic contaminants is facilitated by the organic content of peat. Polarity is believed to play a strong role in sorption of nonionic organics, although the role of various molecular forces in sorption is not well documented (Chiou and Kille 1994). Cohen, *et al.* (1991) found that more decomposed peat provides slightly greater reductions of selected organics than less decomposed peat.

Combined Sand and Peat Moss Filters

Peat generally has been combined with sand to create a sand-peat moss filter. The sand-peat filter system designed by the Metropolitan Washington Council of Governments (Washington, D.C.) has a grass cover on top underlain by twelve to eighteen inches of peat. The peat layer is supported by a 100 mm (4 in.) mixture of sand and peat which is supported by a 0.5 – 0.6 m (20 – 24 in.) layer of fine to medium sized sand. Gravel and an underdrain pipe is placed under the sand. The mixture layer is required because it provides the necessary continuous contact between the peat and the sand layers, ensuring a uniform water flow. Because this is a biological filtration system, it works best during the growing season when the grass cover can provide the additional nutrient reduction that will not occur in the rest of the system (Galli 1990). The sand-peat filter is usually an aerobic system. Modifications to the original design by the Metropolitan Washington Council of Governments have been made to account for unusual site conditions or reduction requirements.

Preliminary Filtration Tests with Stormwater

During the initial design of the MCTT, a sand filter alone was expected to permanently retain any particles that it trapped. Preliminary bench-scale tests, however, showed that sand by itself (especially if recently installed) did not permanently retain the stormwater toxicants (which are mostly associated with very fine particles and which were mostly washed from the sand during later events). There were no mechanisms to permanently retain the pollutants in the fresh sand. This lack of ability to retain stormwater toxicants prompted the investigation of other filtration media. Preliminary research has been conducted at the University of Alabama at Birmingham to further evaluate different filter media as part of this U.S. EPA supported cooperative research agreement for this work (Clark and Pitt 1997). The following list shows the preliminary results from filtration of stormwater runoff using the peat-sand filter:

- Toxicity: > 70% toxicity reduction efficiency,
- Turbidity: increase in turbidity (influent turbidity values were low: < 15 NTU),
- Conductivity: no noticeable reduction (influent conditions were between 50 and 175 μ S/cm),
- pH: effluent 0.5 - 1.0 pH units lower than influent (influent values were between 6.7 and 7.7),
- Apparent color: slight increase in color (influent color was between 15 and 60 HACH color units),
- Chemical Oxygen Demand: slight increase in COD (influent COD values were between 80 and 100 mg/L),
- Particle size distribution: large reductions throughout size range (most influent particle sizes were between 1 and 50 μ m).

Combinations of filtration media, including organic materials (peat moss, activated carbon, composted leaves, and a cotton processing waste material), Zeolite, and sand, were also investigated for their ability to more permanently retain stormwater pollutants (Clark and Pitt 1997). Sand has been mixed with most of these materials in order to maintain adequate hydraulic capacities, especially for peat. Initial clogging tests have shown that channeling still occurred in the Zeolite-sand combination media, significantly decreasing the performance by decreasing the contact time provided by simple gravity flow. The use of a restrictive filter fabric placed on top of the peat-sand filter in the MCTT allows the water to spread over the filter and help prevent preferential channel flow.

The sand-peat filter possesses ion exchange, adsorption, and filtration reduction mechanisms. As the media ages, the performance of these processes will change. Ion exchange capacity and adsorption sites, primarily associated with the peat moss, will be depleted. Filtration, primarily associated with the sand, however, is expected to increase,

especially for the trapping of smaller particles. Improved performance of sand filters with age has been documented by Darby, *et al.* (1991). Eventually though, the sand-peat filter will become clogged by solids and the exchange capacity of the peat will be exceeded, requiring replacement of the media. Replacement is expected to be required about every 3 to 5 years.

Site Specific Design Requirements of the MCTT Main Settling Chamber

The design of the MCTT main settling chamber can be separated into the following general steps:

- determine the pollutant removal goal
- conduct a site survey to determine drainage area and character, subsurface conflicts (existing buried utilities and bed rock), and special surface loading conditions (such as from heavy public works vehicles)
- determine the needed hydraulic grade line for the drainage system receiving the MCTT effluent
- select a series of candidate MCTT tank depths and holding periods for the desired pollutant removal rate from the continuous simulation results for the area nearest to the site that meet the above restraints
- determine critical runoff volumes that need to be captured for the alternative tank depths and holding times
- investigate alternative available tank components and select the most appropriate tank

Of course, the initial catchbasin/grit chamber and the final “filter/sorption” chamber, also need to be designed. Chapter 6 contains an example for the design of a complete MCTT. This chapter is intended to describe the information that was used to develop the main settling chamber design guidelines, the most important pollutant removal component of the MCTT.

A large fraction of the annual runoff volume is generally due to small to moderate sized storm events. In many parts of the country, 85 percent of all the rains are less than 15 mm in depth (and usually last only a few hours in duration). These small rains can generate about 70 percent of the total annual runoff, depending on the land use. The influence of infiltration and initial abstractions is great (being about 1/3 to 2/3 of the total rainfall) for these small rains for typical urban paved areas. Therefore, special small storm hydrology procedures that accurately consider the runoff losses for these small events are needed for water quality investigations, as opposed to conventional large storm hydrology procedures that are used for drainage design (Pitt 1987).

The design of a stormwater treatment device, including the MCTT, is greatly dependent on the rainfall pattern for a specific area. In water quality evaluations, a single “design storm” is not evident because of the many factors comprising runoff quality (runoff volume, runoff flow rate, water temperature, concentrations of many different pollutants, etc.). It is not very clear under which storm condition the combination of these factors is critical for the beneficial uses. In addition, targeting a specific size storm is no guarantee that all storms of lesser magnitude will also be adequately controlled. Continuous simulation is therefore needed to effectively design and evaluate most stormwater quality controls. The following describes the continuous simulation used to develop design guidelines for the MCTT.

Toxicity Reduction through Settling

A critical aspect of the main settling tank design is the reduction of the toxicants through settling. The spreadsheet storage/treatment model used the toxicity reduction values shown in Table 4.5. This table shows the settling rates (m/s) and median toxicity reductions for a 2.1 m (7 ft) deep main settling chamber with the water held for various times (from Figure 4.7). The same settling rates and toxicity reductions would occur if the main settling chamber was half as deep (1.1 m or 3.5 ft in this example) and the water was held for half as long. For this shallower example, however, the treatment tank would have to be twice as large in surface area to provide the same volume. The computer simulation shows the significance of having an adequate volume.

Table 4.5. Median Toxicity Reduction for Different Treatment Holding Times

2.1 m Deep Settling Column Holding Period (h)	Equivalent Settling Rate (m/s)	Median Toxicity Reduction (%) per Individual Rain
6	9.8×10^{-5}	46
12	4.9×10^{-5}	60
24	2.5×10^{-5}	75
36	1.6×10^{-5}	84
48	1.2×10^{-5}	92
72	8.2×10^{-6}	100

Storage/Treatment Trade-Offs in MCTT Design

A computer simulation spreadsheet model (shown in Table 4.6) was developed to determine the toxicity reduction for each individual storm (based on storm depth and interevent time available), the amount of annual rainfall treated, and the overall annual toxicity reduction (Ayyoubi 1993). This information was plotted to obtain design curves to enable the selection of the most effective combination of settling period, holding period, and storage volume. A long holding period would result in better treatment than a short holding period, but may result in water remaining in the MCTT at the beginning of the next storm. This will reduce the effective storage volume, with some of the later storm possibly being diverted around the MCTT, without any treatment. Similarly, a holding time can be too short. This would result in very little water held in the tank at the beginning of the next rain, but the short holding time may not provide adequate treatment. In all cases, the smallest storage volume for a specific removal rate would be desired.

The model was run for various storage capacities, holding periods, and settling tank depths for 21 cities throughout the U.S. having annual rains from about 180 – 1500 mm (7 – 60 in.) (design curves presented in Chapter 6). The model used the rain depths and durations, the time interval between the consecutive storm events, the dimensions of the subsurface tank, and the tank pumpout or drainage time. A random set of 100 rain events from the past 5 to 10 years (from EarthInfo CD-ROMs, Boulder, CO,) was used for each city in these simulations.

Table 4.7 is an example use of this computer program for Birmingham, AL, the site of the pilot-scale MCTT tests presented in Chapter 5 (Ayyoubi 1993). This table presents much detail for each individual event, and for the total evaluation period. This analysis was conducted using rain information from the Birmingham 1976 rain year and was used for the design of the pilot-scale MCTT. This year was selected as most representative of the long-term rain conditions for Birmingham, based on annual rain depth, monthly rain depths, and monthly number of individual rains.

The main settling chamber's available volume before each rain is determined by the computer model. Each value in the chamber "occupied before event" column was zero percent if the pump was capable of emptying the chamber before the beginning of the rain since the last rain. The drainage of the main settling chamber for the Birmingham pilot-scale MCTT was controlled with level-actuated float switches connected to a pump. If the pump was not capable of emptying the chamber before the beginning of the rain, then the value used would be the ratio of the volume of water in the tank at the beginning of the storm to the volume of the tank. The numbers in the chamber "occupied during event" column represent the maximum amount of water present in the chamber for each rain. Each value was calculated based on the difference between the average inflow rate during the respective rain event and the pumping rate. A value of 7% was entered if the pumping rate was greater than or equal to the average influent flowrate (the 7% represents 150 mm of water in a 2.1 m deep tank before the pump is activated). If the pumping rate was less than the influent flowrate, a value equal to the difference between the average influent flowrate and the pumping rate multiplied by the rain duration was entered (not exceeding 100%).

Each value in the "treated runoff" column was the same as the runoff amount (for a particular rain event) if the maximum amount of water in the chamber during treatment was less than 100%. If the maximum amount of water in the chamber during treatment was 100%, the depth of treated runoff was then the sum of the runoff depth needed

83

Table 4.7. Risk Assessment and Design Evaluation of an MCTT for Birmingham, AL, Conditions

Time To Empty Full Tank	=	24 hrs
Chamber Runoff Capacity	=	0.4 in (0.50" Rain)
Chamber Depth	=	7 ft
Chamber Surface Area	=	104 sq ft
Chamber Volume	=	726 cu ft
Depth-to-Time Ratio	=	8.1E-05 ft/s
% Toxicity Reduction For Treated Water	=	75.1%

Rain depths (in)	Accum rain (in)	Rv (1)	Runoff (in)	Accum runoff (in)	Half acre runoff (cu ft)	Rain dur (hr)	Avg Q (cfs)	Time to next rain (hr)	Main settling chamber occupied before event	during event-max	Max H during treat (ft)	Treated runoff (in)	Un- treated runoff (in)	Accum treated runoff (in)	% Tox reduc for storm
0.46	0.46	0.78	0.36	0.36	651	9	0.0201	91	0.00%	52.20%	3.65	0.36	0	0.36	75.1%
0.58	1.04	0.80	0.46	0.82	842	35	0.0067	68	0.00%	7.00%	0.49	0.46	0	0.82	75.1%
0.25	1.29	0.76	0.19	1.01	345	12	0.0080	28	0.00%	7.00%	0.49	0.19	0	1.01	75.1%
0.03	1.32	0.60	0.02	1.03	33	2	0.0045	6	0.00%	7.00%	0.49	0.02	0	1.03	75.1%
0.39	1.71	0.78	0.30	1.34	552	12	0.0128	68	0.00%	26.05%	1.82	0.30	0	1.34	75.1%
0.01	1.72	0.60	0.01	1.34	11	10	0.0003	77	0.00%	7.00%	0.49	0.01	0	1.34	75.1%
0.05	1.77	0.61	0.03	1.37	55	6	0.0026	90	0.00%	7.00%	0.49	0.03	0	1.37	75.1%
0.03	1.80	0.60	0.02	1.39	33	11	0.0008	17	0.00%	7.00%	0.49	0.02	0	1.39	75.1%
2.33	4.13	0.93	2.17	3.56	3933	34	0.0321	106	0.00%	100.00%	7.00	0.54	1.63	1.93	18.8%
0.01	4.14	0.60	0.01	3.56	11	2	0.0015	8	0.00%	7.00%	0.49	0.01	0	1.94	75.1%
0.01	4.15	0.60	0.01	3.57	11	2	0.0015	85	0.00%	7.00%	0.49	0.01	0	1.94	75.1%
0.51	4.66	0.80	0.41	3.98	741	25	0.0082	117	0.00%	7.00%	0.49	0.41	0	2.35	75.1%
0.01	4.67	0.60	0.01	3.98	11	11	0.0003	144	0.00%	7.00%	0.49	0.01	0	2.36	75.1%
0.01	4.68	0.60	0.01	3.99	11	1	0.0030	9	0.00%	7.00%	0.49	0.01	0	2.36	75.1%
0.67	5.35	0.80	0.54	4.52	973	8	0.0338	74	0.00%	100.00%	7.00	0.53	0	2.90	74.6%
0.61	5.96	0.80	0.49	5.01	886	9	0.0273	12	0.00%	84.50%	5.92	0.49	0	3.38	75.1%
0.01	5.97	0.60	0.01	5.02	11	3	0.0010	288	34.50%	7.00%	0.49	0.01	0	3.39	75.1%
0.85	6.82	0.82	0.70	5.72	1265	25	0.0141	37	0.00%	70.08%	4.91	0.70	0	4.09	75.1%
0.01	6.83	0.60	0.01	5.72	11	4	0.0008	11	0.00%	7.00%	0.49	0.01	0	4.09	75.1%
1.02	7.85	0.84	0.86	6.58	1555	19	0.0227	6	0.00%	100.00%	7.00	0.63	0.22	4.73	55.6%
0.01	7.86	0.60	0.01	6.58	11	3	0.0010	55	75.00%	7.00%	0.49	0.01	0	4.73	75.1%
1.48	9.34	0.87	1.29	7.87	2337	17	0.0382	15	0.00%	100.00%	7.00	0.51	0.77	5.25	29.9%
0.01	9.35	0.60	0.01	7.88	11	1	0.0030	12	37.50%	7.00%	0.49	0.01	0	5.25	75.1%
0.01	9.36	0.60	0.01	7.88	11	10	0.0003	12	0.00%	7.00%	0.49	0.01	0	5.26	75.1%

(Continued)

Table 4.7. (Continued).

Time To Empty Full Tank	=	24 hrs
Chamber Runoff Capacity	=	0.4 in (0.50" Rain)
Chamber Depth	=	7 ft
Chamber Surface Area	=	104 sq ft
Chamber Volume	=	726 cu ft
Depth-to-Time Ratio	=	8.1E-05 ft/s
% Toxicity Reduction For Treated Water	=	75.1%

Rain depths (in)	Accum rain (in)	Rv (1)	Runoff (in)	Accum runoff (in)	Half acre runoff (cu ft)	Rain dur (hr)	Avg Q (cfs)	Time to next rain (hr)	Main settling chamber occupied before event	during event-max	Max H during treat (ft)	Treated runoff (in)	Un- treated runoff (in)	Accum treated runoff (in)	% Tox reduc for storm
3.64	13.00	0.95	3.46	11.34	6276	35	0.0498	89	0.00%	100.00%	7.00	0.48	2.98	5.74	10.4%
0.04	13.04	0.60	0.02	11.37	44	8	0.0015	6	0.00%	7.00%	0.49	0.02	0	5.76	75.1%
1.14	14.18	0.86	0.98	12.35	1779	10	0.0494	85	0.00%	100.00%	7.00	0.48	0.50	6.25	36.9%
0.04	14.22	0.60	0.02	12.37	44	15	0.0008	22	0.00%	7.00%	0.49	0.02	0	6.27	75.1%
1.54	15.76	0.88	1.36	13.73	2460	23	0.0297	58	0.00%	100.00%	7.00	0.56	0.80	6.83	30.9%
2.20	17.96	0.92	2.02	15.75	3674	12	0.0850	8	0.00%	100.00%	7.00	0.44	1.58	7.27	16.5%
2.08	20.04	0.92	1.91	17.66	3473	27	0.0357	92	66.67%	100.00%	7.00	0.17	1.74	7.45	6.8%
0.01	20.05	0.60	0.01	17.67	11	10	0.0003	176	0.00%	7.00%	0.49	0.01	0	7.45	75.1%
0.21	20.26	0.76	0.16	17.83	290	5	0.0161	46	0.00%	19.07%	1.33	0.16	0	7.61	75.1%
0.04	20.30	0.60	0.02	17.85	44	14	0.0009	164	0.00%	7.00%	0.49	0.02	0	7.63	75.1%
0.01	20.31	0.60	0.01	17.86	11	2	0.0015	75	0.00%	7.00%	0.49	0.01	0	7.64	75.1%
0.84	21.15	0.82	0.69	18.55	1250	17	0.0204	102	0.00%	100.00%	7.00	0.68	0	8.32	74.1%
1.03	22.18	0.84	0.87	19.41	1570	40	0.0109	126	0.00%	49.63%	3.47	0.87	0	9.19	75.1%
1.71	23.89	0.88	1.50	20.92	2731	27	0.0281	6	0.00%	100.00%	7.00	0.57	0.93	9.76	28.5%
0.30	24.19	0.77	0.23	21.15	419	11	0.0106	49	75.00%	86.92%	6.08	0.23	0	9.99	75.1%
0.26	24.45	0.76	0.20	21.35	359	26	0.0038	43	0.00%	7.00%	0.49	0.20	0	10.18	75.1%
3.84	28.29	0.95	3.65	24.99	6621	38	0.0484	11	0.00%	100.00%	7.00	0.48	3.16	10.67	10.0%
0.01	28.30	0.60	0.01	25.00	11	2	0.0015	19	54.17%	7.00%	0.49	0.01	0	10.67	75.1%
0.07	28.37	0.65	0.05	25.05	83	3	0.0076	40	0.00%	7.00%	0.49	0.05	0	10.72	75.1%
0.01	28.38	0.60	0.01	25.05	11	2	0.0015	111	0.00%	7.00%	0.49	0.01	0	10.73	75.1%
2.31	30.69	0.93	2.15	27.20	3899	30	0.0361	62	0.00%	100.00%	7.00	0.52	1.63	11.25	18.2%
0.27	30.96	0.76	0.21	27.41	372	45	0.0023	11	0.00%	7.00%	0.49	0.21	0	11.45	75.1%
0.05	31.01	0.61	0.03	27.44	55	7	0.0022	76	0.00%	7.00%	0.49	0.03	0	11.48	75.1%
0.48	31.49	0.79	0.38	27.81	688	11	0.0174	8	0.00%	48.97%	3.43	0.38	0	11.86	75.1%

(Continued)

Table 4.7. (Continued).

Time To Empty Full Tank	=	24 hrs
Chamber Runoff Capacity	=	0.4 in (0.50" Rain)
Chamber Depth	=	7 ft
Chamber Surface Area	=	104 sq ft
Chamber Volume	=	726 cu ft
Depth-to-Time Ratio	=	8.1E-05 ft/s
% Toxicity Reduction For Treated Water	=	75.1%

Rain depths (in)	Accum rain (in)	Rv (1)	Runoff (in)	Accum runoff (in)	Half acre runoff (cu ft)	Rain dur (hr)	Avg Q (cfs)	Time to next rain (hr)	Main settling chamber occupied before event	Max H during treat (ft)	Treated runoff (in)	Un- treated runoff (in)	Accum treated runoff (in)	% Tox reduc for storm	
0.01	31.50	0.60	0.01	27.82	11	8	0.0004	57	15.63%	7.00%	0.49	0.01	0	11.87	75.1%
0.01	31.51	0.60	0.01	27.83	11	3	0.0010	112	0.00%	7.00%	0.49	0.01	0	11.87	75.1%
0.01	31.52	0.60	0.01	27.83	11	2	0.0015	163	0.00%	7.00%	0.49	0.01	0	11.88	75.1%
0.01	31.53	0.60	0.01	27.84	11	4	0.0008	41	0.00%	7.00%	0.49	0.01	0	11.89	75.1%
0.03	31.56	0.60	0.02	27.86	33	7	0.0013	9	0.00%	7.00%	0.49	0.02	0	11.90	75.1%
1.78	33.34	0.90	1.60	29.46	2908	26	0.0311	176	0.00%	100.00%	7.00	0.55	1.05	12.45	25.7%
0.01	33.35	0.60	0.01	29.46	11	1	0.0030	63	0.00%	7.00%	0.49	0.01	0	12.46	75.1%
0.46	33.81	0.78	0.36	29.82	651	4	0.0452	85	0.00%	73.03%	5.11	0.36	0	12.82	75.1%
1.17	34.98	0.86	1.01	30.83	1826	25	0.0203	207	0.00%	100.00%	7.00	0.68	0.32	13.50	50.9%
0.26	35.24	0.76	0.20	31.03	359	1	0.0996	72	0.00%	45.23%	3.17	0.20	0	13.70	75.1%
0.03	35.27	0.60	0.02	31.05	33	16	0.0006	8	0.00%	7.00%	0.49	0.02	0	13.72	75.1%
0.01	35.28	0.60	0.01	31.05	11	1	0.0030	94	0.00%	7.00%	0.49	0.01	0	13.72	75.1%
0.09	35.37	0.68	0.06	31.11	111	2	0.0154	47	0.00%	6.97%	0.49	0.06	0	13.78	75.1%
0.26	35.63	0.76	0.20	31.31	359	2	0.0498	101	0.00%	41.07%	2.87	0.20	0	13.98	75.1%
1.01	36.64	0.84	0.85	32.16	1540	13	0.0329	10	0.00%	100.00%	7.00	0.54	0.31	14.52	47.5%
1.63	38.27	0.88	1.43	33.59	2603	7	0.1033	24	58.33%	100.00%	7.00	0.18	1.25	14.70	9.5%
0.17	38.44	0.75	0.13	33.72	231	3	0.0214	10	0.00%	19.38%	1.36	0.13	0	14.83	75.1%
0.23	38.67	0.76	0.17	33.90	317	6	0.0147	24	0.00%	18.70%	1.31	0.17	0	15.00	75.1%
0.07	38.74	0.65	0.05	33.94	83	2	0.0115	143	0.00%	3.04%	0.21	0.05	0	15.05	75.1%
0.30	39.04	0.77	0.23	34.17	419	7	0.0166	18	0.00%	28.58%	2.00	0.23	0	15.28	75.1%
0.54	39.58	0.80	0.43	34.60	784	2	0.1089	192	0.00%	99.67%	6.98	0.43	0	15.71	75.1%
0.06	39.64	0.63	0.04	34.64	69	3	0.0064	19	0.00%	7.00%	0.49	0.04	0	15.75	75.1%
0.93	40.57	0.83	0.77	35.41	1401	3	0.1297	190	0.00%	100.00%	7.00	0.43	0.34	16.18	41.6%
0.86	41.43	0.82	0.71	36.12	1280	13	0.0273	28	0.00%	100.00%	7.00	0.58	0.13	16.75	61.5%

(Continued)

Table 4.7. (Continued).

Time To Empty Full Tank	=	24 hrs
Chamber Runoff Capacity	=	0.4 in (0.50" Rain)
Chamber Depth	=	7 'ft
Chamber Surface Area	=	104 sq ft
Chamber Volume	=	726 cu ft
Depth-to-Time Ratio	=	8.1E-05 ft/s
% Toxicity Reduction For Treated Water	=	75.1%

Rain depths (in)	Accum rain (in)	Rv (1)	Runoff (in)	Accum runoff (in)	Half acre runoff (cu ft)	Rain dur (hr)	Avg Q (cfs)	Time to next rain (hr)	Main settling chamber occupied before during event event-max	Max H during treat (ft)	Treated runoff (in)	Un- treated runoff (in)	Accum treated runoff (in)	% Tox reduc for storm	
0.01	41.44	0.60	0.01	36.12	11	6	0.0005	16	0.00%	7.00%	0.49	0.01	0	16.76	75.1%
0.34	41.78	0.78	0.27	36.39	481	14	0.0096	6	0.00%	7.97%	0.56	0.27	0	17.02	75.1%
0.28	42.06	0.77	0.22	36.61	391	13	0.0084	68	0.00%	7.00%	0.49	0.22	0	17.24	75.1%
0.01	42.07	0.60	0.01	36.61	11	2	0.0015	10	0.00%	7.00%	0.49	0.01	0	17.25	75.1%
1.41	43.48	0.87	1.23	37.84	2226	21	0.0295	32	0.00%	100.00%	7.00	0.56	0.67	17.81	34.3%
0.01	43.49	0.60	0.01	37.84	11	3	0.0010	6	0.00%	7.00%	0.49	0.01	0	17.81	75.1%
0.25	43.74	0.76	0.19	38.03	345	11	0.0087	6	0.00%	1.67%	0.12	0.19	0	18.00	75.1%
0.04	43.78	0.60	0.02	38.06	44	8	0.0015	7	0.00%	7.00%	0.49	0.02	0	18.03	75.1%
0.44	44.22	0.78	0.34	38.40	623	21	0.0082	22	0.00%	7.00%	0.49	0.34	0	18.37	75.1%
0.04	44.26	0.60	0.02	38.43	44	4	0.0030	17	0.00%	7.00%	0.49	0.02	0	18.39	75.1%
0.11	44.37	0.71	0.08	38.50	142	4	0.0098	45	0.00%	2.86%	0.20	0.08	0	18.47	75.1%
0.01	44.38	0.60	0.01	38.51	11	1	0.0030	10	0.00%	7.00%	0.49	0.01	0	18.48	75.1%
0.01	44.39	0.60	0.01	38.52	11	2	0.0013	164	0.00%	7.00%	0.49	0.01	0	18.48	75.1%
0.01	44.40	0.60	0.01	38.52	11	1	0.0030	95	0.00%	7.00%	0.49	0.01	0	18.49	75.1%
0.06	44.46	0.63	0.04	38.56	69	7	0.0027	116	0.00%	7.00%	0.49	0.04	0	18.53	75.1%
0.01	44.47	0.60	0.01	38.57	11	1	0.0030	8	0.00%	7.00%	0.49	0.01	0	18.53	75.1%
0.12	44.59	0.72	0.09	38.65	157	4	0.0109	16	0.00%	4.93%	0.35	0.09	0	18.62	75.1%
0.03	44.62	0.60	0.02	38.67	33	2	0.0045	6	0.00%	7.00%	0.49	0.02	0	18.64	75.1%
0.01	44.63	0.60	0.01	38.68	11	3	0.0010	27	0.00%	7.00%	0.49	0.01	0	18.64	75.1%
2.39	47.02	0.93	2.22	40.90	4034	25	0.0448	147	0.00%	100.00%	7.00	0.49	1.73	19.14	16.6%
0.05	47.07	0.61	0.03	40.93	55	28	0.0005	17	0.00%	7.00%	0.49	0.03	0	19.17	75.1%
0.16	47.23	0.74	0.12	41.05	215	26	0.0023	186	0.00%	7.00%	0.49	0.12	0	19.28	75.1%
0.05	47.28	0.61	0.03	41.08	55	9	0.0017	71	0.00%	7.00%	0.49	0.03	0	19.31	75.1%
0.15	47.43	0.73	0.11	41.19	199	4	0.0138	96	0.00%	10.71%	0.75	0.11	0	19.42	75.1%

(Continued)

Table 4.7. (Continued).

Time To Empty Full Tank	=	24 hrs
Chamber Runoff Capacity	=	0.4 in (0.50" Rain)
Chamber Depth	=	7 ft
Chamber Surface Area	=	104 sq ft
Chamber Volume	=	726 cu ft
Depth-to-Time Ratio	=	8.1E-05 ft/s
% Toxicity Reduction For Treated Water	=	75.1%

Rain depths (in)	Accum rain (in)	Rv (1)	Runoff (in)	Accum runoff (in)	Half acre runoff (cu ft)	Rain dur (hr)	Avg Q (cfs)	Time to next rain (hr)	Main settling chamber occupied before during event event-max	Max H during treat (ft)	Treated runoff (in)	Un- treated runoff (in)	Accum treated runoff (in)	% Tox reduc for storm	
0.01	47.44	0.60	0.01	41.19	11	11	0.0003	6	0.00%	7.00%	0.49	0.01	0	19.43	75.1%
0.64	48.08	0.80	0.51	41.71	929	23	0.0112	94	0.00%	7.00%	0.49	0.51	0	19.94	75.1%
0.54	48.62	0.80	0.43	42.14	784	20	0.0109	284	0.00%	7.00%	0.49	0.43	0	20.37	75.1%
0.23	48.85	0.76	0.17	42.31	317	14	0.0063	71	0.00%	7.00%	0.49	0.17	0	20.55	75.1%
0.96	49.81	0.83	0.80	43.11	1446	4	0.1004	129	0.00%	100.00%	7.00	0.44	0.36	20.99	41.1%
0.01	49.82	0.60	0.01	43.11	11	5	0.0006	14	0.00%	7.00%	0.49	0.01	0	20.99	75.1%
0.22	50.04	0.76	0.17	43.28	303	10	0.0084	130	0.00%	0.13%	0.01	0.17	0	21.16	75.1%
0.12	50.16	0.72	0.09	43.37	157	13	0.0034	16	0.00%	7.00%	0.49	0.09	0	21.24	75.1%
0.02	50.18	0.60	0.01	43.38	22	5	0.0012	10	0.00%	7.00%	0.49	0.01	0	21.26	75.1%
0.72	50.90	0.81	0.58	43.96	1059	35	0.0084	167	0.00%	7.00%	0.49	0.58	0	21.84	75.1%
0.57	51.47	0.80	0.46	44.42	828	28	0.0082	62	0.00%	7.00%	0.49	0.46	0	22.30	75.1%
1.09	52.56	0.85	0.93	45.35	1682	39	0.0120	73	0.00%	69.12%	4.84	0.93	0	23.22	75.1%
0.25	52.81	0.76	0.19	45.54	345	8	0.0120	109	0.00%	14.17%	0.99	0.19	0	23.41	75.1%
0.87	53.68	0.82	0.71	46.25	1295	19	0.0189	115	0.00%	99.18%	6.94	0.71	0	24.13	75.1%
1.35	55.03	0.87	1.17	47.42	2132	16	0.0370	108	0.00%	100.00%	7.00	0.52	0.66	24.64	33.1%
0.20	55.23	0.76	0.15	47.58	276	18	0.0043	24	0.00%	7.00%	0.49	0.15	0	24.80	75.1%

% Treated runoff = 52.1%
% Tox reduction of TOTAL (2) runoff = 39.1%

(1) Source: PITT 1987 (values reflect the average of small and large impervious areas)

(2) TOTAL represents treated plus untreated waters

to fill the chamber, plus the amount of water pumped until the chamber was 100% full. The later value was evaluated based on the amount of time it takes to fill the main settling chamber while pumping during a rain event. This time T was determined as:

$$T = V_{av} / (Q_{in} - Q_{out})$$

Where: V_{av} = available volume of the main settling chamber at the beginning of rain event, m^3

Q_{in} = average inflow rate, m^3/hr

Q_{out} = outflow rate (pumping rate), m^3/hr

When the outflow rate exceeds the average inflow rate (T less than zero), the amount of treated runoff is equal to the runoff. If T is positive and less than the rain duration, then the main settling chamber would fill before the rain ends. Therefore, the amount of water pumped until the main settling chamber is 100% full would be equal to the runoff multiplied by the ratio of T to the rain duration. If T is greater than, or equal to, the rain duration, then the rain event would be over before the main settling chamber could fill, and, therefore, the amount of treated runoff is equal to the runoff. Note that it is possible to treat more than the capacity of the chamber during any given storm, because pumping starts when the water level is 6 inches above the permanent storage, and not when the chamber is completely full. Similar drainage behavior would occur if the drainage was controlled with an orifice at this elevation, instead of with a pump, except that the discharge rate would vary with water depth in the main settling chamber.

The values in the "percent toxicity reduction for storm" column were obtained by multiplying the percent toxicity reduction of treated water (fixed at 75.1% for the example shown in Table 4.11) by the ratio of the amount of treated water during each storm to the total runoff of that same storm. The total annual treated runoff (52.1% for this example) was obtained by dividing the accumulative depths of the treated runoff by the total annual runoff, multiplied by one hundred. The total runoff percent toxicity reduction value (39.1%) was based on the runoff treated at different toxicity reduction values for each rain.

The calculations shown in this table were repeated over a range of drainage or pumping rates, and a range of storage volumes and depths available in the main settling chamber. The drainage times evaluated included: 6, 12, 36, 48, and 72 h, the captured runoff depths ranged from 1.8 – 61 mm (0.07 – 2.39 in.) (corresponding to rain depths of 2.5 – 65 mm, or 0.10 – 2.57 in.).

If the MCTT is full from a previous rain (because of the required holding period), the next storm would bypass the MCTT with no treatment. Birmingham rains typically occur about every 3 to 5 d, so it would be desirable to have the holding period less than this value. Similarly, if the storage volume was small, only a small fraction of a large rain would be captured and treated, requiring a partial bypass for most rains. The annual toxicity reductions are calculated by knowing the individual storm median toxicity reductions and the annual percentage of runoff treated. As an example (see Table 4.7), if the holding period was 24 h for a 2.1 m (7 ft) deep settling chamber, the individual median storm toxicity reduction would be about 75%. If the MCTT was large enough to contain the runoff from a 38 mm (1.5 in) rain, then about 98% of the annual runoff would be treated, for an annual expected toxicity reduction of 73% ($0.75 \times 0.98 = 0.73$).

Figure 4.8 is a plot for Birmingham for different annual control levels associated with holding periods from 6 – 72 h and storage volumes from 2.5 – 51 mm (0.1 – 2.0 in.) of runoff for a 2.1 m (7 ft) deep MCTT. This figure can be used to determine the size of the main settling chamber and the minimum required detention time to obtain a desired level of control (toxicity reduction). If the tank is shallower than 2.1 m (7 ft), then the holding periods should be similarly decreased. If the tank is only 1 m (3.5 ft) deep, then the required holding periods would only be half as long, but the surface area would have to be twice as large to obtain the same storage volume. This plot shows that the most effective holding time and storage volume for a 70% toxicity removal goal, is 72 hours and 0.86 inch of runoff. A shorter holding period would require a larger holding tank for the same level of control. Shorter holding periods may only be more cost-effective for small removal goals (<50%). If a 6 hour holding time was used, the maximum toxicant removal would only be about 46% for this depth of tank, irrespective of the tank holding volume.

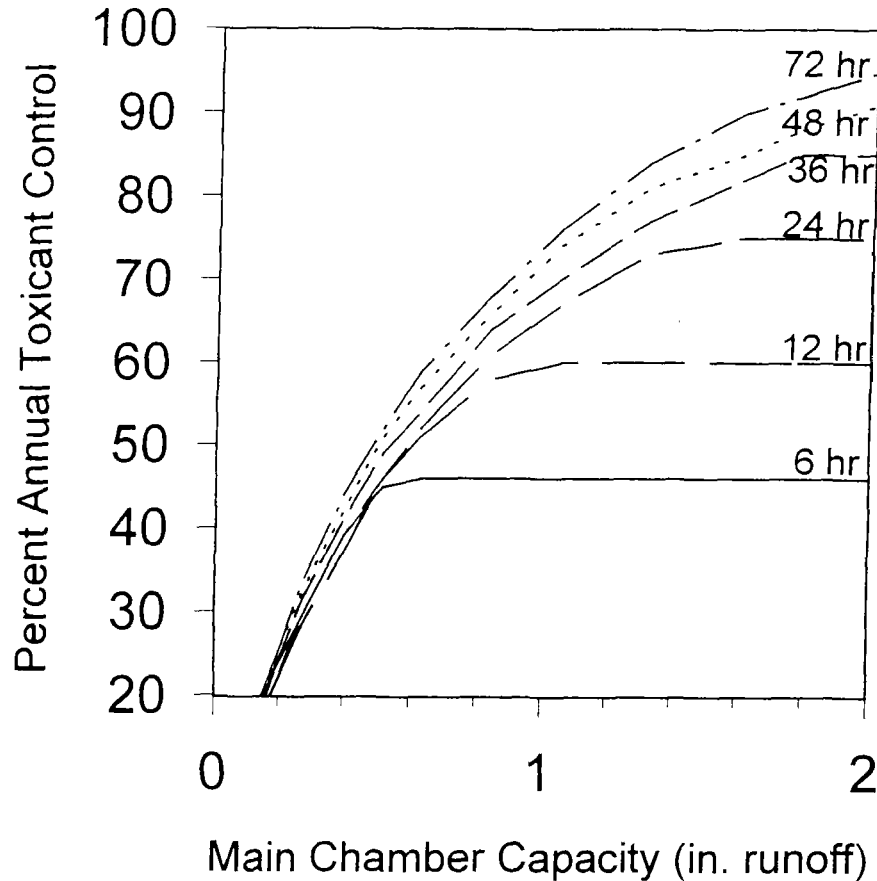


Figure 4.8 Effects of storage volume and treatment time on annual toxicity reduction, 2.1 m settling depth).

Additional Considerations in MCTT Design and Construction

The settling depth is the working settling depth and represents the variable water depth range in the main settling chamber. An additional 0.3 m (1 ft) is needed on the bottom of the main settling tank for the inlet flow distribution network and for storage of captured solids, at least. In addition, another 0.15 m (0.5 ft) is needed above this settling depth for the sorbent pillows. Therefore, another 0.45 m (1.5 ft) (minimum) is needed in addition to the settling depth, plus the MCTT top and bottom wall thickness, plus backfill cover, for the complete system depth.

The chambers of the MCTT should be vented, mosquito proofed, and be made easily accessible for maintenance. Maintenance for the MCTT would consist of inspections, cleaning of the catchbasin, and renewing of the sorbent pillows every 6 – 12 mo. The ion exchange/sorption capacity of the sand-peat media should last from 3 – 5 years before requiring replacement. Filter media research being conducted by the University of Alabama at Birmingham (Clark and Pitt 1997), and later complete results of the full-scale MCTT tests in Wisconsin, will provide more information on likely MCTT maintenance schedules.

Chapter 5

Pilot-Scale and Preliminary Full-Scale Test Results of the MCTT

This chapter describes field tests of the MCTT. Pilot-scale tests were conducted in Birmingham, AL, at a parking lot site on the campus of the University of Alabama at Birmingham. The Birmingham tests included 13 rains, from May through November 1994. The state of Wisconsin has since installed two full-scale MCTT units. One of these is located at the City of Milwaukee public works Ruby Garage, and another is located at a new municipal parking area in Minocqua. The Wisconsin Department of Natural Resources (DNR) monitored seven events in Minocqua and the U.S. Geological Survey, in contract with the DNR, monitored 15 events in Milwaukee that are summarized in this report.

Pilot-Scale MCTT Design

The pilot-scale MCTT that was tested during this research was designed to incorporate all possible features of the full-scale device. The catchbasin/grit chamber is made of a 25 cm (10 in.) diameter vertical PVC pipe containing approximately 6 L of 3 cm (1 in.) diameter plastic Jaeger Products (Houston, Texas) Tri-Packs[®] packing column spheres. The main settling chamber is 1.3 m² (14 ft²) in area by 1.2 m (4 ft) deep with a total capacity of 1.6 m³ (55 ft³) and includes plate settlers, aerators, and PIG[®] Mat (New Pig Corp., Tipton, Pennsylvania) sorbent pads. During use, the main settling chamber was filled almost to its full 1.2 m depth and was pumped to within a few cm of the bottom when emptying. With a 72 h settling time, the settling rate provided was about 4×10^{-6} m/s and was expected to result in a median toxicity reduction of about 90%. The filter chamber is 1.5 m² (16 ft²) in area and contains a 50/50 mixture of sand and peat 0.3 m (1 ft) deep directly on 0.2 m (0.6 ft) of sand placed over a fine plastic screen and coarse gravel that covers the underdrain. Amoco 4557 (Gunderboom[™]) filter fabric also covers the top of the filter media to distribute the water over the filter surface by reducing the water infiltration rate through the filter and to provide additional pollutant reduction. This extra pollutant reduction is mostly by sorption of very fine particles and oils to the filter fabric material, not by filtering. Any large particles that could be trapped mechanically had already been removed in the main settling chamber. The surface hydraulic loading rate of this filter/ion exchange chamber was between 1.5 and 6 m per day (5 and 20 ft per day). The sand had the following size: 71% finer than #30 sieve (0.6 mm), 65% finer than #40 sieve (0.425 mm), and 0.5% finer than #50 sieve (0.18 mm). The effective size (D_{10}) of the sand was 0.31 mm and the uniformity coefficient (D_{60}/D_{10}) was 1.45.

While the actual MCTT would be an underground unit, the pilot-scale unit was built upon a trailer for mobility. While this necessitated the use of pumps for filling the device with runoff, building a mobile unit offered several advantages. The pilot-scale unit was constructed offsite, it can be moved to any desired location, and maintained and operated with greater ease. Additionally, the cost of this method was much lower than building an underground device. The unit was set up to capture runoff samples from a parking and vehicle service area on the campus of the University of Alabama at Birmingham. This site featured several attributes of critical source areas including paved parking, fueling pumps, and a motorpool garage with vehicle service. Figures 5.1 – 5.4 are photographs of the MCTT located at the UAB parking facility.

Leaching of Materials used for the Construction of Treatability Test Equipment

An important consideration when constructing any treatability apparatus, including the pilot-scale MCTT, is potential contamination of the test solutions by materials used in the construction of the device. Therefore, before the pilot-scale MCTT was constructed, a series of tests were conducted to examine the leachability of different potential construction materials. Samples of the various materials were left to soak in de-ionized water for set periods of time, and then the water was analyzed for a broad list of constituents of interest.

Table 5.1 lists potential contaminants from some materials that may be used in bench-scale and pilot-scale test equipment (Cowgill 1988). Cowgill found that extensive steam cleaning (at least 5 washings using steam produced from distilled water) practically eliminated all contamination problems for sampling equipment. Cemented materials should probably be avoided, as is evident from this table. Threaded or bolted together components are much preferable.

Table 5.1. Potential Sample Contamination from Sampler Material

Material:	Contaminant:
PVC - threaded joints	chloroform
PVC - cemented joints	methylethyl ketone, toluene, acetone, methylene chloride, benzene, ethyl acetate, tetrahydrofuran, cyclohexanone, organic tin compounds, and vinyl chloride
Teflon™	nothing
polypropylene and polyethylene	plasticizers and phthalates
fiberglass reinforced epoxy material (FRE)	nothing
stainless steel	chromium, iron, nickel, and molybdenum
glass	boron and silica

source: Cowgill (1988)

This project included testing the leaching potentials for many materials that may be used in bench-scale and pilot-scale treatment units. Samples of each material were immersed for a period of 72 h in approximately 500 mL of laboratory grade 18 megohm water. A sample blank was also prepared. Analyses conducted on each of these samples, and the sample blank, were the same to be performed for the pilot-scale MCTT, with the exception of solids and metals analysis. Table 5.2 presents the contaminants that were found in the leaching water at the end of the test in high concentrations that may affect the test results. The most serious problems occur with plywood, including both treated and untreated wood. Attempting to seal the wood with Formica and caulking was partially successful, but toxicants were still leached. Covering of the Formica clad plywood with polyethylene plastic sheeting was finally used to eliminate any potential problem. Fiberglass screening material, especially before cleaning, also causes a potential problem with plasticizers and other organics. PVC and aluminum may be acceptable materials, if phthalate esters and aluminum contamination can be tolerated.

These tables indicate that care must be taken when selecting test equipment. The use of Teflon™ reduces most of the problems, but it is quite expensive. Delrin™ is almost as effective, is somewhat less expensive, and is much easier to machine when manufacturing custom equipment. Both of these materials are fragile and cannot withstand rough handling. Glass is not usable for most large treatability test equipment, but is commonly used in bench-scale tests.

Table 5.3 is a summary of the basic materials considered for construction of the pilot-scale MCTT, indicating the relative problems associated with each material and the constituents of greatest concern. Results indicated the plastic screen used to support the filter media to be the only material to be of potential concern. Prior to installation, the screen was rinsed with tap water which was shown by further testing to reduce leaching of toxicants. The plywood used for the MCTT structure showed potential leaching problems, but this was of minimal concern as the plywood was covered by Formica™ and sheet plastic and never contacted the test water.

Pilot-Scale MCTT Operation

During a storm event, runoff from the parking lot drained to an existing storm sewer inlet. A 65 L (15 gal.) tub was mounted inside this inlet which filled with runoff during the event. A float switch within the tub triggered two sump pumps to direct flow into the catchbasin/grit chamber of the unit. Pumped runoff filled the catchbasin storage volume and then discharged into the settling chamber. During filling, an air pump supplied air to aeration stones located in the main settling chamber. When the settling chamber filled to approximately 75 mm (3 in.) from the top of the settling chamber, a float switch cut power to the sump pumps, the air pump, the two automatic samplers, and an analog clock. The clock measured the total amount of time electricity was supplied to the unit and was used for tracking the treatment time. Filling of the settling chamber took a minimum of 30 min. Longer filling times occurred for storm events that produced intermittent runoff. After a quiescent settling period of a nominal 72 h, settling chamber effluent was pumped through the filter media, sampled, and discharged.

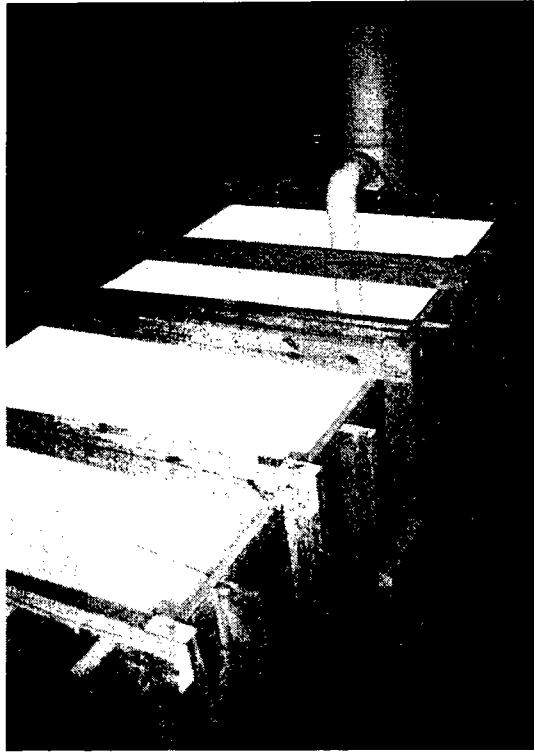


Figure 5.1 Pilot-scale MCTT under construction.

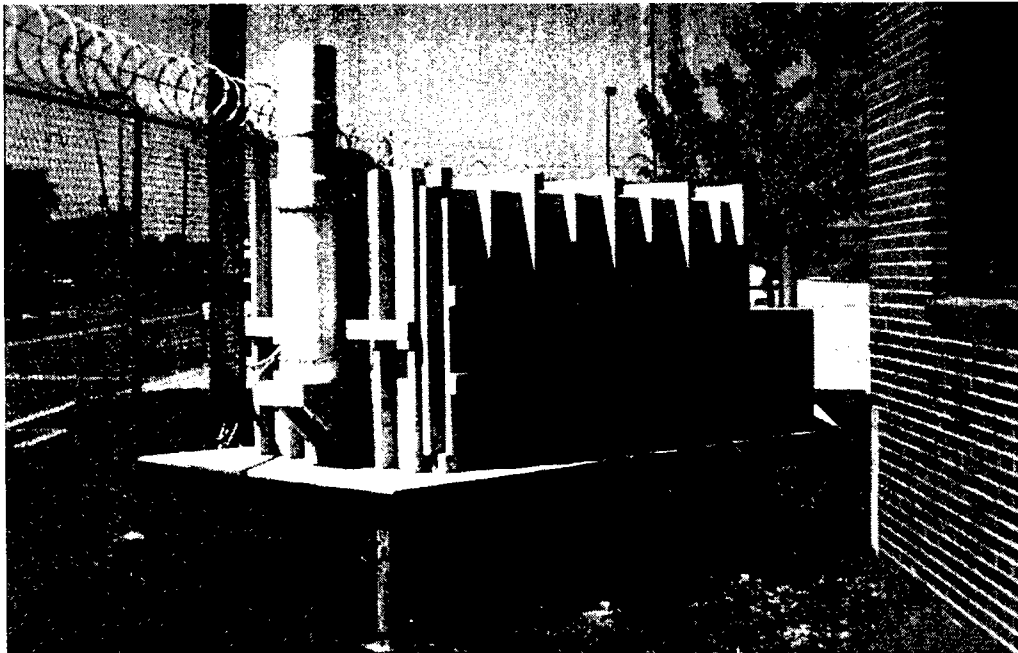


Figure 5.2 Pilot-scale MCTT in place at the UAB parking facility.

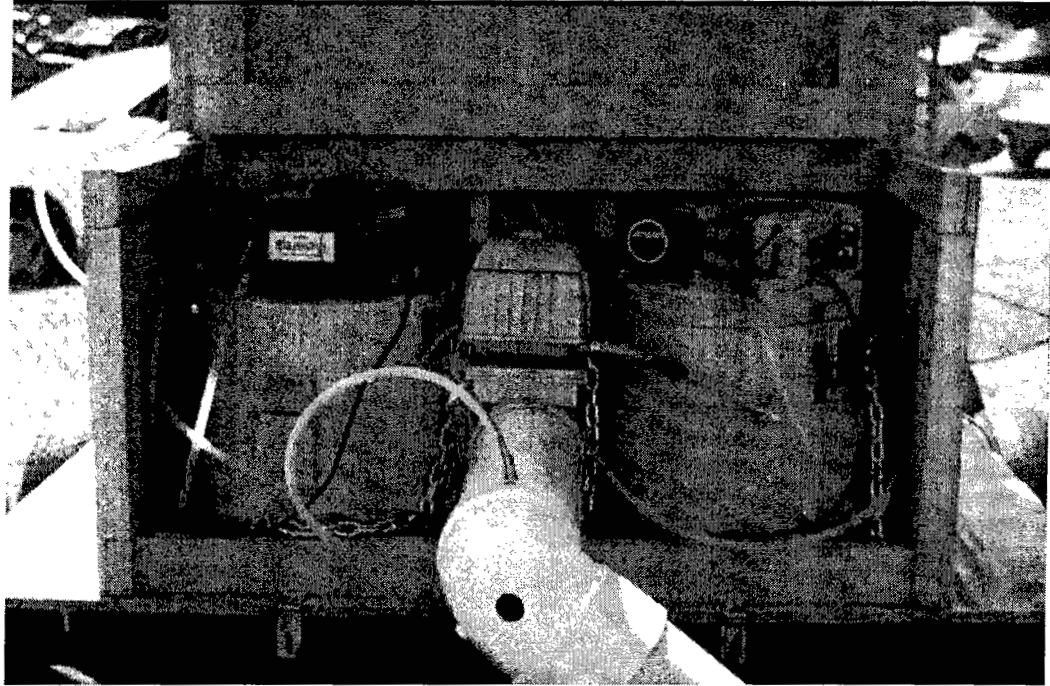


Figure 5.3 Automatic samplers installed on the pilot-scale MCTT.

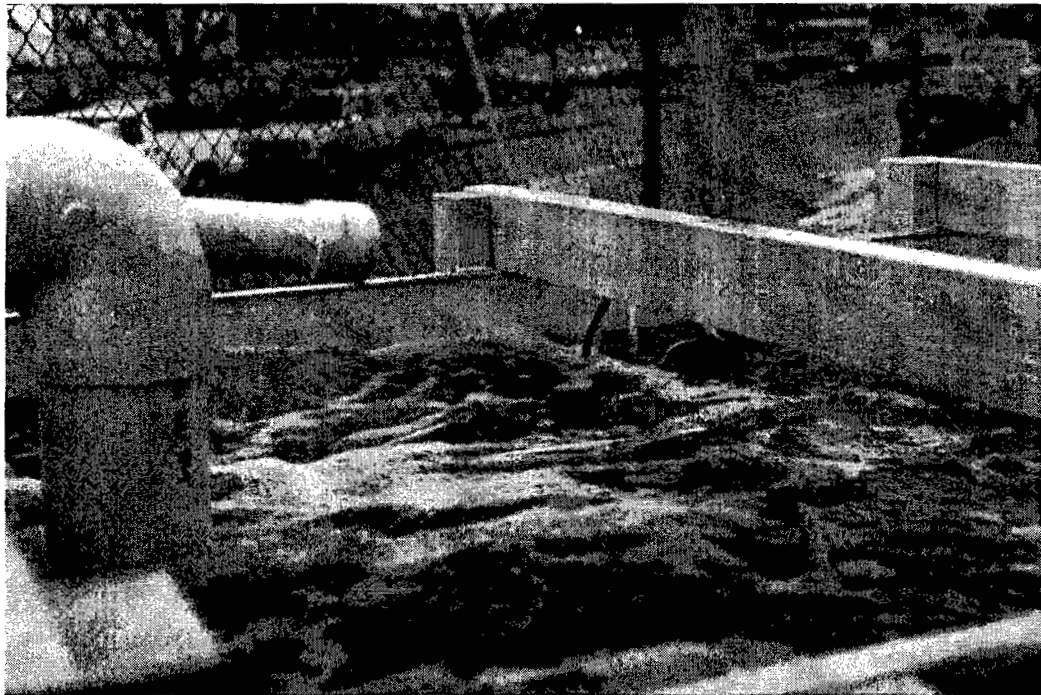


Figure 5.4 Pilot-scale MCTT during a storm event.

Table 5.2. Potential Sample Contamination from Materials that may be used in Treatability Test Apparatus

Material:	Contaminant observed:
untreated plywood	toxicity, chloride, sulfate, sodium, potassium, calcium, 2,4-dimethylphenol, benzylbutyl phthalate, bis(2-ethylhexyl) phthalate, phenol, N-nitro-so-di-n-propylamine, 4-chloro-3-methylphenol, 2,4-dinitrotoluene, 4-nitrophenol, alpha BHC, gamma BHC, 4,4'-DDE, endosulfan II, methoxychlor, and endrin ketone
treated plywood (CCA)	toxicity, chloride, sulfate, sodium, potassium, hexachloroethane, 2,4-dimethylphenol, bis(2-chloroethoxyl) methane, 2,4-dichlorophenol, benzylbutyl phthalate, bis(2-ethylhexyl) phthalate, phenol, 4-chloro-3-methylphenol, acenaphthene, 2,4-dinitrotoluene, 4-nitrophenol, alpha BHC, gamma BHC, beta BHC, 4,4'-DDE, 4,4'-DDD, endosulfan II, endosulfan sulfate, methoxychlor, endrin ketone, and copper (likely), chromium (likely), arsenic (likely)
treated plywood (CCA) and Formica	toxicity, chloride, sulfate, sodium, potassium, bis(2-chloroethyl) ether* , diethylphthalate, phenanthrene, anthracene, benzylbutyl phthalate, bis(2-ethylhexyl) phthalate, phenol* , N-nitro-so-di-n-propylamine, 4-chloro-3-methylphenol* , 4-nitrophenol, pentachlorophenol, alpha BHC, 4,4'-DDE, endosulfan II, methoxychlor, endrin ketone, and copper (likely), chromium (likely), arsenic (likely)
treated plywood (CCA), Formica and silica caulk	lowered pH, toxicity, bis(2-chloroethyl) ether* , hexachlorocyclopentadiene, diethylphthalate, bis(2-ethylhexyl) phthalate, phenol* , N-nitro-so-di-n-propylamine, 4-chloro-3-methylphenol* , alpha BHC, heptachlor epoxide, 4,4'-DDE, endosulfan II, and copper (likely), chromium (likely), arsenic (likely)
Formica and silica caulk	lowered pH, toxicity, 4-chloro-3-methylphenol, aldrin, and endosulfan I
silica caulk	lowered pH, toxicity, and heptachlor epoxide
PVC pipe	N-nitrosodiphenylamine, and 2,4-dinitrotoluene
PVC pipe with cemented joint	bis(2-ethylhexyl) phthalate* , acenaphthene, and endosulfan sulfate
plexiglass and plexiglass cement	naphthalene, benzylbutyl phthalate, and bis(2-ethylhexyl) phthalate, and endosulfan II
aluminum	toxicity, and aluminum (likely)
plastic aeration balls	2,6-dinitrotoluene
filter fabric material	acenaphthylene, diethylphthalate, benzylbutyl phthalate, bis(2-ethylhexyl) phthalate, and pentachlorophenol
sorbent pillows	diethylphthalate, and bis(2-ethylhexyl) phthalate
black plastic fittings	pentachlorophenol
reinforced PVC tubing	diethylphthalate, and benzylbutyl phthalate
fiberglass window screening	toxicity, dimethylphthalate, diethylphthalate* , bis(2-ethylhexyl) phthalate, di-n-octyl phthalate, phenol, 4-nitrophenol, pentachlorophenol, and 4,4'-DDD
Delrin™	benzylbutyl phthalate
Teflon™	nothing (likely)
glass	zinc (likely)

note: * signifies that the observed concentrations in the leaching solution were very large compared to the other materials. Not all of the heavy metals had been verified.

Table 5.3. Pilot-Scale MCTT Construction Material Leach Test

MATERIAL	USE	LEACH POTENTIAL
PVC pipe and cement	catchbasin construction and filter effluent piping	LOW
Jaeger Tri-Packs® packing column spheres	stripping column	LOW
polyethylene sheeting	settling chamber liner	LOW (n-nitroso-di-n-propylamine)
Plexiglas™ and cement	lamella plate construction	LOW (conductivity, chloride, sodium)
PIG® Mat absorbent pillow material	settling chamber floating oil absorbent	LOW (chloride)
Formica™ and caulk	sand-peat filter chamber lining	LOW (toxicity, conductivity, pH, nitrobenzene, 4-chloro-3-methylphenol)
aluminum angle bracket	sand- peat filter chamber corner reinforcement	LOW (toxicity, conductivity, chloride, calcium, pentachlorophenol)
Amoco 4557 filter fabric (Gunderboom™)	sand-peat filter cover	LOW (toxicity, conductivity, sulfate, pentachlorophenol)
plastic screen	filter media support	HIGH (toxicity)
treated plywood	structural support (non-contact)	LOW (phenol, 4-nitrophenol, pentachlorophenol, di-n-octylphthalate)
		HIGH (toxicity, hexachloroethane, 2,4-dimethylphenol, 4-chloro-3-methylphenol, 4-nitrophenol; likely heavy metals)

Pilot-Scale MCTT Sampling and Analytical Techniques

Two automatic samplers, an ISCO 2700 and American Sigma 800 SL, were used to collect time-composited samples from the pilot-scale MCTT in 10 L (2.5 gal.) glass sample containers. During filling of the unit, samples were collected from the influent to the catchbasin and between the catchbasin and settling chamber. During filtration, samples were collected from the settling chamber effluent (or the sand-peat filter influent) and from the filter effluent. All samples collected were promptly transferred to the laboratory for analysis. Table 5.4 lists the analyses conducted and methods used. Table 5.5 shows sample volumes collected for individual analyses. Appendix E contains detailed descriptions of the laboratory methods used for the pilot-scale evaluations.

A reading of pH was conducted immediately when the sample arrived in the laboratory. Within 24 h, a portion of the chilled samples was filtered through a 0.45 µm membrane filter using an all glass filtering apparatus. The filtered and unfiltered sample portions were then divided and preserved as follows:

- unfiltered samples in two 250 mL amber glass bottles (Teflon™ lined lids) (no preservative) for total forms of toxicity, COD, and gas chromatography (GC) analyses (using mass spectrophotometric, MSD, and electron capture, ECD, detectors).
- filtered sample in one 250 mL amber glass bottle (Teflon™ lined lids) (no preservative) for filtered forms of toxicity, COD, and GC analyses (using MSD and ECD detectors).
- unfiltered sample in one 250 mL high density polyethylene (no preservatives) for SS and VSS, turbidity, color, particle size, and conductivity.
- filtered sample in one 250 mL high density polyethylene (no preservatives) for anion and cation analyses (using ion chromatography), hardness, TDS, VDS, and alkalinity.
- unfiltered sample in one 250 mL high density polyethylene (HNO₃ preservative to pH<2) for total forms of heavy metals, using the graphite furnace atomic adsorption spectrophotometer.
- filtered sample in one 125 mL high density polyethylene (HNO₃ preservative to pH<2) for filtered forms of heavy metals, using the graphite furnace atomic adsorption spectrophotometer.

All samples were chilled on ice or in a refrigerator to 4°C (except for the HNO₃ preserved samples for heavy metal analyses) and analyzed within the holding times shown below. The HNO₃ preserved samples were held at room temperature until digested. The following list shows the holding times for the various groups of constituents:

- immediately after sample collection: pH
- within 24 hours: toxicity, ions, alkalinity, color, turbidity
- within 7 days: GC extractions and solids
- within 40 days: GC analyses
- within 6 months: heavy metal digestions and analyses.

Table 5.4. Compounds Analyzed During MCTT Tests

Organic Toxicants by GC/MSD - filtered and unfiltered (1 to 10 µg/L MDL)

Polycyclic aromatic hydrocarbons
Phthalate esters
Phenols

Organic Toxicants by GC/ECD - filtered and unfiltered (0.01 to 0.1 µg/L MDL)

Chlorinated insecticides

Heavy Metals by graphite furnace–atomic adsorption spectrophotometry (GFAA) - filtered and unfiltered (1 to 5 µg/L MDL)

Cadmium
Copper
Lead
Zinc

Toxicity Screening by Microtox™ - filtered and unfiltered

Nutrients by Ion Chromatography - filtered (1 mg/L MDL)

Nitrate
Nitrite
Ammonia
Phosphate

Major Ions by Ion Chromatography - filtered (0.1 to 1 mg/L MDL)

Cations (calcium, magnesium, potassium, sodium, and lithium)
Anions (chloride, sulfate, and fluoride)

Conventional Analyses

COD
Color
Specific Conductance
Hardness
Alkalinity
pH
Turbidity
Solids (total, suspended, dissolved, and volatile forms)

Particle size (Coulter Counter Multisizer IIe)

Table 5.5. Analytes and Volumes Collected

Constituent	Volume (mL)	Filtered?	Unfiltered?
Microtox™ toxicity screen	10 mL	yes	yes
Turbidity	30 mL	yes	yes
Conductivity	70 mL		yes
pH	25 mL		yes
color	25 mL		yes
hardness	100 mL		yes
alkalinity	50 mL		yes
anions (F ⁻ , Cl ⁻ , NO ₂ ⁻ , NO ₃ ²⁻ , SO ₄ ²⁻ , and PO ₄ ²⁻)	25 mL	yes	
cations (Li ⁺ , Na ⁺ , NH ₄ ⁺ , K ⁺ , Ca ²⁺ , and Mg ²⁺)	25 mL	yes	
total solids	100 mL		yes
dissolved solids	100 mL	yes	
semi-volatile compounds (by GC/MSD)	315 mL	yes	yes
chlorinated insecticides (by GC/ECD)	315 mL	yes	yes
particle size	20 mL		yes
metals (Pb, Cr, Cd, Cu, and Zn)	70 mL	yes	yes
COD	10 mL	yes	yes

Results of the Pilot-Scale MCTT Evaluation Tests

The pilot-scale MCTT was evaluated for 13 storm events. The performance of the MCTT was found to provide levels of control comparable to those predicted. Based solely upon the design of the settling chamber, percent toxicity reductions were predicted to be near the 90% reduction level. Actual performance of the overall MCTT was found to have a median value of 96%. The median toxicity reduction of the filtered samples was found to be 87%. Tables 5.6 through 5.9 display summarized results for the pilot-scale MCTT. Tables 5.6, 5.7, and 5.8 show results for the catchbasin, the settling chamber, and the sand-peat filter, respectively. Table 5.9 gives summary results for the overall MCTT. Included in these tables are the minimum, maximum, median, standard deviation, and coefficient of variation (COV) for influent concentration conditions and percent reductions. One-sided probability (p) values for the concentration differences across the chamber/device are also displayed. Complete performance data is presented in Appendices A and B.

Exact 1-sided probabilities were calculated by the Wilcoxon Signed Rank Test for paired observations using StatXact-Turbo™ software by Cytel Software Corporation. The exact probability calculated is based upon sign and magnitude of concentration differences occurring across each chamber and across the entire MCTT, while omitting zero differences. The software calculated an exact p value as opposed to a p value obtained asymptotically which would inherently decrease accuracy for the relatively small sample size. The software also expedited data analysis by performing the test in a batch mode. Values of $p < 0.05$, signifying less than a 5% chance that the inlet and outlet values are the same, are typically used to identify significant differences. This research uses a p value of 0.05 as the level of significance, but the tables provide the actual values calculated for individual interpretation.

Table 5.10 shows performance summaries for the settling chamber, sand-peat chamber, and for the overall MCTT for the major constituents of interest. The catchbasin was not found to provide significant toxicity reductions, as expected, and is therefore not included on this table. The catchbasin was used to provide grit and other coarse solids control to reduce maintenance in the other chambers. Significant (1-sided p value ≤ 0.05) concentration changes occurring across the MCTT are given in Table 5.11.

By design, the settling chamber was assumed to provide most of the toxicity reductions. The other two chambers and secondary features were added for extra benefit, especially to reduce variations in performance for the highly variable runoff conditions. However, good toxicity reductions occurred in both the settling chamber and the sand-peat filter. The high levels of Microtox™ toxicity reductions observed indicate excellent reductions of critical toxic contaminants by the MCTT.

Table 5.6. MCTT Catchbasin Chamber Performance Summary

	IDL	Units	Catchbasin Chamber Inlet Concentration					COV	Catchbasin 1-sided P Value	Catchbasin Chamber Percent Reduction				
			Minimum	Maximum	Median	Std. Dev.	Minimum			Maximum	Median	Std. Dev.	COV	
<i>CONVENTIONAL ANALYSIS</i>														
Total Solids	2.5	mg/L	29	255	105	70.5	0.58	0.2429	-45	57	8	27	6.3	
Volatile Total Solids	2.5	mg/L	10	105	43	29.1	0.59	0.2395	-36	36	0	25	13	
Total Suspended Solids	2.5	mg/L	7	137	41	39.4	0.81	0.1543	-157	88	17	65	7.4	
Volatile Suspended Solids	2.5	mg/L	2	46	17	12.6	0.69	0.2288	-300	72	10	100	-4.7	
Dissolved Solids	2.5	mg/L	13	152	64	39.6	0.55	-0.3862	-43	27	-7	22	-4.0	
Volatile Dissolved Solids	2.5	mg/L	5	66	27	18.5	0.60	0.2275	-100	53	0	41	-6.8	
Turbidity	0.75	NTU	2	16	5.5	3.7	0.64	0.0215	-15	70	23	28	1.3	
Turbidity (filtered)	0.75	NTU	ND	1.6	ND	0.4	0.70	0.2405	-317	60	7	93	-4.8	
Apparent Color (unfiltered)	N/A	Hach*	16	58	27	14.5	0.43	0.5176	-115	38	0	36	-6.5	
Color (filtered)	N/A	Hach*	4	55	32	14.7	0.47	0.3135	-125	22	0	37	-5.3	
Conductivity	N/A	µS/cm²	14	124	55	28.4	0.45	0.3477	-36	26	0	18	-17	
pH	N/A	std.	6.34	7.44	7.04	0.3	0.04	-0.4526	-3	5	0	1.8	12.7	
Chemical Oxygen Demand	1.1	mg/L	ND	197	42	55.5	1.00	0.4028	-800	62	-29	239	-2.67	
Chemical Oxygen Demand (filtered)	1.1	mg/L	ND	110	23	36.7	1.05	-0.1875	-129	73	-13	56	-27	
<i>TOXICITY</i>														
Relative Toxicity	5	125%	ND	70	24	20.9	0.88	0.4464	-71	100	4	53	2.7	
Relative Toxicity (filtered)	5	125%	ND	61	16	17.8	0.73	-0.2402	-200	500	0	163	19	
<i>METALS</i>														
Cadmium	1	µg/L	ND	2.9	ND	1.3	1.44	-0.1655	-307	475	0	218	5.5	
Cadmium (filtered)	1	µg/L	ND	2.5	ND	1.3	2.17	0.0203	-63	200	21	67	1.9	
Copper	0.25	µg/L	ND	96.7	23.7	25.4	0.86	-0.3424	-85	1183	-19	335	4.1	
Copper (filtered)	0.25	µg/L	6.8	35.6	13.3	8.9	0.53	-0.0839	-712	62	-18	245	-2.0	
Lead	1.25	µg/L	3.5	70.8	16	17.5	0.85	0.3386	-124	79	10	65	-16	
Lead (filtered)	1.25	µg/L	ND	11.9	2.1	3.4	1.38	0.1462	-311	275	-21	146	-7.1	
Zinc	0.5	µg/L	42	4022	177.8	1071	2.24	0.1219	-144	99	27	65	5.7	
Zinc (filtered)	0.5	µg/L	ND	60.2	13.3	18.0	0.99	-0.1736	-1188	77	-13	381	-2.3	

Note: N/A = not applicable; ND = value below detection limit; negative p values indicate probability of increase; negative percent reductions indicate percent increase.

Table 5.6. (continued)

	IDL	Units	Catchbasin Chamber Inlet Concentration		Minimum	Maximum	Median	Std. Dev.	COV	Catchbasin 1-sided P Value	Catchbasin Chamber Percent Reduction		Minimum	Maximum	Median	Std. Dev.	COV
<i>IONS</i>																	
Ammonium	0.25	mg/L	ND	0.459	ND	0.156	1.097	0.2324	-89	42	-10	45	-4.0				
Calcium	0.25	mg/L	1.173	15.35	8.748	3.773	0.44	-0.3424	-39	34	-7	23	-3.7				
Lithium	0.025	mg/L	ND	0.005	ND	0.002	1.672	0.1563	-50	100	N/A	75	1.2				
Magnesium	0.062	mg/L	0.158	1.981	1.078	0.531	0.489	-0.5000	-34	33	-3	20	-14				
Potassium	0.062	mg/L	0.249	1.669	0.539	0.394	0.563	-0.2487	-56	42	-7	29	-3.5				
Sodium	0.062	mg/L	0.441	13.35	1.057	3.429	1.706	-0.1115	-62	57	-11	30	-3.2				
Hardness (as CaCO ₃)	6.25	mg/L	6	71	38	16.52	0.432	0.1338	-23	52	5	22	2.7				
Chloride	0.025	mg/L	0.651	2.915	1.208	0.609	0.483	-0.4662	-194	16	-3	55	-3.8				
Fluoride	0.025	mg/L	ND	0.107	ND	0.03	1.038	-0.2527	-333	53	-28	104	-2.0				
Nitrate	0.25	mg/L	ND	7.403	1.889	2.091	0.722	-0.1879	-36	49	2	20	-328				
Nitrite	0.25	mg/L	ND	ND	ND	0.065	1.611	-0.3125	-688	100	-550	295	-1.96				
Phosphate	0.25	mg/L	ND	0.628	ND	0.206	2.479	-0.3125	-24	100	N/A	88	2.3				
Sulfate	0.25	mg/L	1.017	23.9	10.42	7.147	0.71	-0.1527	-206	10	-2	58	-2.8				
Bicarbonate	N/A	mg/L	12.37	80.33	36.62	18.48	0.491	0.2709	-28	52	3	23	5.1				
Carbonate	N/A	mg/L	0.001	0.056	0.02	0.017	0.877	0.1488	-300	86	5	96	-7.5				
<i>ORGANICS</i>																	
Phenol	0.38	µg/L	ND	8.04	0.4	2.162	1.88	-0.5000	-395	379	53	214	16				
N-Nitroso-di-n-propylamine	1.0	µg/L	ND	39.75	1.45	10.89	2.063	0.1563	-3019	690	70	943	-5.8				
Hexachloroethane	0.40	µg/L	ND	2.38	0.45	1.03	1.205	-0.1484	-1611	808	-7	560	-28				
Nitrobenzene	0.48	µg/L	ND	12.81	ND	3.563	2.28	-0.1875	-517	871	34	332	8.7				
2-Nitrophenol	0.90	µg/L	ND	5.87	ND	2.122	1.369	0.1250	-7000	675	56	1978	-4.4				
2,4-Dimethylphenol	0.68	µg/L	ND	16.74	0.69	7.201	41.98	-0.0625	-385	539	57	237	3.0				
Hexachlorobutadiene	0.22	µg/L	ND	28.91	0.71	9.069	2.282	0.2188	-683	524	106	302	4.8				
4-Chloro-3-methylphenol	0.75	µg/L	ND	19.67	2.32	9.68	6.295	0.5000	-284	213	73	154	7.6				
4-Nitrophenol	0.60	µg/L	ND	105.3	2.04	33.45	2.737	-0.4688	-2279	95	-49	802	-1.9				
Pentachlorophenol	0.90	µg/L	ND	17.55	ND	6.469	2.198	-0.3750	-238	1481	36	426	3.72				
Fluoranthene	0.55	µg/L	ND	1.44	ND	0.523	0.976	0.6250	-104	88	12	60	-9.6				
Pyrene	0.48	µg/L	ND	0.83	ND	0.282	0.786	-0.5000	-60	80	7	46	5.4				
Bis(2-ethylhexyl)phthalate	0.62	µg/L	ND	9.85	2.11	2.546	1.008	0.5000	-121	5033	28	1397	3.6				
Di-n-octylphthalate	0.62	µg/L	0.05	0.96	ND	0.325	0.824	0.2500	-135	76	14	63	-22				

Note: N/A = not applicable; ND = value below detection limit; negative p values indicate probability of increase; negative percent reductions indicate percent increase.

Table 5.7. MCTT Settling Chamber Performance Summary

	IDL	Units	Settling Chamber Inlet Concentration					Settling Chamber 1-sided P Value	Settling Chamber Percent Reduction				
			Minimum	Maximum	Median	Std. Dev.	COV		Minimum	Maximum	Median	Std. Dev.	COV
<i>CONVENTIONAL ANALYSIS</i>													
Total Solids	2.5	mg/L	34	202	110	52.27	0.49	0.0017	-15	50	31	21	0.76
Volatile Total Solids	2.5	mg/L	12	81	51	22.86	0.50	0.0049	-28	53	36	26	0.97
Total Suspended Solids	2.5	mg/L	ND	81	26	25.94	0.74	0.0010	-800	100	91	257	19.49
Volatile Suspended Solids	2.5	mg/L	ND	30	15	9.31	0.59	0.0024	-175	117	64	77	1.52
Dissolved Solids	2.5	mg/L	18	121	73	30.95	0.43	0.2288	-18	36	0	16	9.39
Volatile Dissolved Solids	2.5	mg/L	8	53	30	15.83	0.54	0.0381	-88	62	12	35	4.54
Turbidity	0.75	NTU	1.4	9.1	3.3	2.45	0.58	0.0005	-6	86	50	27	0.54
Turbidity (filtered)	0.75	NTU	ND	1.5	ND	0.43	0.75	0.0371	-40	70	30	32	1.55
Apparent Color (unfiltered)	N/A	Hach*	15	58	32	12.80	0.38	0.0044	-17	45	16	16	1.02
Color (filtered)	N/A	Hach*	9	55	32	13.70	0.45	0.0015	-10	39	23	15	0.76
Conductivity	N/A	µS/cm ²	19	101	61	25.02	0.40	-0.0662	-53	19	-15	19	-1.46
pH	N/A	std.	6.52	7.32	6.96	0.26	0.04	-0.3074	-7	9	0	4.3	-7.75
Chemical Oxygen Demand	1.1	mg/L	ND	101	41	35.47	0.74	0.0093	-130	100	53	61	1.58
Chemical Oxygen Demand (filtered)	1.1	mg/L	3	75	55	28.83	0.73	0.0017	-200	100	55	82	2.00
<i>TOXICITY</i>													
Relative Toxicity	5	125%	ND	42	24	15.28	0.73	0.0537	-700	93	18	238	-3.89
Relative Toxicity (filtered)	5	125%	ND	41	27	14.40	0.57	0.0049	-229	104	69	89	1.99
<i>METALS</i>													
Cadmium	1	µg/L	ND	11.8	ND	3.63	1.86	0.0083	-75	130	21	52	1.93
Cadmium (filtered)	1	µg/L	ND	1.9	ND	1.11	3.52	0.2148	-240	26	0	94	-2.16
Copper	0.25	µg/L	6.5	47.6	23.9	10.47	0.43	0.0320	-49	71	23	34	1.69
Copper (filtered)	0.25	µg/L	11.4	68.4	17.4	20.15	0.75	0.2847	-1224	91	13	361	-3.87
Lead	1.25	µg/L	3.5	57.3	14.6	17.66	0.94	0.0002	40	119	88	21	0.26
Lead (filtered)	1.25	µg/L	ND	8.4	2.8	2.86	0.93	0.0535	-200	129	33	89	4.99
Zinc	0.5	µg/L	4.5	336.6	164.1	100.4	0.66	0.0046	-171	84	39	68	2.93
Zinc (filtered)	0.5	µg/L	2.2	107.5	13.6	29.26	1.09	-0.3386	-155	54	-34	62	-2.84

Note: N/A = not applicable; ND = value below detection limit; negative p values indicate probability of increase; negative percent reductions indicate percent increase.

Table 5.7. (continued)

	IDL	Units	Settling Chamber Inlet Concentration		Settling Chamber		Settling Chamber		Settling Chamber		Percent Reduction		
			Minimum	Maximum	Median	Std. Dev.	COV	1-sided P Value	Minimum	Maximum	Median	Std. Dev.	COV
<i>IONS</i>													
Ammonium	0.25	mg/L	ND	0.341	ND	0.106	0.876	-0.0178	-491	27	-62	168	-1.6
Calcium	0.25	mg/L	1.626	15.11	8.742	3.46	0.403	-0.1697	-75	12	-5	29	-2.0
Lithium	0.025	mg/L	ND	ND	ND	9E-04	2.778	-0.2500	33	100	N/A	47	0.71
Magnesium	0.062	mg/L	0.211	1.829	1.028	0.479	0.458	-0.0081	-211	9	-29	62	-1.3
Potassium	0.062	mg/L	0.266	1.335	0.547	0.358	0.495	0.1750	-90	21	6	30	-13.7
Sodium	0.062	mg/L	0.716	5.803	1.349	1.332	0.871	0.1902	-182	38	3	58	-5.4
Hardness (as CaCO ₃)	6.25	mg/L	ND	58	35	13.62	0.405	-0.1960	-120	50	-8	46	-3.2
Chloride	0.025	mg/L	0.737	2.53	1.264	0.55	0.414	-0.2593	-50	15	-1	20	-3.1
Fluoride	0.025	mg/L	ND	0.09	0.029	0.026	0.806	-0.4961	-180	100	-36	82	-5.3
Nitrate	0.25	mg/L	ND	7.837	2.391	2.155	0.723	0.0046	-13	100	27	36	1.1
Nitrite	0.25	mg/L	ND	0.146	0.042	0.044	1.024	-0.0093	-674	100	-308	264	-1.52
Phosphate	0.25	mg/L	ND	0.683	ND	0.239	2.019	-0.3125	-31	100	N/A	75	1.3
Sulfate	0.25	mg/L	1.51	23.67	11.53	6.863	0.632	0.5151	-44	11	0	16	-4.9
Bicarbonate	N/A	mg/L	15.84	47.89	33.16	10.34	0.316	-0.0024	-73	7	-23	29	-0.95
Carbonate	N/A	mg/L	0.004	0.047	0.009	0.012	0.886	-0.0161	-167	38	-23	73	-1.5
<i>ORGANICS</i>													
Phenol	0.38	µg/L	ND	5	0.53	1.39	1.594	0.3125	-500	94	3	214	-2.7
N-Nitroso-di-n-propylamine	1.0	µg/L	ND	5.26	ND	3.018	3.765	0.0938	-208	227	81	106	2.1
Hexachloroethane	0.40	µg/L	ND	7.7	1.18	2.422	1.53	0.0078	-933	422	82	331	12
Nitrobenzene	0.48	µg/L	ND	2.76	0.54	1.083	1.307	0.0625	-3086	1272	26	1052	-6.1
2-Nitrophenol	0.90	µg/L	ND	2.24	ND	0.983	3.218	0.1250	-204	320	6	165	8.4
2,4-Dimethylphenol	0.68	µg/L	ND	81.25	0.6	22.97	3.81	0.0313	-141	586	53	207	1.9
Hexachlorobutadiene	0.22	µg/L	ND	26.19	1.44	7.203	2.049	0.1250	-129	191	29	88	2.8
4-Chloro-3-methylphenol	0.75	µg/L	ND	9.03	1.69	7.756	6.56	0.2813	-500	1014	93	370	4.5
4-Nitrophenol	0.60	µg/L	ND	120	6.9	40.43	3.289	-0.5000	-287	1576	50	474	3.2
Pentachlorophenol	0.90	µg/L	ND	46.46	ND	13.44	3.019	0.1250	-282	363	107	175	1.72
Fluoranthene	0.55	µg/L	ND	1.24	ND	0.422	0.962	0.1250	-300	200	111	125	1.5
Pyrene	0.48	µg/L	ND	0.77	ND	0.255	0.809	0.1250	-100	400	103	116	0.91
Bis(2-ethylhexyl)phthalate	0.62	µg/L	ND	10.34	1.92	2.64	1.048	0.0020	34	1667	99	454	2.0
Di-n-octylphthalate	0.62	µg/L	ND	0.72	ND	0.249	0.709	N/A	71	300	98	63	0.53

Note: N/A = not applicable; ND = value below detection limit; negative p values indicate probability of increase; negative percent reductions indicate percent increase.

Table 5.8. MCTT Sand-peat Chamber Performance Summary

	IDL	Units	Sand - Peat Chamber Inlet Concentration					Sand-Peat 1-sided P Value	Sand - Peat Chamber Percent Reduction				
			Minimum	Maximum	Median	Std. Dev.	COV		Minimum	Maximum	Median	Std. Dev.	COV
<i>CONVENTIONAL ANALYSIS</i>													
Total Solids	2.5	mg/L	21	111	65.5	26.89	0.40	0.1763	-51	24	3	25	-8.27
Volatile Total Solids	2.5	mg/L	10	54	24.5	13.84	0.48	-0.0146	-44	13	-30	19	-0.82
Total Suspended Solids	2.5	mg/L	ND	11	1.5	4.19	1.14	-0.1191	-500	45	-400	240	-1.45
Volatile Suspended Solids	2.5	mg/L	ND	11	4.5	4.57	1.10	-0.1641	-217	550	0	209	3.47
Dissolved Solids	2.5	mg/L	21	101	70.5	25.25	0.39	0.0820	-29	25	8	16	3.25
Volatile Dissolved Solids	2.5	mg/L	5	48	25	13.81	0.56	-0.0313	-160	13	-10	50	-1.56
Turbidity	0.75	NTU	0.76	3.6	1.6	0.75	0.44	-0.0005	-584	-4	-150	200	-0.91
Turbidity (filtered)	0.75	NTU	ND	2.1	ND	0.52	1.15	-0.0005	-429	-64	-133	119	-0.69
Apparent Color (unfiltered)	N/A	Hach*	13	41	26.5	8.39	0.32	-0.0010	-262	0	-75	83	-0.78
Color (filtered)	N/A	Hach*	9	41	22.5	9.01	0.41	-0.0005	-322	-30	-100	84	-0.71
Conductivity	N/A	µS/cm ²	29	92	68	20.54	0.32	0.0005	7	51	21	12	0.50
pH	N/A	std.	6.29	7.27	6.975	0.24	0.03	0.0010	-1	18	7	5.2	0.69
Chemical Oxygen Demand	1.1	mg/L	ND	53	25	19.44	0.79	-0.3359	-123	100	-55	85	-11.81
Chemical Oxygen Demand (filtered)	1.1	mg/L	ND	45	22.5	16.85	0.88	-0.4434	-103	100	-5	68	36.40
<i>TOXICITY</i>													
Relative Toxicity	5	125%	ND	33	11.5	10.38	0.82	0.0078	-175	1200	70	368	2.73
Relative Toxicity (filtered)	5	125%	ND	24	6.5	9.60	1.00	0.0537	-67	1000	67	309	1.56
<i>METALS</i>													
Cadmium	1	µg/L	ND	8.8	ND	2.83	2.17	0.4961	-600	75	-40	189	-2.00
Cadmium (filtered)	1	µg/L	ND	3.4	ND	1.38	2.86	-0.1055	-250	167	-21	97	-4.48
Copper	0.25	µg/L	6.1	40.6	18.35	9.67	0.53	0.3823	-322	49	25	107	-4.28
Copper (filtered)	0.25	µg/L	6.3	156.2	20.6	40.95	1.35	0.3188	-617	86	18	196	-4.70
Lead	1.25	µg/L	ND	6.4	2.9	2.56	0.92	0.0078	-133	109	18	60	5.24
Lead (filtered)	1.25	µg/L	ND	4.7	1.65	1.87	0.99	0.3408	-400	139	5	167	-2.72
Zinc	0.5	µg/L	12.2	198.4	58.85	56.57	0.78	0.0874	-5908	94	62	1796	-3.61
Zinc (filtered)	0.5	µg/L	4.4	57.6	18.25	21.21	0.82	0.1826	-352	104	69	142	322

Note: N/A = not applicable; ND = value below detection limit; negative p values indicate probability of increase; negative percent reductions indicate percent increase.

Table 5.8. (continued)

	IDL	Units	Sand - Peat Chamber Inlet Concentration					Sand-Peat	Sand - Peat Chamber Percent Reduction				
			Minimum	Maximum	Median	Std. Dev.	COV	1-sided P Value	Minimum	Maximum	Median	Std. Dev.	COV
<i>IONS</i>													
Ammonium	0.25	mg/L	ND	0.929	ND	0.263	0.882	-0.1201	-258	21	-7	101	-1.8
Calcium	0.25	mg/L	2.848	16.1	9.2	3.364	0.381	0.0005	18	77	38	19	0.44
Lithium	0.025	mg/L	ND	0.003	ND	0.001	1.61	-0.5000	0	100	N/A	47	1.4
Magnesium	0.062	mg/L	0.657	2.183	1.394	0.463	0.366	-0.1602	-67	35	-4	27	-4.2
Potassium	0.062	mg/L	0.241	1.185	0.61	0.309	0.462	-0.0737	-77	19	-16	29	-1.3
Sodium	0.062	mg/L	0.52	4.989	1.234	1.204	0.791	-0.1030	-45	27	-11	23	-1.7
Hardness (as CaCO ₃)	6.25	mg/L	11	60	33	14.6	0.44	0.0078	-64	35	24	28	1.8
Chloride	0.025	mg/L	0.732	2.041	1.22	0.472	0.363	-0.2598	-372	18	-10	113	-3.1
Fluoride	0.025	mg/L	ND	0.109	0.029	0.03	0.929	0.0391	-100	76	52	58	1.7
Nitrate	0.25	mg/L	ND	4.886	1.448	1.455	0.785	-0.1602	-475	47	-5	152	-3.2
Nitrite	0.25	mg/L	ND	0.843	0.057	0.265	1.477	0.0244	38	100	59	27	0.36
Phosphate	0.25	mg/L	ND	0.892	ND	0.26	2.783	-0.3125	42	100	N/A	41	0.58
Sulfate	0.25	mg/L	1.343	21.69	11.06	6.064	0.609	-0.3188	-306	17	-10	92	-2.5
Bicarbonate	N/A	mg/L	27.41	50.66	36.82	7.749	0.198	0.0005	36	86	58	15	0.25
Carbonate	N/A	mg/L	0.005	0.053	0.011	0.013	0.825	0.0005	13	100	80	26	0.36
<i>ORGANICS</i>													
Phenol	0.38	µg/L	ND	4.62	ND	1.504	1.69	0.2188	-500	10150	103	3064	3.2
N-Nitroso-di-n-propylamine	1.0	µg/L	ND	4.83	ND	1.681	1.296	0.0625	-5400	4550	64	2236	-23
Hexachloroethane	0.40	µg/L	ND	2.96	ND	1.019	1.863	-0.4063	-700	5162	89	1578	3.3
Nitrobenzene	0.48	µg/L	ND	4.46	ND	2.44	97.61	0.5000	-152	667	70	225	1.5
2-Nitrophenol	0.90	µg/L	ND	5.65	ND	2.009	2.091	0.2500	-55	2955	86	869	2.4
2,4-Dimethylphenol	0.68	µg/L	ND	11.23	ND	5.378	-5.53	0.4375	-155	213	41	119	2.8
Hexachlorobutadiene	0.22	µg/L	ND	5.9	1.35	2.455	1.701	0.0625	-6855	156	97	2089	-3.3
4-Chloro-3-methylphenol	0.75	µg/L	ND	9.37	1.205	4.782	3.334	0.2501	-154	3425	104	1023	2.8
4-Nitrophenol	0.60	µg/L	ND	121	ND	51.57	5.296	-0.2188	-683	2853	13	913	4.0
Pentachlorophenol	0.90	µg/L	ND	4.91	ND	4.41	-2.35	0.3750	-340	9200	-36	2801	3.64
Fluoranthene	0.55	µg/L	ND	ND	ND	0.085	-25.6	0.3750	-89	280	0	103	3.7
Pyrene	0.48	µg/L	ND	ND	ND	0.048	-7.19	0.1250	-100	320	25	155	1.4
Bis(2-ethylhexyl)phthalate	0.62	µg/L	ND	ND	ND	0.248	4.73	0.1563	-650	167	-188	300	-1.7
Di-n-octylphthalate	0.62	µg/L	ND	ND	ND	0.058	3.153	N/A	-100	150	0	75	3.3

Note: N/A = not applicable; ND = value below detection limit; negative p values indicate probability of increase; negative percent reductions indicate percent increase.

Table 5.9. Overall MCTT Performance Summary

	IDL	Units	MCTT Inlet Concentration				COV	MCTT 1-sided P Value	MCTT Percent Reduction				
			Minimum	Maximum	Median	Std. Dev.			Minimum	Maximum	Median	Std. Dev.	COV
<i>CONVENTIONAL ANALYSIS</i>													
Total Solids	2.5	mg/L	29	255	105	70.5	0.58	0.0005	-7	59	32	20	0.59
Volatile Total Solids	2.5	mg/L	10	105	43	29.1	0.59	0.0127	-40	55	19	31	2.0
Total Suspended Solids	2.5	mg/L	7	137	41	39.4	0.81	0.0002	25	100	83	22	0.28
Volatile Suspended Solids	2.5	mg/L	2	46	17	12.6	0.69	0.0027	-200	115	66	89	2.6
Dissolved Solids	2.5	mg/L	13	152	64	39.6	0.55	0.0784	-108	54	7	39	116
Volatile Dissolved Solids	2.5	mg/L	5	66	27	18.5	0.60	0.4629	-180	39	0	57	-3.9
Turbidity	0.75	NTU	2	16	5.5	3.7	0.64	0.1331	-245	62	40	99	-6.2
Turbidity (filtered)	0.75	NTU	ND	1.6	ND	0.4	0.70	-0.0320	-309	42	-92	111	-1.1
Apparent Color (unfiltered)	N/A	Hach*	16	58	27	14.5	0.43	-0.0007	-194	12	-55	58	-0.84
Color (filtered)	N/A	Hach*	4	55	32	14.7	0.47	-0.0032	-850	13	-49	237	-2.1
Conductivity	N/A	µS/cm ²	14	124	55	28.4	0.45	0.0276	-57	58	11	31	2.4
pH	N/A	std.	6.34	7.44	7.04	0.3	0.04	0.0046	-2	20	8	7.3	0.93
Chemical Oxygen Demand	1.1	mg/L	ND	197	42	55.5	1.00	0.0305	-40	100	54	46	0.86
Chemical Oxygen Demand (filtered)	1.1	mg/L	ND	110	23	36.7	1.05	0.1680	-63	100	10	55	1.9
<i>TOXICITY</i>													
Relative Toxicity	5	125%	ND	70	24	20.9	0.88	0.0022	-83	185	96	66	0.74
Relative Toxicity (filtered)	5	125%	ND	61	16	17.8	0.73	0.0015	-800	192	87	261	18
<i>METALS</i>													
Cadmium	1	µg/L	ND	2.9	ND	1.3	1.44	0.1338	-215	700	18	263	2.9
Cadmium (filtered)	1	µg/L	ND	2.5	ND	1.3	2.17	0.1602	-155	75	16	69	-3.6
Copper	0.25	µg/L	ND	96.7	23.7	25.4	0.86	0.2119	-159	1950	22	566	3.3
Copper (filtered)	0.25	µg/L	6.8	35.6	13.3	8.9	0.53	-0.4250	-558	93	17	197	-2.8
Lead	1.25	µg/L	3.5	70.8	16	17.5	0.85	0.0002	29	110	93	22	0.26
Lead (filtered)	1.25	µg/L	ND	11.9	2.1	3.4	1.38	0.3345	-565	99	42	196	-3.6
Zinc	0.5	µg/L	42	4022	177.8	1071	2.24	0.0005	-3	97	91	31	0.42
Zinc (filtered)	0.5	µg/L	ND	60.2	13.3	18.0	0.99	0.2119	-923	103	46	323	-4.7

Note: N/A = not applicable; ND = value below detection limit; negative p values indicate probability of increase; negative percent reductions indicate percent increase.

Table 5.9. (continued)

	IDL	Units	MCTT Inlet Concentration				MCTT 1-sided P Value	MCTT Percent Reduction				
			Maximum	Median	Std. Dev.	COV		Minimum	Maximum	Median	Std. Dev.	COV
<i>IONS</i>												
Ammonium	0.25	mg/L	0.459	ND	0.156	1.097	-0.0034	-651	31	-403	281	-0.97
Calcium	0.25	mg/L	15.35	8.748	3.773	0.44	0.0017	-99	80	33	47	1.7
Lithium	0.025	mg/L	0.005	ND	0.002	1.672	0.3281	0	100	N/A	42	0.88
Magnesium	0.062	mg/L	1.981	1.078	0.531	0.489	-0.0171	-209	43	-63	68	-1.2
Potassium	0.062	mg/L	1.669	0.539	0.394	0.563	-0.0461	-153	43	-23	51	-1.7
Sodium	0.062	mg/L	13.35	1.057	3.429	1.706	-0.0647	-192	73	-26	67	-1.9
Hardness (as CaCO ₃)	6.25	mg/L	71	38	16.52	0.432	0.0125	-200	67	30	71	6.9
Chloride	0.025	mg/L	2.915	1.208	0.609	0.483	-0.0386	-343	26	-13	100	-2.0
Fluoride	0.025	mg/L	0.107	ND	0.03	1.038	0.1475	-267	100	32	116	-14
Nitrate	0.25	mg/L	7.403	1.889	2.091	0.722	0.0105	-30	68	24	31	1.2
Nitrite	0.25	mg/L	0.239	0.012	0.065	1.611	-0.1250	-2717	100	-668	984	-2.05
Phosphate	0.25	mg/L	0.628	ND	0.206	2.479	-0.1875	100	100	N/A	N/A	N/A
Sulfate	0.25	mg/L	23.9	10.42	7.147	0.71	-0.0105	-229	15	-27	71	-1.4
Bicarbonate	N/A	mg/L	80.33	36.62	18.48	0.491	0.0007	-42	87	43	37	0.84
Carbonate	N/A	mg/L	0.056	0.02	0.017	0.877	0.0049	-600	100	81	196	23.7
<i>ORGANICS</i>												
Phenol	0.38	µg/L	8.04	0.4	2.162	1.88	0.1094	-1910	215	100	589	-10
N-Nitroso-di-n-propylamine	1.0	µg/L	39.75	1.45	10.89	2.063	0.0625	-969	2797	92	918	4.3
Hexachloroethane	0.40	µg/L	2.38	0.45	1.03	1.205	-0.5000	-1482	477	102	541	-6.6
Nitrobenzene	0.48	µg/L	12.81	ND	3.563	2.28	0.1250	-5557	189	18	1625	-3.1
2-Nitrophenol	0.90	µg/L	5.87	ND	2.122	1.369	0.2500	-3800	200	40	1111	-3.9
2,4-Dimethylphenol	0.68	µg/L	16.74	0.69	7.201	41.98	0.1250	-182	268	118	141	1.6
Hexachlorobutadiene	0.22	µg/L	28.91	0.71	9.069	2.282	0.0938	-548	1957	111	609	3.9
4-Chloro-3-methylphenol	0.75	µg/L	19.67	2.32	9.68	6.295	0.1563	-106	476	92	147	1.6
4-Nitrophenol	0.60	µg/L	105.3	2.04	33.45	2.737	0.4219	-1069	3283	-4	1042	5.7
Pentachlorophenol	0.90	µg/L	17.55	ND	6.469	2.198	0.1250	-1850	215	11	563	-4.05
Fluoranthene	0.55	µg/L	1.44	ND	0.523	0.976	0.1250	-233	200	104	107	1.3
Pyrene	0.48	µg/L	0.83	ND	0.282	0.786	0.0625	98	175	111	24	0.20
Bis(2-ethylhexyl)phthalate	0.62	µg/L	9.85	2.11	2.546	1.008	0.0020	-667	193	99	226	5.2
Di-n-octylphthalate	0.62	µg/L	0.96	ND	0.325	0.824	0.2500	81	200	101	34	0.31

Note: N/A = not applicable; ND = value below detection limit; negative p values indicate probability of increase; negative percent reductions indicate percent increase.

Table 5.10. Median Percent Reductions by Chamber

Constituent	Main Settling Chamber (percent)	Sand-Peat Chamber (percent)	Overall Device (percent)
Common Constituents			
total solids	31^a	2.6	32
suspended solids	91	-400	83
turbidity	50	-150	40
conductivity	-15	21	11
apparent color	16	-75	-55
pH	-0.3	6.7	7.9
COD	53	-55	54
Nutrients			
nitrate	27	-5	24
ammonium	-62	-7	-400
Toxicants			
Microtox™ toxicity (unfiltered)	18	70	96
Microtox™ toxicity (filtered)	69	67	87
lead	88	18	93
zinc	39	62	91
n-Nitro-di-n-propylamine	81	64	92
hexachlorobutadiene	29	97	100
pyrene	100	25	100
bis (2-ethylhexyl) phthalate	99	N/A	99

^a Note: Bold italics indicate Wilcoxon 1-sided p value ≤0.05

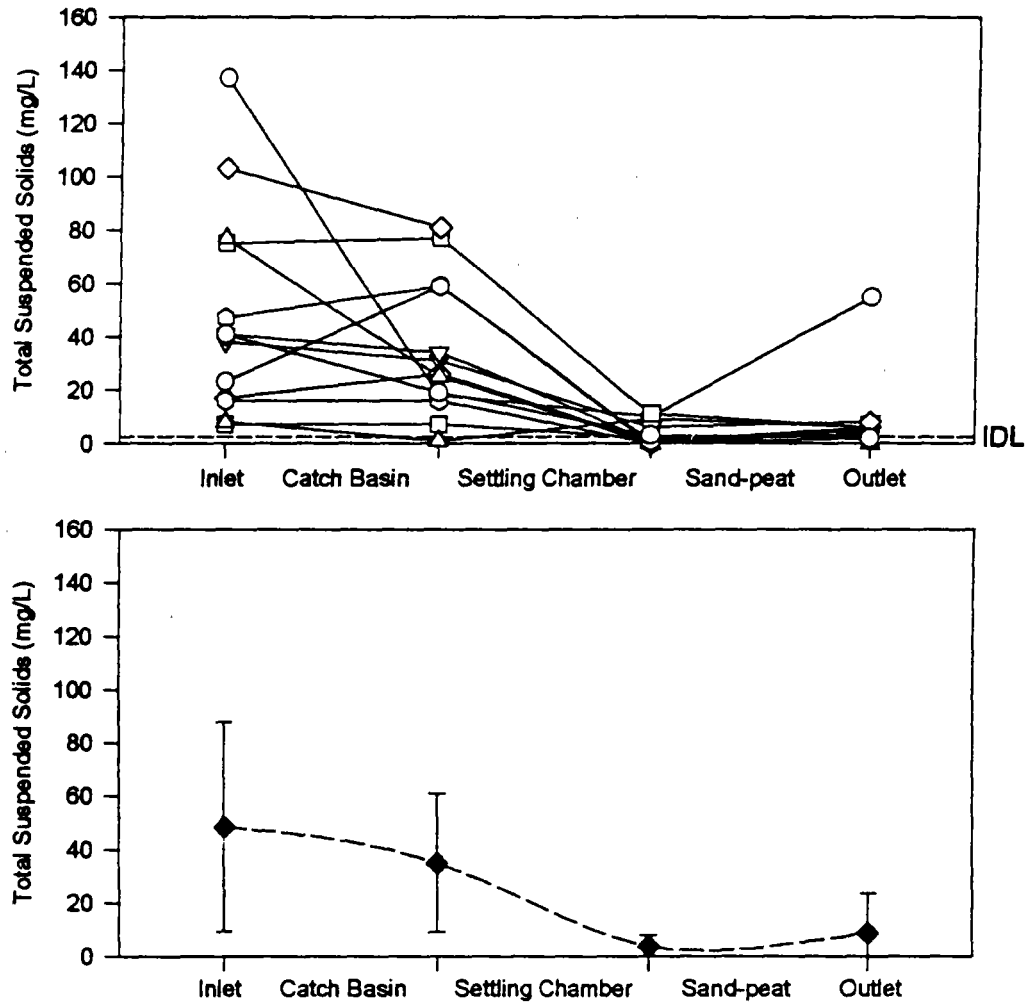
Figures 5.5 through 5.8 are example plots of the concentrations of SS, unfiltered toxicity, unfiltered zinc, and unfiltered bis(2-ethylhexyl) phthalate as the stormwater passed through the MCTT. Appendix A includes similar plots for the remaining constituents tested. The four data locations on these plots correspond to the four sampling locations on the MCTT. The sample location labeled “inlet” is the overall inlet to the MCTT (and the inlet to the catchbasin/grit chamber). The location labeled “catchbasin” is the effluent from the catchbasin (and inlet to the main settling chamber). Similarly, the location labeled “settling chamber” is the outlet from the settling chamber (and the inlet to the sand-peat chamber). Finally, the location labeled “peat-sand” is the outlet from the sand-peat chamber (and the outlet from the MCTT). Individual samples are traced through the MCTT on separate lines. Therefore, the slopes of the lines indicate the relative reduction rates (mg/L reduction) for each sample and for each individual major unit process in the MCTT. If the lines are all parallel between two sampling locations, then the reduction rates are similar. If a line has a positive slope, then a concentration increase occurred. If the lines have close to zero slope, then little reduction has occurred (as for the catchbasin/grit chamber for most constituents and samples).

The suspended solids trends shown on Figure 5.5 show the significant reductions in suspended solids concentrations through the main settling chamber, with little benefit from the catchbasin/grit chamber and the sand-peat chamber. However, the first storm had a significant increase in suspended solids concentration as it passed through the sand and peat due to flushing of fines from the incompletely washed media.

Table 5.11. Significant (1-sided p value < 0.05) Concentration Changes for MCTT

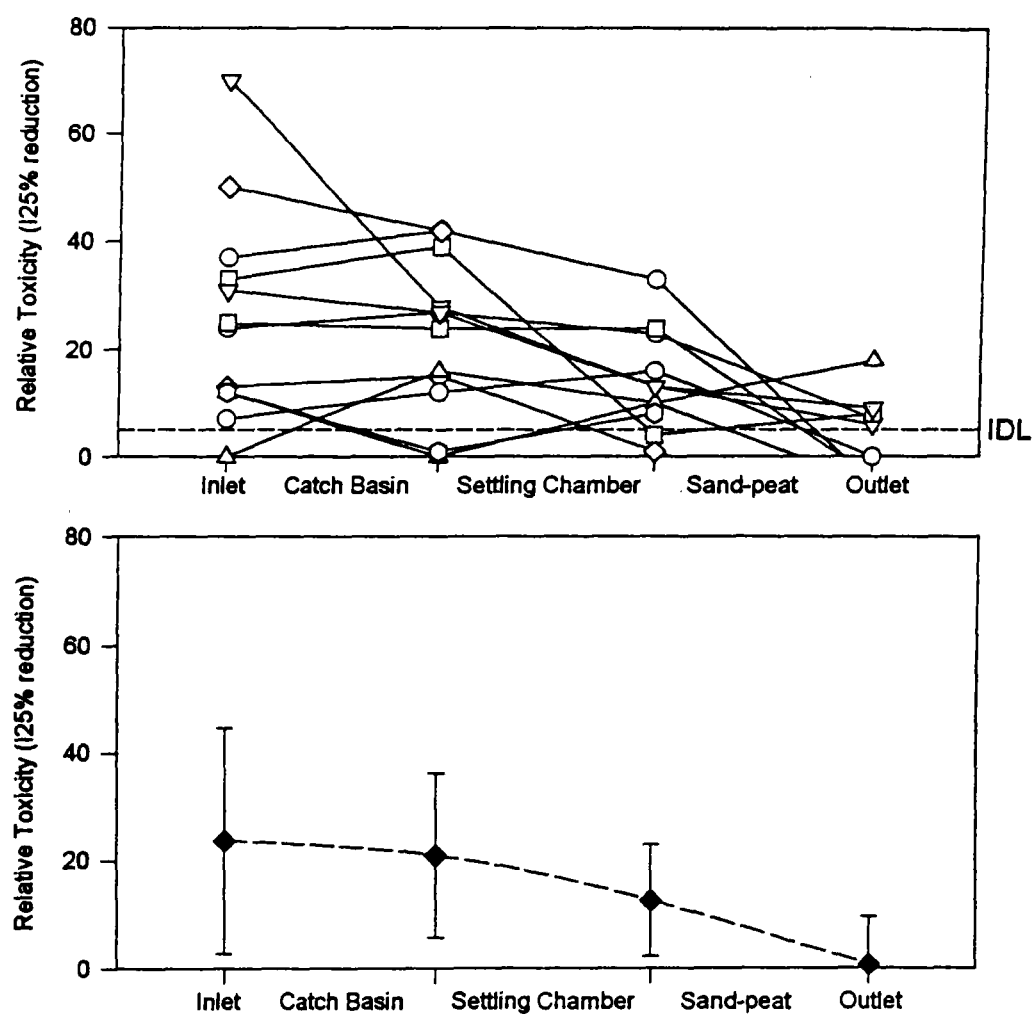
Constituent	Median Percent Reduction
Very High Constituent Reductions (>80%)	
Suspended Solids	83
Toxicity (unfiltered)	96
Toxicity (filtered)	87
Lead	93
Zinc	91
Carbonate	81
Bis(2-ethylhexyl)phthalate	99
High Constituent Reductions (50 to 80%)	
Volatile Suspended Solids	66
Chemical Oxygen Demand	54
Moderate Constituent Reductions (25 to 50%)	
Total Solids	32
Calcium	33
Hardness	30
Bicarbonate	43
Low Constituent Reductions (0 to 25%)	
Volatile Total Solids	19
Conductivity	11
pH	8
Nitrate	24
Constituent Increases	
Turbidity (dissolved)	-92
Apparent Color	-55
Color	-49
Ammonium	-400
Magnesium	-63
Potassium	-23
Chloride	-13
Sulfate	-27

The relative toxicity changes (as measured using a Azur Environmental Microtox™ unit) are shown on Figure 5.6 and indicate significant reductions in toxicity, especially for the moderate and highly toxic samples. No effluent samples were considered toxic (all effluent samples were “non toxic”, or causing less than a 20% light reduction after 25 to 45 minutes of exposure). Figures 5.7 and 5.8 are for zinc and bis(2-ethylhexyl) phthalate, a metallic and an organic toxicant, and show significant and large reductions in concentrations, mostly through the main settling chamber (corresponding to the large fraction of stormwater toxicants found in the particulate sample fraction). Zinc also had further important decreases in concentrations in the peat/sand chamber. Zinc and toxicity are examples where the use of the filtration/sorption chamber was needed to provide the highest levels of control. Otherwise, it may be tempting to simplify the MCTT by removing the last chamber. Another option would be to remove the main settling chamber and only use the pre-treating catchbasin as a grit chamber before the “filtraton” chamber (similar in design to conventional stormwater sand filters). This option is also not recommended because of the short life that the filter would have before it would clog (Clark and Pitt 1997). In addition, the bench-scale tests showed that a treatment train was needed to provide some redundancy, even for a single sampling site, because of frequent storm to storm variability in sample treatability.



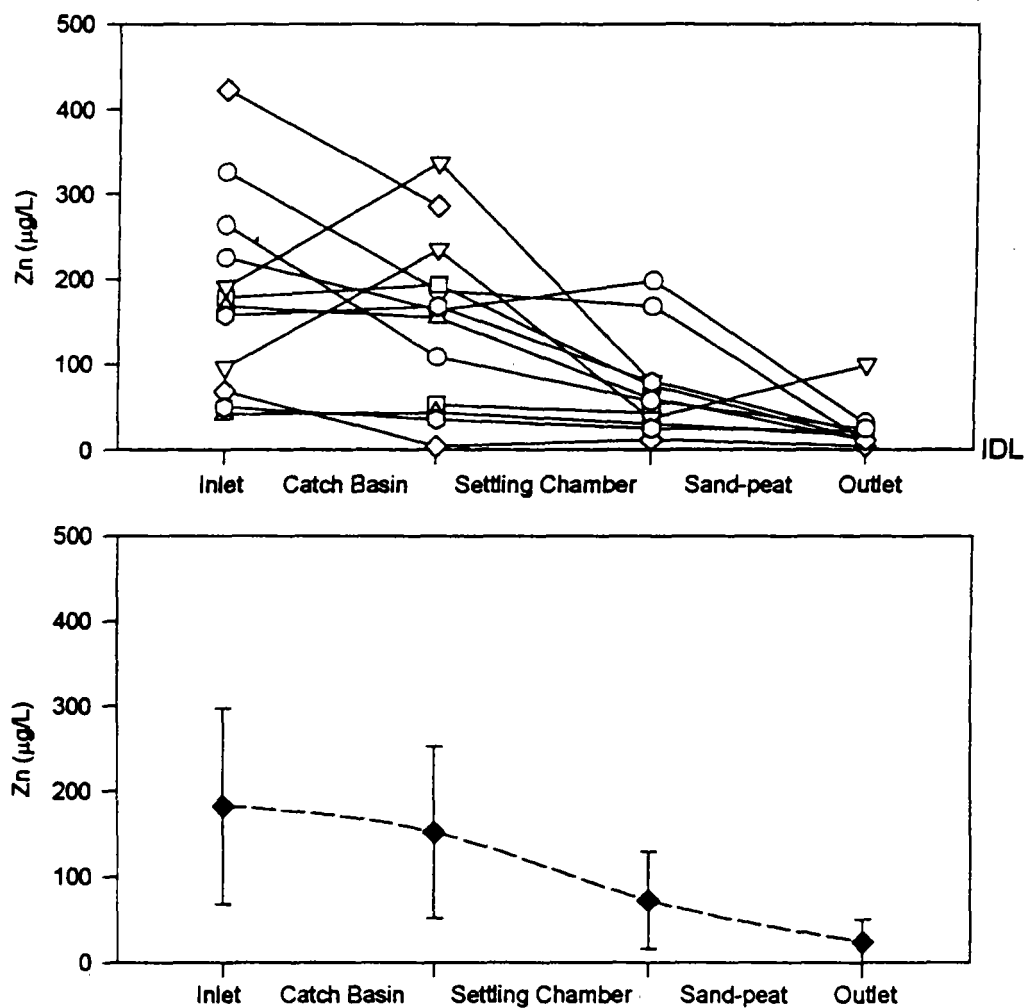
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.1543	0.0010	-0.1191	0.0002
Min. Percent Reduction	-157	-800	-500	25
Max. Percent Reduction	88	100	45	100
Median Percent Reduction	17	91	-400	83
Std. Dev. of Percent Reduction	65	257	240	22
COV of Percent Reduction	7.4	19	-1.5	0.28

Figure 5.5 MCTT performance for suspended solids.



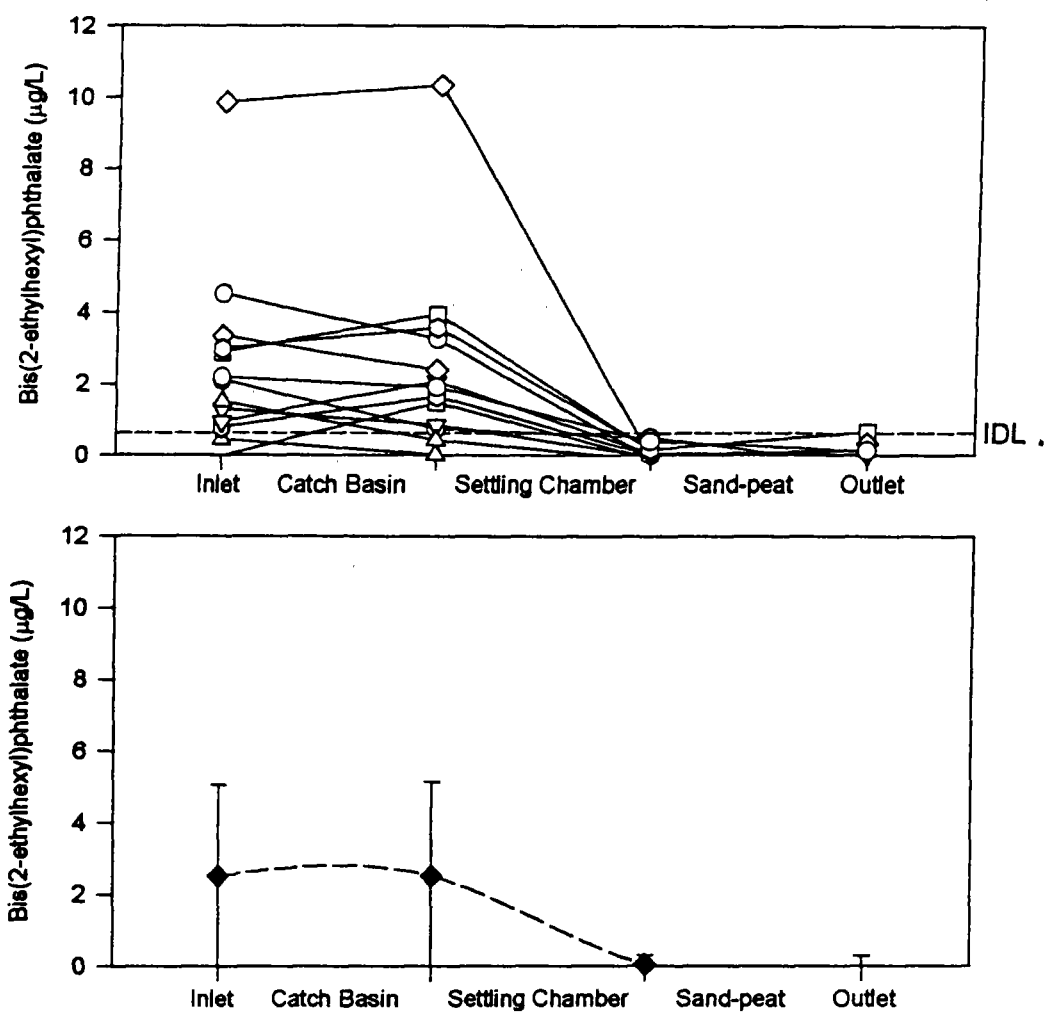
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.4464	0.0537	0.0078	0.0022
Min. Percent Reduction	-71	-700	-175	-83
Max. Percent Reduction	100	93	1200	185
Median Percent Reduction	4	18	70	96
Std. Dev. of Percent Reduction	53	238	368	66
COV of Percent Reduction	2.7	-3.9	2.7	0.74

Figure 5.6 MCTT performance for relative toxicity, by Microtox™, - unfiltered sample.



	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.1219	0.0046	0.0874	0.0005
Min. Percent Reduction	-144	-171	-5908	-3
Max. Percent Reduction	99	84	94	97
Median Percent Reduction	27	39	62	91
Std. Dev. of Percent Reduction	65	68	1796	31
COV of Percent Reduction	5.7	2.9	-3.6	0.42

Figure 5.7 MCTT performance for zinc - unfiltered sample.



	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.5000	0.0020	0.1563	0.0020
Min. Percent Reduction	-121	34	-650	-667
Max. Percent Reduction	5033	1667	167	193
Median Percent Reduction	28	99	-188	99
Std. Dev. of Percent Reduction	1397	454	300	226
COV of Percent Reduction	3.6	2.0	-1.7	5.2

Figure 5.8 MCTT performance for bis(2-ethylhexyl)phthalate - unfiltered sample.

Numerous other organic compounds were also analyzed, but only about 15 of the 70 target compounds were detected in sufficient frequency, or at high enough concentrations, to be reported. The organic analyte described above (bis(2-ethylhexyl) phthalate) was representative of the 15 compounds that were detected in sufficient concentrations. In all cases, the concentrations observed were representative of stormwater concentrations expected to be found in similar parking areas. However, the frequency of the organic compounds detected were substantially greater (being from 30 to 80% for the 15 primary compounds, compared to 10 to 30% for most past stormwater studies). As expected, few samples had detectable filterable organic toxicant concentrations. The use of the Microtox™ toxicity screening procedure (for both filterable and total sample fractions) was therefore important as an indicator of the “treatability” of the toxic components of the samples.

Appendix A includes plotted data, plotted mean and standard deviation error bars for the data, and summary tables for each parameter. Appendix B includes tabular data with summary tables. Plotted data in Appendix A also displays the instrument detection limit (IDL), where applicable. A definition of the IDL is the “concentration that produces a signal greater than three standard deviations of the mean noise level” for the given instrument. Generally, the IDL is equal to 0.5 of the lower limit of detection, (LLD), 0.25 of the method detection limit (MDL), and 0.1 of the upper limit of quantification (Greenberg, *et al.* 1992). The IDL, as given in the appendices, has been estimated by multiplying the established MDL for each respective analysis by 0.25. The IDL is presented as a reference line in Appendix A to show the relative magnitudes of reported concentrations to respective instrument and method detection capabilities.

Storm events 11 and 12 had missing data due to handling and sampling errors. During event 11, a sampler hose became dislodged, preventing the collection of a sample between the settling chamber and the sand-peat filter. A broken sample bottle resulted in loss of the MCTT/sand-peat effluent sample for event 12. While not initially planned, event 13 was treated by the device to offset the impact of these missing data.

Variability of results may be in part due to the variability of the stormwater runoff treated. In the sand-peat filter, the presence of some constituents likely effects the reduction of others due to interferences and competition for sorption sites. Such competition was observed in a study of sorption of various dyes in a peat bed (Allen, *et al.* 1988). Inconsistent metal reductions in the sand-peat filter may also be due to excessive velocities (hydraulic loadings) through the media not allowing adequate contact time. Research into the area of determining proper velocities has been noted to be lacking (Karamanov, *et al.* 1994).

Preliminary Full-Scale MCTT Test Results

Preliminary results from the full-scale tests of the MCTT in Wisconsin (Corsi, Blake, and Bannerman, personal communication) were encouraging and collaborate the high levels of treatment observed during the Birmingham pilot-scale tests. Table 5.12 shows the treatment levels that have been observed during seven tests in Minocqua (during one year of operation) and 15 tests in Milwaukee (also during one year of operation), compared to the pilot-scale Birmingham test results (13 events). These data indicate high reductions for SS (83 to 98%), COD (60 to 86%), turbidity (40 to 94%), phosphorus (80 to 88%), lead (93 to 96%), zinc (90 to 91%), and for many organic toxicants (generally 65 to 100%). The reductions of dissolved heavy metals (filtered through 0.45 µm filters) were also all greater than 65% during the full-scale tests. None of the organic toxicants were ever observed in effluent water from either full-scale MCTT, even considering the excellent detection limits available at the Wisconsin State Dept. of Hygiene Laboratories that conducted the analyses. The influent organic toxicant concentrations were all less than 5 µg/L and were only found in the unfiltered sample fractions. The Wisconsin MCTT effluent concentrations were also very low for all of the other constituents monitored: <10 mg/L for SS, <0.1 mg/L for phosphorus, <5 µg/L for cadmium and lead, and <20 µg/L for copper and zinc. The pH changes in the Milwaukee MCTT were much less than observed during the Birmingham pilot-scale tests, possibly because of added activated carbon in the final chamber in Milwaukee. Color was also much better controlled in the full-scale Milwaukee MCTT.

The Milwaukee installation is at a public works garage and serves about 0.1 ha (0.25 acre) of pavement. This MCTT was designed to withstand very heavy vehicles driving over the unit. The estimated cost was \$54,000 (including a \$16,000 engineering cost), but the actual total capital cost was \$72,000. The high cost was likely due to uncertainties

associated with construction of an unknown device by the contractors and because it was a retro-fit installation. It therefore had to fit within very tight site layout constraints. As an example, installation problems occurred due to

Table 5.12. Preliminary Performance Information for Full-Scale MCTT Tests, Compared to Birmingham Pilot-Scale MCTT Results (median reductions and median effluent quality)

	Milwaukee MCTT (15 events)	Minocqua MCTT (7 events)	Birmingham MCTT (13 events)
suspended solids	98 (<5 mg/L)	85 (10 mg/L)	83 (5.5 mg/L)
volatile suspended solids	94 (<5 mg/L)	na ^a	66 (6 mg/L)
COD	86 (13 mg/L)	na	60 (17 mg/L)
turbidity	94 (3 NTU)	na	40 (4.4 NTU)
pH	-7 (7.9 pH)	na	8 (6.4 pH)
ammonia	47 (0.06 mg/L)	na	-210 (0.31 mg/L)
nitrates	33 (0.3 mg/L)	na	24 (1.5 mg/L)
Phosphorus (total)	88 (0.02 mg/L)	80 (<0.1 mg/L)	nd ^b
Phosphorus (filtered)	78 (0.002 mg/L)	na	nd
Microtox [®] toxicity (total)	na	na	100 (0%)
Microtox [®] toxicity (filtered)	na	na	87 (3%)
Cadmium (total)	91 (0.1 µg/L)	na	18 (0.6 µg/L)
Cadmium (filtered)	66 (0.05 µg/L)	na	16 (0.5 µg/L)
Copper (total)	90 (3 µg/L)	65 (15 µg/L)	15 (15 µg/L)
Copper (filtered)	73 (1.4 µg/L)	na	17 (21 µg/L)
Lead (total)	96 (1.8 µg/L)	nd (<3 µg/L)	93 (<2 µg/L)
Lead (filtered)	78 (<0.4 µg/L)	na	42 (<2 µg/L)
Zinc (total)	91 (<20 µg/L)	90 (15 µg/L)	91 (18 µg/L)
Zinc (filtered)	68 (<8 µg/L)	na	54 (6 µg/L)
benzo(a)anthracene	>45 (<0.05 µg/L)	>65 (<0.2 µg/L)	nd
benzo(b)fluoranthene	>95 (<0.1 µg/L)	>75 (<0.1 µg/L)	nd
dibenzo(a,h)anthracene	89 (<0.02 µg/L)	>90 (<0.1 µg/L)	nd
fluoranthene	98 (<0.1 µg/L)	>90 (<0.1 µg/L)	100 (<0.6 µg/L)
indeno(1,2,3-cd)pyrene	>90 (<0.1 µg/L)	>95 (<0.1 µg/L)	nd
phenanthrene	99 (<0.05 µg/L)	>65 (<0.2 µg/L)	nd
pentachlorophenol	na	na	100 (<1 µg/L)
phenol	na	na	99 (<0.4 µg/L)
pyrene	98 (<0.05 µg/L)	>75 (<0.2 µg/L)	100 (<0.5 µg/L)

na^a: not analyzed

nd^b: not detected in most of the samples

sanitary sewerage not being accurately located as mapped. Figures 5.9 – 5.14 are photographs of the MCTT installation at the Ruby Garage site in Milwaukee. Figure 5.9 shows the Ruby garage drainage area, with snow blade storage. Figures 5.10 – 5.12 are photographs of the Ruby garage MCTT being installed. Figure 5.13 shows the catchbasin inlet and connecting piping to the MCTT during construction. Figure 5.14 shows the sorbent pillows on top of the inclined tube settlers in the main settling chamber.

The Minocqua site is at a 1 ha (2.5 acre) newly paved parking area serving a state park and commercial area. It was located in a grassed area and was also a retro-fit installation, designed to fit within an existing storm drainage system. The installed capital cost of this MCTT was about \$95,000. Figures 5.15 – 5.22 show photographs of the MCTT in Minocqua. Figure 5.15 shows the drainage area, a newly paved parking area. Figures 5.16 and 5.17 show the installation of the 3.0 X 4.6 m (10ft X 15ft) box culverts used for the main settling chamber (13 m, or 42 ft long) and the filtering chamber (7.3 m, or 24 ft long). Figure 5.18 shows the placement of the tube settlers and Figure 5.19 shows the filter fabric being unrolled for placement in the final chamber. Figure 5.20 shows the grit chamber (a 7.6 m³, 2,000 gal. baffled septic tank), and Figure 5.21 shows the interior of the final filtration chamber. Figure 5.22 shows the site after final construction.

It is anticipated that MCTT costs could be substantially reduced if designed to better integrate with a new drainage system and not installed as a retro-fitted stormwater control practice. Plastic tank manufacturers have also expressed an interest in preparing pre-fabricated MCTT units that could be sized in a few standard sizes for small critical

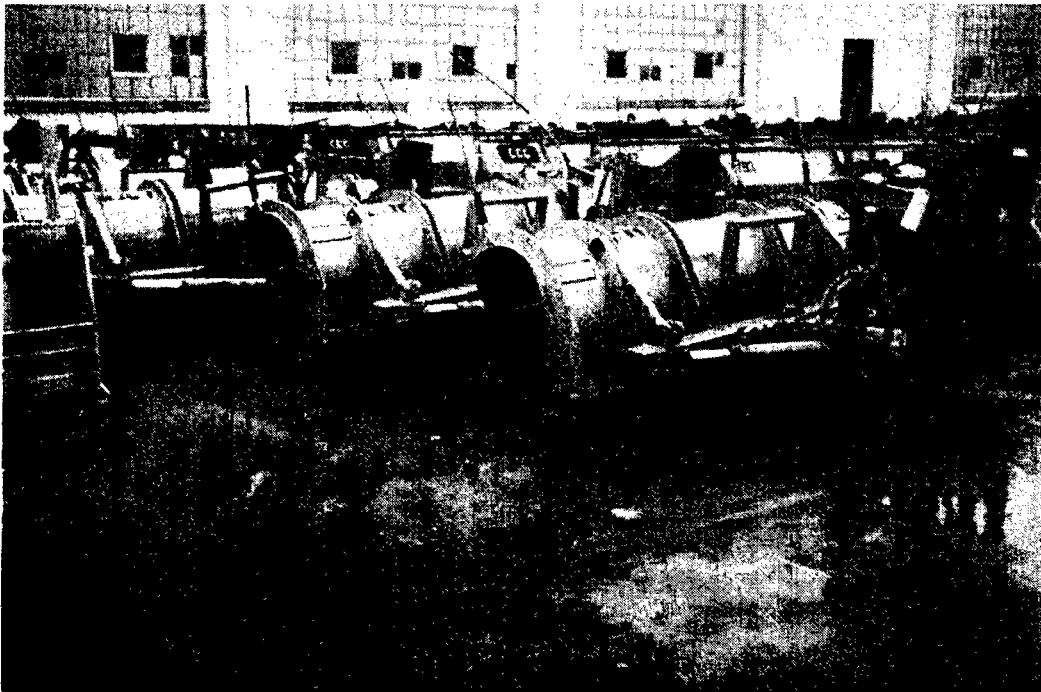


Figure 5.9 Ruby Garage, Milwaukee, drainage area (WI DNR photo).

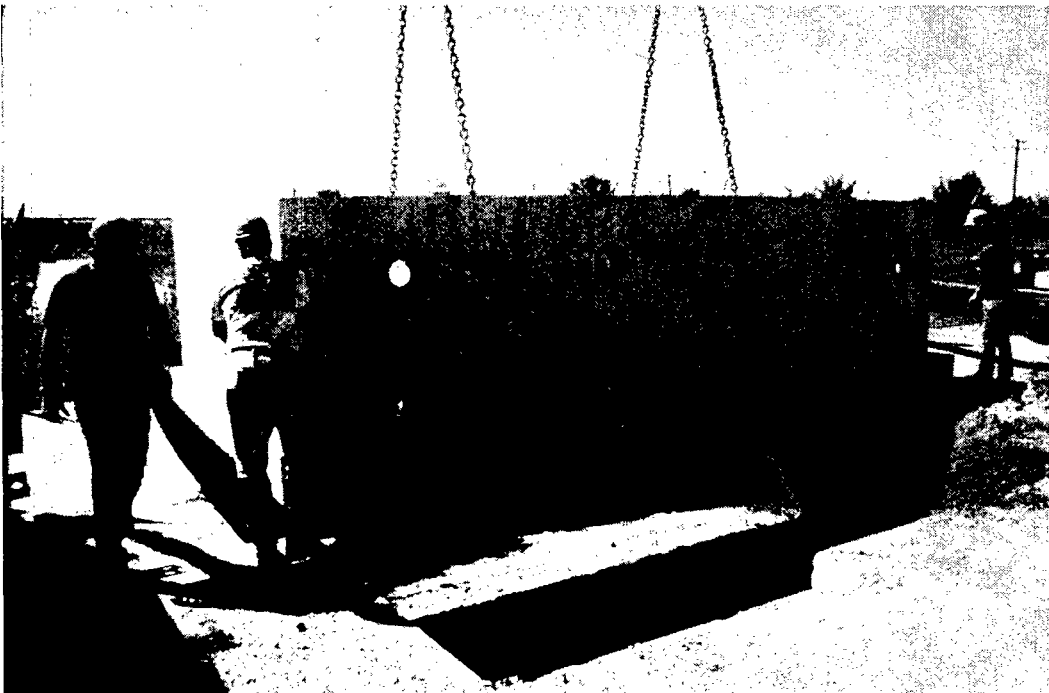


Figure 5.10 Ruby Garage, Milwaukee, MCTT installation (WI DNR photo).

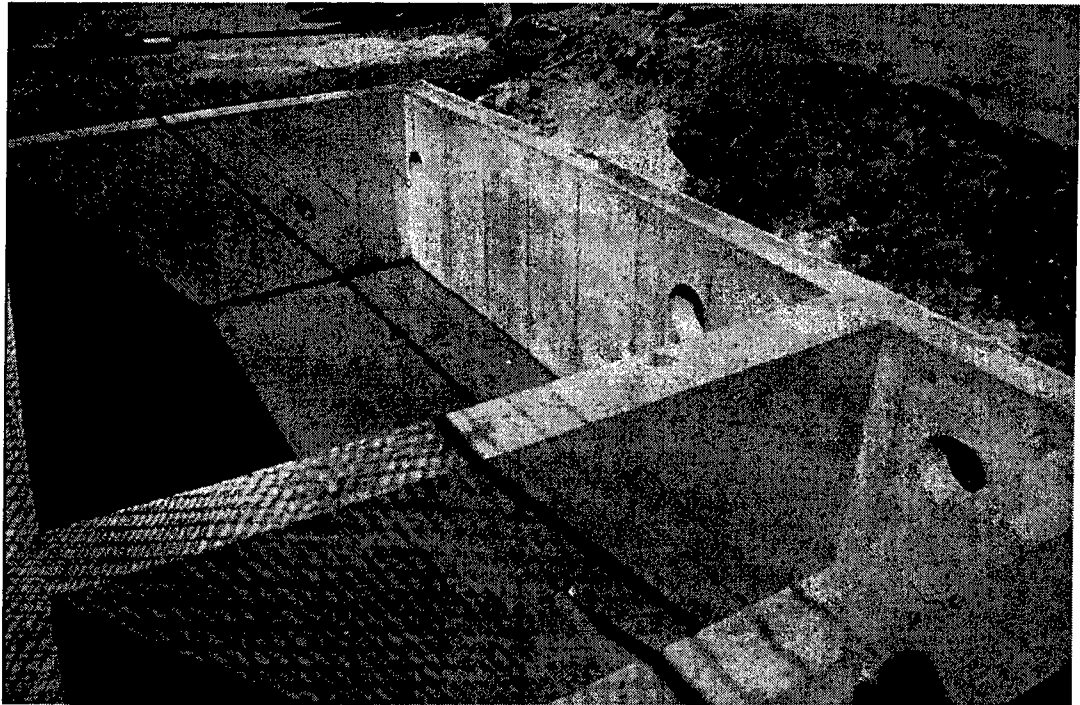


Figure 5.11 Ruby Garage, Milwaukee, MCTT installation (WI DNR photo).

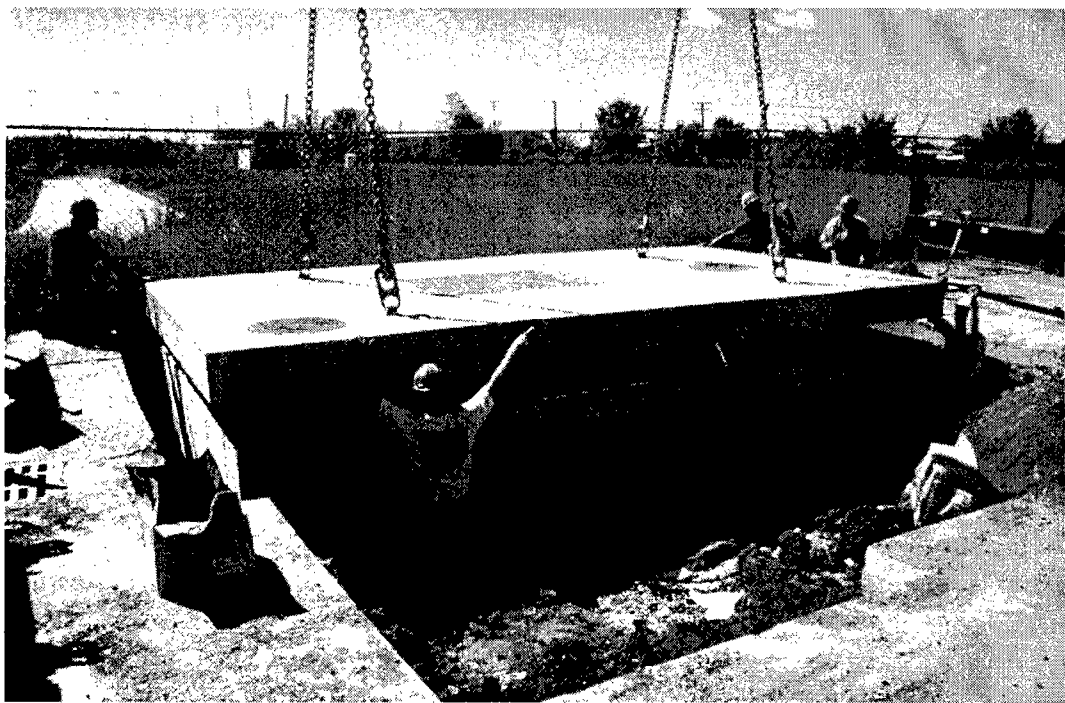


Figure 5.12 Ruby Garage, Milwaukee, MCTT installation (WI DNR photo).



Figure 5.13 Ruby Garage, Milwaukee, MCTT catchbasin inlet and piping (WI DNR photo).



Figure 5.14 Ruby Garage, Milwaukee, MCTT main settling chamber inclined tube settlers and sorbent pillows (WI DNR photo).



Figure 5.15 Minocqua, WI, MCTT, drainage area (WI DNR photo).

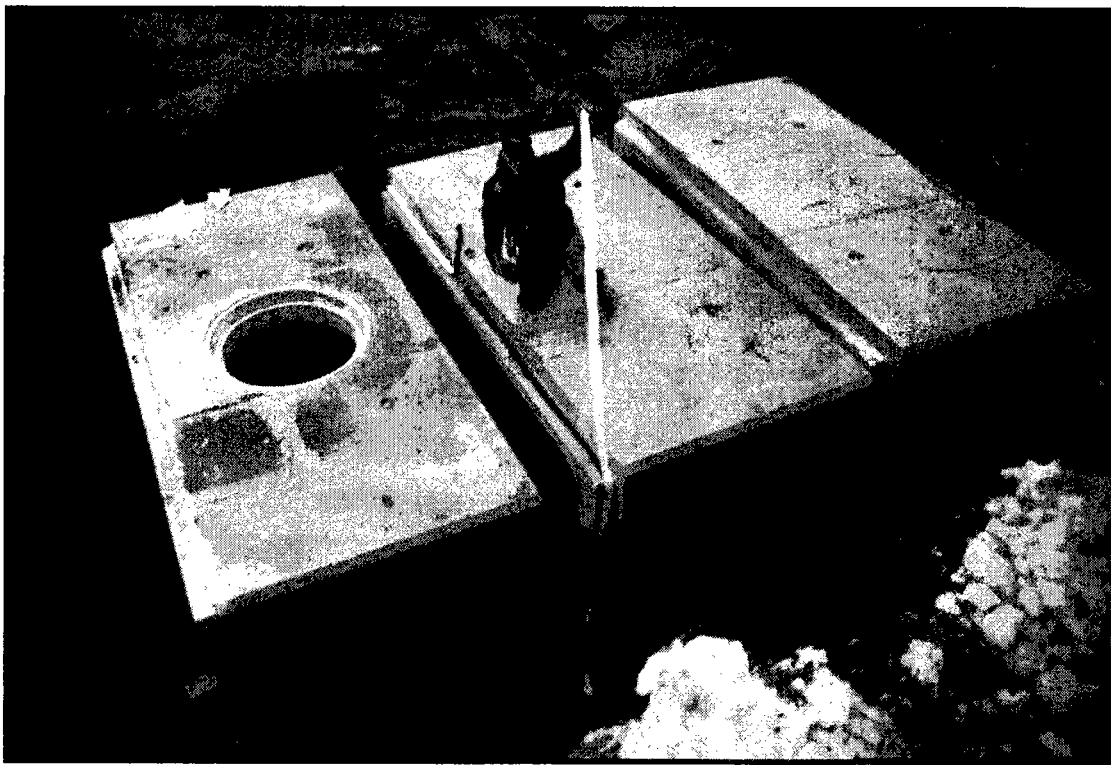


Figure 5.16 Minocqua, WI, MCTT, installation of box culverts (WI DNR photo).



Figure 5.17 Minocqua, WI, MCTT, installation of box culverts (WI DNR photo).



Figure 5.18 Minocqua, WI, MCTT, placement of tube settlers (WI DNR photo).



Figure 5.19 Minocqua, WI, MCTT, filter fabric being prepared for installation (WI DNR photo).

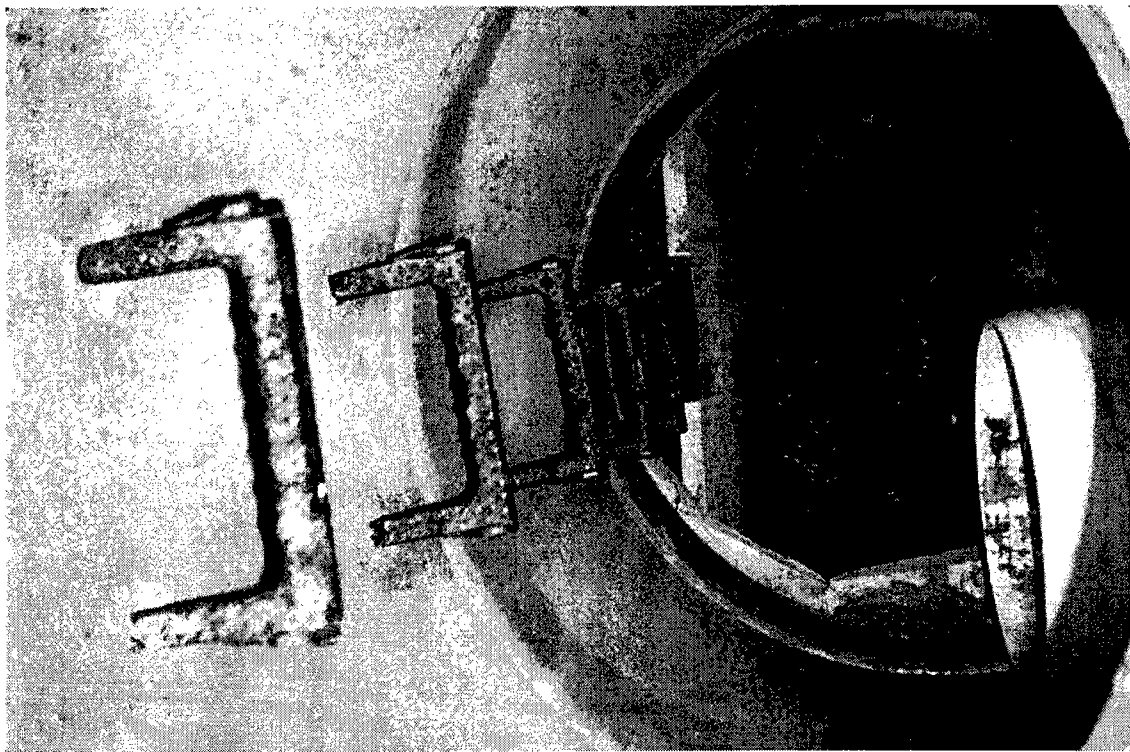


Figure 5.20 Minocqua, WI, MCTT, grit chamber.

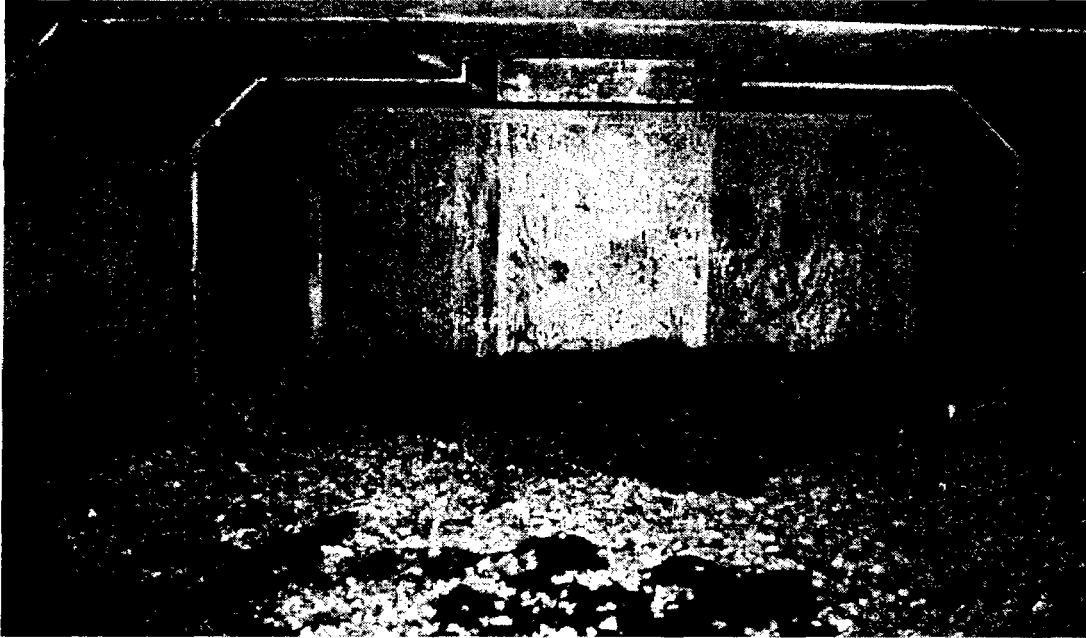


Figure 5.21 Minocqua, WI, MCTT, interior of final filtration chamber.



Figure 5.22 Minocqua, WI, MCTT, site after installation.

Chapter 6

General Design Procedures for the MCTT

Design Procedure

The MCTT consists of three main components, as noted previously. The initial catchbasin inlet/grit chamber design is based on prior catchbasin performance studies (especially Lager, *et al.* 1977, Pitt 1979, and Pitt 1985). The development of the main settling chamber for toxicant control is described in Chapter 4 of this report, based on Ayyoubi's master's thesis (1993). The final "filtration" chamber design is based on Clark's master's thesis (1996). This section summarizes the integrated design of the MCTT, by examining each of these three components separately.

The most critical step in the design of the MCTT is the sizing of the main settling chamber. The design of the filtration/sorption chamber is important as it acts as a polishing unit mainly for the reduction of filterable toxicants. The filtration/sorption chamber also helps to reduce the variability in the overall performance of the MCTT. The catchbasin inlet acts as an initial grit chamber to reduce maintenance problems in the later MCTT components.

The design of the MCTT can be separated into the following general steps:

- determine the pollutant removal goal
- conduct a site survey to determine drainage area and character, subsurface conflicts (existing buried utilities and bedrock), and special surface loading conditions (such as from heavy public works vehicles)
- determine the needed hydraulic grade line for the drainage system receiving the MCTT effluent
- select a series of candidate MCTT tank depths and holding periods for the desired pollutant removal rate in the main settling chamber using the design curves for the area nearest to the site that meets the above site restraints and goals
- determine critical runoff volumes that need to be captured for the alternative tank depths and holding times for the main settling chamber
- investigate alternative available tank components and select the most appropriate tank
- select the most appropriate filtration/sorption media (usually a peat/sand mixture, with activated carbon, if possible)
- size the filtration/sorption chamber to obtain the desired flow rate and mass of media
- size the catchbasin/grit chamber as a pre-treatment unit. This can be located adjacent to the MCTT, or it can be located at inlets upstream to the MCTT.

The following sections of this chapter address the major steps: selecting the pollutant removal goal, sizing the initial catchbasin/grit chamber, selecting alternative main settling tank sizes, and sizing the sorption/filtration chamber. This chapter also illustrates the design processes with an example for Detroit, MI. The chapter also contains material specifications that were used during this research for the construction of the pilot- and full-scale MCTT units.

Pollutant Removal Goal

The first major step in the specific design of any stormwater control device is establishing the pollutant removal goal. This goal should be based on an understanding of the receiving water problems and the sources of the problems. As noted, the MCTT was developed to control toxicant pollutants at critical source areas. In most cases, a desired pollutant removal goal would be fairly large. The MCTT units tested during this project all had very high removals of organic and metallic toxicants and suspended solids (mostly >90% reductions), with smaller removals

of nutrients. The design curves presented later in this chapter are used to size the main settling chamber of the MCTT, based on the desired toxicity reduction in that chamber. However, the data from the monitored facilities enable the overall removal of other pollutants to be estimated.

Table 6.1 shows the constituent removal rates for the complete MCTT, compared to the design toxicity reduction for the main settling chamber of the MCTT alone. It is apparent that the overall MCTT provides additional treatment than the main settling chamber alone. As an example, the overall MCTT provides about an additional 30% in toxicity reduction beyond the main settling chamber alone. This additional treatment can be considered in the sizing of the MCTT for a specific removal goal. This table can therefore be used to estimate the removal rates of other critical pollutants for a candidate MCTT design. As an example, if the main settling chamber is designed for a 70% reduction in toxicity, the overall MCTT removals would be approximately:

Microtox® toxicity	91% (1.3 X 70%)
Suspended solids	77% (1.1 X 70%)
Lead	84% (1.2 X 70%)
Zinc	84% (1.2 X 70%)
Most organic toxicants	91% (1.3 X 70%)
COD	50% (0.72 X 70%)
Nitrates	22% (0.32 X 70%)

Similarly, if the desired overall suspended solids removal is 85%, the toxicity removal in the main settling chamber that would be used for MCTT sizing, would be approximately 77% (85%/1.1). The removal estimates for these other pollutants are approximate because of the variability in performance observed. Obviously, no removal can be greater than 100%, and small MCTT units (having small expected toxicity reductions in the main settling chamber alone) have not been tested. Therefore, as the main settling chamber toxicity removal varies from about 75%, these estimates of removal for other pollutants would have increasing errors.

Table 6.1. Full MCTT Pollutant Removals Compared to Design Toxicity Reductions

Constituent	Ratio of Constituent Removal to Design Toxicity Removal Goal (median)
Very High Removals:	
Microtox® toxicity	1.3
Microtox® toxicity (filtered)	1.2
Suspended solids	1.1
Lead	1.2
Zinc	1.2
Fluoranthene	1.3
Pyrene	1.3
Pentachlorophenol	1.3
Phenol	1.3
High Removals:	
Volatile suspended solids	0.87
COD	0.72
Zinc (filtered)	0.72
Moderate Removals:	
Turbidity	0.53
Lead (filtered)	0.56
Low Removals:	
NO ₃	0.32
Cadmium	0.24
Cadmium (filtered)	0.21
Copper	0.20
Copper (filtered)	0.23

Catchbasin Inlet Chamber Design

Further background information for catchbasins, including recent field performance trials and summaries of earlier research, is available in another associated report currently being prepared as part of this research project (Pitt, *et al.* 1997). This other report also contains monitoring information from field tests of inlet filters and presents alternative enhanced catchbasin designs. However, the conventional catchbasin, described below, was found to be most effective for almost all conditions. The commercially available inlet filters that were tested performed poorly, with rapid clogging. Some types of inlet screens are useful for trapping litter, however, and may be important in some applications. The conventional catchbasin must contain a sump to trap particulates and to reduce scour losses of previously trapped material. If the sump is too small, very little benefit is realized with a catchbasin. The scour depth of a catchbasin sump is about 0.3 m (1 ft), with deeper sumps needed for sediment storage between cleaning operations.

The geometry of a catchbasin was found to be very important by Lager, *et al.* (1977) and later confirmed by Aronson, *et al.* (1983). The basic catchbasin (having an appropriately sized sump) and an inverted outlet is the most robust configuration for a basic storm drain inlet. In almost all full-scale field investigations, this design has been shown to withstand extreme flows with little scouring losses, no significant differences between supernatant water quality and runoff quality, and minimal insect problems. It will trap the bed-load from the stormwater (especially important in areas using sand for winter traction control) and will trap a moderate amount of SS (about 30 to 45% of the annual loadings). The largest fraction of the sediment in the flowing stormwater will be trapped, in preference to the finer material that has greater amounts of associated pollutants. Their hydraulic capacities are designed using conventional procedures (grating and outlet dimensions), while the sump is designed based on the desired cleaning frequency. Figure 6.1 is this basic recommended configuration for an effective catchbasin.

The size of the catchbasin sump is controlled by three factors: the runoff flow rate, the SS concentration in the runoff, and the desired frequency at which the catchbasin will be cleaned without sacrificing efficiency. Figure 6.2 shows the percent SS removed versus the influent flow rate, as presented by Pitt (1985). The volume of sediment captured in catchbasin sumps was calculated using this relationship for a one acre paved drainage area and for runoff having 50 to 1000 mg/L SS concentrations. The 1976 Birmingham, AL, rain year was used to obtain typical rain depths and flow rates for each rain. The R_v (volumetric runoff coefficient) was obtained from the small storm hydrology tests conducted by Pitt (1987). Figure 6.3 shows the amounts of rainfall treated before the catchbasin sump is 60% full, when the SS deposition is approximately in equilibrium with scour and the capture efficiency is assumed to be reduced to zero (Pitt 1985). The equation for this capture rate is:

$$\% \text{ SS Reduction} = 44 \times (0.51)^Q \times (1.1)^{Q^{1.2}}$$

where Q is the influent flowrate in ft^3/s (CFS). The volume of SS removed was evaluated assuming a specific gravity of 2.5. Table 6.2 shows the approximate accumulation of SS for different total rainfall depths.

An estimate of the required catchbasin sump volume and cleanout frequency can be calculated using this table and specific site conditions. For example, assume the following conditions:

- paved drainage area: 1.3 ha (3.3 acres),
- 250 mg/L SS concentration, and
- 640 mm (25 in.) of rain per year.

The sediment accumulation rate in the catchbasin sump would be about $0.24 \text{ m}^3/\text{ha}$ ($3.4 \text{ ft}^3/\text{acre}$) of pavement per year. For a 1.3 ha (3.3 acre) paved drainage area, the annual accumulation would therefore be about 0.3 m^3 (10 ft^3). The catchbasin sump diameter should be at least four times the diameter of the outlet pipe. Therefore, if the outlet from the catchbasin is a 250 mm (10 in.) diameter pipe, the sump should be at least 1 m (40 in.) in diameter (having a surface area of 0.8 m^2 , or 9 ft^2). The annual accumulation of sediment in the sump for this situation would therefore be about 0.4 m (1.3 ft). If the sump is to be cleaned about every two years, the total accumulation between cleanings would therefore be about 0.8 m (2.6 ft). An extra 0.3 m (1 ft) of sump depth should be provided as a safety factor because of potential scour during unusual rains. Therefore, a total sump depth of about 1.1 m (3.6 ft) should be used. In no case should the total sump depth be less than about 1 m (3 ft) and the sump diameter less than about

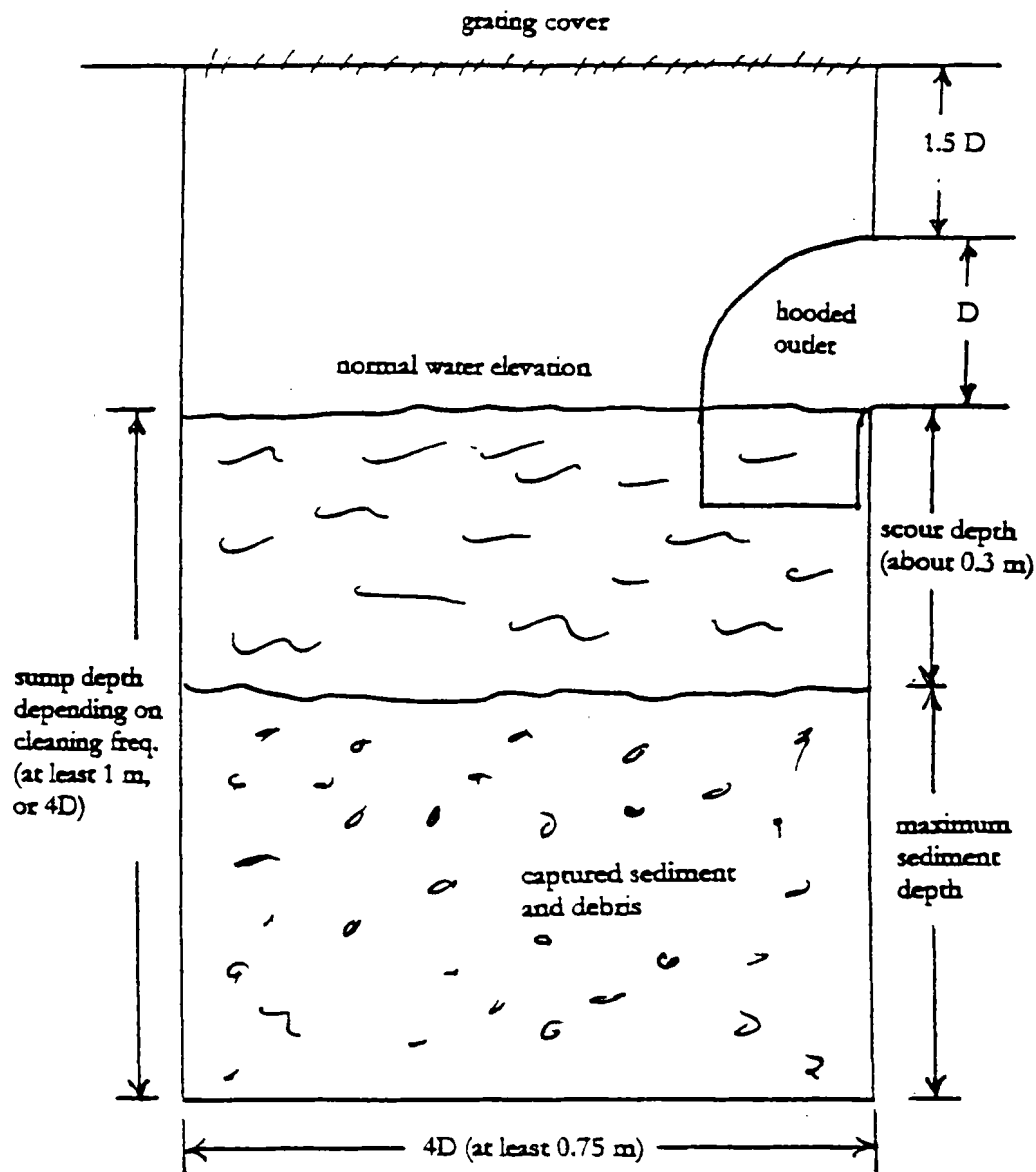


Figure 6.1 Conventional catchbasin with inverted sump (Pitt, et al. 1997).

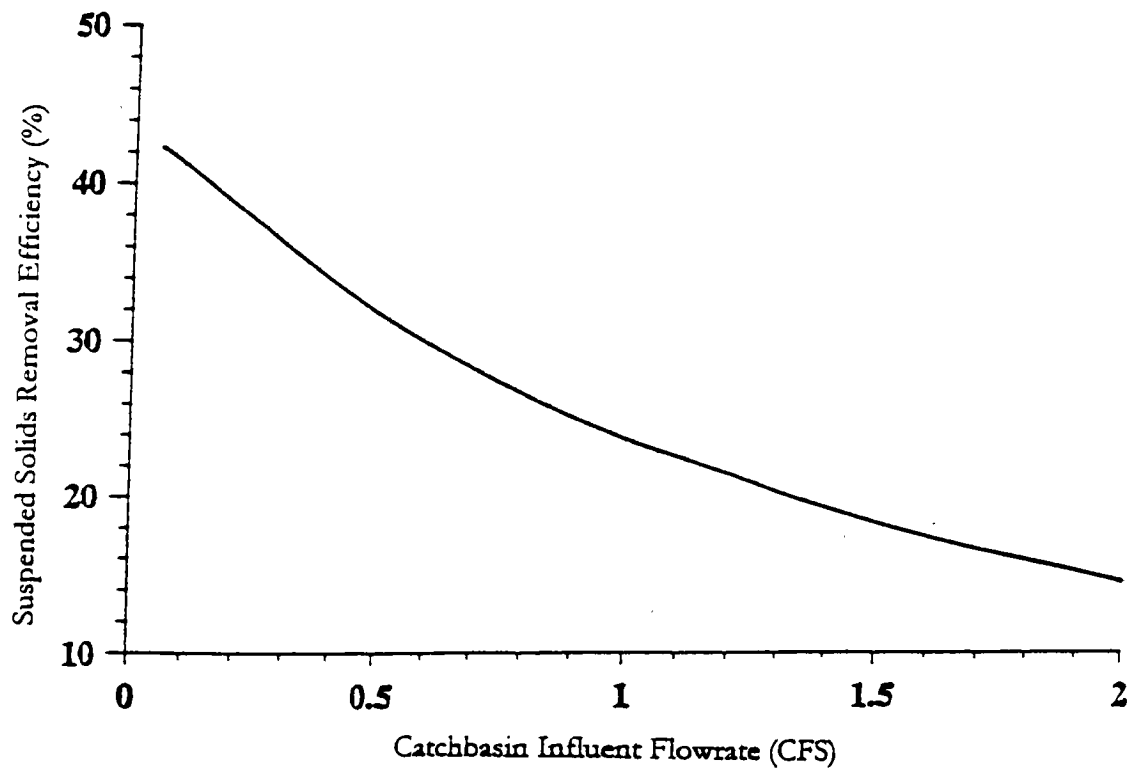


Figure 6.2 Suspended solids capture vs flowrate (Pitt, et al. 1997).

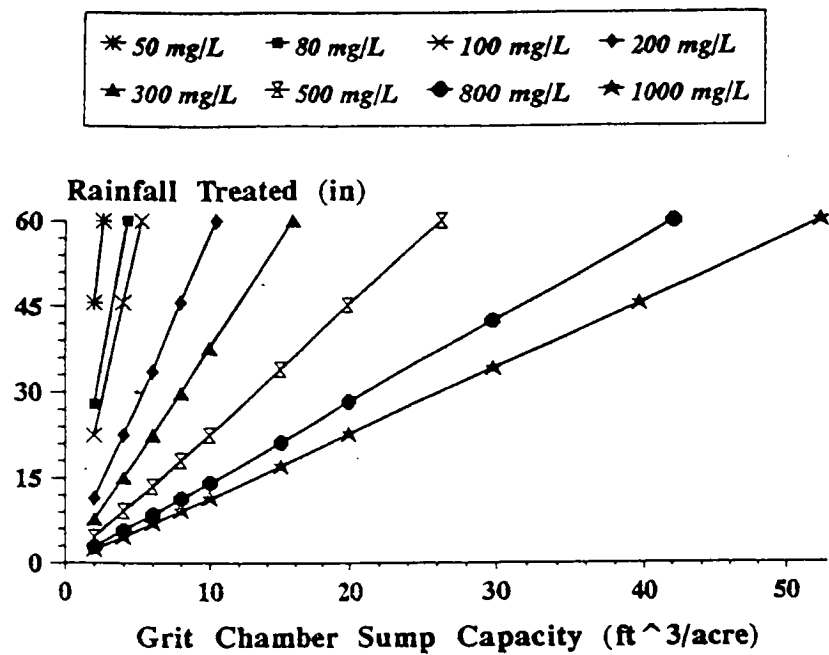


Figure 6.3 Amount of rainfall treated before catchbasin sumps are 60% full (Pitt, et al. 1997).

**Table 6.2 Approximate Suspended Solids Accumulations in Catchbasin Sump
(ft³/acre of pavement)**

Total Rainfall (inches)	50 mg/L SS conc.	100 mg/L SS conc.	250 mg/L SS conc.	500 mg/L SS conc.
5	0.13	0.27	0.67	1.3
10	0.27	0.54	1.3	2.7
15	0.40	0.81	2.0	4.0
25	0.67	1.3	3.4	6.7
50	1.3	2.7	6.7	13
100	2.7	5.4	13	27
200	5.4	11	27	54

0.75 m (2.5 ft). This would provide an effective sump volume of about 0.8 m³ (9 ft³) assuming a safety factor of about 1.6.

Main Settling Chamber Design

The design of the MCTT is very site specific, as noted previously, being highly dependent on local rains (rain depths, rain intensities, and interevent times). A computer model, described previously, was therefore developed to determine the amount of annual rainfall treated, the toxicity reduction rate for each individual storm, and the overall toxicity reduction associated with a long series of rains for different locations in the U.S. These design guidelines were determined by continuous simulation of the rainfall-runoff process and MCTT performance using 100 random rains (rain depths, rain durations, and interevent periods) obtained over a 5 to 10-year period for each city. Earth-Info™ (Golden, Colorado) CD-ROM rainfall data compilations of National Weather Service data were used to obtain this rain information. Table 6.3 shows the resultant required main settling chamber sizes for 21 cities having rain depths ranging from 180 mm (7.1 in.) (Phoenix) to 1500 mm (60 in.) (New Orleans) per year. Design curves for each of these cities for different MCTT settling depths are shown in Figures 6.4 to 6.23, at the end of this chapter.

**Table 6.3. MCTT Main Settling Chamber Required Sizes
(all 48 h holding times, except as noted, with 5 foot settling depths).**

City	Annual Rain Depth (in.)	Runoff Capacity (in.) for 70% Toxicant Control	Runoff Capacity (in.) for 90% Toxicant Control
Phoenix, AZ	7.1	0.25 (24 h)	0.35
Reno, NV	7.5	0.20 (18 h)	0.20
Bozeman, MT	12.8	0.25	0.40
Los Angeles, CA	14.9	0.30	0.45
Rapid City, SD	16.3	0.20 (18 h)	0.22
Minneapolis, MN	26.4	0.32	0.50
Dallas, TX	29.5	0.50	0.96
Madison, WI	30.8	0.32	0.52
Milwaukee, WI	30.9	0.36	0.65
Detroit, MI	31.0	0.24	0.50
Austin, TX	31.5	0.22 (18 h)	0.32
St. Louis, MO	33.9	0.30	0.49
Buffalo, NY	37.5	0.35	0.50
Seattle, WA	38.8	0.25	0.40
Newark, NJ	42.3	0.48	0.96
Portland, ME	43.5	0.42	0.72
Atlanta, GA	48.6	0.55	0.95
Little Rock, AR	49.2	0.52	0.85
Miami, FL	57.6	0.40	0.73
New Orleans, LA	59.7	0.80	0.92

The overall range in MCTT size varies by more than three times for the same level of treatment for the different cities. The required size of the main settling chamber generally increases as the annual rain depth increases. However, the interevent period and the rain depth for individual rains determines the specific runoff treatment

volume requirement. As an example, Seattle requires a much smaller MCTT than other cities having similar annual total rains because of the small rain depths for each rain (it experiences many small rains, of relatively low intensity). Rapid City requires a smaller MCTT, compared to Los Angeles, because Los Angeles has much larger rains when it does rain. Similarly, Dallas requires an unusually large MCTT because of its high rain intensities and large individual rains, compared to upper Midwest cities that have similar annual total rain depths. In all cases, the most effective holding time is 2 d for 90% toxicant control (for the 1.5 m, or 5 ft, settling chamber depth). In most cases, a toxicity reduction goal of about 70% in the main settling chamber is probably the most cost-effective choice, considering the additional treatment that will be provided in the sand-peat chamber.

The required runoff depth storage capacity increases as the depth of the main settling chamber increases. As an example, for 90% toxicant control at Milwaukee, the storage requirement for a 1.5 m (5 ft) settling depth was shown to be 16.5 mm (0.65 in.) on Table 6.3. Figure 6.14 indicates that the required storage volume for a 0.6 m (2 ft) settling chamber would only be 14 mm (0.55 in.) of runoff, while it would increase to 19 mm (0.75 in.) of runoff for a 2.1 m (7 ft) settling depth and to 23 mm (0.9 in.) for a 2.7 m (9 ft) settling depth. The greater runoff depths require more time for the stormwater particulates to settle and be trapped in the chamber, while the shallower tanks require a greater surface area. The best tank design for a specific location is based on site specific conditions, especially the presence of subsurface utilities or groundwater and hydraulic grade line requirements. A large surface tank is usually much more expensive, even though the required volume is less, especially if heavy traffic will be traveling over the tank.

As an example, for a 0.6 m (2 ft) settling depth, a combination of a 48 h holding time and 11 mm (0.45 in.) runoff storage volume would satisfy a 75% treatment goal for Milwaukee (the site of the Ruby Garage full-scale MCTT installation), as shown on Figure 6.14. This 11 mm runoff volume corresponds to a rain depth of about 13 mm (0.51 in.) for pavement (Pitt 1987). The 11 mm runoff storage volume corresponds to a chamber “live” volume of 22 m³ (770 ft³) and a surface area of 10 m² (110 ft²) for a 0.2 ha (0.5 acre) paved drainage area. The surface area of the MCTT would therefore be about 0.5 percent of the drainage area. This device would capture and treat about 80% of the annual runoff at a 95% level, resulting in an annual toxicity reduction of about 75% (0.8 X 0.95). The size of the main settling chamber would need to be greater than this because “dead” storage must be added to provided for standing water below the outlet orifice (or pump) which would keep the inclined tubes submerged and to prevent scour.

Drainage of Main Settling Chamber

The main settling chamber needs to be empty at the end of the selected storage time to be able to treat runoff from the next rain. The water leaves the main settling chamber and enters the final filter/sorption chamber. During the pilot-scale MCTT tests, a small pump emptied the main settling chamber after three days of storage. A float switch was used to control the water levels through switching the pump. The pumping rate was selected based on the desired hydraulic loading rate on the filter material. The full-scale MCTT devices in Wisconsin were operated using orifices to control the water drainage from the main settling chamber into the final chamber. Therefore, the full-scale tests included continuous flows from the settling chamber into the last chamber, as long as water was above the orifice. The orifice was located at the desired “dry-weather” depth, close to the top of the tube settlers. The following equation can be used to estimate the orifice diameter for different settling chamber surface areas, settling depths, and desired drainage times:

$$D_o = 0.113 [A_t / (C_d \times t)]^{0.5} (h_1)^{0.25}$$

where: D_o = orifice diameter, in.,

A_t = surface area of main settling chamber of MCTT, ft²,

C_d = orifice coefficient,

t = desired MCTT drainage time, h, and

h_1 = settling depth, ft.

The MCTT at Minocqua, WI, has a main settling chamber made of 3.0 m X 4.6 m (10 ft x 15 ft) box culvert sections, having a total length of 13 m (42 ft). The surface area is therefore 59 m² (630 ft²). The settling depth is 1.5

m (5 ft), and the desired drainage time is 72 h. The desired orifice diameter, using the above equation (and an orifice coefficient of 1.0, corresponding to a well-rounded entrance), was calculated to be 13 mm (0.5 in.). In contrast, the MCTT at Ruby Garage in Milwaukee, WI, has a main settling chamber with a surface area 14 m² (150 ft²) and a settling depth of only 0.6 m (2 ft). The desired drainage time was the same as at Minocqua. The calculated orifice diameter for the Milwaukee MCTT was 5 mm (0.2 in.).

These are both small diameter holes through which almost all of the stormwater from the drainage area must eventually pass. Keeping the orifices clear is obviously of great importance. At both full-scale MCTT sites, the orifices are protected with a solid (removable) box covering the orifice with screening on the bottom side where the water enters. The boxes are relatively large to provide a large screened area. The screening holes are smaller than the orifices to help prevent clogging. In addition, the orifices are designed to be inefficient (having C_d coefficients as small as possible) enabling slightly larger diameters than calculated above. The Ruby Garage MCTT experienced clogging once during the first year of operation, requiring manual cleaning. The material clogging the orifice was a mat from a biological growth that was growing on the inside of the MCTT main settling chamber. Care therefore needs to be taken to provide easy access to the orifice for cleaning and to protect the orifice as much as possible from clogging. One of the MCTT access locations should therefore be located directly above the orifice, if possible. An overflow/bypass should also be provided in case the orifice cannot be quickly cleaned.

Final Filtration-Sorption-Ion Exchange Chamber

Additional treatment beyond the level provided in the main settling chamber would result from the filter-sorption-ion exchange chamber. The pumped or drained effluent from the main settling chamber is directed towards a mixed peat-sand chamber, which should provide a surface hydraulic loading rate of between 1.5 and 6 m per day (5 and 20 ft per day), and have a depth of at least 0.5 m (18 in.). In addition to the pumped effluent, any excess runoff after the main settling chamber is full could also be directed towards the filter. Detailed information on stormwater filtration, including information useful for designing the filtration/sorption chamber of the MCTT, is also available in another associated report currently being prepared (Clark and Pitt 1997). The following guidelines are from this other report.

Summarized information from the EPA sponsored filtration experiments (Clark and Pitt 1997) can be used to develop design guidelines for the third "filtration" (sorption-ion exchange) chamber of the MCTT. The design of a stormwater filter needs to be divided into two phases. The first phase is the selection of the filtration media to achieve the desired pollutant reduction goals. The second phase is the sizing of the filter to achieve the desired run time before replacement of the media. The main objective of the associated research reported by Clark and Pitt (1997) was to monitor a variety of filtration media to determine their pollutant reduction capabilities. However, it soon became apparent that the filters were more limited by clogging caused by suspended solids in the stormwater, long before reductions in their pollutant reduction capabilities could be identified. Therefore, measurements in filter run times, including flow rates and clogging parameters, were added to the research activities. Pretreatment of the stormwater so the SS content is about 10 mg/L is likely necessary in order to take advantage of the pollutant retention capabilities of most of the media. The MCTT provides this necessary pretreatment through sedimentation in the main settling chamber.

Selection of Filtration Media for Pollutant Reduction Capabilities

The selection of the filter media needs to be based on the desired pollutant reduction performance and the associated site conditions. If based on a wide range of pollutants for pretreated stormwater (such as provided in the main settling chamber), then the rankings (best media listed first) for the tested media were as follows:

- 1) peat moss-sand (with degradation in color, turbidity, and pH)
- 2) activated carbon-sand (no degradation, but fewer benefits)
- 3) Enretech-sand, forest/sand, filter fabrics, or sand alone (few changes, either good or bad)
- 4) compost-sand (many negative changes)

(Note: if the stormwater was not pretreated, with associated shortened run times, then the rankings were much different, with compost-sand being near the top of the list). The following list summarizes the likely significant reductions in concentrations observed for the filters:

Sand: With pretreatment, sand filtration has little additional benefit. Likely minimum effluent concentrations: 10 mg/L for SS, 50 HACH color units, 10 NTU for turbidity.

Peat moss-sand: Medium to high levels of control for most pollutants for pre-settled stormwater. Largest range and number of pollutants benefited under pre-settled conditions. Caused increases in color and turbidity, and reductions in pH (by about ½ to 1 pH unit). Likely minimum effluent concentrations: 5 mg/L for SS, 85 HACH color units, 10 - 25 NTU for turbidity.

Activated carbon-sand: Very good control for most pollutants. Caused no adverse changes for any pollutant. Likely minimum effluent concentrations: 5 mg/L for SS, 25 HACH color units, 5 NTU for turbidity.

Zeolite-sand: No likely benefits for pre-settled stormwater. Caused increased color and turbidity on pre-settled stormwater. Likely minimum effluent concentrations: 10 mg/L for SS, 75 HACH color units, 15 NTU for turbidity.

Compost-sand: Worsened water quality for many pollutants if stormwater was pre-settled. Increased color under all conditions and had increased phosphate and potassium in effluent. Likely minimum effluent concentrations: 10 mg/L for SS, 100 HACH color units, 10 NTU for turbidity.

Enretech-sand: Had little effect on pre-settled stormwater. Likely minimum effluent concentrations: 10 mg/L for SS, 80 HACH color units, 10 NTU for turbidity.

Filter fabrics: No significant and/or important reductions for any pollutants using either untreated or pre-settled stormwater.

Design of Filters for Specified Filtration Durations

The filtration durations measured during these tests can be used to develop preliminary filter designs. It is recommended that allowable suspended solids loadings be used as the primary controlling factor in stormwater filtration design. Clogging is assumed to occur when the filtration rate becomes less than about 1 m/day. Obviously, the filter would still function at smaller filtration flow rates, especially for the smallest rains in arid areas, but an excessive amount of filter by-passing would likely occur for moderate rains in humid areas. Tables 6.4 and 6.5 summarize the observed filtration capacities of the different media tested.

Table 6.4. Filtration Capacity as a Function of Suspended Solids Loadings (small-scale tests)

Filtration Media	Capacity to 20 m/day (gSS/m ²)	Capacity to 10 m/day (gSS/m ²)	Capacity to <1 m/day (gSS/m ²)
Sand	150-450	400->2000	1200-4000
Peat-sand	100-300	150-1000	200-1700
Peat	?	?	200
Leaves	?	?	2100
Activated carbon-sand	150-900	200-1100	500->2000
Zeolite-sand	200-700	800-1500	1200->2000
Compost-sand	100-700	200-750	350-800
Enretech-sand	75-300	125-350	400-1500

Table 6.5. Filtration Capacity as a Function of Pretreated Water Loading (influent <10 mg SS /L) (small-scale tests)

Filtration Media	Capacity to 20 m/day (m)	Capacity to 10 m/day (m)	Capacity to <1 m/day (m)
Sand	6-20	8->25	13->40
Peat-sand	3-17	4-22	7-30
Activated carbon-sand	5-25	6->25	15->40
Zeolite-sand	7-25	8->25	14->40
Compost-sand	3-20	4-30	6->30
Enretech-sand	3-11	4-25	15->30

The most restrictive materials (the Enretech and Forest Products media) are very fibrous and still show compaction, even when mixed with sand. The most granular media (activated carbon and the Zeolite) are relatively uniform in shape and size, but have sand interspersed to fill the voids to slow the water to increase the contact time for better pollutant reduction. The sand has the highest filtration rates because it has the most uniform shape and size.

The flow rates through filters that have thoroughly dried between filter runs significantly increases. Our small-scale tests restricted complete drying during normal inter-event periods. Drying may occur more commonly with the full-scale filters in the MCTT. Wetting and drying of filters (especially peat) has been known to produce solution channels through the media that significantly increases the flow. If these solution channels extend too far through the filter, they would reduce pollutant reduction performance. Adequate filter depths will minimize this problem. The filter fabrics did not indicate any flow rate improvements with wetting and drying, while the peat moss/sand filter had the greatest improvement in flow capacity (by about ten times), as expected. The other media showed much more modest improvements (but still about two to three times).

The filter capacity ranges may be grouped into the following approximate categories, as shown on Table 6.6.

Table 6.6. Filter Media Categories and Filtration Capacities (allowing interevent drying of media)

Capacity to <1 m/day (gSS/m ²)	Capacity to 10 m/day (gSS/m ²)	Filtration Media Category
5,000	1,250	Enretech-sand; Forest-sand
5,000	2,500	Compost-sand; Peat-sand
10,000	5,000	Zeolite-sand; Act. Carbon-sand
15,000	7,500	Sand

Filter designs can be made based on the predicted annual discharge of suspended solids to the filtration device and the desired filter replacement interval. As an example, Table 6.7 shows typical volumetric runoff coefficients (Rv) that can be used to approximate the fraction of the annual rainfall that would occur as runoff for various land uses and surface conditions. In addition, Table 6.8 summarizes likely suspended solids concentrations associated with different urban areas and waters.

Table 6.7. Typical Volumetric Runoff Coefficients for Different Land Use Areas

Area	Annual Average Volumetric Runoff Coefficient (Rv)
Low density residential land use	0.15
Medium density residential land use	0.3
High density residential land use	0.5
Commercial land use	0.8
Industrial land use	0.6
Paved areas	0.85
Sandy soils	0.1
Clayey soils	0.3

Table 6.8. Typical Suspended Solids Concentrations for Different Source Areas

Source Area	Suspended Solids Concentration (mg/L)
Roof runoff	4 – 25
Paved parking areas	40 – 1600
Paved storage areas	40 – 200
Paved driveways	400
Streets	250 – 1300
Paved walkways	20 – 400
Unpaved parking and storage areas	700
Landscaped areas	100 – 1000
Detention pond water	20
Mixed stormwater	150
Effluent after high level of pre-treatment of stormwater (such as by the main settling chamber in the MCTT)	5

Using the information in the above tables and the local annual rain depth, it is possible to estimate the annual suspended solids loading from an area. The following three examples illustrate these simple calculations.

1) A 1.0 ha paved parking area, in an area receiving 1.0 m of rain per year:

$$(50 \text{ mg SS/L}) (0.85 \text{ Rv}) (1 \text{ m/y}) (1 \text{ ha}) (10,000 \text{ m}^2/\text{ha}) (1,000 \text{ L/m}^3) (\text{g}/1,000 \text{ mg}) = 425,000 \text{ g SS/y}$$

Therefore, if a peat-sand filter is to be used, having an expected suspended solids capacity of 5,000 g/m² before clogging, then 85 m² of this filter will be needed for each year of desired operation for this 1.0 ha site. This is about 0.9% of the paved area per year of operation. If this water is pre-treated so the effluent has about 5 mg/L SS, then only about 0.2% of the contributing paved area would be needed for the filter. A sand filter would only be about 1/3 of this size because of its greater capacity before clogging (but with decreased pollutant retention).

2) A 1.0 ha medium density residential area having 1.0 m of rain per year:

$$(150 \text{ mg SS/L}) (0.3 \text{ Rv}) (1 \text{ m/y}) (1 \text{ ha}) (10,000 \text{ m}^2/\text{ha}) (1,000 \text{ L/m}^3) (\text{g}/1,000 \text{ mg}) = 450,000 \text{ g SS/y}$$

The unit area loading of suspended solids for this residential area is about the same as in the previous example, requiring about the same percentage of the drainage area dedicated for the filter. The reduced amount of runoff is balanced by the increased suspended solids concentration.

3) A 1.0 ha rooftop in an area having 1.0 m of rain per year:

$$(10 \text{ mg SS/L}) (0.85 \text{ Rv}) (1 \text{ m/y}) (1 \text{ ha}) (10,000 \text{ m}^2/\text{ha}) (1,000 \text{ L/m}^3) (\text{g}/1,000 \text{ mg}) = 85,000 \text{ g SS/y}$$

The unit area loading of suspended solids from this area is much less than for the other areas and would only require a filter about 0.2% of the roofed drainage area per year of operation. Pretreatment of this water (such as in the MCTT) would only marginally improve the filter performance and is not recommended for this condition.

It is recommended that the filter media be at least 50 cm in depth and be sized to provide a hydraulic loading rate of between 1.5 and 6 m/d for the MCTT. In addition, it is highly recommended that significant pre-treatment of the water be used to reduce the suspended solids concentrations to about 10 mg/L before filtration for pollutant

reduction. This pre-treatment can be accomplished using the main sedimentation chamber in the MCTT. The selection of the specific filtration media should be based on the desired pollutant reductions, but should in all cases include amendments to plain sand if immediate and permanent pollutant reductions are desired.

Example Design of Full-Scale MCTT

The following is an example preliminary design for a full-scale MCTT for a public works garage in Detroit, MI. It was prepared for the Rouge River National Demonstration Project for consideration as a local demonstration project. The design is divided into the major steps, as indicated previously.

Determine the Pollutant Removal Goal

The first step in designing a stormwater management practice is to identify the pollutant removal goal, or range of likely goals for consideration. In the MCTT, this process is based on the toxicity removal goal in the main settling chamber, the control parameter. This value can be estimated, based on the removal goals of other pollutants for the complete MCTT, as shown previously.

The toxicity removal goal in the main settling chamber for this example design was within the range of 70 to 90%. The final removal will be determined based on site constraints and cost. These removals would result in the approximate overall MCTT removals for other pollutants as shown in Table 6.9. Obviously, the high level of treatment associated with the 90% toxicity removal goal in the main settling chamber results in very high removals for most toxicants and many of the conventional pollutants. In most cases, the pollutant reductions associated with the more modest 70% toxicant removal goal for the main settling chamber are adequate. This design example shows the results associated with both of these goals for comparison. It is probably best to consider a range of options for most stormwater management programs. The costs associated with each option, along with their pollutant removal capabilities, can then be used in a decision analysis procedure in order to select the best combination of control practices that should be used in an area.

Table 6.9. Example Pollutant Removals for Example Design Alternatives

Example Constituents	Pollutant Removal if 70% toxicity goal in main settling chamber	Pollutant Removal if 90% toxicity goal in main settling chamber
Very High Removals: Microtox® toxicity, Microtox® toxicity (filtered), suspended solids, lead, zinc, fluoranthene pyrene, pentachlorophenol, and phenol	80 to 90%	Close to 100%
High Removals: Volatile suspended solids, COD, and zinc (filtered)	50 to 60%	65 to 80%
Moderate Removals: Turbidity and lead (filtered)	About 40%	About 50%
Low Removals: Nitrate, cadmium, cadmium (filtered), copper, and copper (filtered)	15 to 25%	20 to 30%

Main Settling Chamber Design

The initial steps, after the pollutant removal goals are identified, include site surveys of candidate MCTT locations. These site surveys include the following, at a minimum:

- conduct a site survey to determine drainage area and character, subsurface conflicts (existing buried utilities and bedrock), and special surface loading conditions (such as from heavy public works vehicles)

- determine the needed hydraulic grade line for the drainage system receiving the MCTT effluent

The following steps are then conducted, using the MCTT design curves for the city of interest:

- select a series of candidate MCTT tank depths and holding periods for the desired pollutant removal rate in the main settling chamber from the continuous simulation results for the area nearest to the site that meet the above restraints and toxicity removal goals
- determine critical runoff volumes that need to be captured for the alternative tank depths and holding times for the main settling chamber
- investigate alternative available tank components and select the most appropriate tank

The filtration/sorption chamber is then designed, using the information previously presented:

- select the most appropriate filtration/sorption media (usually a peat/sand mixture, with activated carbon, if possible)
- size the filtration/sorption chamber to obtain the desired flow rate and mass of media

Finally, the catchbasin/grit chamber is designed, based on existing or new inlet arrangements.

The following paragraphs present these steps for the example Detroit MCTT facility. The discussion describes how the design curve was prepared, using local rain information. Similar processes were used to develop the design curves for the 21 cities throughout the U.S. that are presented as Figures 6.4 through 6.24.

Rainfall for Detroit and Expected Performance of MCTT

The local Detroit rain patterns (depths, durations, and antecedent dry periods) for the past 10 years were examined and used to develop a 100 event random rain set that represents the long-period conditions. Detroit rains from 1950 through 1991 were obtained from the 1993 version of the Earthinfo CD ROM (Boulder, CO) which contained hourly rainfall depths for Detroit. These rains were extracted from the CD ROM and converted into separate rainfall events using the rain utilities in SLAMM (the *Source Loading and Management Model*) (Pitt and Voorhees 1995).

This rain information was used to model MCTT treatment capacity and treatment duration tradeoffs for specific storage and treatment options, using the spreadsheet model previously presented. This model was used to examine the effects of different holding times (6 to 72 hours) and tank capacities (5 mm – 40 mm, or 0.2 – 1.5 inches) for different tank live storage depths (0.6 m – 2.7 m, or 2 – 9 feet). The model was run about 200 times to create a summary for the different options.

The treatment benefits were plotted, as shown in Figure 6.9 for Detroit. These analyses indicated that for a 1.5 m (5 ft) live chamber depth and desired 75% toxicity reductions in the main settling chamber, the smallest MCTT would have a storage capacity of about 9.1 mm (0.36 in.) and should hold the stormwater for 48 hours. Holding the stormwater for longer periods of time would result in better treatment of the water flowing through the MCTT, but a smaller fraction of the annual stormwater would flow through the unit, resulting in less overall annual toxicity reductions. Similarly, holding the water for a shorter period of time would increase the amount of annual stormwater that would pass through the MCTT, but the stormwater would receive less treatment.

Site Surveys

Alternate sites for the proposed MCTT were examined. Site maps were used to estimate the drainage areas at potential locations at the candidate public works yard. Three locations were examined. The upper manhole location would have a relatively small area and the distance from the pavement surface to the pipe crown was only 1.4 m (4.7 ft), too shallow for an effective MCTT. The middle manhole location had a paved yard, plus roof, drainage area of about 0.4 ha (1.0 acres) and the distance from the pavement surface to the pipe crown was 1.8 m (5.9 ft) which would allow a shallow MCTT. The lower manhole location had a drainage area of about 0.6 ha (1.5 acres) and the distance from the pavement surface to the pipe crown was 2.1 m (6.9 ft). The deeper pipe locations were preferred, allowing more efficient MCTT configurations. All existing drainage pipes were 0.3 m (12 inch) in diameter.

The inside vertical dimensions of an MCTT for this site are approximately as follows:

- about 0.15 m (6 in.) for underflow into the main settling chamber (and supports for the inclined tube settlers),
- about 0.6 m (2 ft) for the inclined tube settlers,
- the live settling depth (usually from 0.6 m – 2.7 m, or 2 to 9 ft),
- about 0.15 m (6 in.) freeboard above the live settling depth for absorbent pillows.

Therefore, about 1 m (3 ft) is required, in addition to the live settling depth, for the inside depth of the MCTT. It would be possible to reduce some of the dimensions slightly, but 1.6 m (5 ft) is seen as the likely minimum dimension for an MCTT having a live settling depth of 0.6 m (2 ft). The wall thickness of the bottom and top plates of the MCTT must also be added to these depth requirements. As this is to be located in a heavy weight traffic area, it is expected that 150 mm (6 in.) of heavily reinforced concrete may be needed as the roof of the MCTT (needs to be determined by a structural engineer). With decreasing live settling depths, the surface area of the MCTT must increase to compensate (to obtain the needed tank volume).

MCTT Sizing Options

The following tables summarize the needed MCTT sizes for 70 and 90% toxicity reductions in the main settling chamber for the different main settling chamber heights (the complete MCTT would have increased toxicant reductions, as noted previously). A 70% reduction of toxicants (as indicated by the Azur Environmental Microtox® toxicity screening test) in the main settling chamber would require the capture of 5.1 mm (0.20 in.) of runoff and a holding time of 24 hours, when using a 0.6 m (2 ft) settling depth, as shown on Figure 6.9. In contrast, a 90% reduction would require the capture of 10 mm (0.40 in.) of runoff. The following describes the calculations needed to obtain the actual sizes for the MCTT for the 70% level of treatment in the main settling chamber.

Pavement area: 0.60ha (1.5ac, or 63,600ft²)

Runoff volume: (0.20in) (63,600ft²) (ft/12in) = 1,060ft³ (29 m³)

Surface area of main settling chamber: 1,060ft³/2ft depth = 530ft² (49 m²)

Surface area of settling chamber, as a percentage of drainage area: (100) (530ft²/63,600ft²) = 0.83%

The sand/peat “filter” size is determined by the following calculations:

Needed average drainage rate: 1,060ft³/24h = 44ft³/h (1.2 m³/h)

The maximum filtration rate is 2 m/d (6 ft/d), or 0.08 m/h (0.25 ft/h) for the filter, based on Austin, TX, stormwater filtration guidelines

Required area of filtration chamber: (44 ft³/h)/0.25 ft/h = 176 ft² (16 m²)

Surface area of filtration chamber, as a percentage of drainage area: (100) (176ft²/63,600ft²) = 0.28%

The surface area of the main settling chamber plus the “filter” chamber is therefore: 0.83% + 0.28% = 1.11%. The life of the “filtration” media can be estimated knowing the mass of suspended solids that will be discharged from the main settling chamber and directed to the “filtration” chamber. The effluent of the main settling chamber has a suspended solids concentration of approximately 5 mg/L, the volumetric runoff coefficient (Rv) for pavement is about 0.85, and the annual rain depth for Detroit is 790 mm (31 in.). The estimated annual discharge from the main settling chamber is therefore:

$(1.5\text{ac})(43,560\text{ft}^2/\text{ac})(0.85\text{Rv})(3\text{lin/y})(5\text{mgSS/L})(\text{ft}/12\text{in})(7.48\text{gal}/\text{ft}^3)(3.78\text{L}/\text{gal}) = 21,280,000\text{mgSS}/\text{y}$, or 20,280gSS/y, or 20kgSS/y

The unit area filter loading rate is therefore 1.3kgSS/m²-y, with a 176ft² (16.1m²) filter area. The peat/sand filter has an estimated lifetime loading capacity, before clogging (flow <1 m/d), of about 5kgSS/m². The estimated lifetime of the sand/peat media is therefore about 4 years, before media replacement may be needed. The final filter fabric layer on top of the peat/sand media may extend the lifetime of the media before clogging, requiring replacement of the fabric instead of the media. The preliminary chemical break-through tests (Clark, *et al.* 1997) indicate that clogging, even with the extensive pre-treatment provided by the main settling chamber, will occur before the pollutant removal capacity of the peat/sand will be exceeded. The following tables summarize the calculated sizes for the various MCTT options for this Detroit site:

- 0.6 m (2 ft) live settling depths and 24 h holding times (would require about 1.5 m, or 5 ft, of depth above the drainage pipe crown):

Toxicity Reduction	Settling Chamber Capacity (in. of runoff)	Settling Chamber Area (% of drainage area)	Mixed Media "Filter" Area (% of drainage area)	Total MCTT Area (% of drainage area)
70%	0.20 inch	0.83%	0.28%	1.11%
90%	0.40 inch	1.67%	0.56%	2.22%

If the drainage area was 0.6 ha (1.5 acres or 63,600 ft²), then the surface area of the MCTT for 70% toxicity reduction would be about 50 m² (530 ft²) for the main settling chamber and about 17 m² (180 ft²) for the "filter" chamber. The inside depth of the chambers would be about 1.5 m (5 ft), and if an 1.5 m X 2.4 m (5 X 8 ft) box culvert was used as the MCTT chambers, 20 m (66 ft) would be required for the length for the main settling chamber and 7 m (23 ft) for the "filter" chamber. The surface areas (and culvert lengths, if still 1.5 m X 2.4 m, or 5 X 8 ft) would be increased by about twice for 90% toxicity reduction in the main settling chamber.

- 1.5 m (5 ft) live settling depths and 48 h holding times (would require about 2.4 m, or 8 ft, of depth above the drainage pipe crown):

Toxicity Reduction	Settling Chamber Capacity (in. of runoff)	Settling Chamber Area (% of drainage area)	Mixed Media "Filter" Area (% of drainage area)	Total MCTT Area (% of drainage area)
70%	0.29 inch	0.48%	0.20%	0.68%
90%	0.51 inch	0.85%	0.35%	1.20%

If the drainage area was 0.6 ha (1.5 acres, or 63,600 ft²), then the surface area of the MCTT for 70% toxicity reduction would be about 30 m² (320 ft²) for the main settling chamber and about 12 m² (130 ft²) for the "filter" chamber. The inside depth of the chambers would be about 2.4 m (8 ft), and if an 2.4 m X 3.0 m (8 X 10 ft) box culvert was used as the MCTT chambers, 9.8 m (32 ft) would be required for the length for the main settling chamber and 4.0 m (13 ft) for the "filter" chamber. The surface areas (and culvert lengths, if still 2.4 m X 3.0 m, or 8 X 10 ft) would be increased by about 1.8 times for 90% toxicity reduction in the main settling chamber.

- 2.1 m (7 ft) live settling depths and 72 h holding times (would require about 3.0 m, or 10 ft, of depth above the drainage pipe crown):

Toxicity Reduction	Settling Chamber Capacity (in. of runoff)	Settling Chamber Area (% of drainage area)	Mixed Media "Filter" Area (% of drainage area)	Total MCTT Area (% of drainage area)
70%	0.31 inch	0.37%	0.14%	0.51%
90%	0.64 inch	0.76%	0.30%	1.06%

If the drainage area was 0.6 ha (1.5 acres, or 63,600 ft²), then the surface area of the MCTT for 70% toxicity reduction would be about 22 m² (240 ft²) for the main settling chamber and about 8.4 m² (90 ft²) for the “filter” chamber. The inside depth of the chambers would be about 3.0 m (10 ft), and if a 3.0 m X 3.7 m (10 X 12 ft) box culvert was used as the MCTT chambers, 6.1 m (20 ft) would be required for the length for the main settling chamber and 2.3 m (7.5 ft) for the “filter” chamber. The surface areas (and culvert lengths, if still 3.0 m X 3.7 m, or 10 X 12 ft) would be increased by about 2.1 times for 90% toxicity reduction in the main settling chamber.

- 2.7 m (9 ft) live settling depths and 72 h holding times (would require about 3.7 m, or 12 ft of depth above the drainage pipe crown):

Toxicity Reduction	Settling Chamber Capacity (in. of runoff)	Settling Chamber Area (% of drainage area)	Mixed Media “Filter” Area (% of drainage area)	Total MCTT Area (% of drainage area)
70%	0.36 inch	0.33%	0.17%	0.50%
90%	0.74 inch	0.69%	0.34%	1.03%

If the drainage area was 0.6 ha (1.5 acres, or 63,600 ft²), then the surface area of the MCTT for 70% toxicity reduction would be about 20 m² (210 ft²) for the main settling chamber and about 10 m² (110 ft²) for the “filter” chamber. The inside depth of the chambers would be about 3.7 m (12 ft), and if a 3.7 m X 4.6 m (12 X 15 ft) culvert was used as the MCTT chambers, 4.3 m (14 ft) would be required for the length for the main settling chamber and 2.3 m (7.5 ft) for the “filter” chamber. The surface areas (and culvert lengths, if still 3.7 m X 4.6 m, or 12 X 15 ft) would be increased by about 2.1 times for 90 % toxicity reduction in the main settling chamber.

Catchbasin/Grit Chamber Design

The last step is to size the catchbasin/grit chamber as a pre-treatment unit. The catchbasin can be located adjacent to the MCTT, or it can be located at inlets upstream to the MCTT. During the pilot-scale Birmingham tests, the catchbasin was located adjacent to the rest of the MCTT units for convenience. However, at the Milwaukee, WI, full-scale MCTT installation, the existing inlet was modified and used as a catchbasin, upstream of the main settling and “filtration” chambers. In Minocqua, WI, the upstream inlets were fitted with the aeration balls in nylon net bags, but a large sump (a 1200 gal precast concrete septic tank) was located before the main settling chamber to serve as the grit chamber/sump.

The general dimensions for a catchbasin/grit chamber were described earlier. For the 305 mm (12 in.) diameter outlet pipe at this site, the catchbasin should be 1.2 m (48 in.) in diameter. The scour depth is about 305 mm (12 in.) for any catchbasin, so the sump should be sized to provide sufficient sacrificial storage capacity. Table 6.2 indicated that the annual sediment accumulation for a site having 790 mm (31 in.) of rain per year, with influent SS concentrations of 100 mg/L, would be about 0.29 m³/ha-y (4.2 ft³/ac-y). The 1.2 m (48 in.) diameter sump has a cross-sectional area of about 1.2 m² (12.6 ft²), indicating a sediment accumulation rate of about 100 mm (0.33 ft) per year. If the influent SS concentration was a high 250 mg/L, then the sediment accumulation rate in the sump would be about 240 mm (0.8 ft) per year. A sump depth of 0.6 m (2 ft) (in addition to the 305 mm, 1 ft, scour depth) would therefore provide at least 2 years, to more than 5 years of storage.

Maintenance Activities

No effective stormwater pollution control device can be considered maintenance-free. In order to be effective, the stormwater control device must accumulate pollutants, especially sediment and other debris. As noted previously, the MCTT is designed for reasonable maintenance. The MCTT is intended to be periodically examined about every 6 months, with major maintenance activities every several years.

The chambers of the MCTT should be vented, mosquito proofed, and be made easily accessible for maintenance. Maintenance for the MCTT would consist of inspections, cleaning of the catchbasin, and renewing of the sorbent pillows every 6 – 12 mo. The ion exchange/sorption capacity of the sand-peat media should last from 3 – 5 years before requiring replacement. Specific site conditions may warrant more frequent maintenance, which should be evident after the first few site examinations.

Preliminary Material Specifications

- A removable grid needs to be placed in the catchbasin inlets a few inches above any possible water surface to support a nylon mesh bag (locally available) which contains about a foot thickness of Jaeger 25 mm (1 in.) Tri-Pack High Performance column packing balls (available from W. J. May & Assoc. of Nashville, TN (615) 662-1276, or from Jaeger Products of Houston at (800) 678-0345). Several of these bags need to be made for rotating during cleaning. The support needs to be made of material and constructed so as not to snag and tear the mesh bags.
- The inclined tube settlers can be purchased from Meurer Research (Golden, CO, 303-279-8373) (or alternative). These are about 0.6 m (2 ft) thick and have 0.1 m (4 in.) tubes. The estimated cost for these is about \$25 per ft² (for 1.2 m, or 4 ft tall units). They will have to be supported on some type of grid about 0.15 m (6 in.) off the bottom of the tank. Do not use any galvanized metal or treated wood in the installation where water contact is possible (stainless steel, aluminum or plastic are acceptable).
- Floating sorbent pillows can be purchased from New Pig Corp. (Tipton, PA, 800-643-6465) (or alternative). 75 mm X 3.0 m (3 in. X 10 ft) "Spaghetti Socks" float and are about \$12 each. About 5 to 10 should be placed in the MCTT main settling chamber at one time.
- The MCTT tank accesses need to be sufficient in size for entry, cleanout and installation. For example, the inclined tube settler sections need to be able to fit through the accesses easily (large 1.8 m X 1.8 m, or 6 ft X 6 ft accesses with hinged steel covers may be better than smaller round manhole covers).
- There should be no direct connection between the main settling chamber and the filtration tank chambers (such as over the top of a tank divider) besides the orifice, because overtopping water would easily scour the filter media. A suitable bypass/overflow should be provided to prevent flooding if the orifice clogs. This bypass/overflow should be around the last filter/sorption chamber, connecting the downstream discharge directly with the main settling chamber.
- The 0.3 – 0.45 m (12 - 18 in.) of mixed filter media is comprised of ½ sand mixed with ½ peat moss. The surface of the mixed filter media is to be covered with a "Gunderboom" fabric material (Amoco 4557, available from Ray Bauer Assoc. in New York at (516) 671-6535 or from Polar Supply, Co. of Anchorage at (907) 563-5000, or from a local Amoco filter fabric distributor). The fabric needs to be one piece (or carefully seamed) and is to cover the top of the media and extend about 0.15 m (6 in.) up the sides of the tank to minimize leakage at the edges. The edges should be anchored to the walls of the MCTT, or weighted with concrete cinder blocks. Do not use loose stone to weigh down the filter fabric (as shown in Figure 5.21) because of difficulties in removing the fabric for cleaning or replacement. The water jet coming from the orifice will need to be directed to some type of splash plate to diffuse the water before it hits the fabric. It can be directed into a perforated pipe laying on the top of the fabric, extending the length of the filter, to serve as a rough flow distributor. The mixed media filter material is laid over another filter fabric and then 0.15 m (6 in.) of sand. The sand is also above another filter fabric and then gravel underdrain material. These bottom two layers of filter fabric also need to extend up the tank several inches and preferably be one piece (or carefully sewn). The top filter fabric acts as a flow distributor and the Amoco fabric also tends to sorb dissolved oils.
- The filter sand material needs to be clean and have an effective size (D_{10}) of about 0.3 mm and an uniformity coefficient (D_{60}/D_{10}) of about 1.5. After the filter media installation is complete, it needs to be carefully rinsed using clean water until the water runs clear to remove any fines.

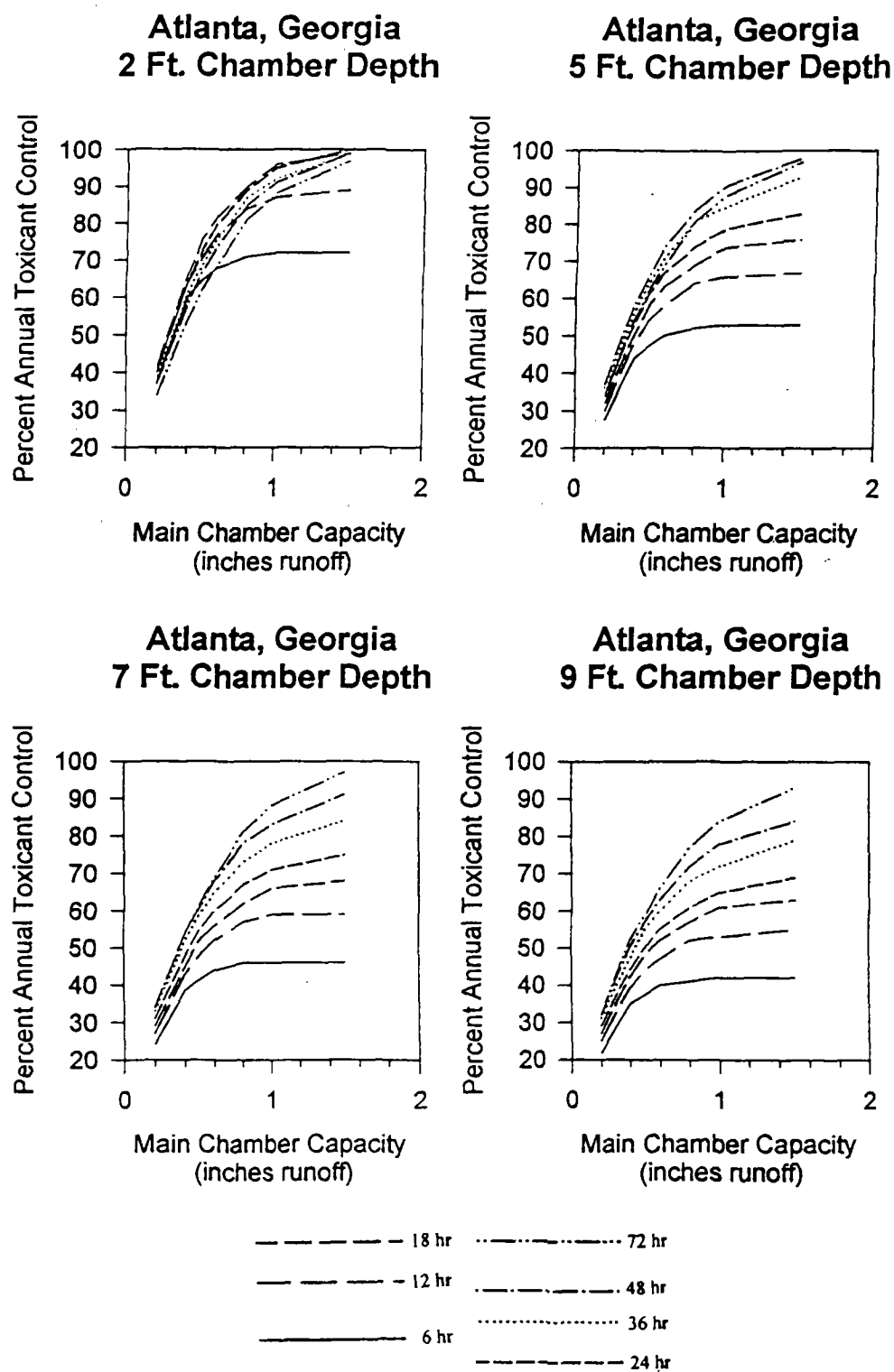


Figure 6.4 MCTT design curves for Atlanta, GA.

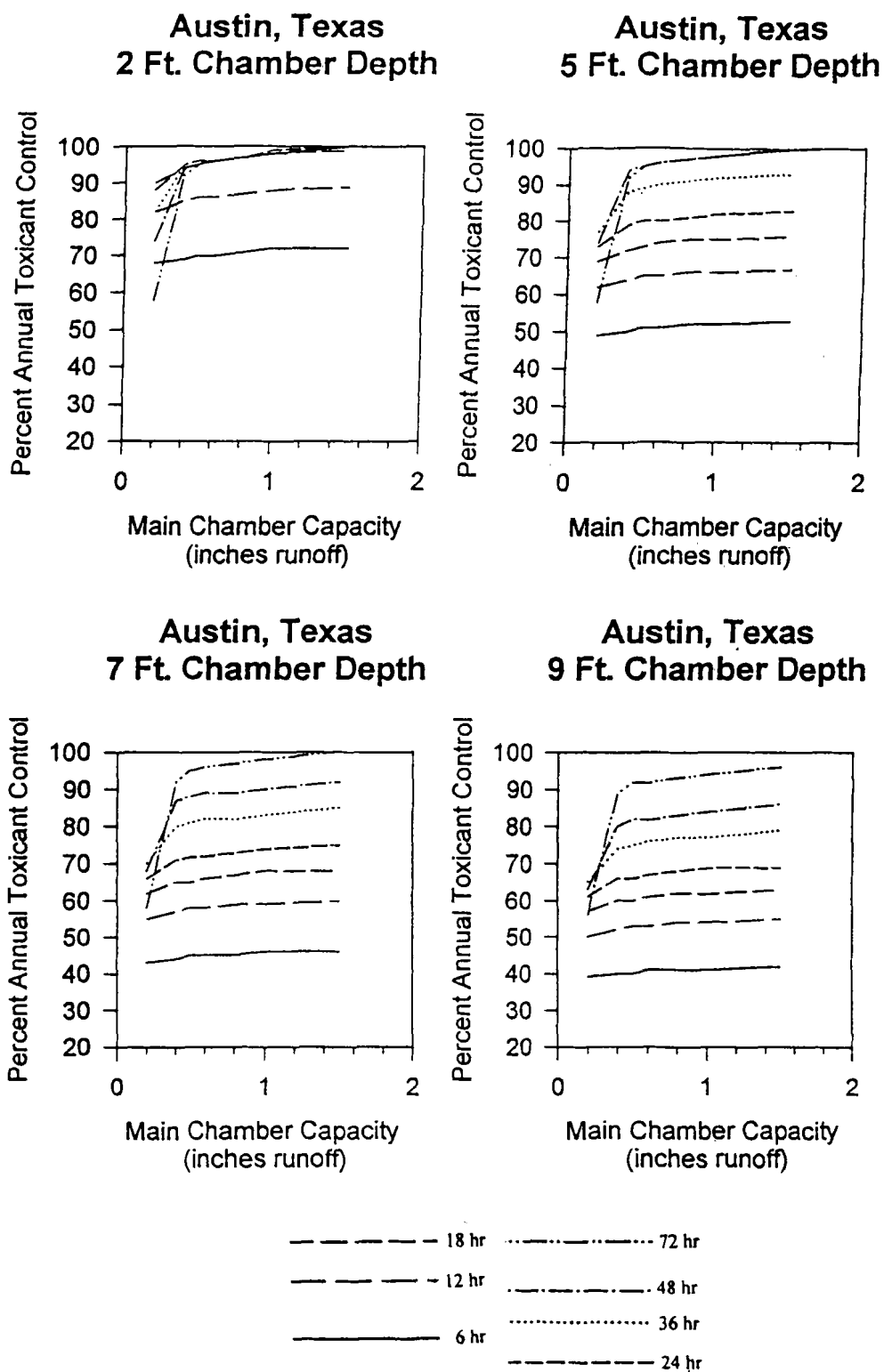
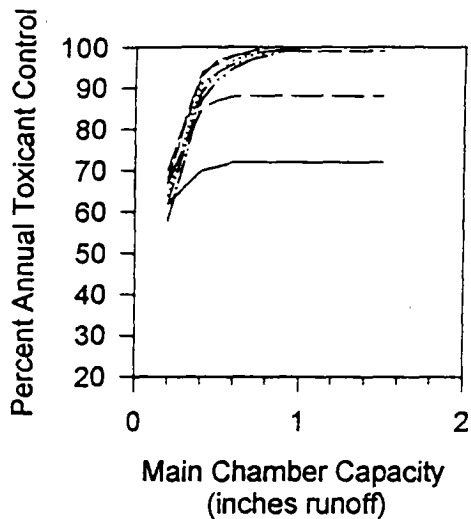
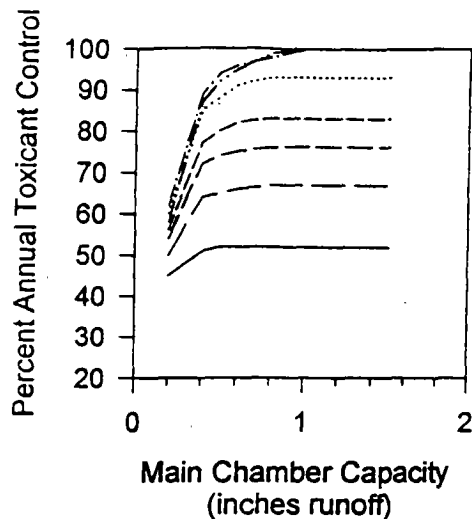


Figure 6.5 MCTT design curves for Austin, TX.

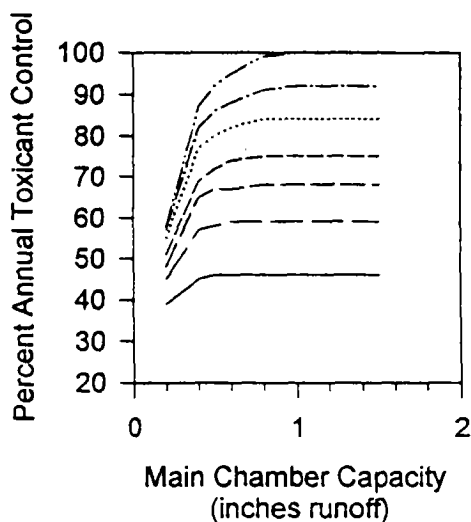
**Bozeman, Montana
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**Bozeman, Montana
5 Ft. Chamber Depth**



**Bozeman, Montana
7 Ft. Chamber Depth**



**Bozeman, Montana
9 Ft. Chamber Depth**

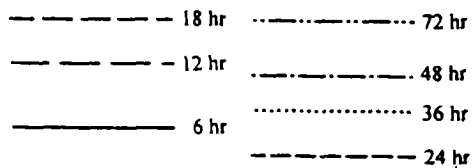
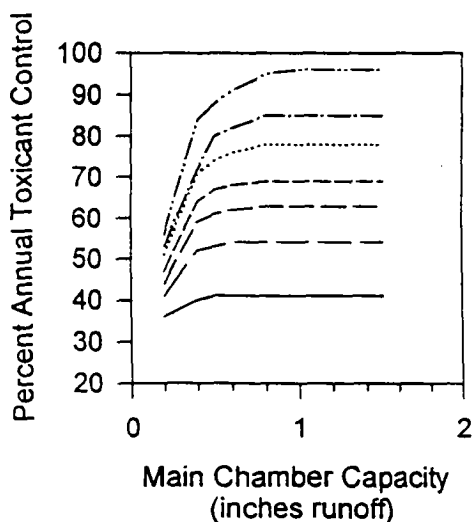
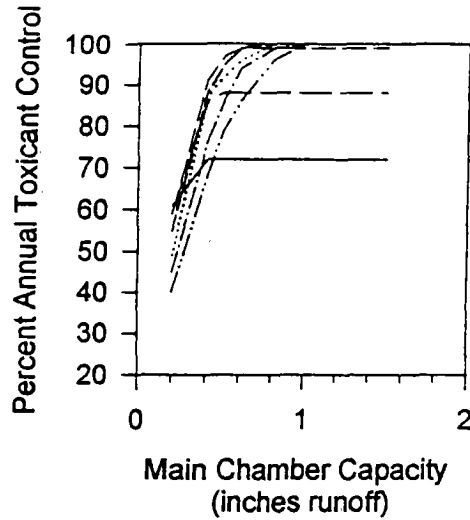
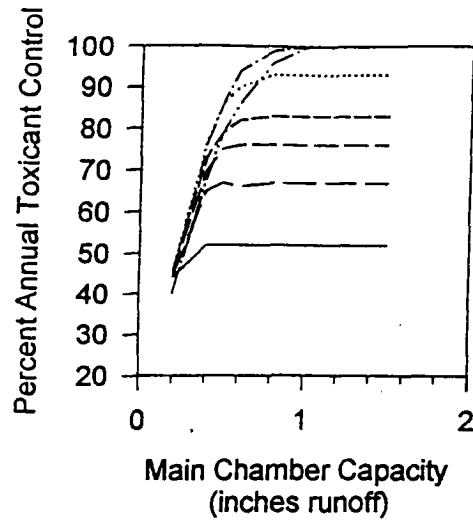


Figure 6.6 MCTT design curves for Bozeman, MT.

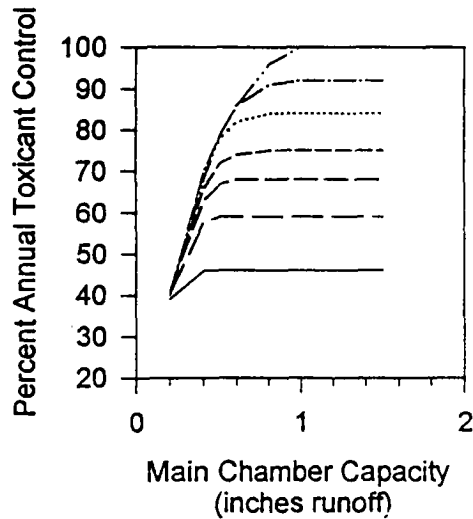
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**Buffalo, New York
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**Buffalo, New York
7 Ft. Chamber Depth**



**Buffalo, New York
9 Ft. Chamber Depth**

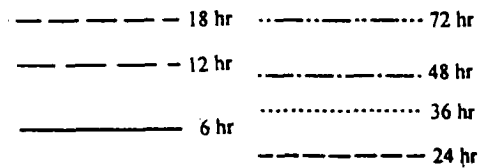
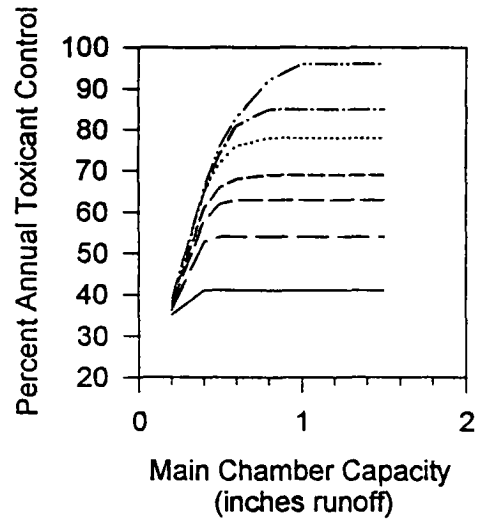


Figure 6.7 MCTT design curves for Buffalo, NY.

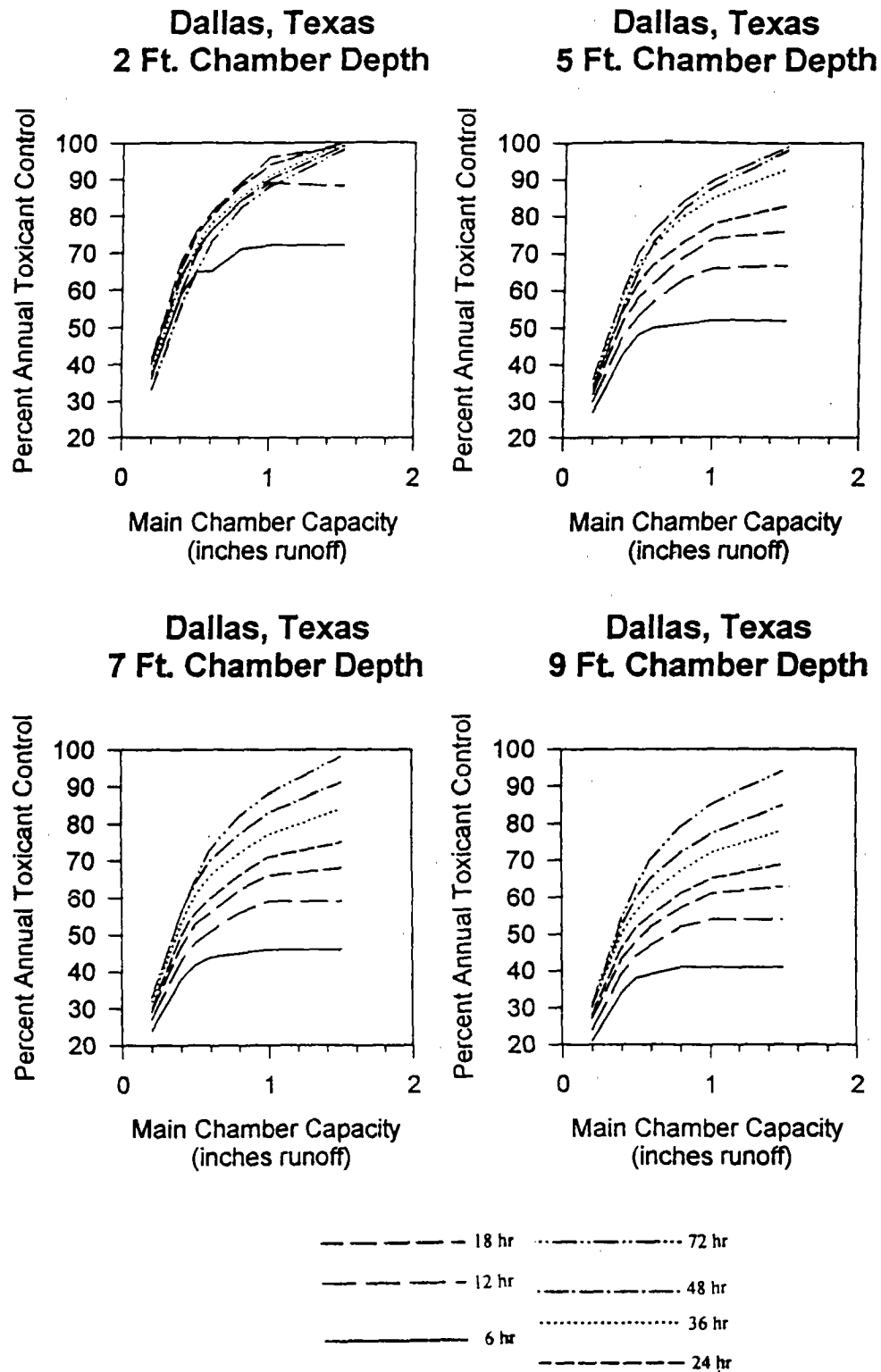
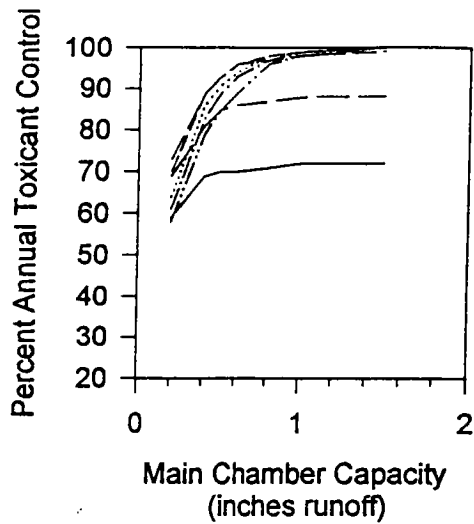
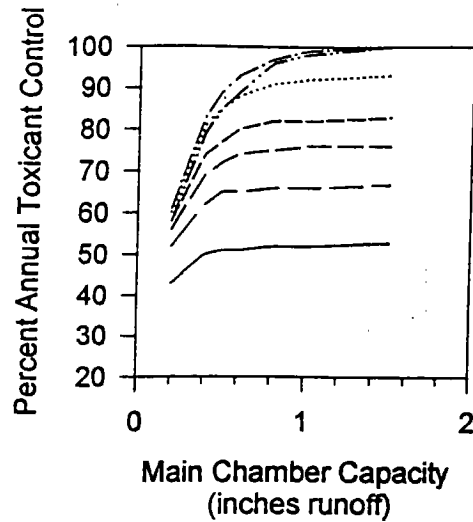


Figure 6.8 MCTT design curves for Dallas, TX.

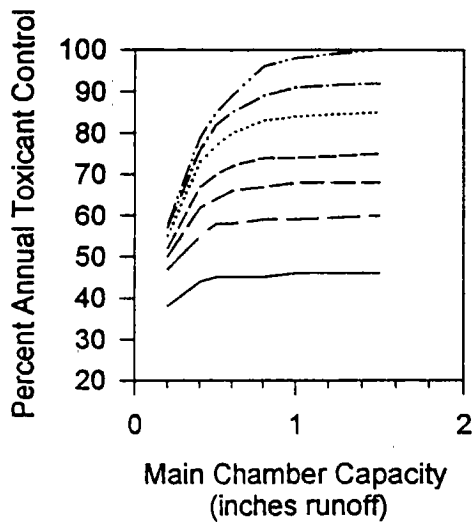
**Detroit, Michigan
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**Detroit, Michigan
5 Ft. Chamber Depth**



**Detroit, Michigan
7 Ft. Chamber Depth**



**Detroit, Michigan
9 Ft. Chamber Depth**

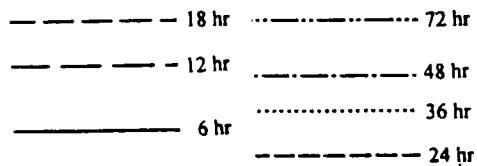
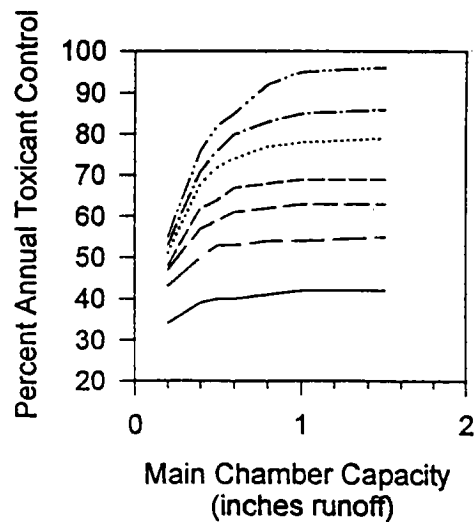
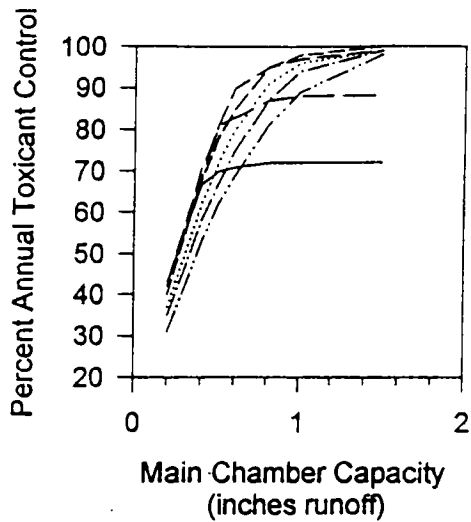
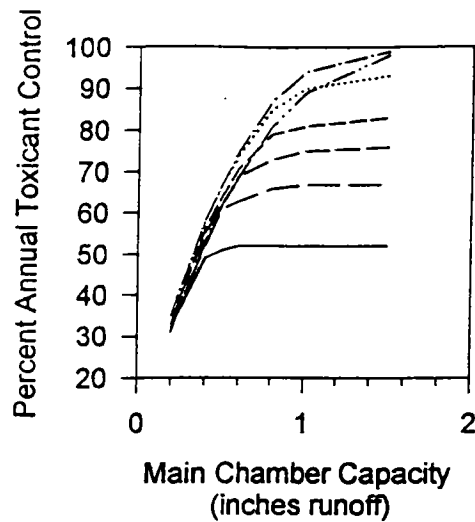


Figure 6.9 MCTT design curves for Detroit, MI.

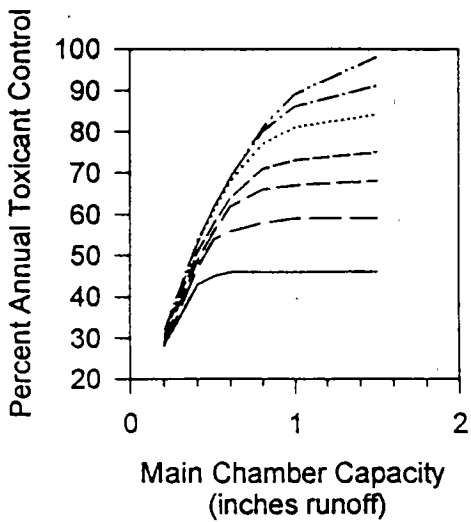
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**Little Rock, Arkansas
5 Ft. Chamber Depth**



**Little Rock, Arkansas
7 Ft. Chamber Depth**



**Little Rock, Arkansas
9 Ft. Chamber Depth**

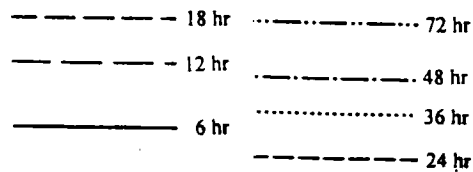
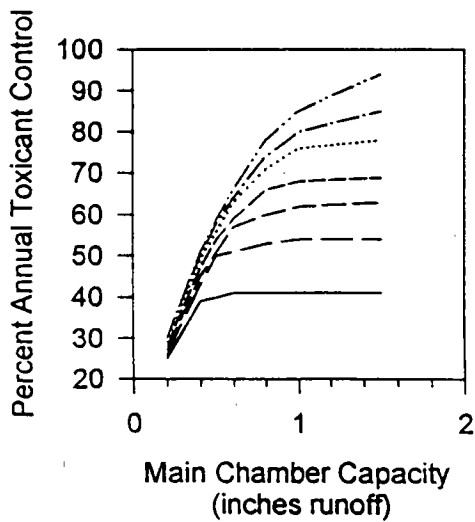
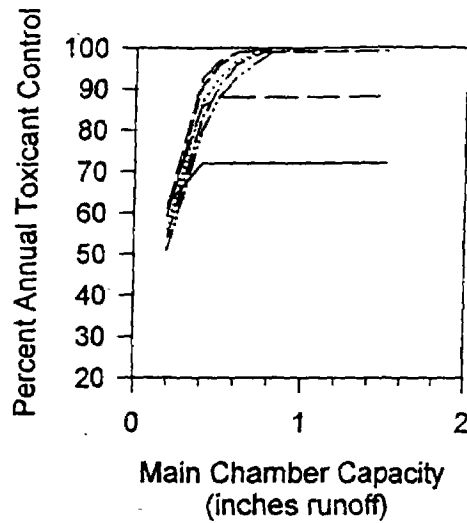
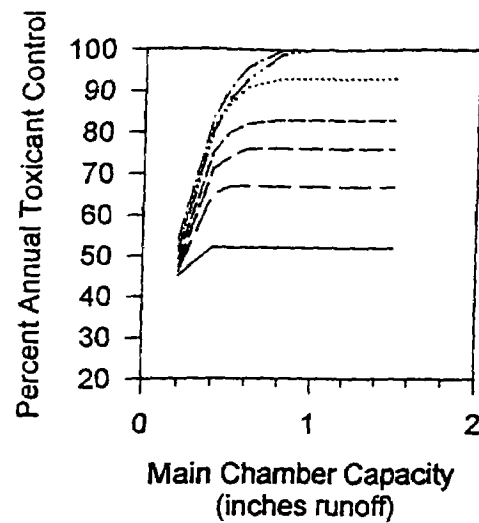


Figure 6.10 MCTT design curves for Little Rock, AR.

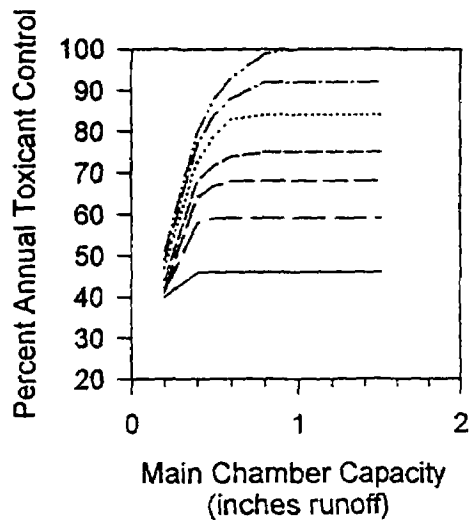
**Los Angeles, California
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**Los Angeles, California
5 Ft. Chamber Depth**



**Los Angeles, California
7 Ft. Chamber Depth**



**Los Angeles, California
9 Ft. Chamber Depth**

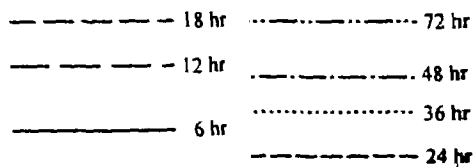
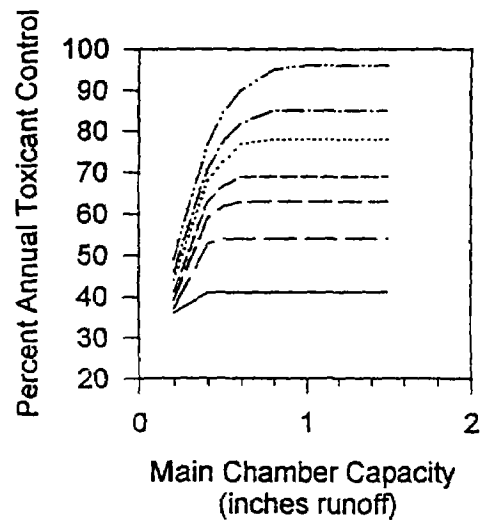
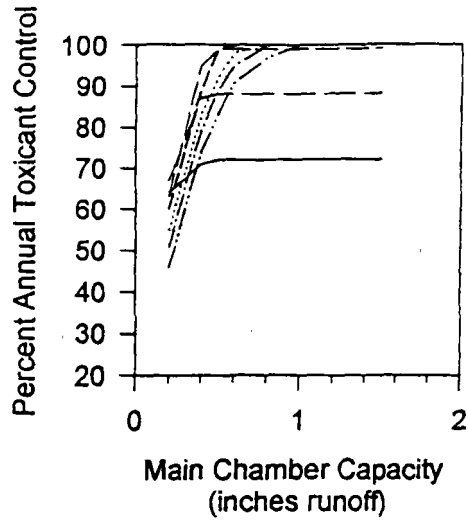
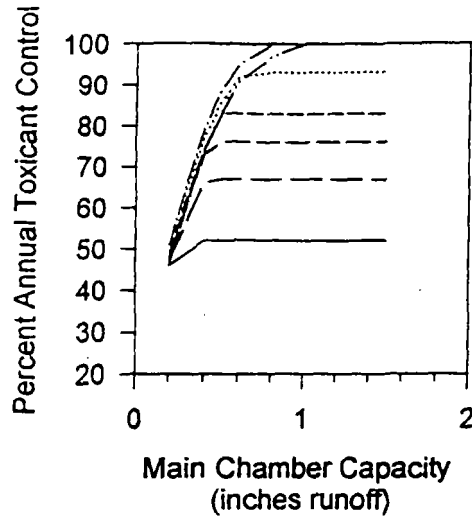


Figure 6.11 MCTT design curves for Los Angeles, CA.

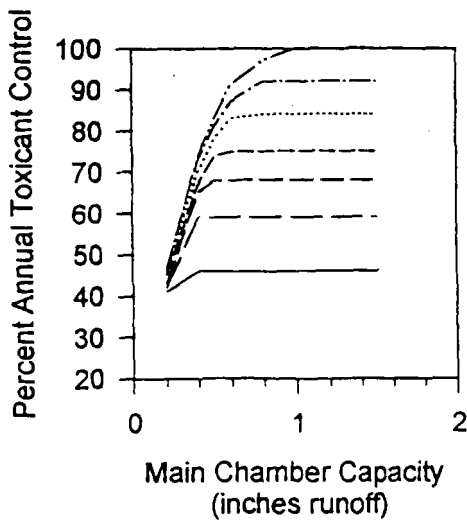
**Madison, Wisconsin
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**Madison, Wisconsin
5 Ft. Chamber Depth**



**Madison, Wisconsin
7 Ft. Chamber Depth**



**Madison, Wisconsin
9 Ft. Chamber Depth**

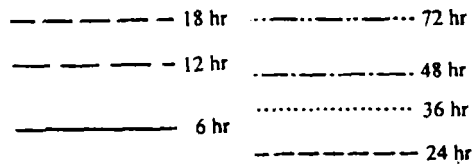
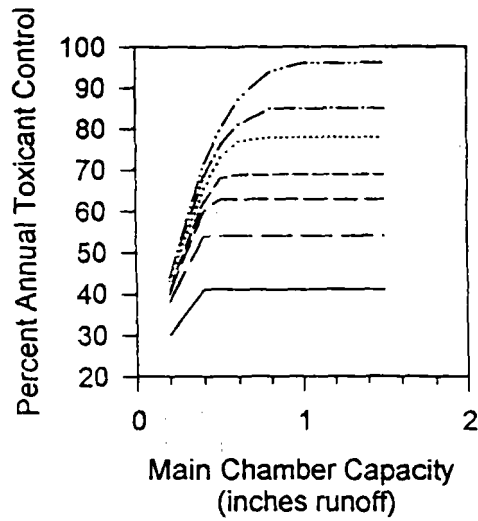


Figure 6.12 MCTT design curves for Madison, WI.

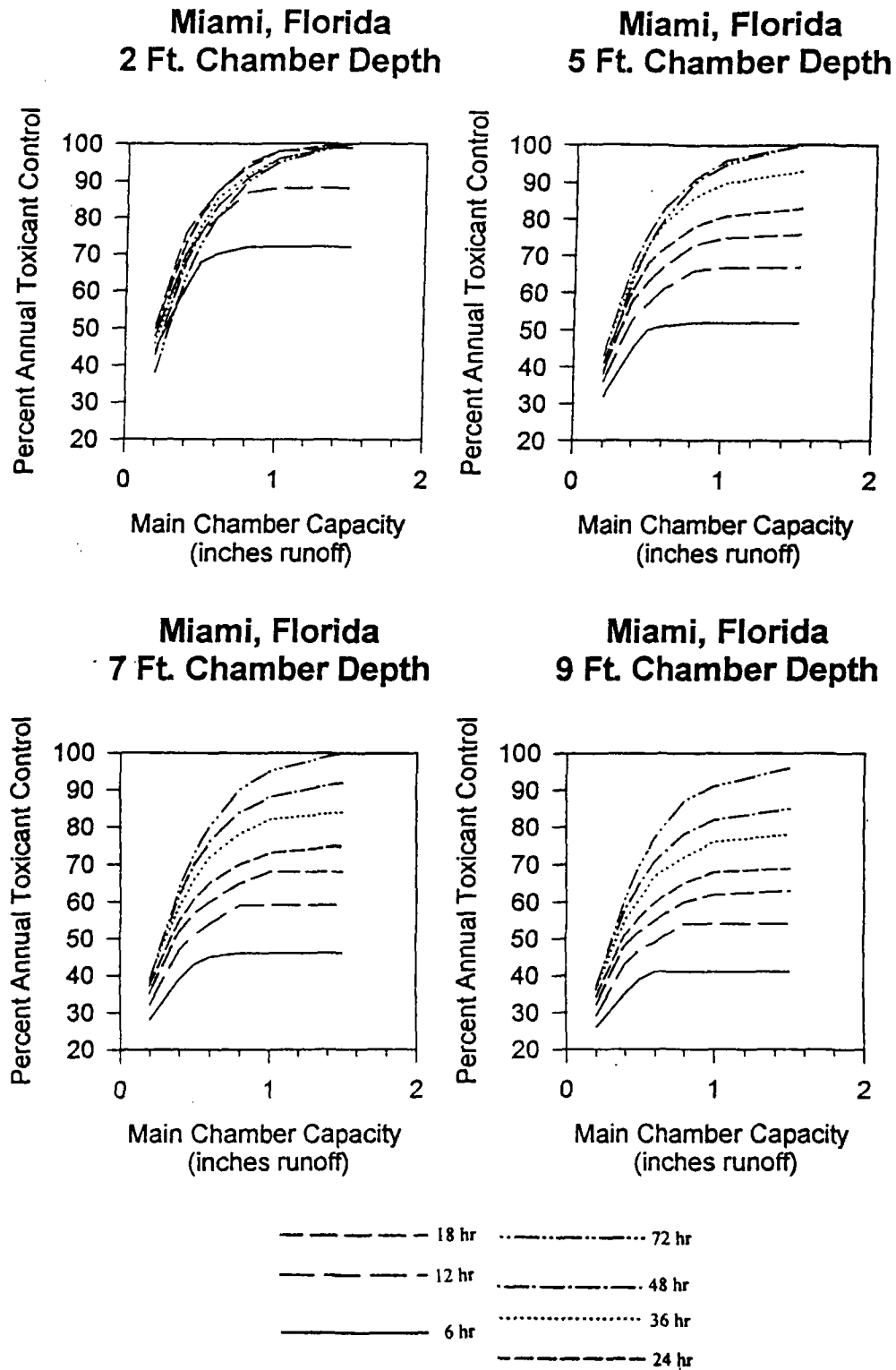


Figure 6.13 MCTT design curves for Miami, FL.

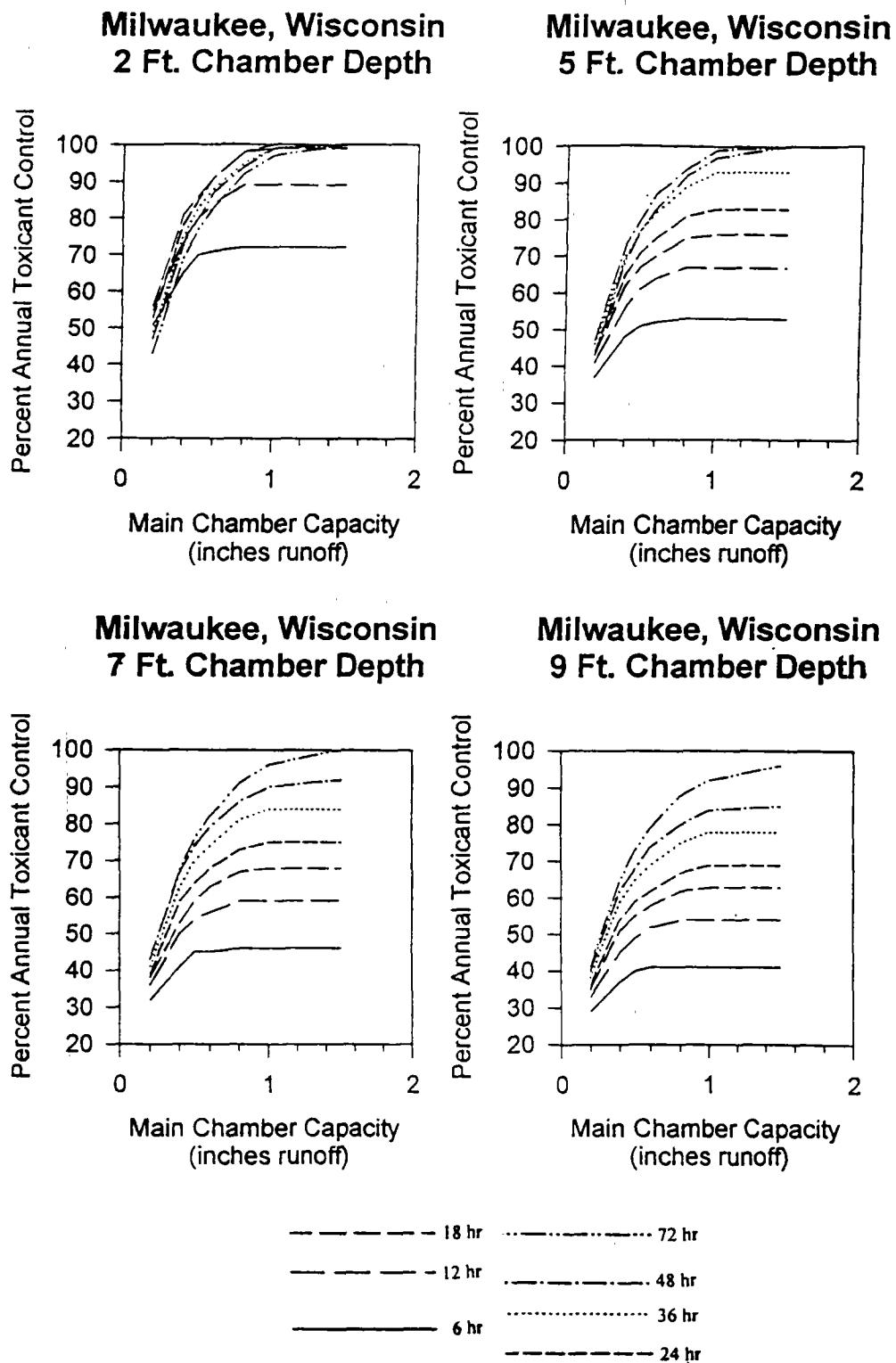
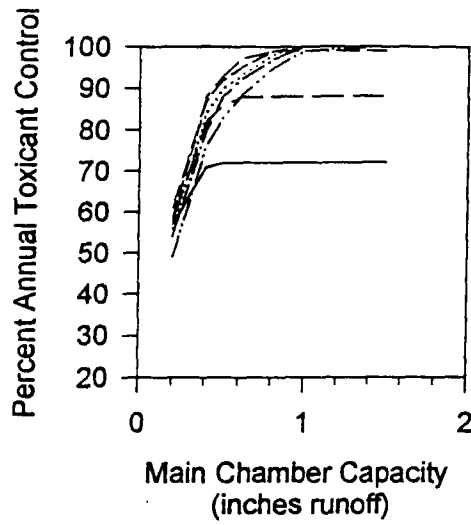
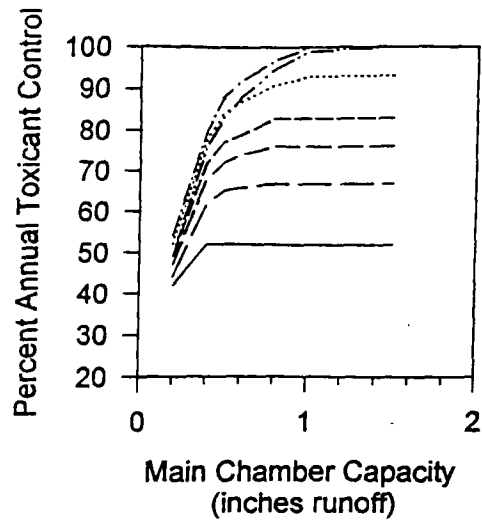


Figure 6.14 MCTT design curves for Milwaukee, WI.

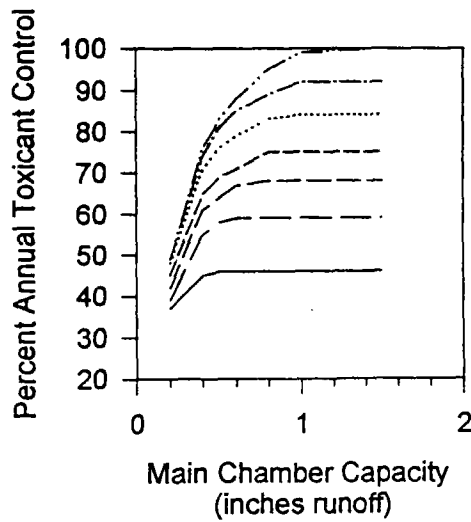
**Minneapolis, Minnesota
2 Ft. Chamber Depth**



**Minneapolis, Minnesota
5 Ft. Chamber Depth**



**Minneapolis, Minnesota
7 Ft. Chamber Depth**



**Minneapolis, Minnesota
9 Ft. Chamber Depth**

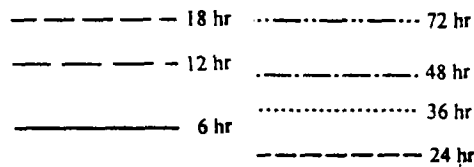
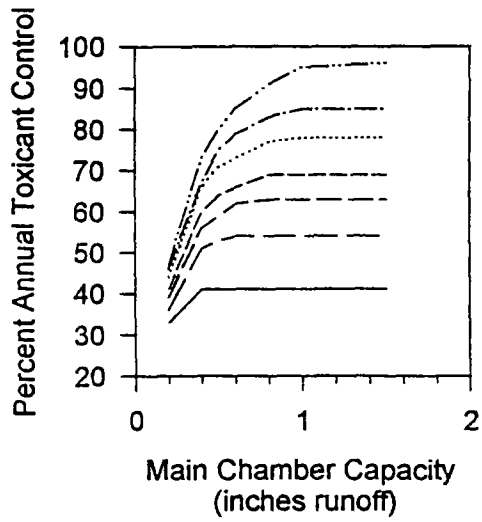
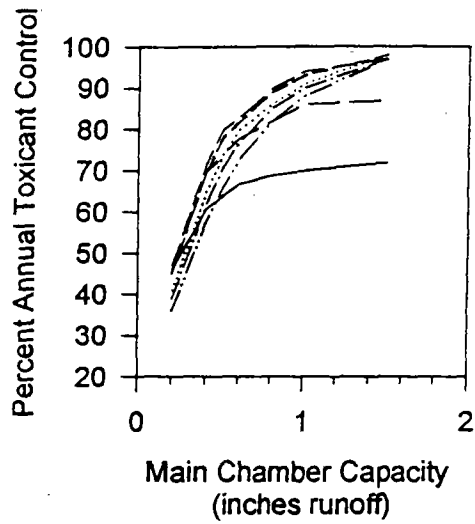
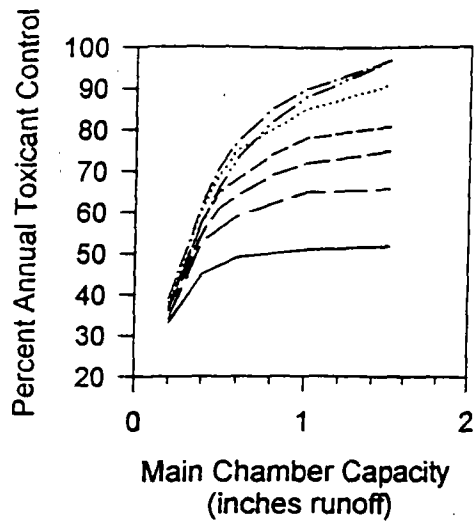


Figure 6.15 MCTT design curves for Minneapolis, MN.

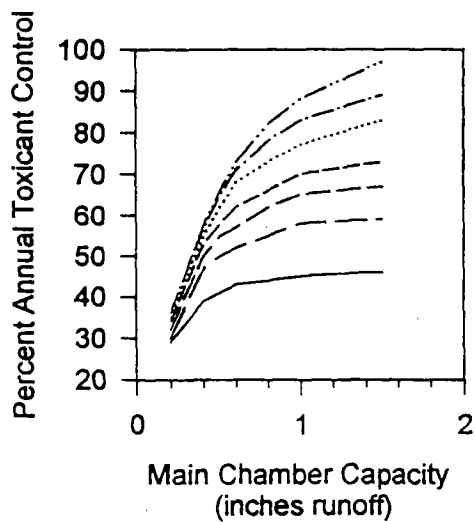
**Newark, New Jersey
2 Ft. Chamber Depth**



**Newark, New Jersey
5 Ft. Chamber Depth**



**Newark, New Jersey
7 Ft. Chamber Depth**



**Newark, New Jersey
9 Ft. Chamber Depth**

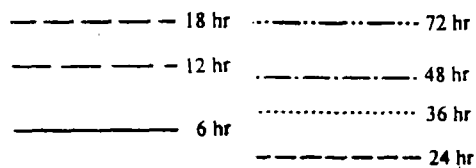
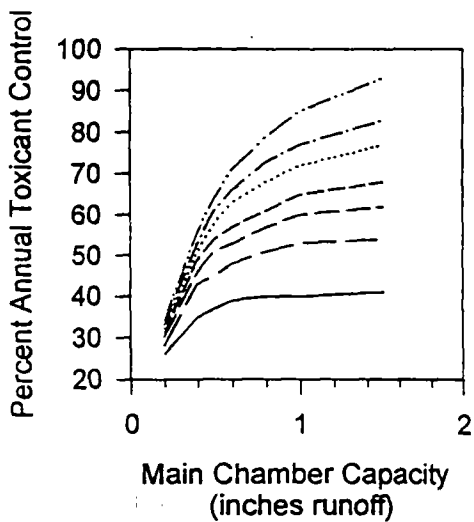
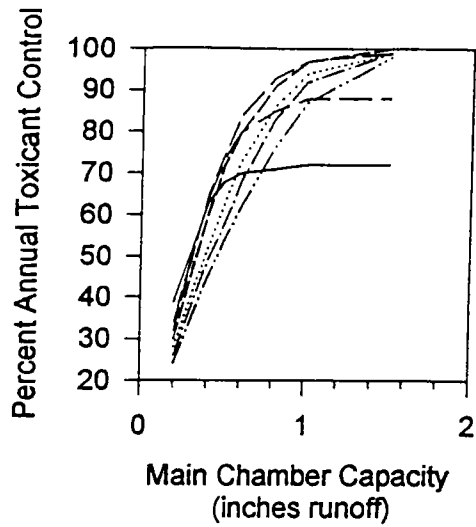
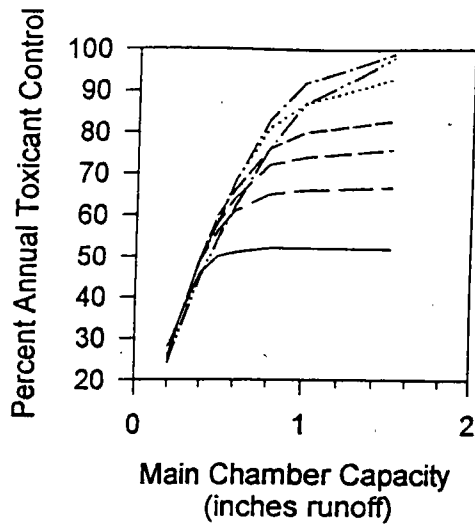


Figure 6.16 MCTT design curves for Newark, NJ.

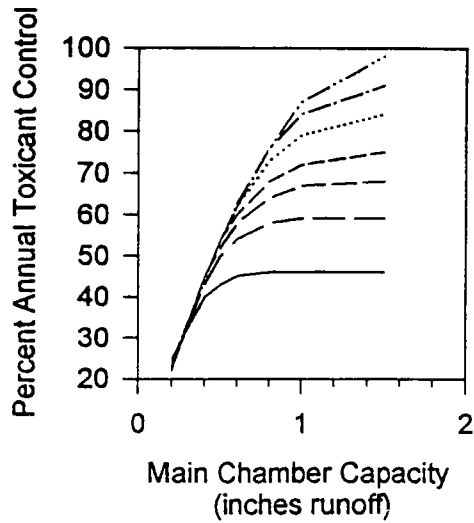
**New Orleans, Louisiana
2 Ft. Chamber Depth**



**New Orleans, Louisiana
5 Ft. Chamber Depth**



**New Orleans, Louisiana
7 Ft. Chamber Depth**



**New Orleans, Louisiana
9 Ft. Chamber Depth**

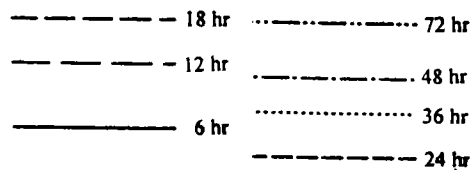
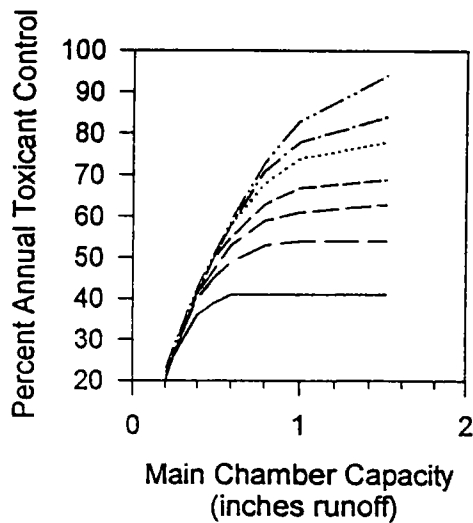
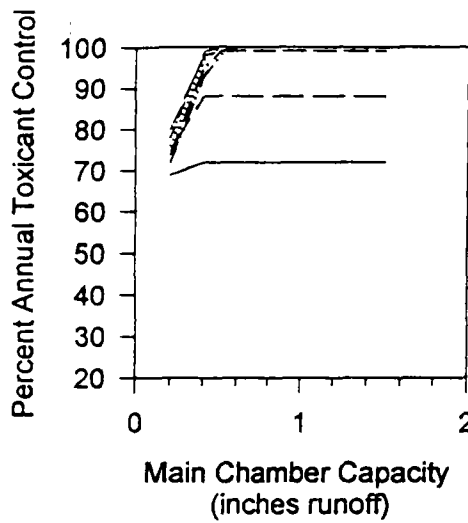
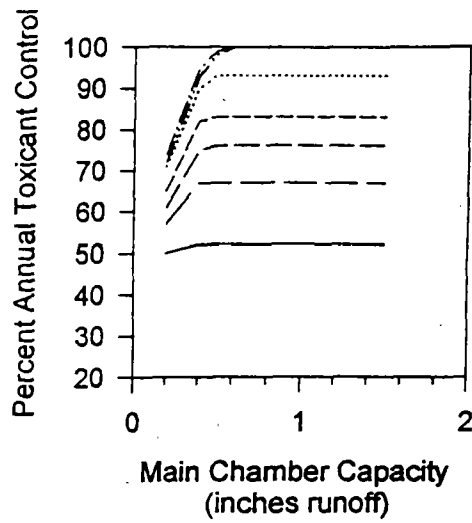


Figure 6.17 MCTT design curves for New Orleans, LA.

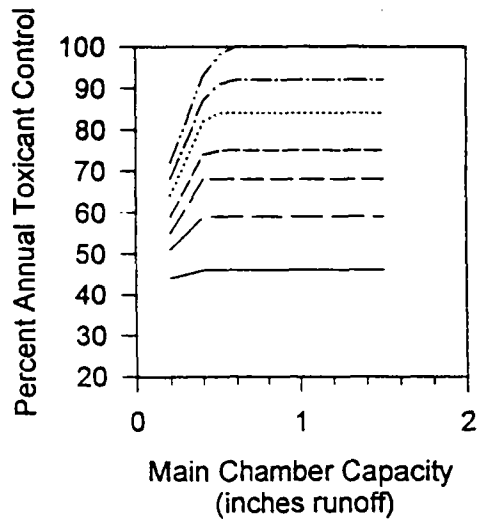
**Phoenix, Arizona
2 Ft. Chamber Depth**



**Phoenix, Arizona
5 Ft. Chamber Depth**



**Phoenix, Arizona
7 Ft. Chamber Depth**



**Phoenix, Arizona
9 Ft. Chamber Depth**

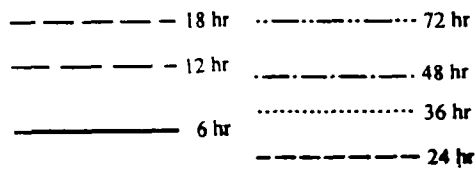
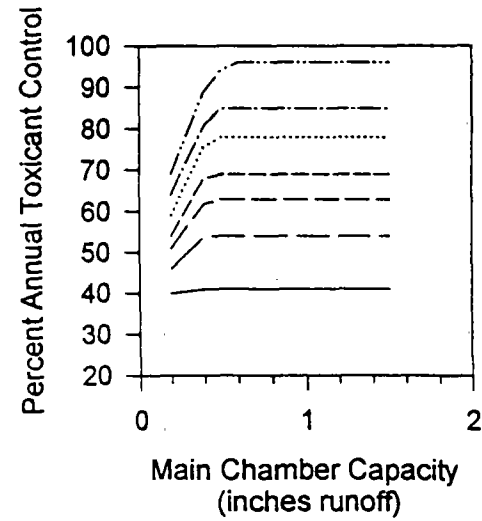
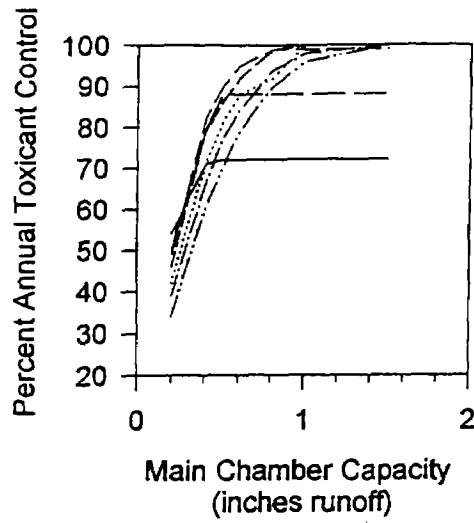
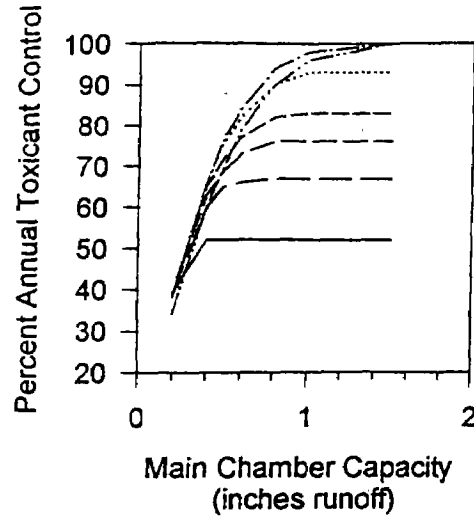


Figure 6.18 MCTT design curves for Phoenix, AZ.

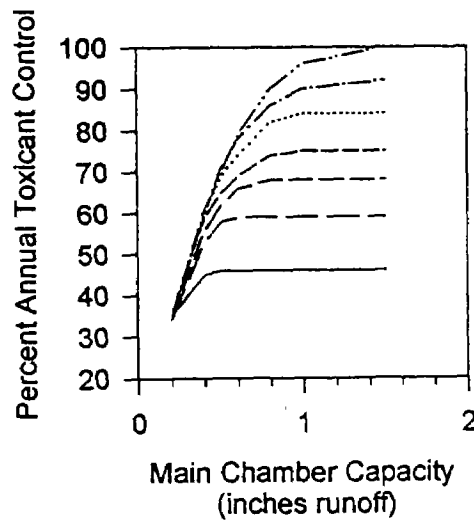
**Portland, Maine
2 Ft. Chamber Depth**



**Portland, Maine
5 Ft. Chamber Depth**



**Portland, Maine
7 Ft. Chamber Depth**



**Portland, Maine
9 Ft. Chamber Depth**

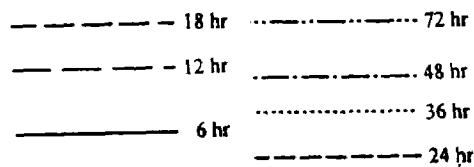
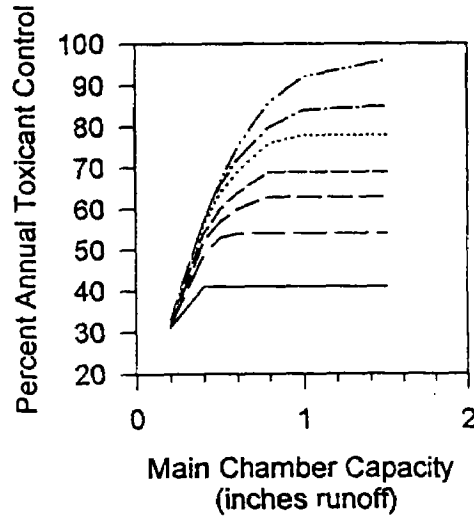
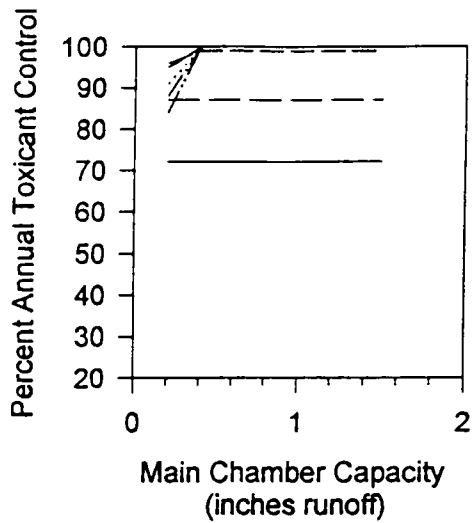
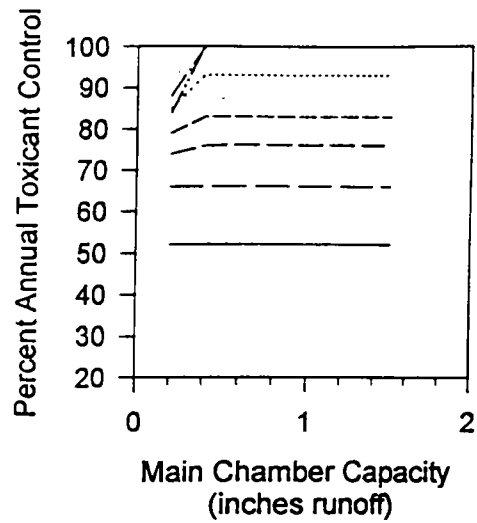


Figure 6.19 MCTT design curves for Portland, ME.

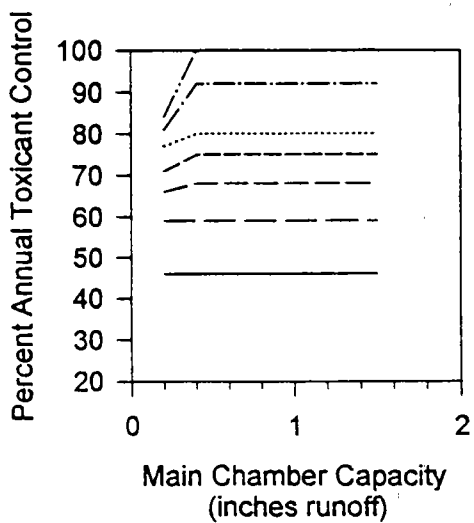
**Rapid City, South Dakota
2 Ft. Chamber Depth**



**Rapid City, South Dakota
5 Ft. Chamber Depth**



**Rapid City, South Dakota
7 Ft. Chamber Depth**



**Rapid City, South Dakota
9 Ft. Chamber Depth**

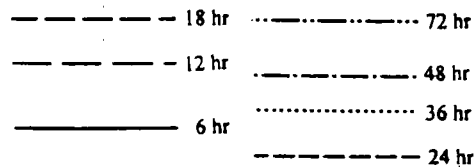
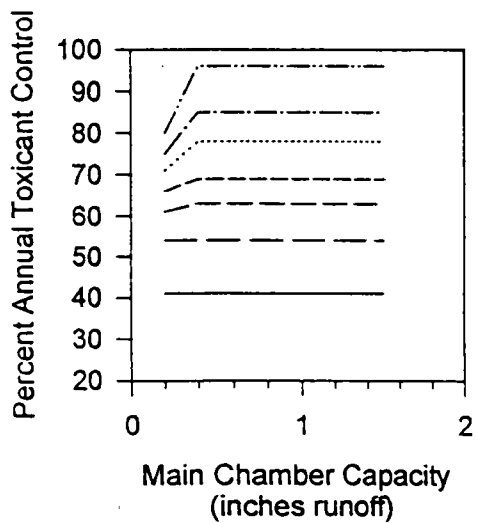
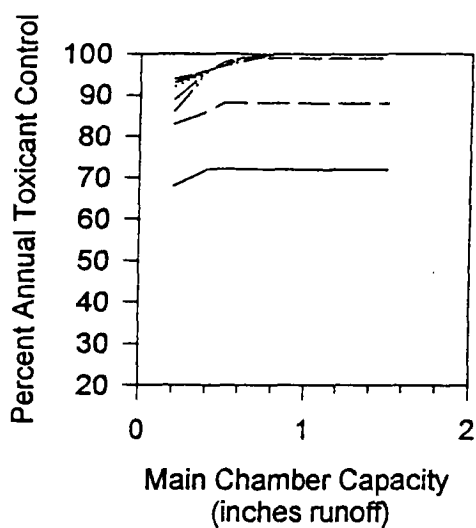
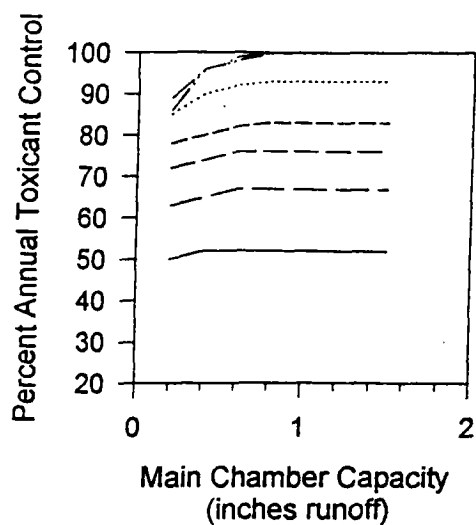


Figure 6.20 MCTT design curves for Rapid City, SD.

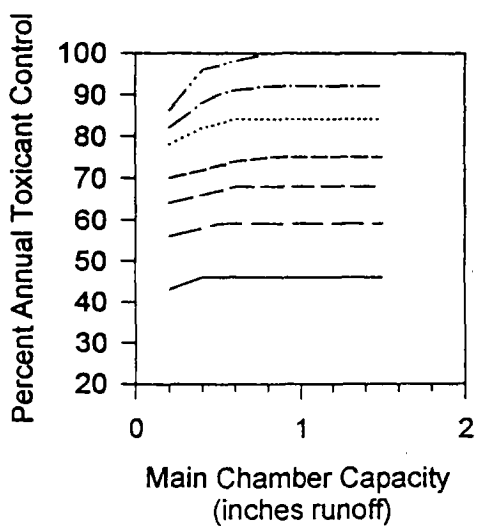
**Reno, Nevada
2 Ft. Chamber Depth**



**Reno, Nevada
5 Ft. Chamber Depth**



**Reno, Nevada
7 Ft. Chamber Depth**



**Reno, Nevada
9 Ft. Chamber Depth**

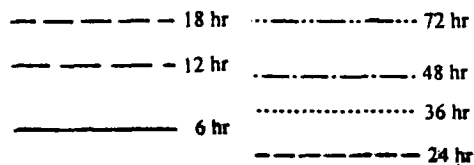
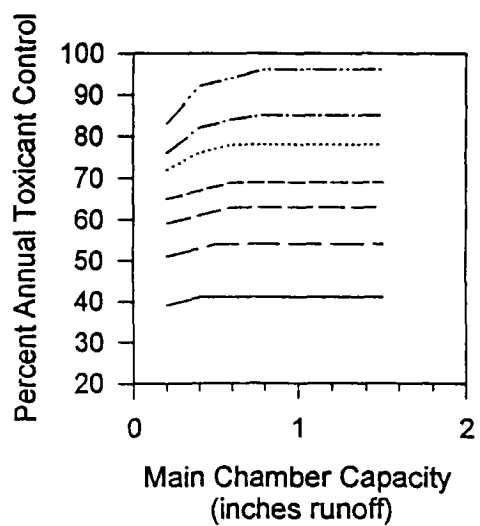


Figure 6.21 MCTT design curves for Reno, NV.

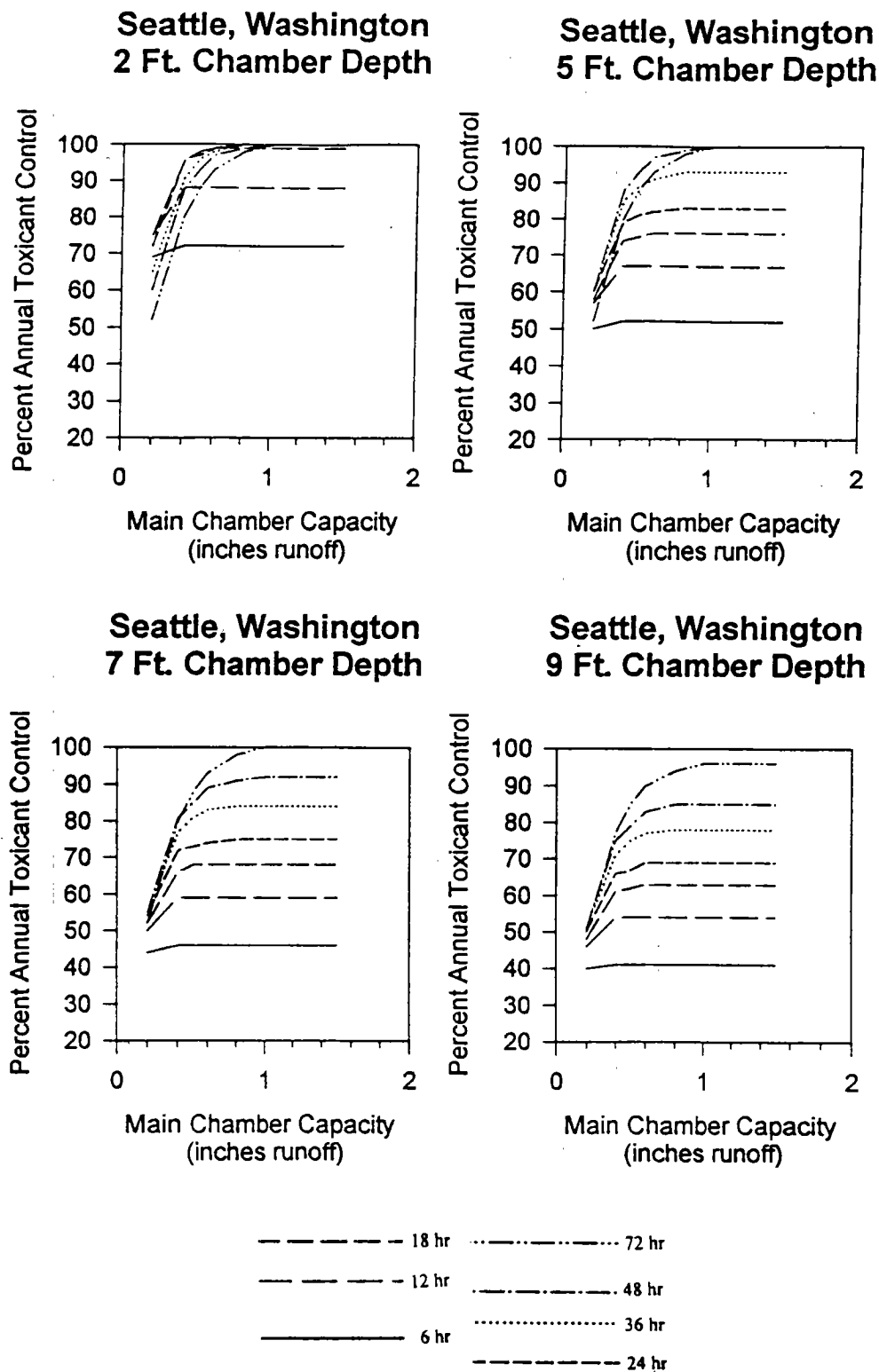


Figure 6.22 MCTT design curves for Seattle, WA.

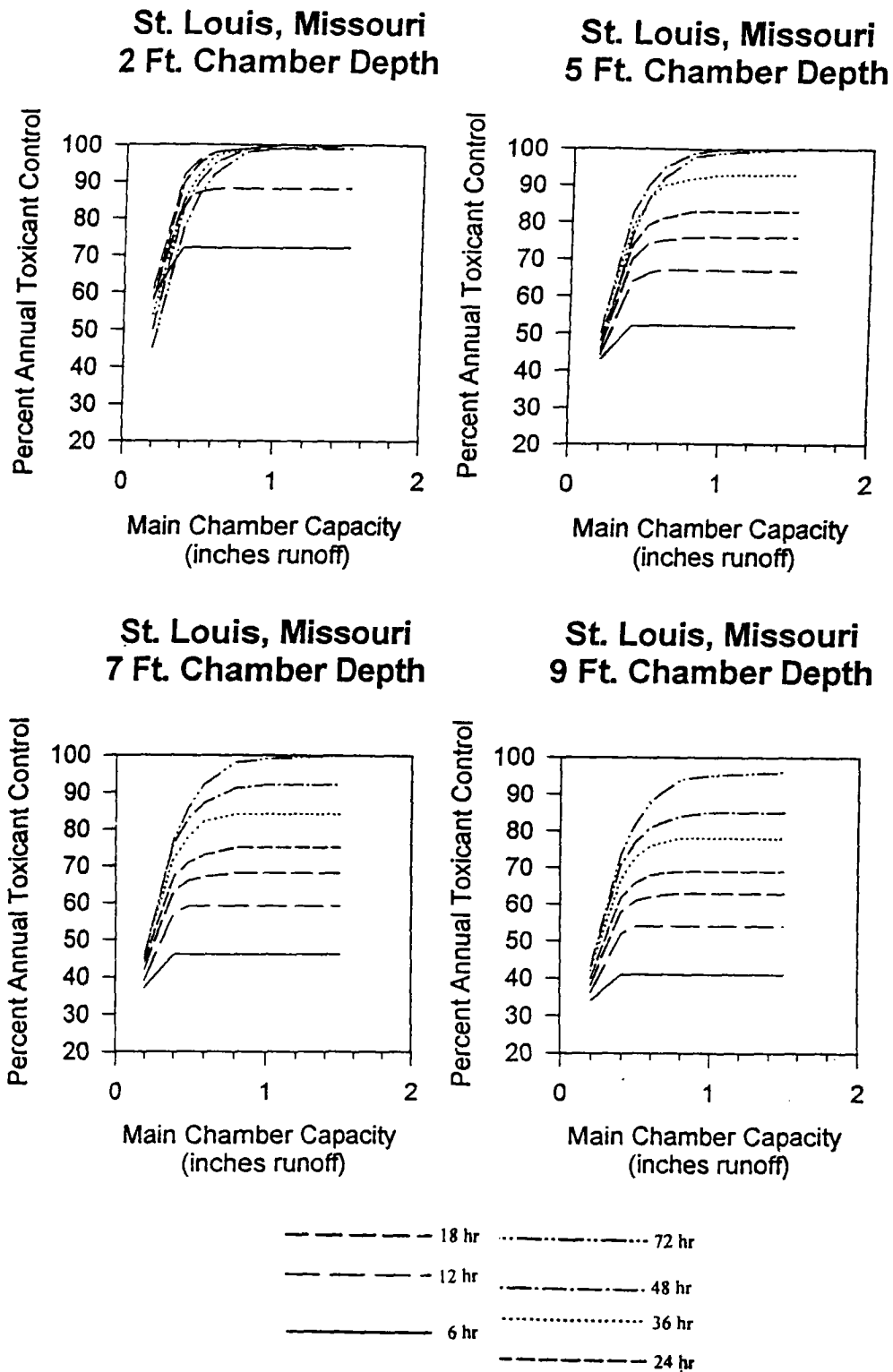


Figure 6.23 MCTT design curves for St. Louis, MO.

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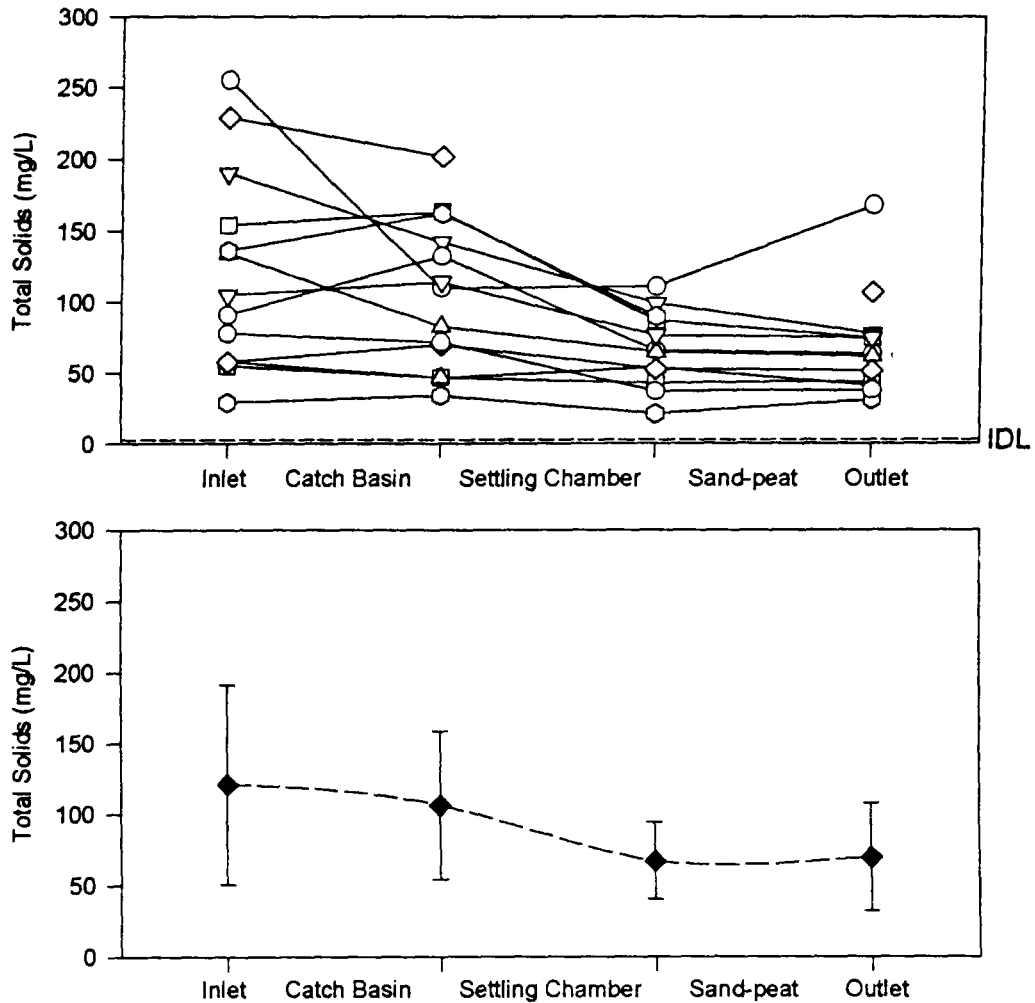
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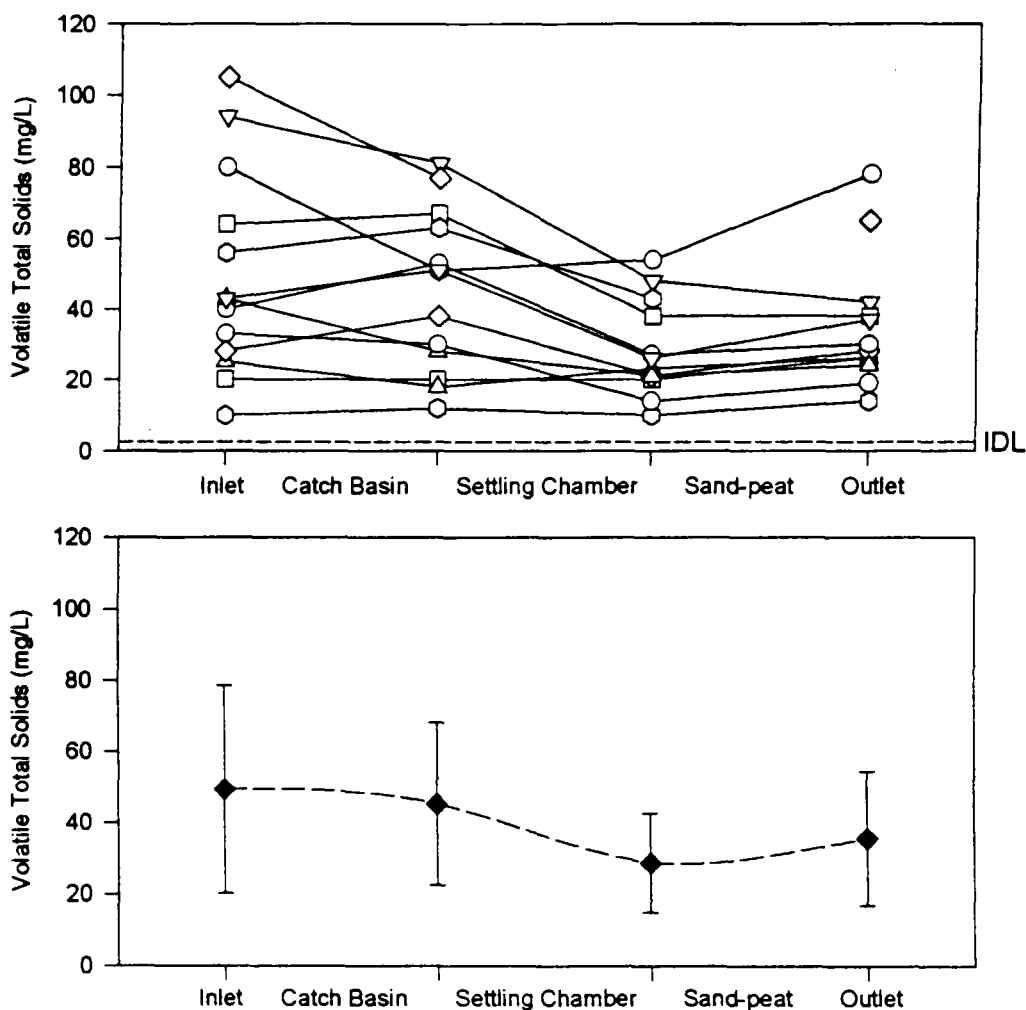
Appendix A
Plotted MCTT Performance Data

TABLE A-1.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Total Solids



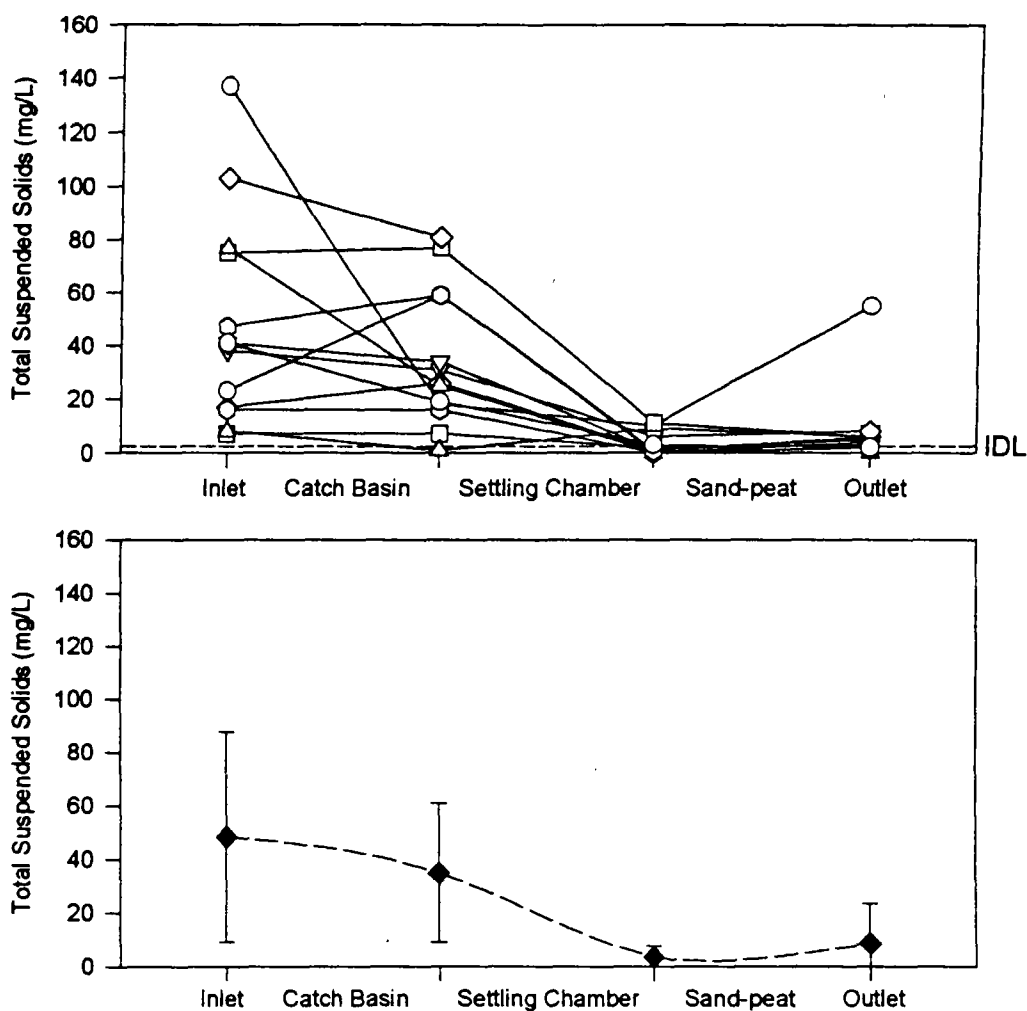
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.2429	0.0017	0.1763	0.0005
Min. Percent Reduction	-45	-15	-51	-7
Max. Percent Reduction	57	50	24	59
Median Percent Reduction	8	31	3	32
Std. Dev. of Percent Reduction	27	21	25	20
COV of Percent Reduction	6.3	0.76	-8.3	0.59

TABLE A-2.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Volatile Total Solids



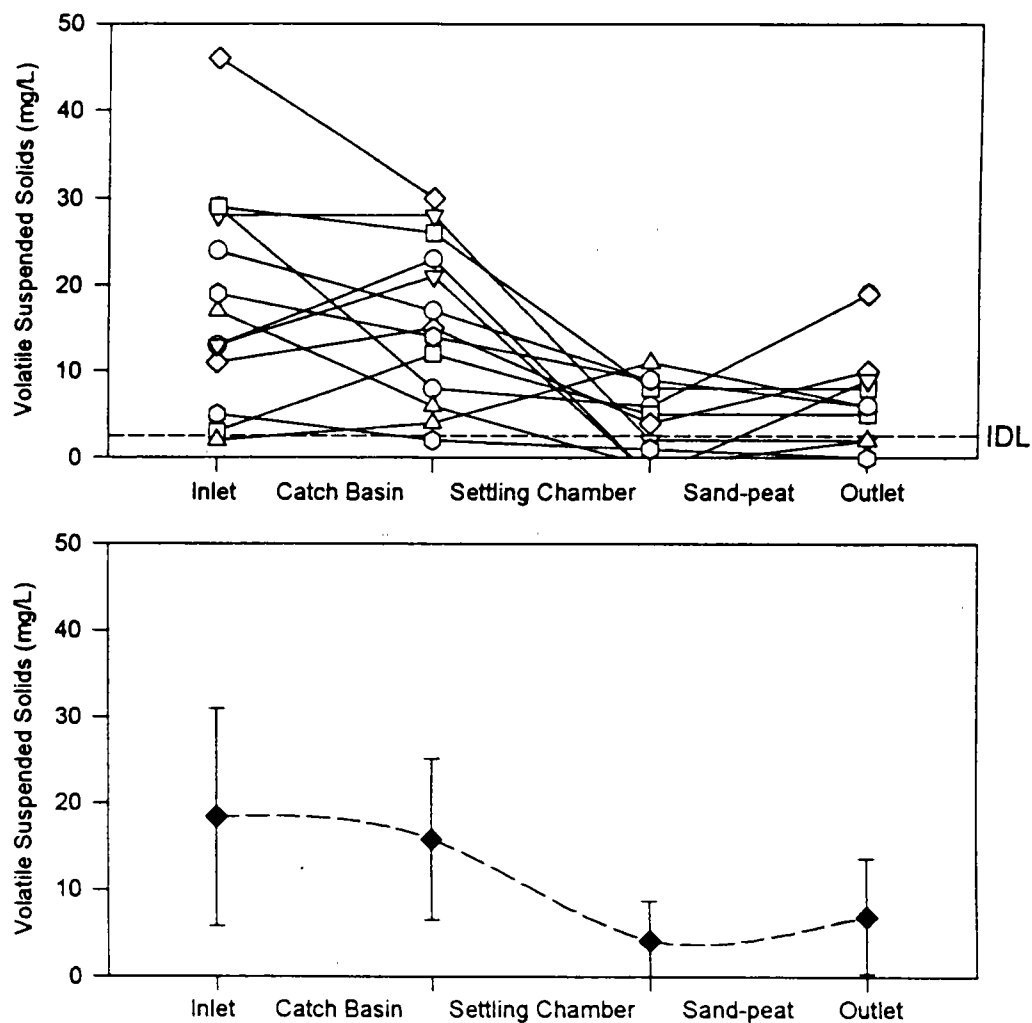
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.2395	0.0049	-0.0146	0.0127
Min. Percent Reduction	-36	-28	-44	-40
Max. Percent Reduction	36	53	13	55
Median Percent Reduction	0	36	-30	19
Std. Dev. of Percent Reduction	25	26	19	31
COV of Percent Reduction	13	0.97	-0.82	2.0

TABLE A-3.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Total Suspended Solids



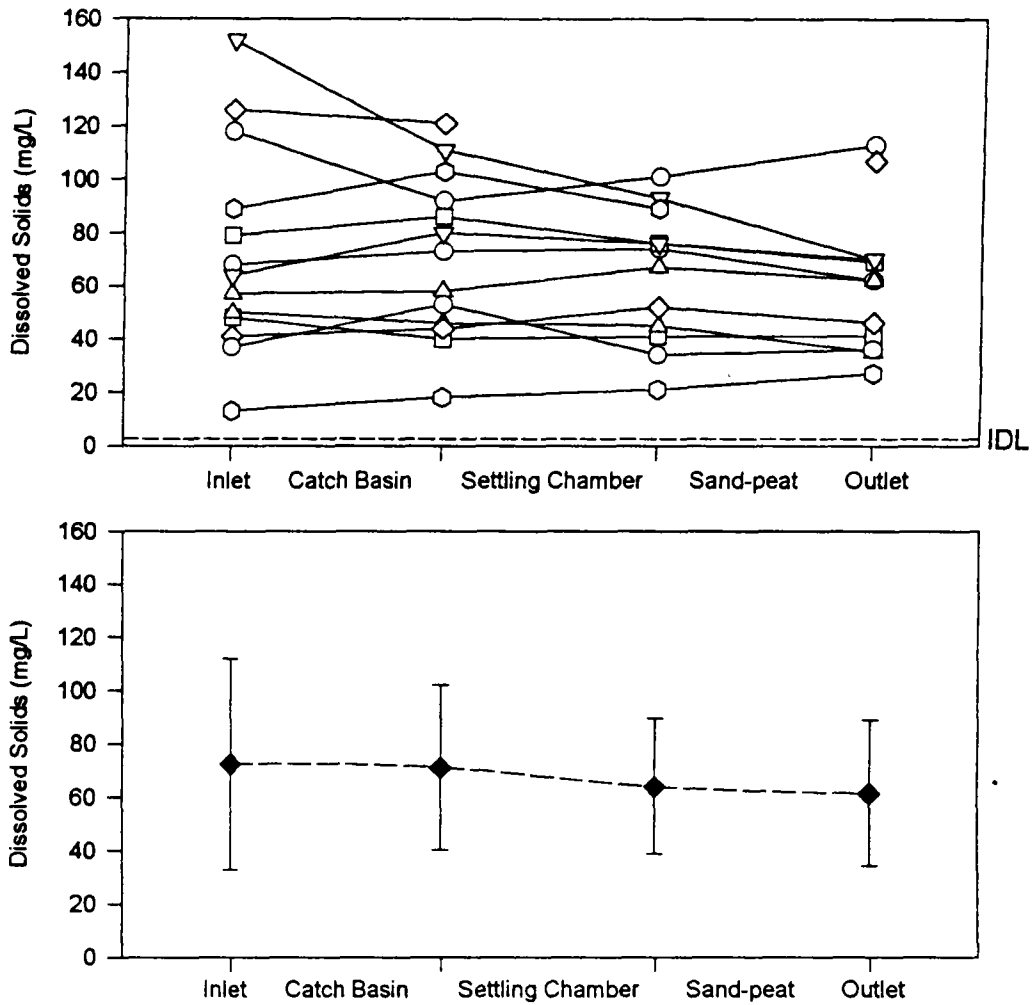
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.1543	0.0010	-0.1191	0.0002
Min. Percent Reduction	-157	-800	-500	25
Max. Percent Reduction	88	100	45	100
Median Percent Reduction	17	91	-400	83
Std. Dev. of Percent Reduction	65	257	240	22
COV of Percent Reduction	7.4	19	-1.5	0.28

TABLE A-4.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Volatile Suspended Solids



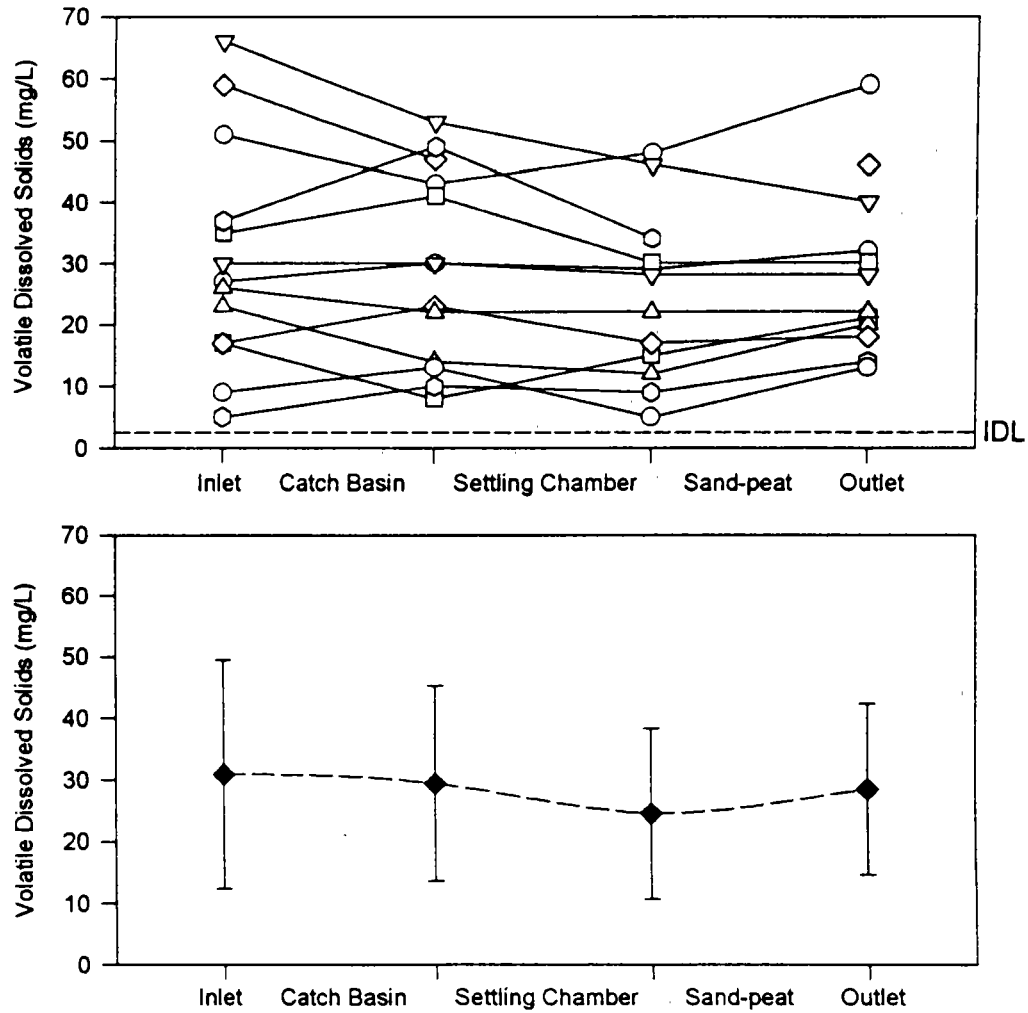
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.2288	0.0024	-0.1641	0.0027
Min. Percent Reduction	-300	-175	-217	-200
Max. Percent Reduction	72	100	100	100
Median Percent Reduction	10	64	0	66
Std. Dev. of Percent Reduction	100	77	209	89
COV of Percent Reduction	-4.7	1.5	3.5	2.6

TABLE A-5.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Dissolved Solids



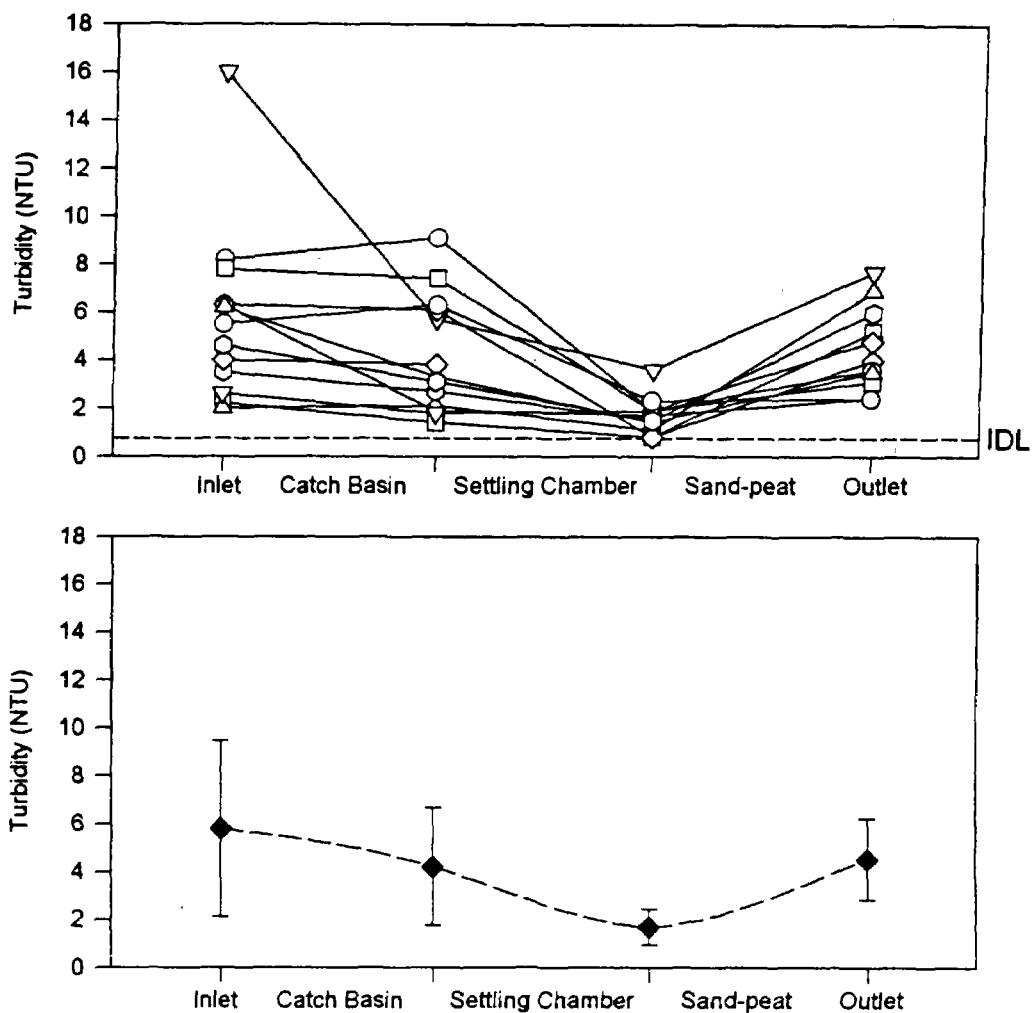
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.3862	0.2288	0.0820	0.0784
Min. Percent Reduction	-43	-18	-29	-108
Max. Percent Reduction	27	36	25	54
Median Percent Reduction	-7	0	8	7
Std. Dev. of Percent Reduction	22	16	16	39
COV of Percent Reduction	-4.0	9.4	3.2	116

TABLE A-6.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Volatile Dissolved Solids



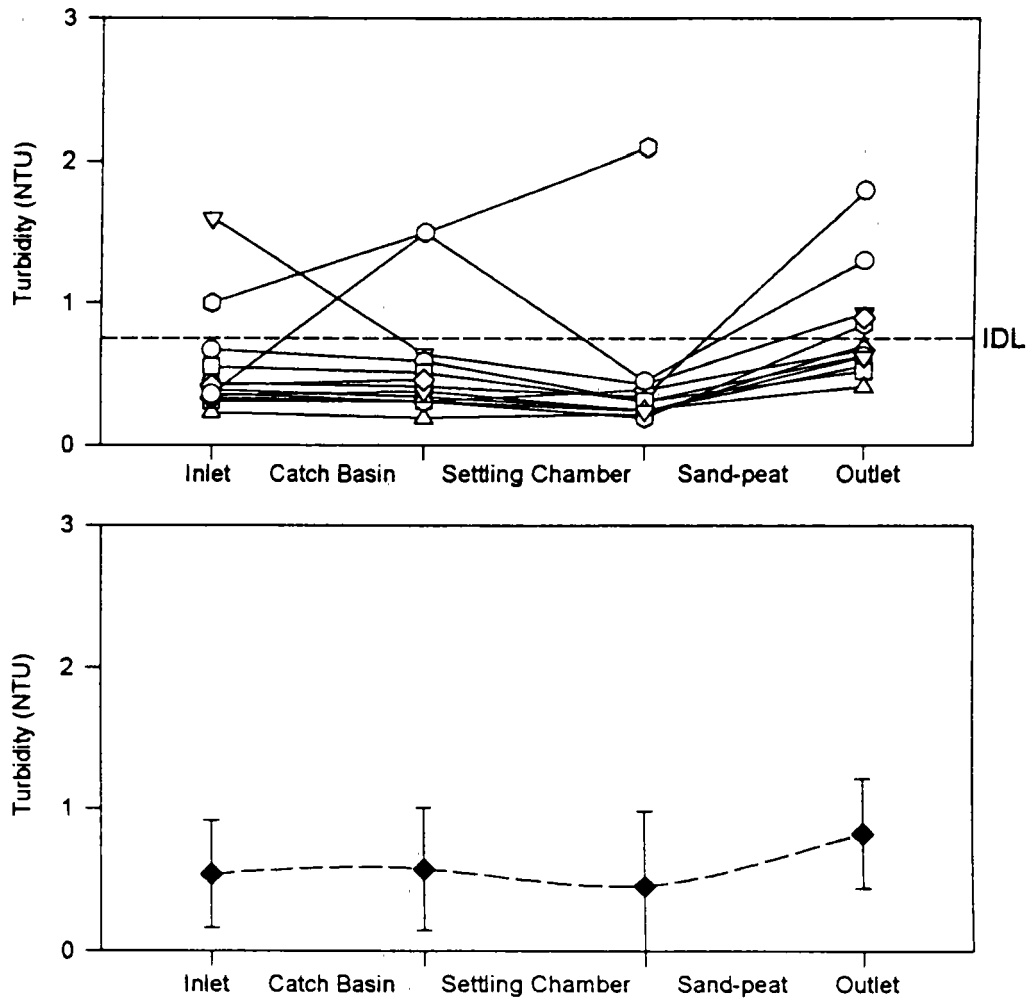
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.2275	0.0381	-0.0313	0.4629
Min. Percent Reduction	-100	-88	-160	-180
Max. Percent Reduction	53	62	13	39
Median Percent Reduction	0	12	-10	0
Std. Dev. of Percent Reduction	41	35	50	57
COV of Percent Reduction	-6.8	4.5	-1.6	-3.9

TABLE A-7.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Turbidity



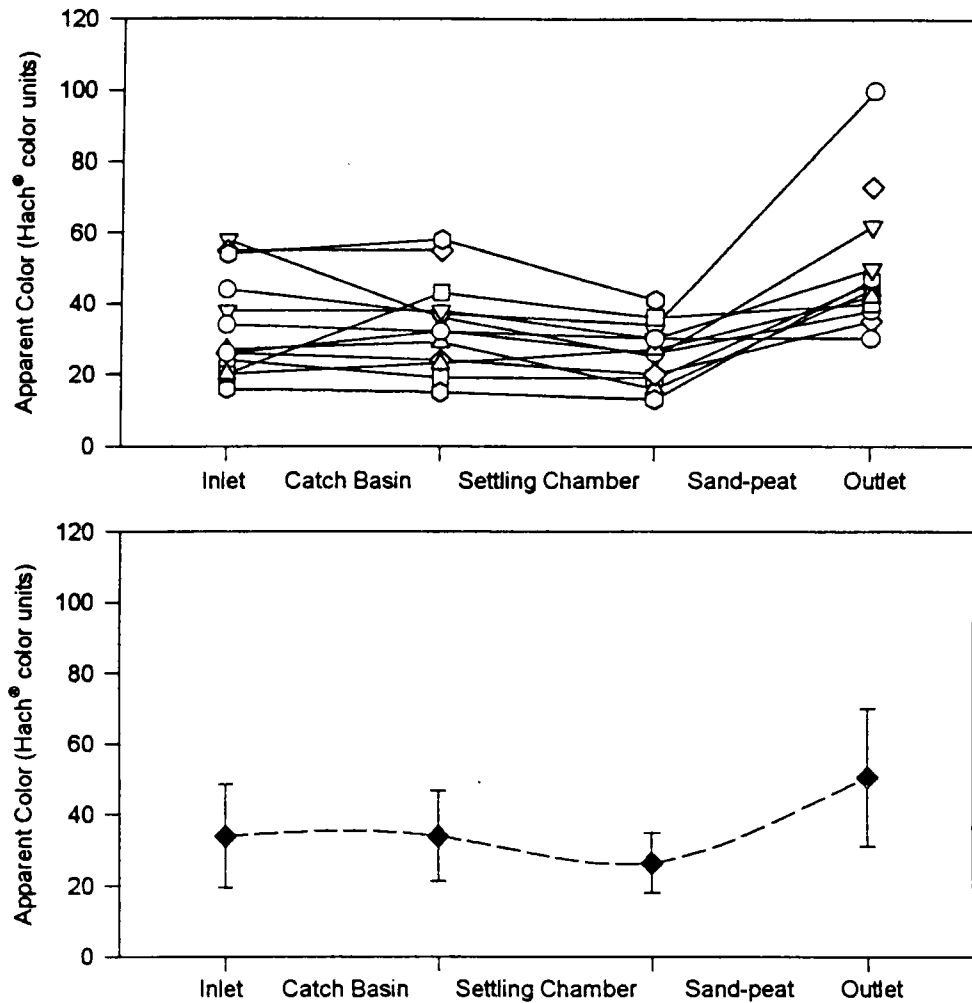
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.0215	0.0005	-0.0005	0.1331
Min. Percent Reduction	-15	-6	-584	-245
Max. Percent Reduction	70	86	-4	62
Median Percent Reduction	23	50	-150	40
Std. Dev. of Percent Reduction	28	27	200	99
COV of Percent Reduction	1.3	0.54	-0.91	-6.2

TABLE A-8.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Turbidity



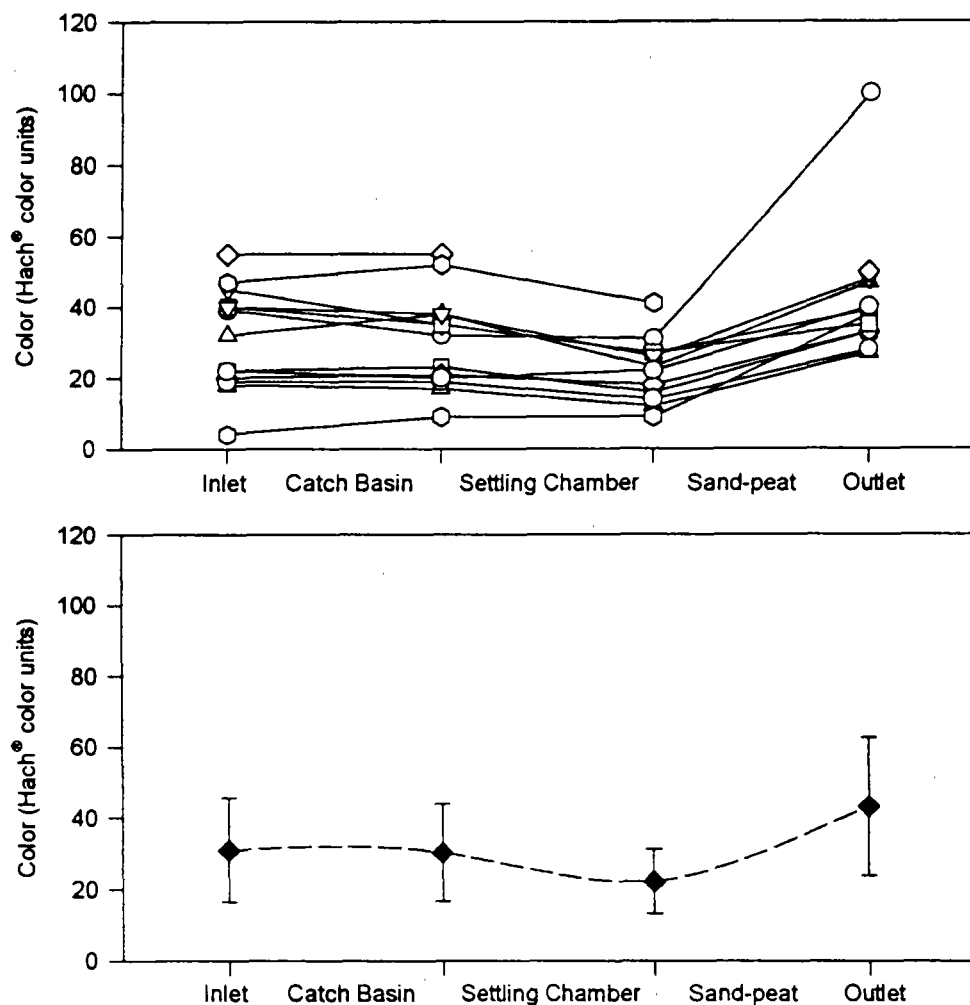
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.2405	0.0371	-0.0005	-0.0320
Min. Percent Reduction	-317	-40	-429	-309
Max. Percent Reduction	60	70	-64	42
Median Percent Reduction	7	30	-133	-92
Std. Dev. of Percent Reduction	93	32	119	111
COV of Percent Reduction	-4.8	1.6	-0.69	-1.1

TABLE A-9.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Apparent Color



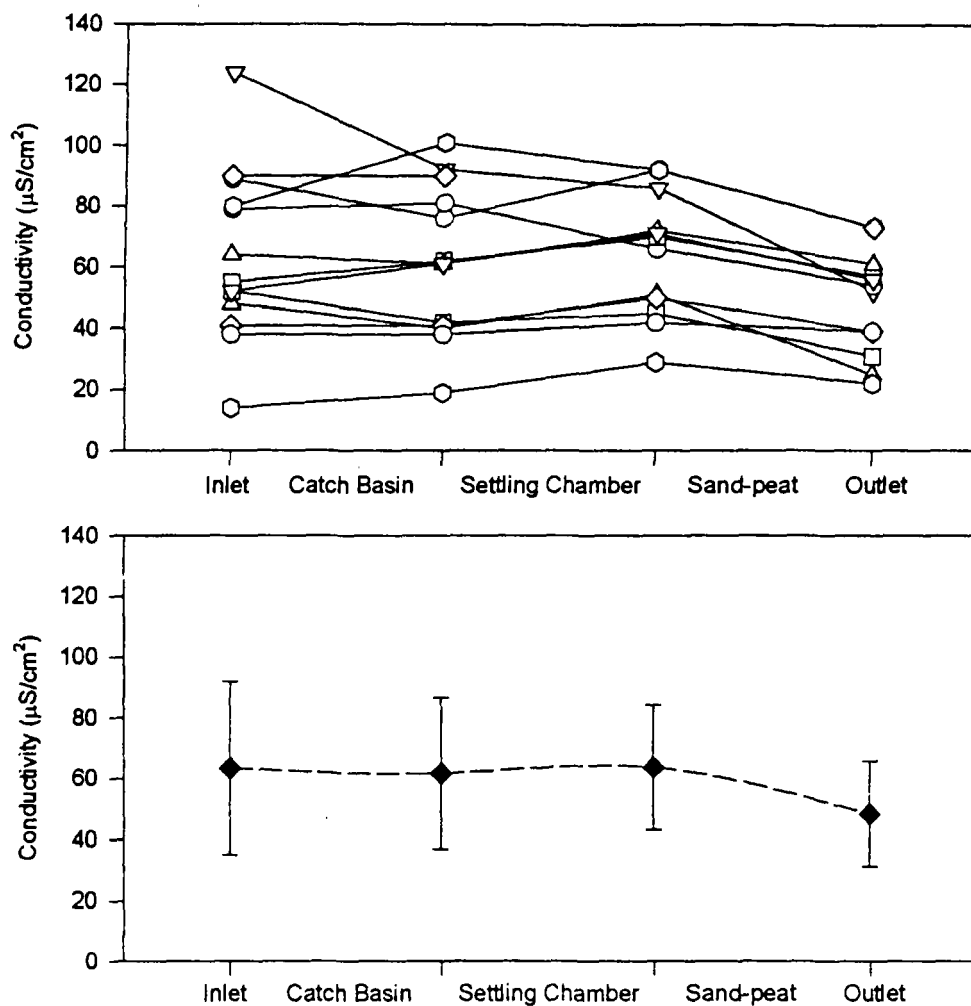
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.5176	0.0044	-0.0010	-0.0007
Min. Percent Reduction	-115	-17	-262	-194
Max. Percent Reduction	38	45	0	12
Median Percent Reduction	0	16	-75	-55
Std. Dev. of Percent Reduction	36	16	83	58
COV of Percent Reduction	-6.5	1.0	-0.78	-0.84

TABLE A-10.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Color



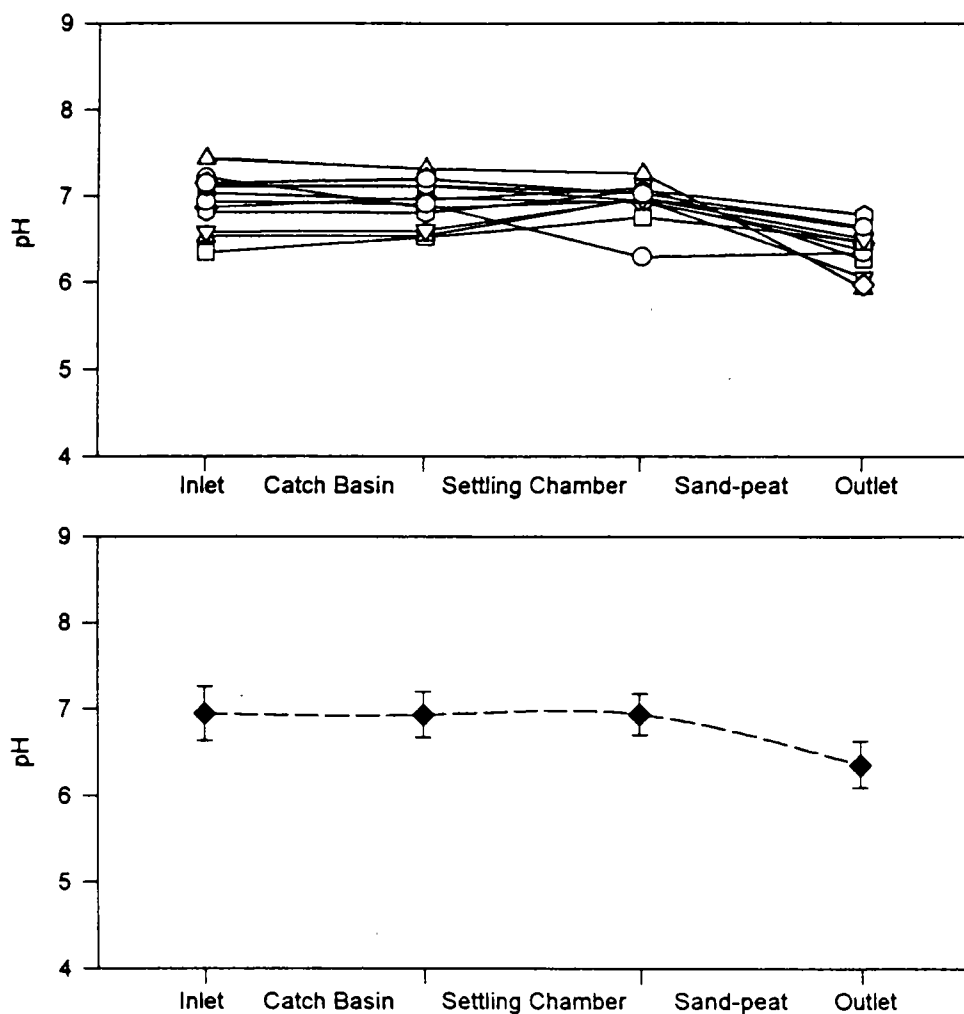
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.3135	0.0015	-0.0005	-0.0032
Min. Percent Reduction	-125	-10	-322	-850
Max. Percent Reduction	22	39	-30	13
Median Percent Reduction	0	23	-100	-49
Std. Dev. of Percent Reduction	37	15	84	237
COV of Percent Reduction	-5.3	0.76	-0.71	-2.1

TABLE A-11.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Conductivity



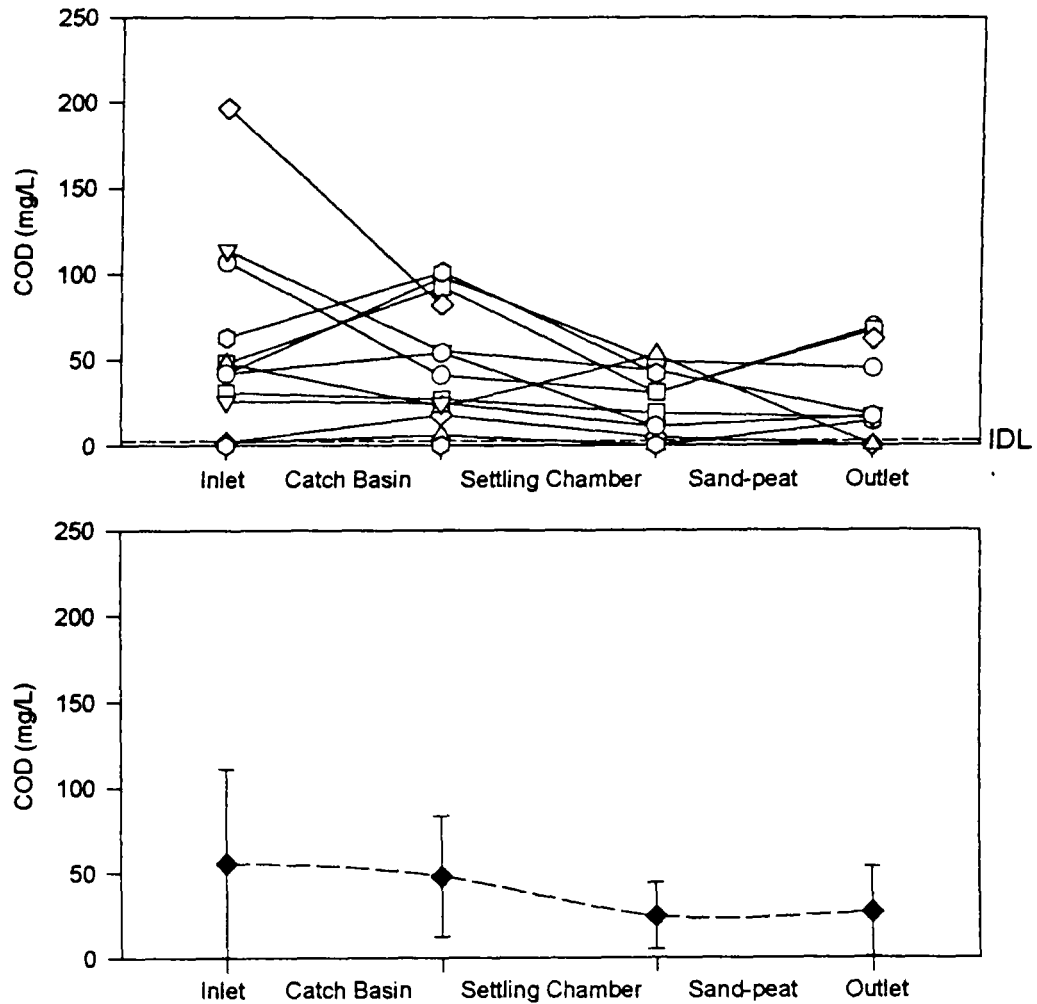
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.3477	-0.0662	0.0005	0.0276
Min. Percent Reduction	-36	-53	7	-57
Max. Percent Reduction	26	19	51	58
Median Percent Reduction	0	-15	21	11
Std. Dev. of Percent Reduction	18	19	12	31
COV of Percent Reduction	-17	-1.5	0.50	2.4

TABLE A-12
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
pH



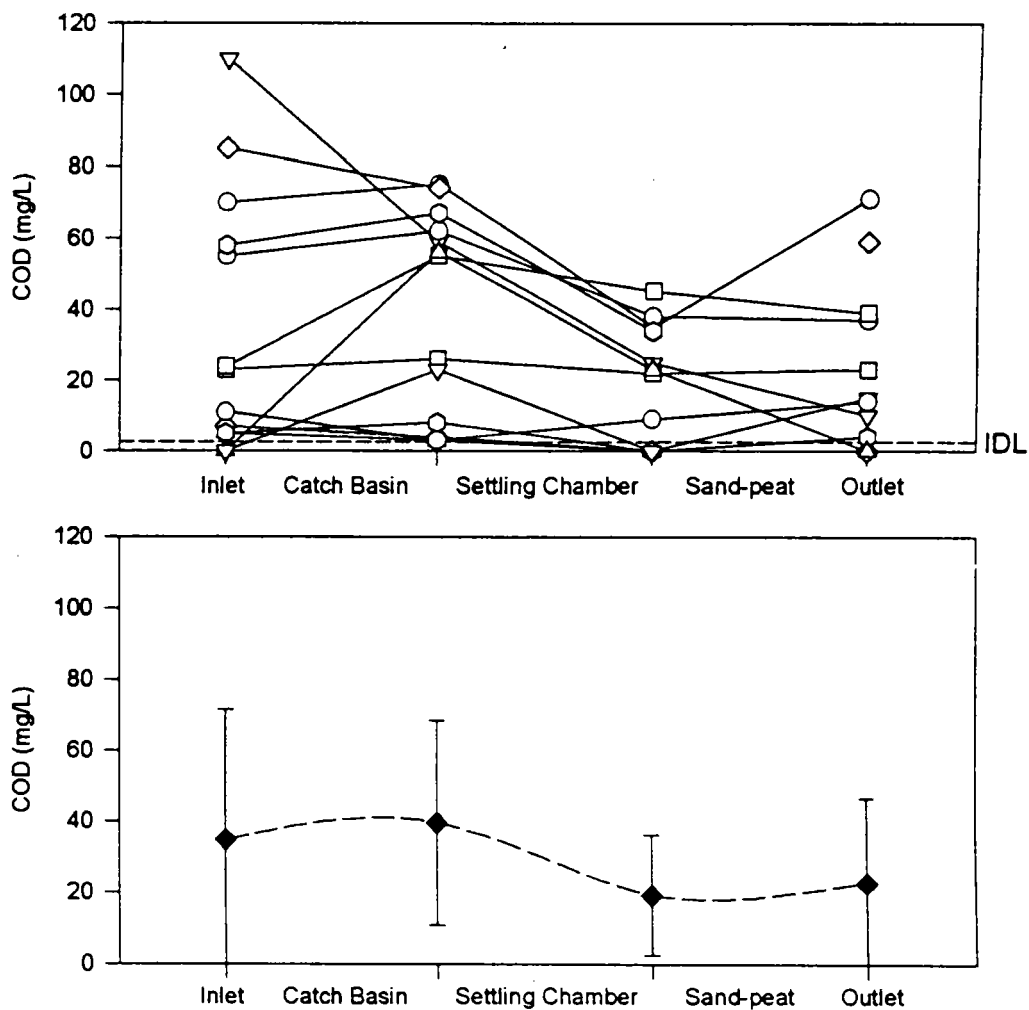
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.4526	-0.3074	0.0010	0.0046
Min. Percent Reduction	-3	-7	-1	-2
Max. Percent Reduction	5	9	18	20
Median Percent Reduction	0	0	7	8
Std. Dev. of Percent Reduction	1.8	4.3	5.2	7.3
COV of Percent Reduction	12.7	-7.7	0.69	0.93

TABLE A-13.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Chemical Oxygen Demand



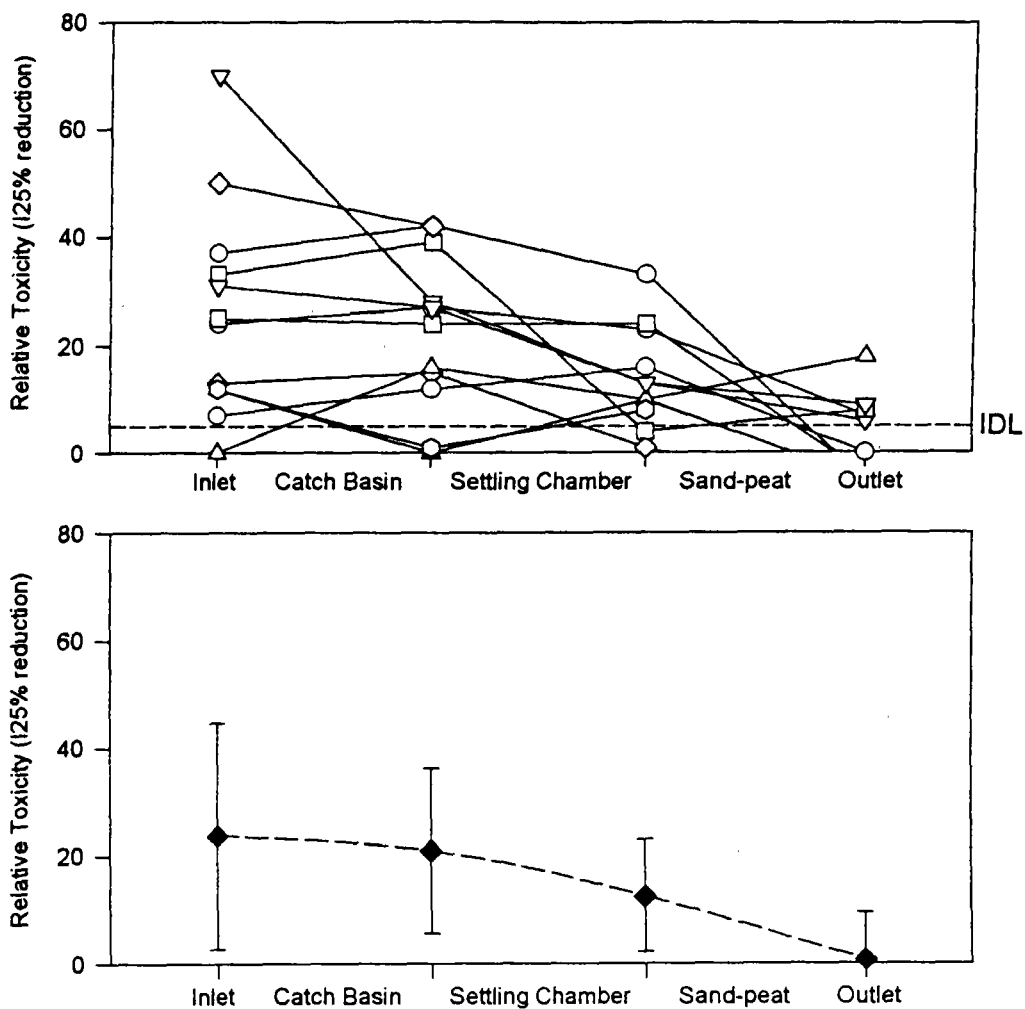
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.4028	0.0093	-0.3359	0.0305
Min. Percent Reduction	-800	-130	-123	-40
Max. Percent Reduction	62	100	100	100
Median Percent Reduction	-29	53	-55	54
Std. Dev. of Percent Reduction	239	61	85	46
COV of Percent Reduction	-2.67	1.58	-11.81	0.86

TABLE A-14.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Chemical Oxygen Demand



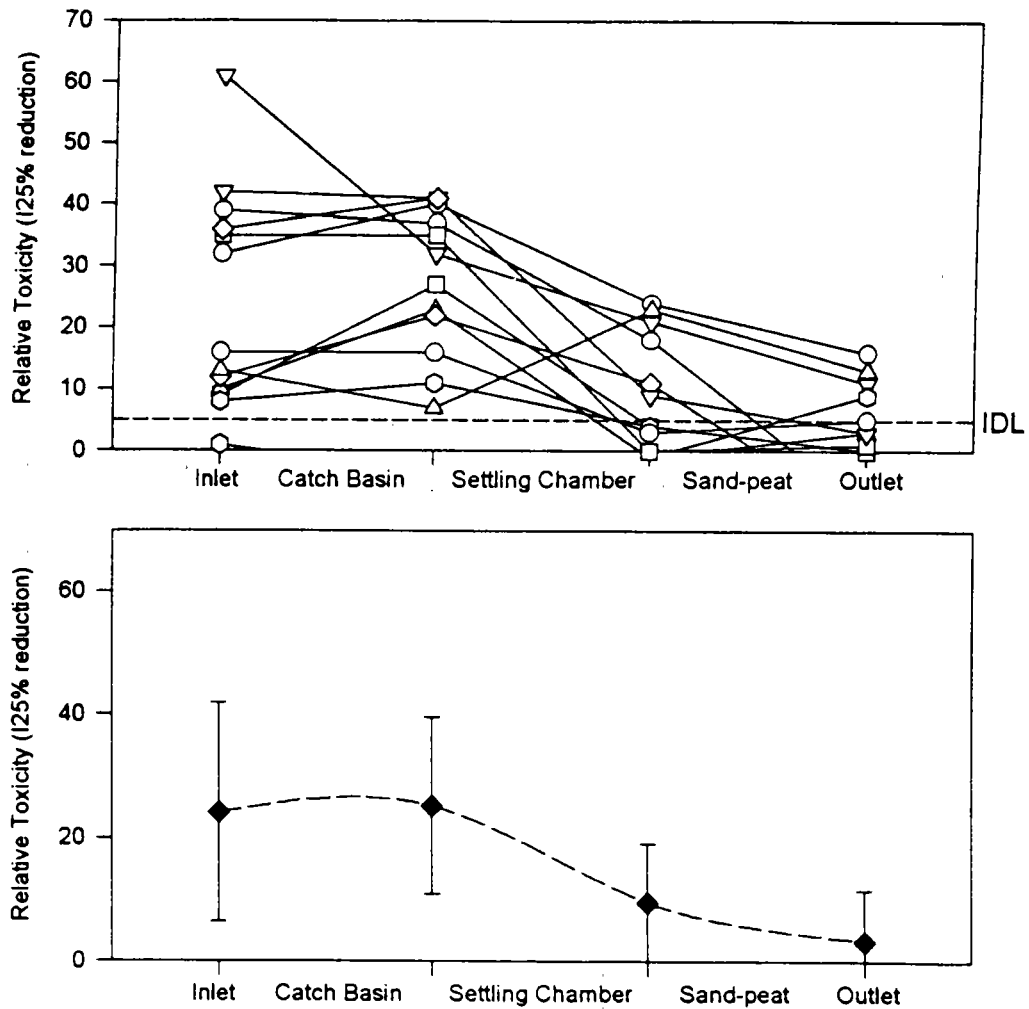
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.1875	0.0017	-0.4434	0.1680
Min. Percent Reduction	-129	-200	-103	-63
Max. Percent Reduction	73	100	100	100
Median Percent Reduction	-13	55	-5	10
Std. Dev. of Percent Reduction	56	82	68	55
COV of Percent Reduction	-27	2.0	36	1.9

Table A-15.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Relative Toxicity



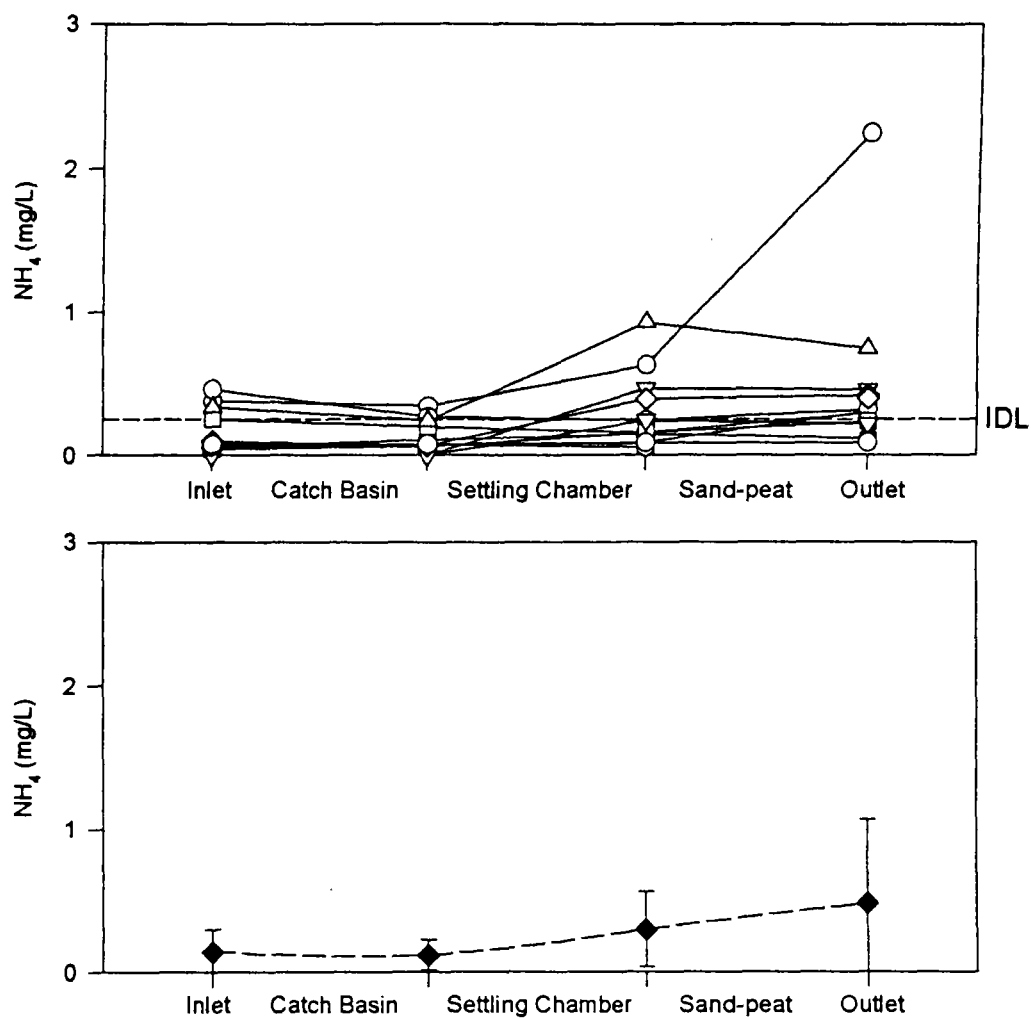
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.4464	0.0537	0.0078	0.0022
Min. Percent Reduction	-71	-700	-175	-83
Max. Percent Reduction	100	93	1200	185
Median Percent Reduction	100	93	100	100
Std. Dev. of Percent Reduction	53	238	368	66
COV of Percent Reduction	2.7	-3.9	2.7	0.74

TABLE A-16.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Relative Toxicity



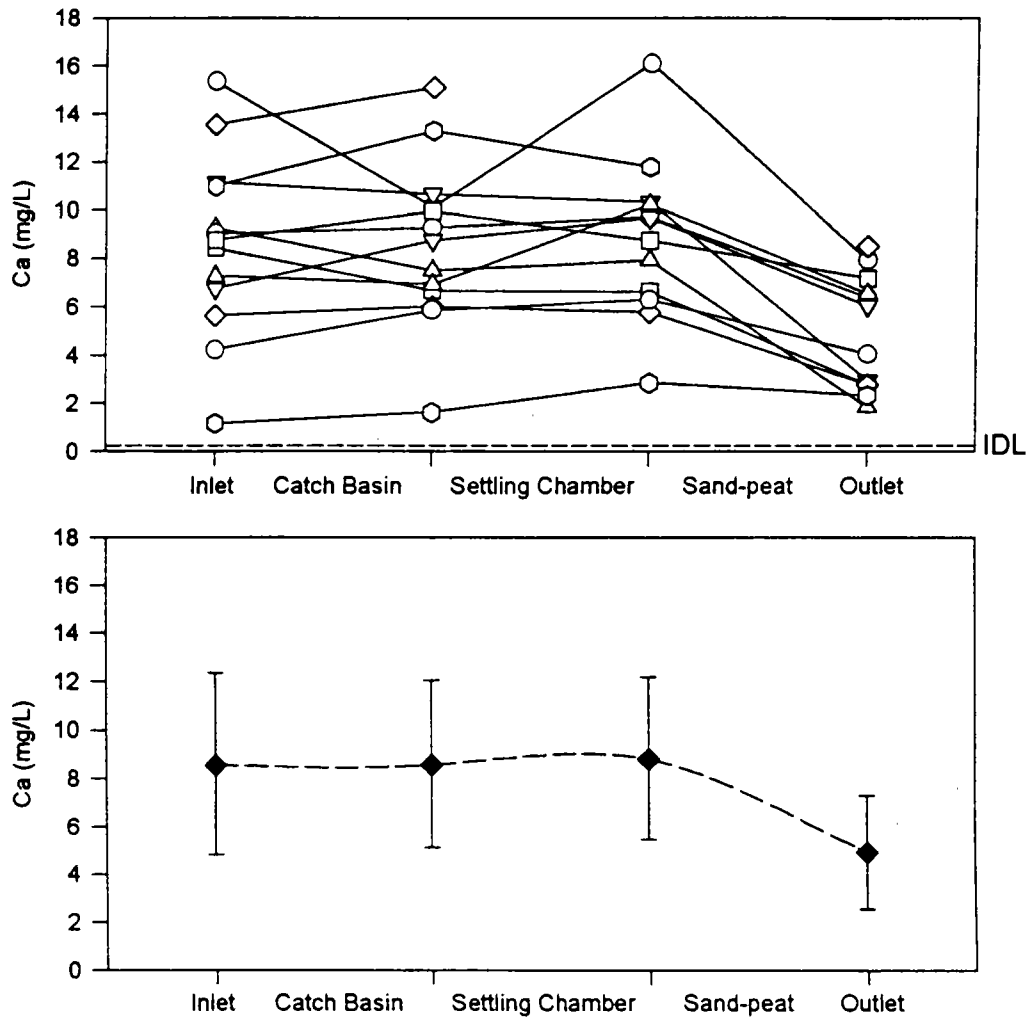
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.2402	0.0049	0.0537	0.0015
Min. Percent Reduction	-200	-229	-67	-800
Max. Percent Reduction	100	100	100	100
Median Percent Reduction	0	69	67	87
Std. Dev. of Percent Reduction	163	89	309	261
COV of Percent Reduction	19	2.0	1.6	18

TABLE A-17.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Ammonium



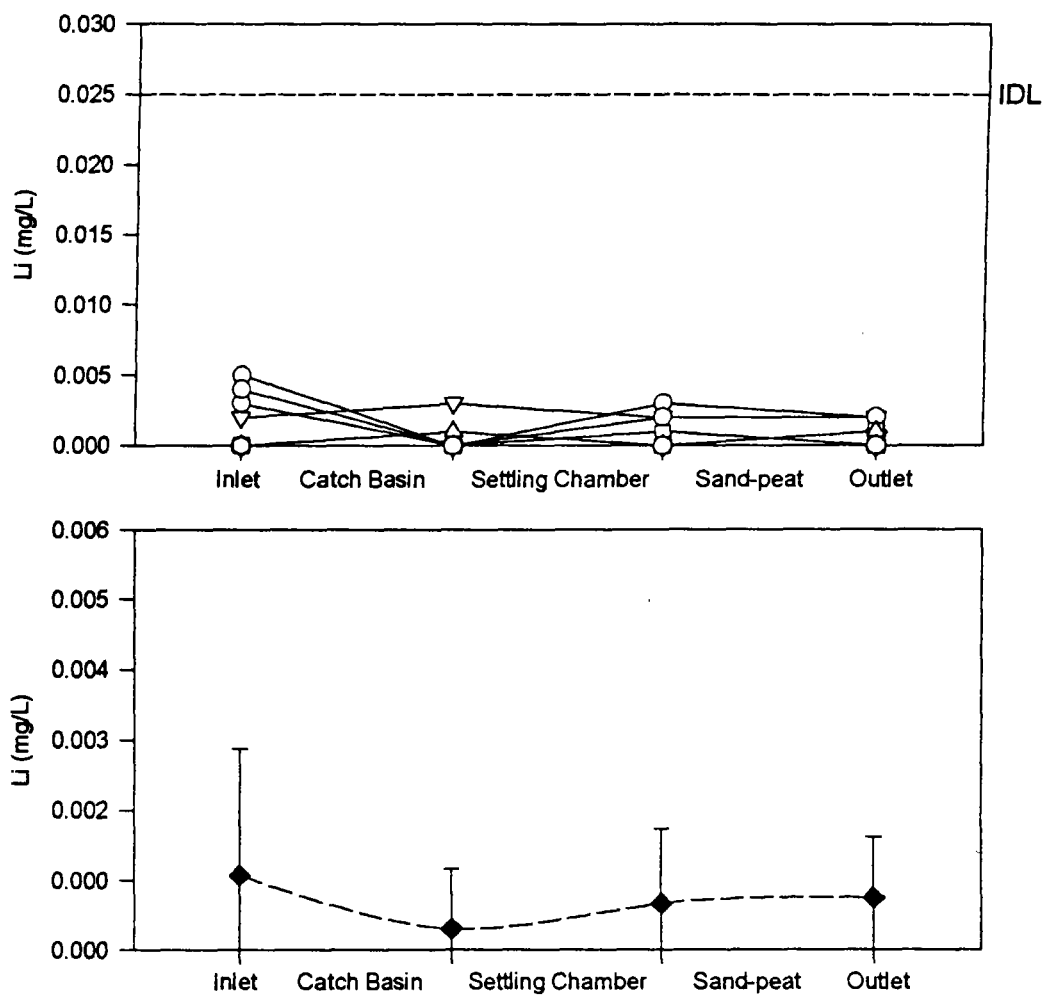
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.2324	-0.0178	-0.1201	-0.0034
Min. Percent Reduction	-89	-491	-258	-651
Max. Percent Reduction	42	27	21	31
Median Percent Reduction	-10	-62	-7	-403
Std. Dev. of Percent Reduction	45	168	101	281
COV of Percent Reduction	-4.0	-1.6	-1.8	-0.97

TABLE A-18.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Calcium



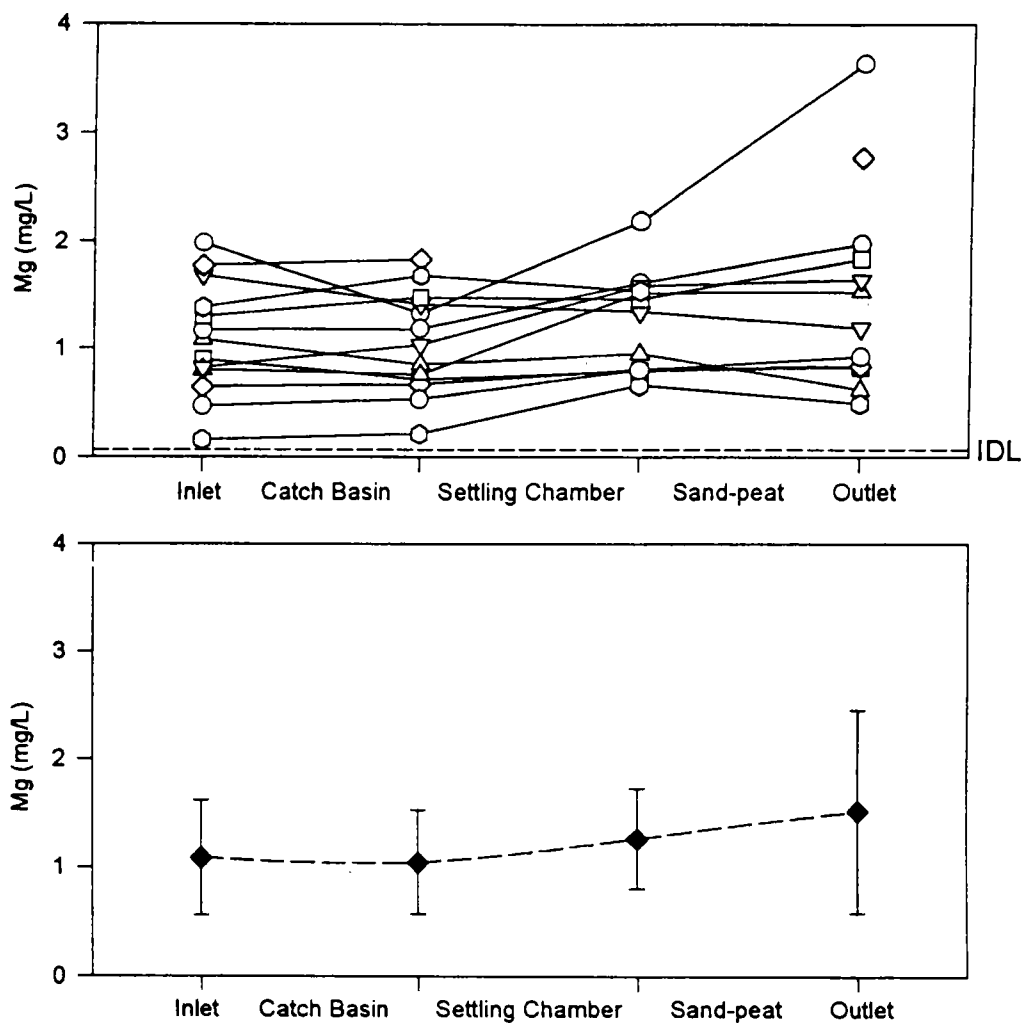
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.3424	-0.1697	0.0005	0.0017
Min. Percent Reduction	-39	-75	18	-99
Max. Percent Reduction	34	12	77	80
Median Percent Reduction	-7	-5	38	33
Std. Dev. of Percent Reduction	23	29	19	47
COV of Percent Reduction	-3.7	-2.0	0.44	1.7

TABLE A-19.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Lithium



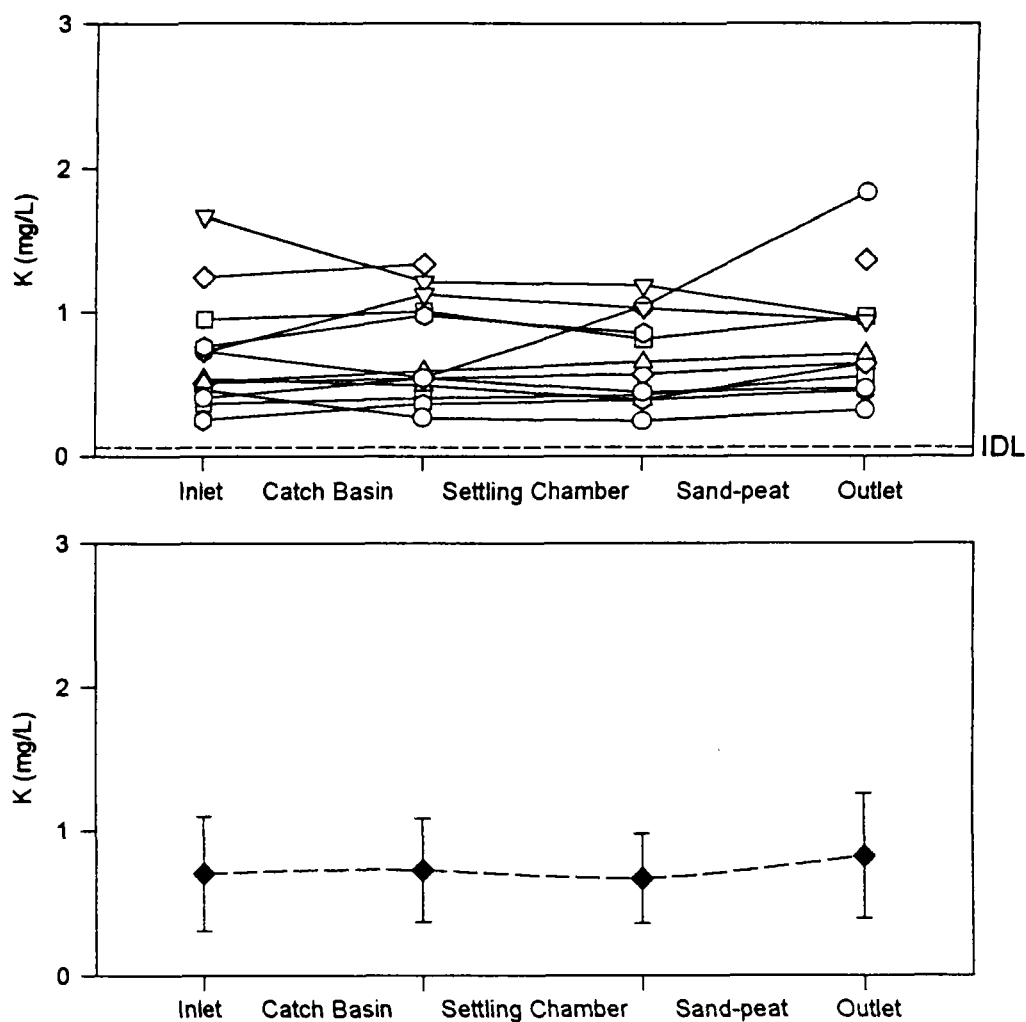
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.1563	-0.2500	-0.5000	0.3281
Min. Percent Reduction	-50	33	0	0
Max. Percent Reduction	100	100	100	100
Median Percent Reduction	N/A	N/A	N/A	N/A
Std. Dev. of Percent Reduction	75	47	47	42
COV of Percent Reduction	1.2	0.71	1.4	0.88

TABLE A-20.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Magnesium



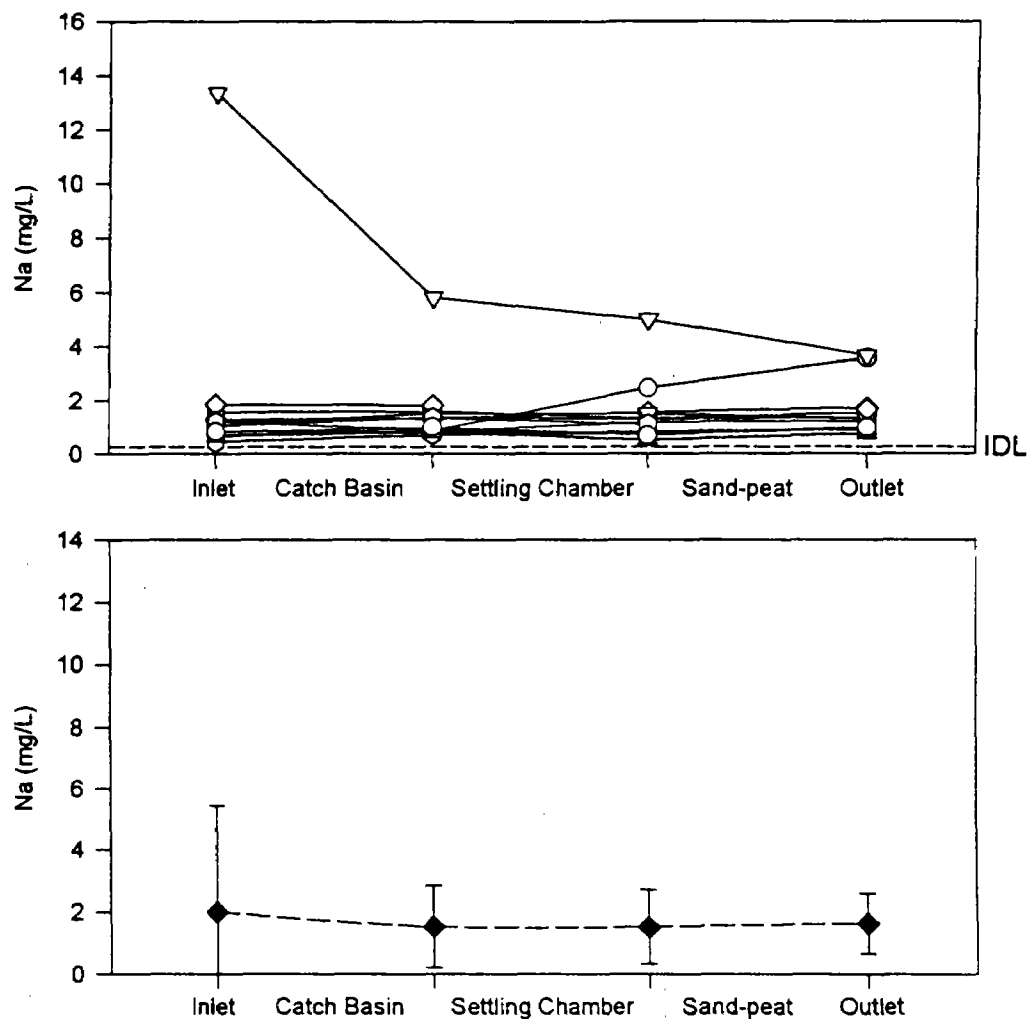
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.5000	-0.0081	-0.1602	-0.0171
Min. Percent Reduction	-34	-211	-67	-209
Max. Percent Reduction	33	9	35	43
Median Percent Reduction	-3	-29	-4	-63
Std. Dev. of Percent Reduction	20	62	27	68
COV of Percent Reduction	-14	-1.3	-4.2	-1.2

TABLE A-21.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Potassium



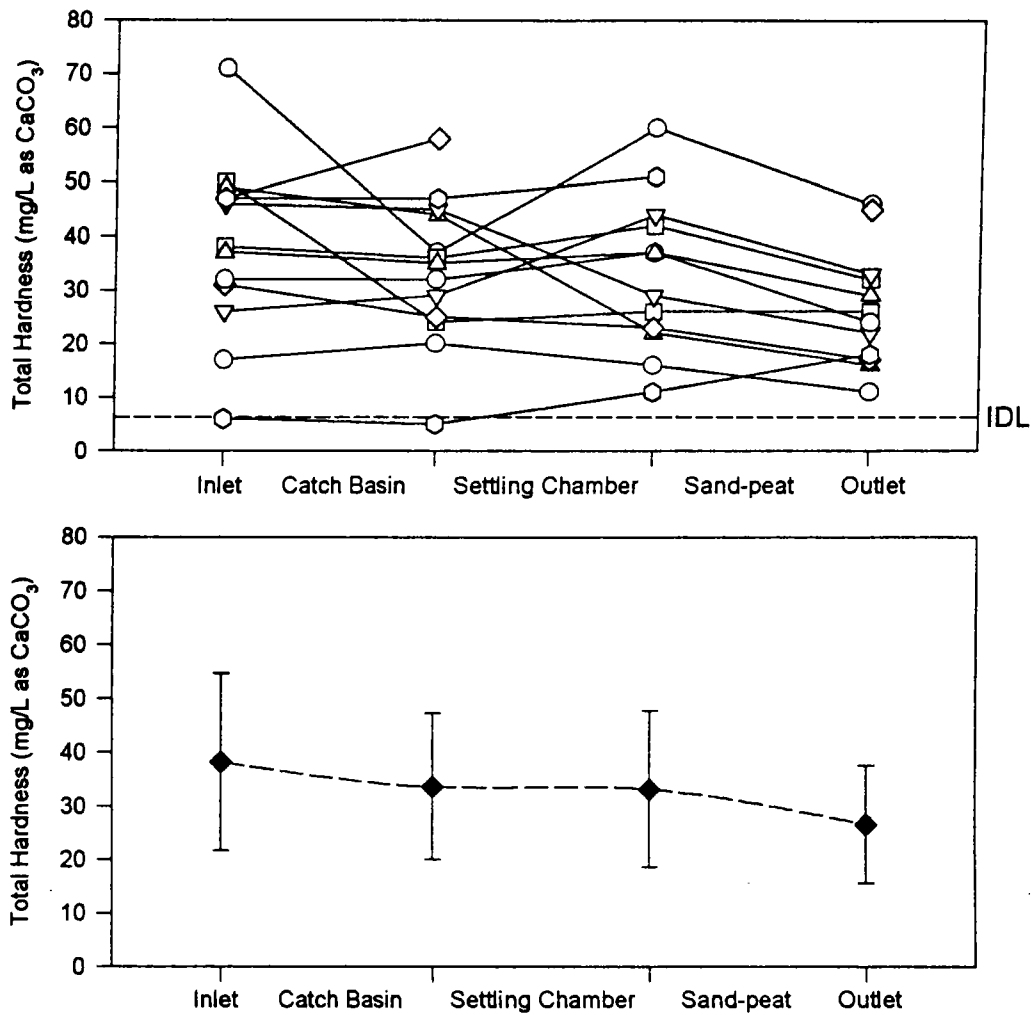
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.2487	0.1750	-0.0737	-0.0461
Min. Percent Reduction	-56	-90	-77	-153
Max. Percent Reduction	42	21	19	43
Median Percent Reduction	-7	6	-16	-23
Std. Dev. of Percent Reduction	29	30	29	51
COV of Percent Reduction	-3.5	-13.7	-1.3	-1.7

TABLE A-22.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Sodium



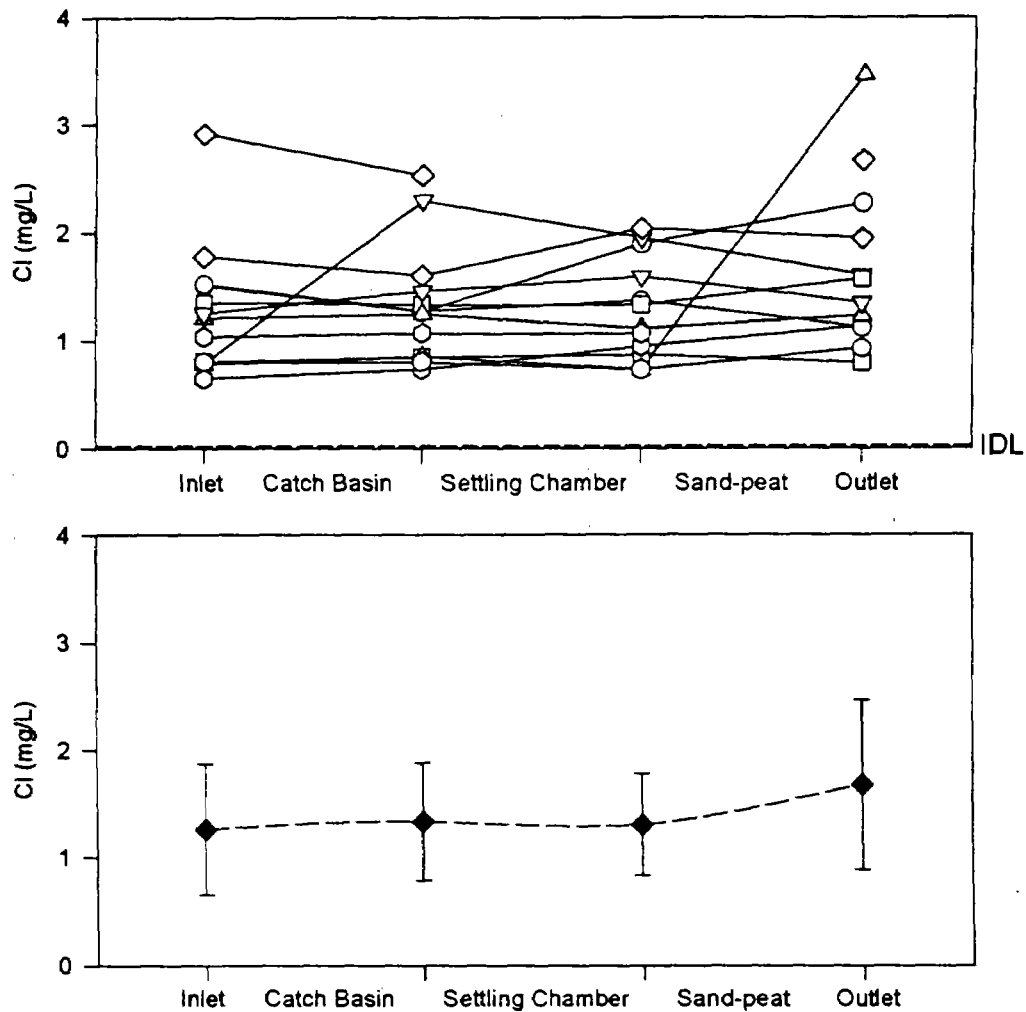
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.1115	0.1902	-0.1030	-0.0647
Min. Percent Reduction	-62	-182	-45	-192
Max. Percent Reduction	57	38	27	73
Median Percent Reduction	-11	3	-11	-26
Std. Dev. of Percent Reduction	30	58	23	67
COV of Percent Reduction	-3.2	-5.4	-1.7	-1.9

TABLE A-23.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Total Hardness



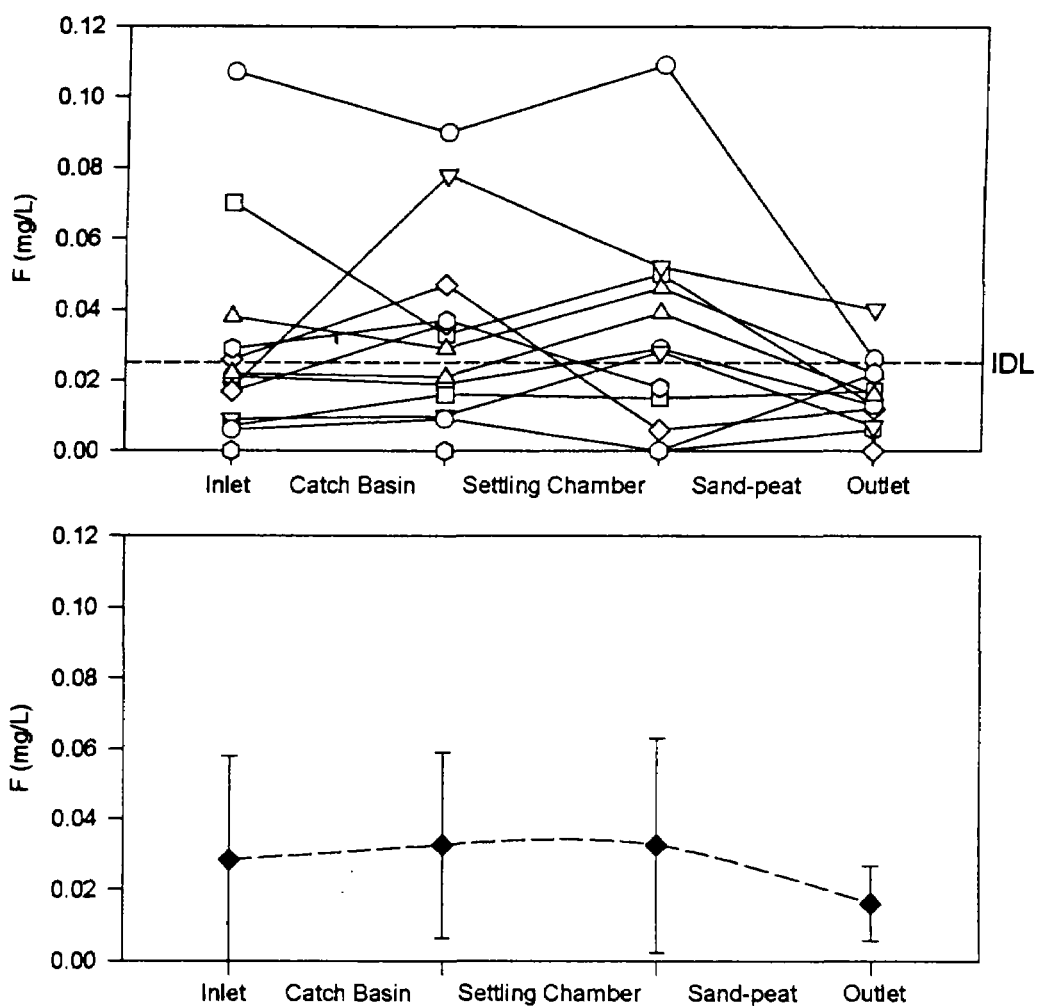
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.1338	-0.1960	0.0078	0.0125
Min. Percent Reduction	-23	-120	-64	-200
Max. Percent Reduction	52	50	35	67
Median Percent Reduction	5	-8	24	30
Std. Dev. of Percent Reduction	22	46	28	71
COV of Percent Reduction	2.7	-3.2	1.8	6.9

TABLE A-24.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Chloride



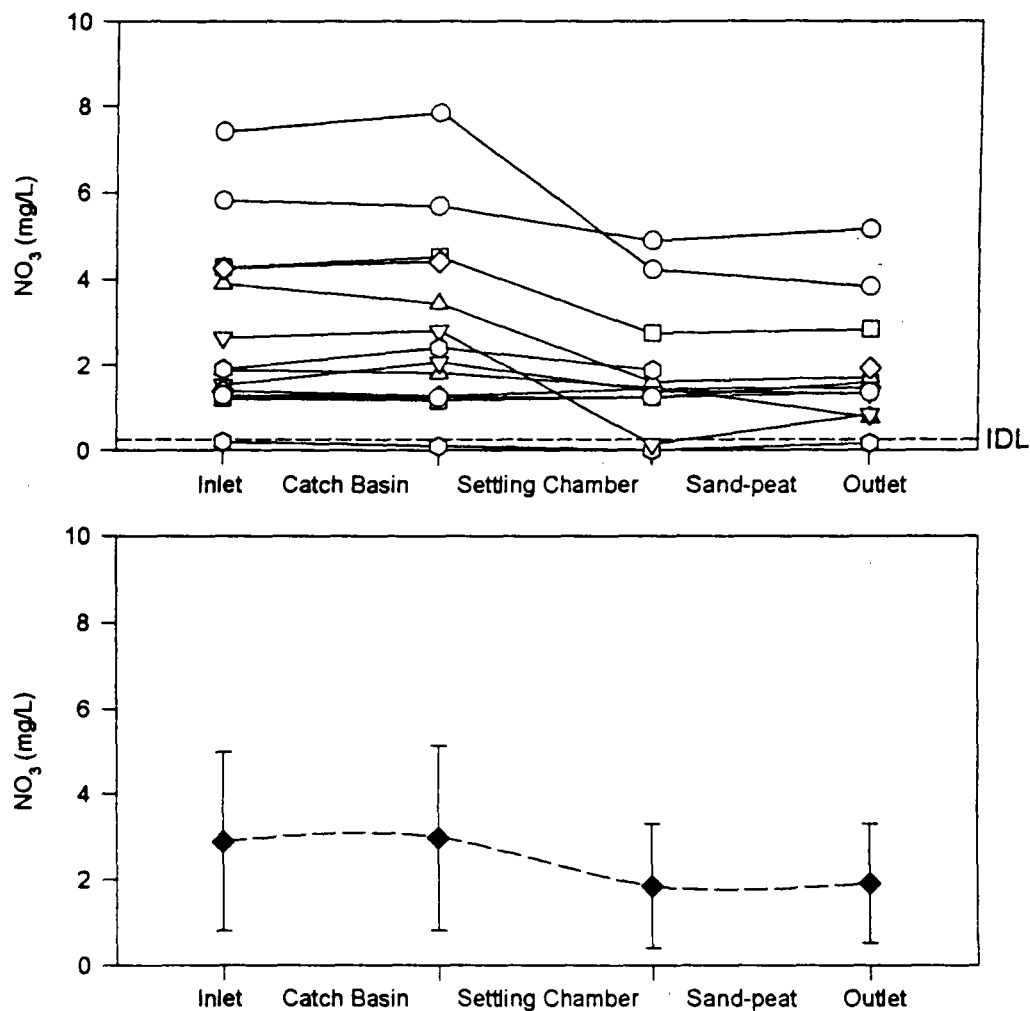
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.4662	-0.2593	-0.2598	-0.0386
Min. Percent Reduction	-194	-50	-372	-343
Max. Percent Reduction	16	15	18	26
Median Percent Reduction	-3	-1	-10	-13
Std. Dev. of Percent Reduction	55	20	113	100
COV of Percent Reduction	-3.8	-3.1	-3.1	-2.0

TABLE A-25.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Fluoride



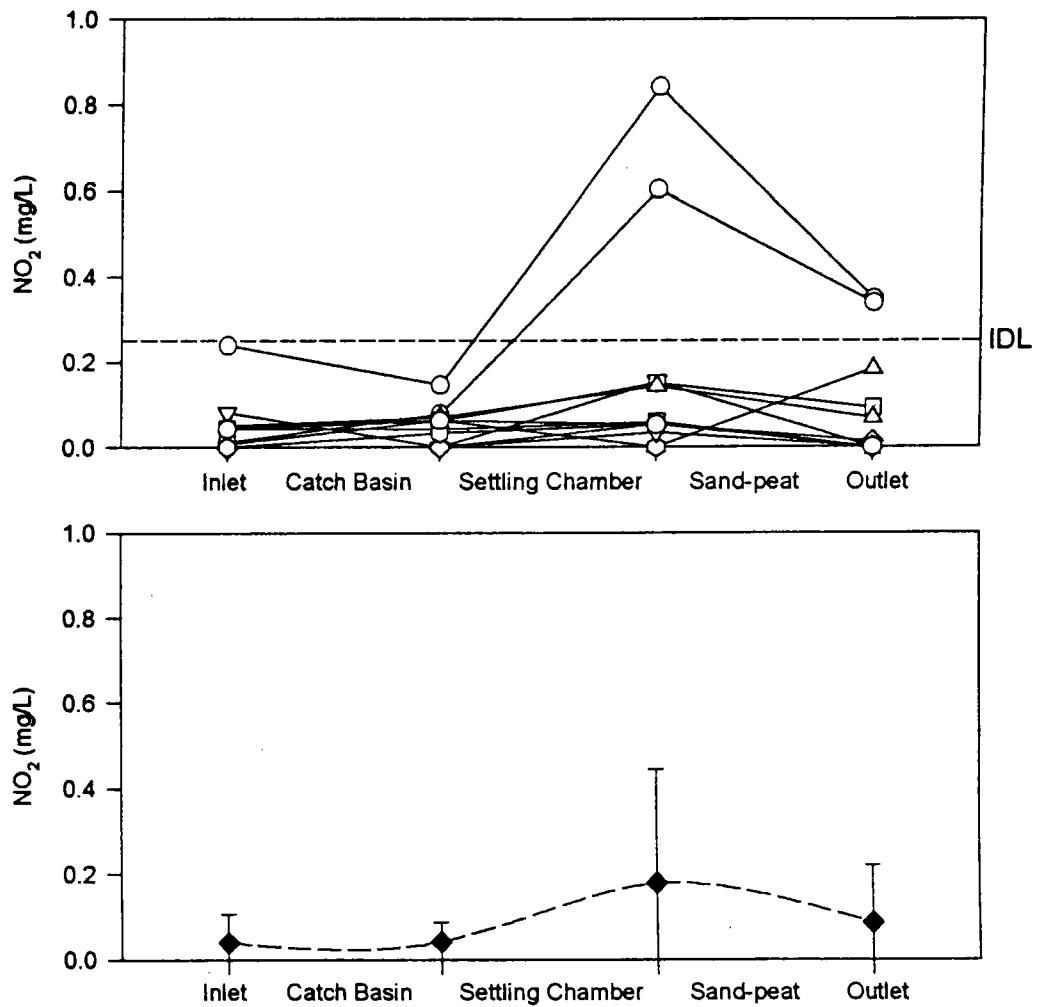
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.2527	-0.4961	0.0391	0.1475
Min. Percent Reduction	-333	-180	-100	-267
Max. Percent Reduction	53	100	76	100
Median Percent Reduction	-28	-36	52	32
Std. Dev. of Percent Reduction	104	82	58	116
COV of Percent Reduction	-2.0	-5.3	1.7	-14

TABLE A-26.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Nitrate



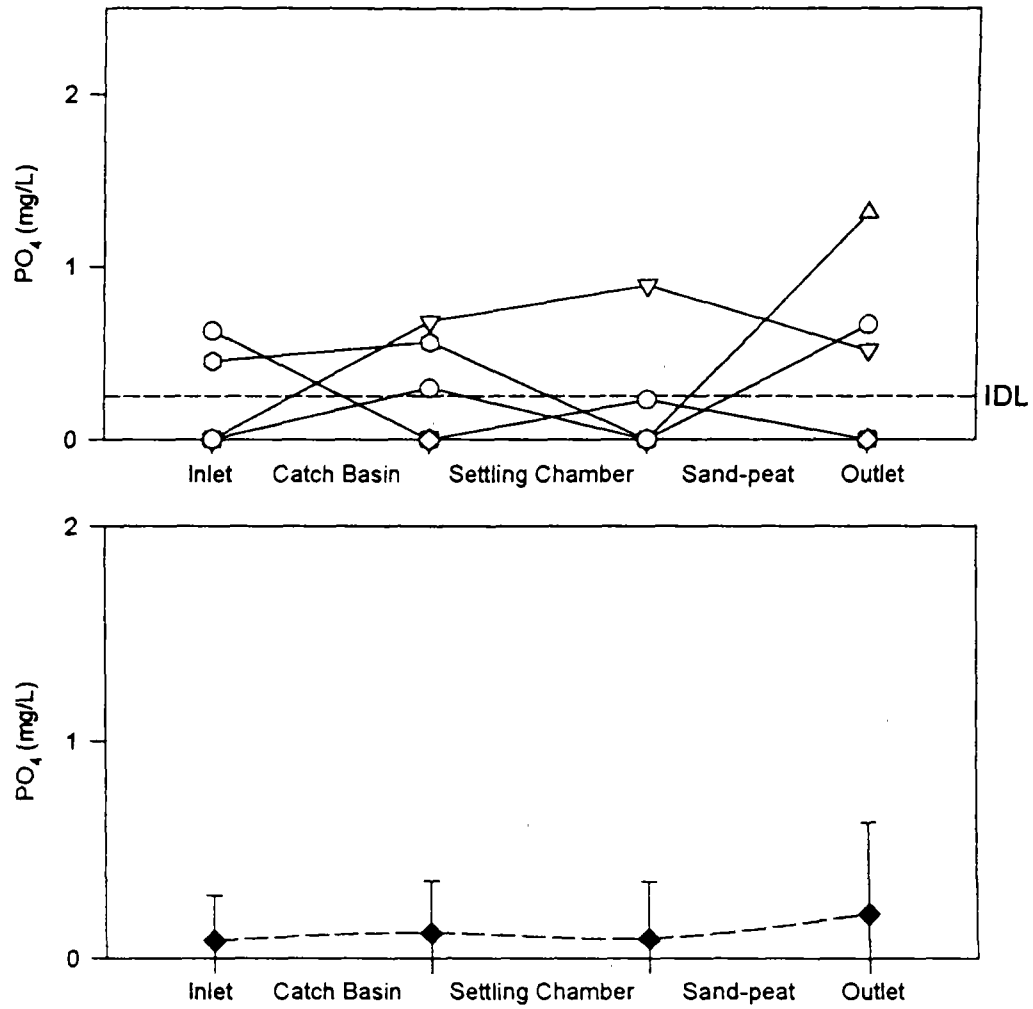
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.1879	0.0046	-0.1602	0.0105
Min. Percent Reduction	-36	-13	-475	-30
Max. Percent Reduction	49	100	47	68
Median Percent Reduction	2	27	-5	24
Std. Dev. of Percent Reduction	20	36	152	31
COV of Percent Reduction	-328	1.1	-3.2	1.2

TABLE A-27.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Nitrite



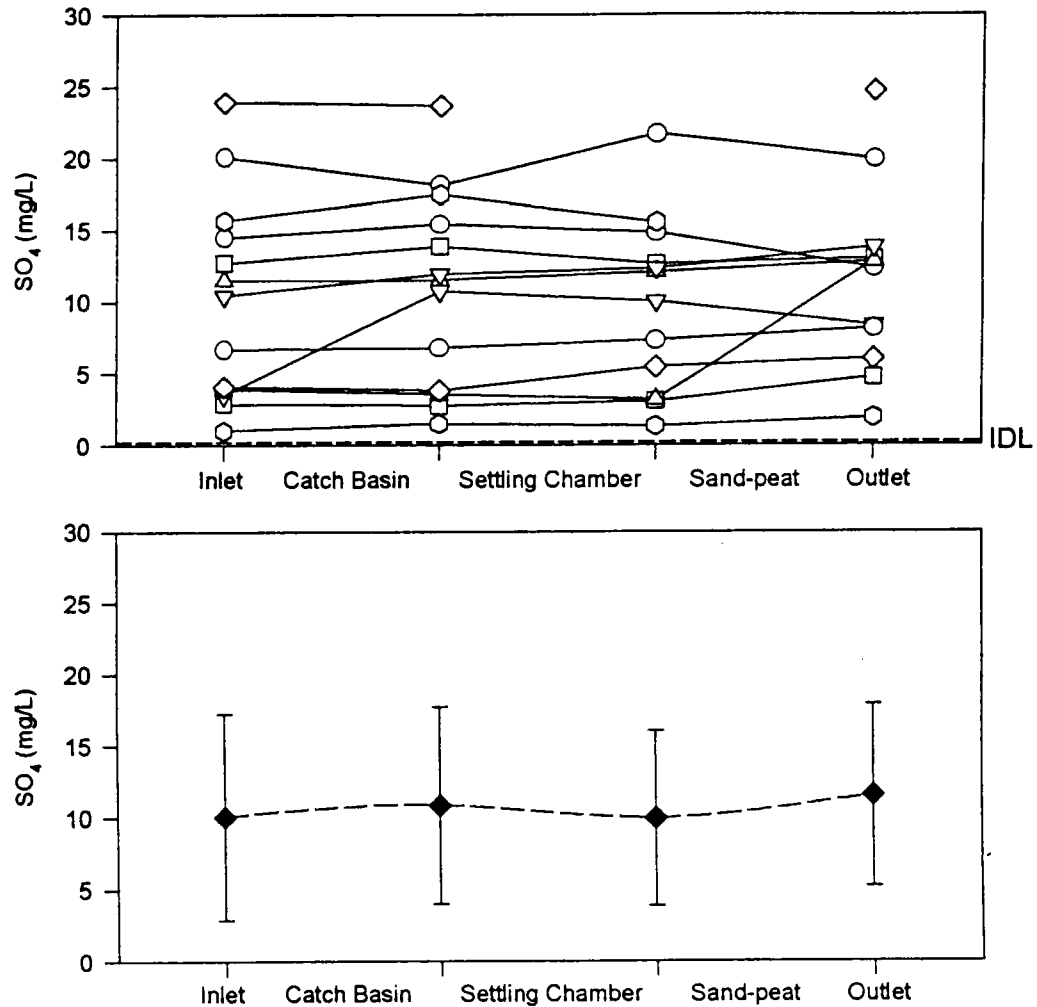
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.3125	-0.0093	0.0244	-0.1250
Min. Percent Reduction	-688	-674	38	-2717
Max. Percent Reduction	100	100	100	100
Median Percent Reduction	-32	-84	74	-40
Std. Dev. of Percent Reduction	295	264	27	984
COV of Percent Reduction	-1.96	-1.52	0.36	-2.05

TABLE A-28.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Phosphate



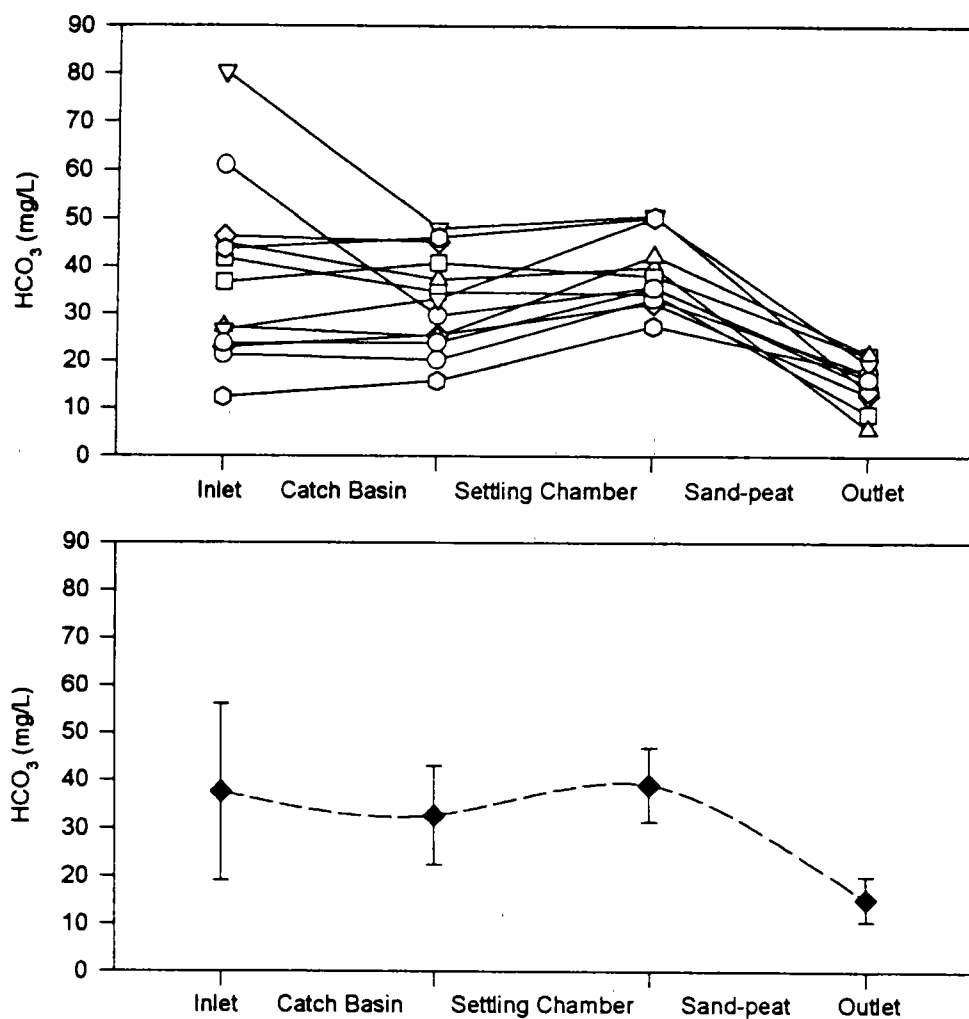
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.3125	-0.3125	-0.3125	-0.1875
Min. Percent Reduction				
Max. Percent Reduction				
Median Percent Reduction				
Std. Dev. of Percent Reduction				
COV of Percent Reduction				

TABLE A-29.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Sulfate



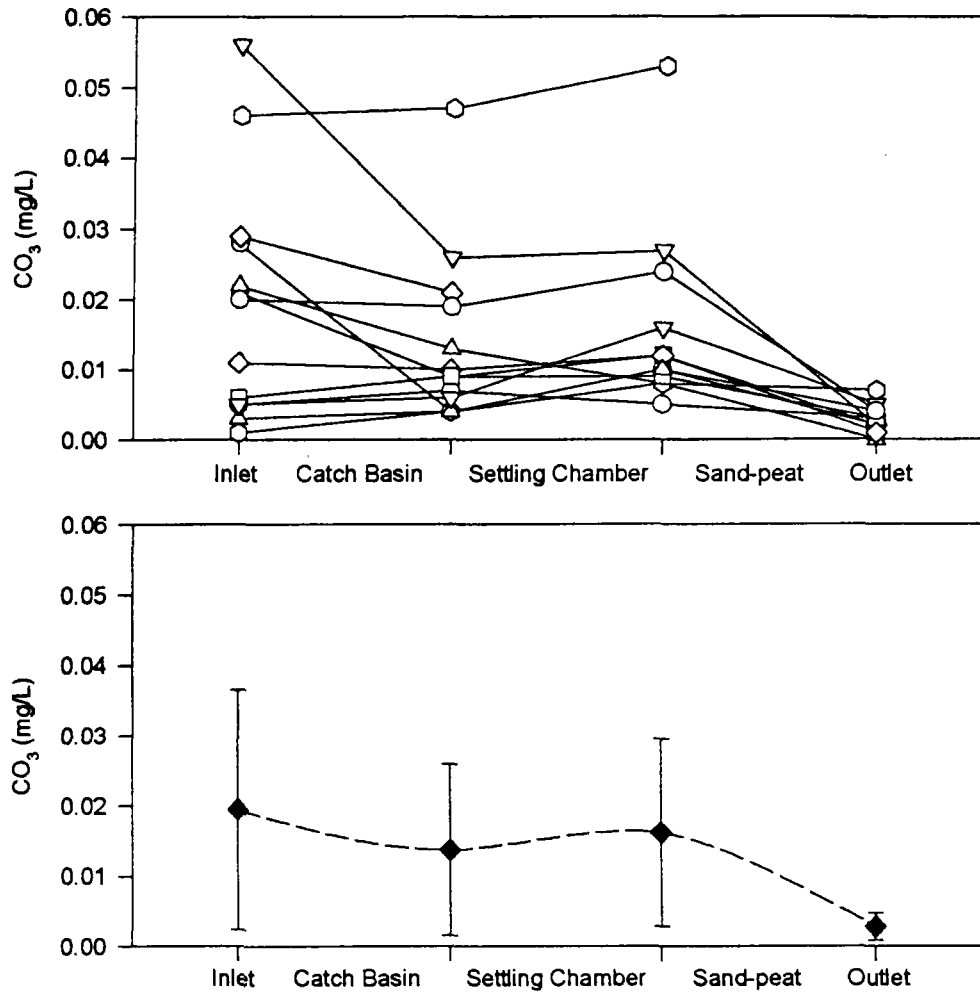
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.1527	0.5151	-0.3188	-0.0105
Min. Percent Reduction	-206	-44	-306	-229
Max. Percent Reduction	10	11	17	15
Median Percent Reduction	-2	0	-10	-27
Std. Dev. of Percent Reduction	58	16	92	71
COV of Percent Reduction	-2.8	-4.9	-2.5	-1.4

TABLE A-30
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Bicarbonate



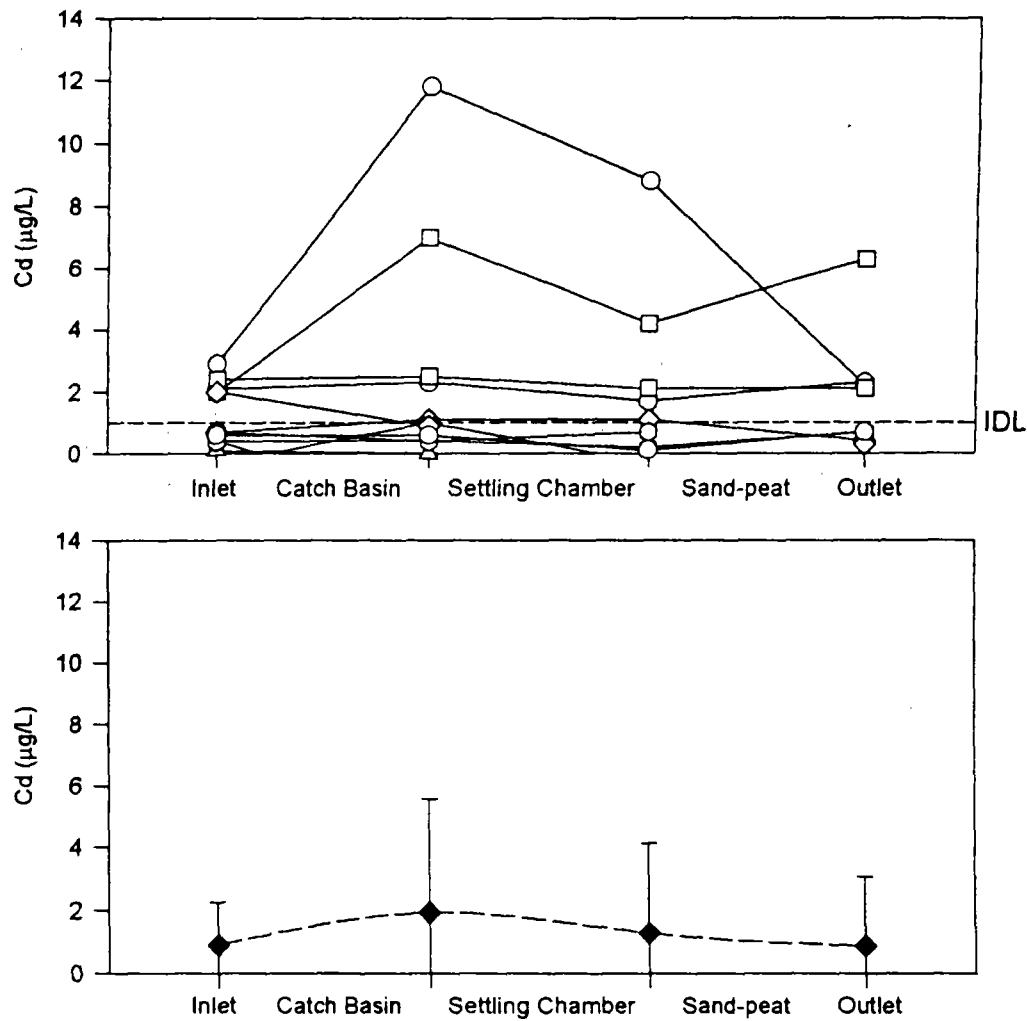
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.2709	-0.0024	0.0005	0.0007
Min. Percent Reduction	-28	-73	36	-42
Max. Percent Reduction	52	7	86	87
Median Percent Reduction	3	-23	58	43
Std. Dev. of Percent Reduction	23	29	15	37
COV of Percent Reduction	5.1	-0.95	0.25	0.84

TABLE A-31.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Carbonate



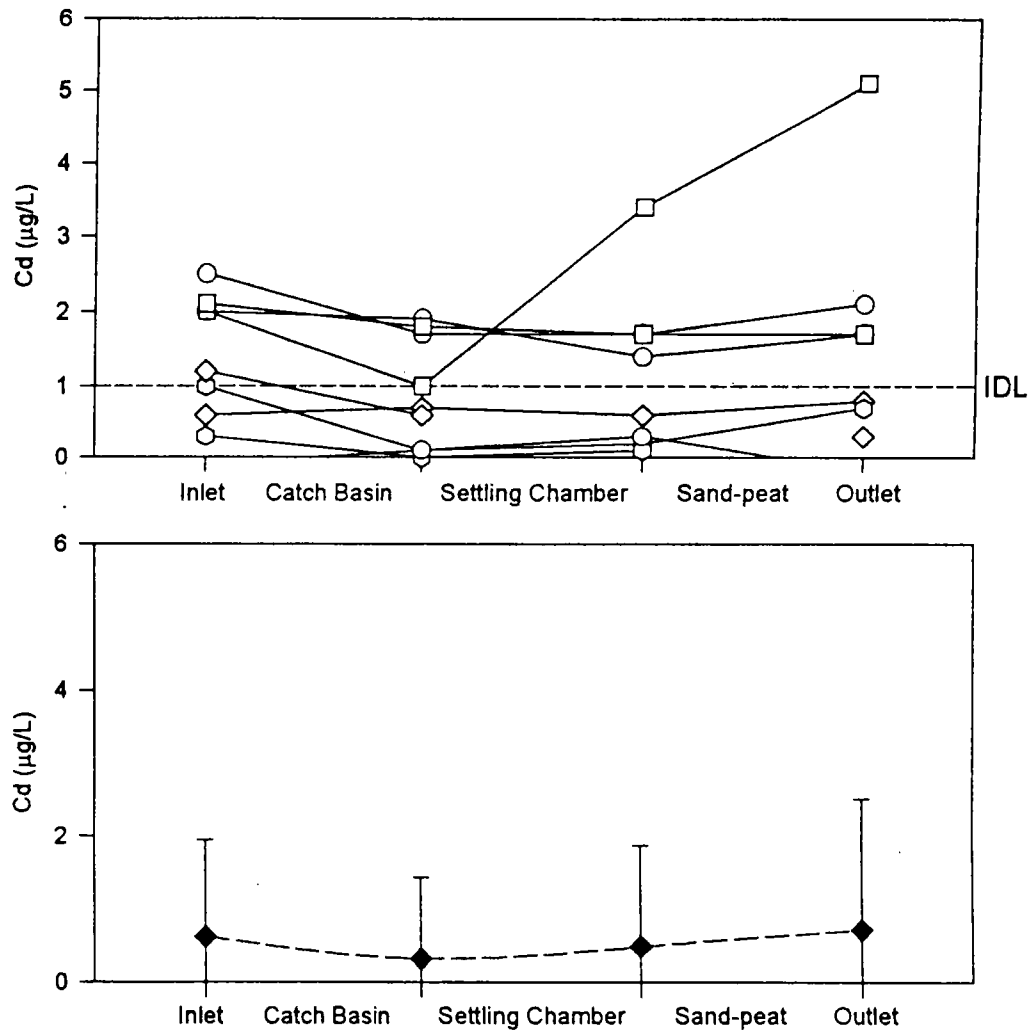
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.1488	-0.0161	0.0005	0.0049
Min. Percent Reduction	-300	-167	13	-600
Max. Percent Reduction	86	38	100	100
Median Percent Reduction	5	-23	80	81
Std. Dev. of Percent Reduction	96	73	26	196
COV of Percent Reduction	-7.5	-1.5	0.36	23.7

TABLE A-32.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Cadmium



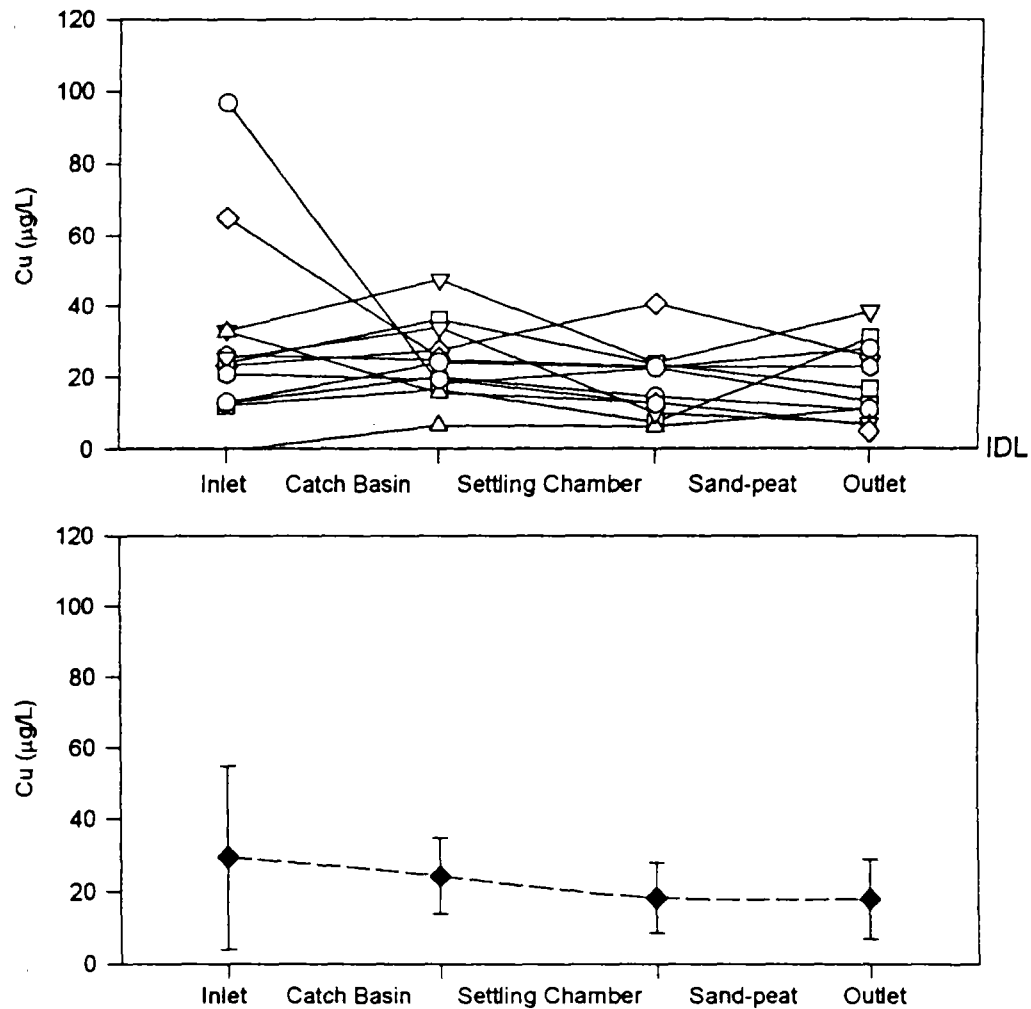
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.1655	0.0083	0.4961	0.1338
Min. Percent Reduction	-307	-75	-600	-215
Max. Percent Reduction	100	100	75	100
Median Percent Reduction	0	25	-40	18
Std. Dev. of Percent Reduction	218	52	189	263
COV of Percent Reduction	5.5	1.9	-2.0	2.9

TABLE A-33.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Cadmium



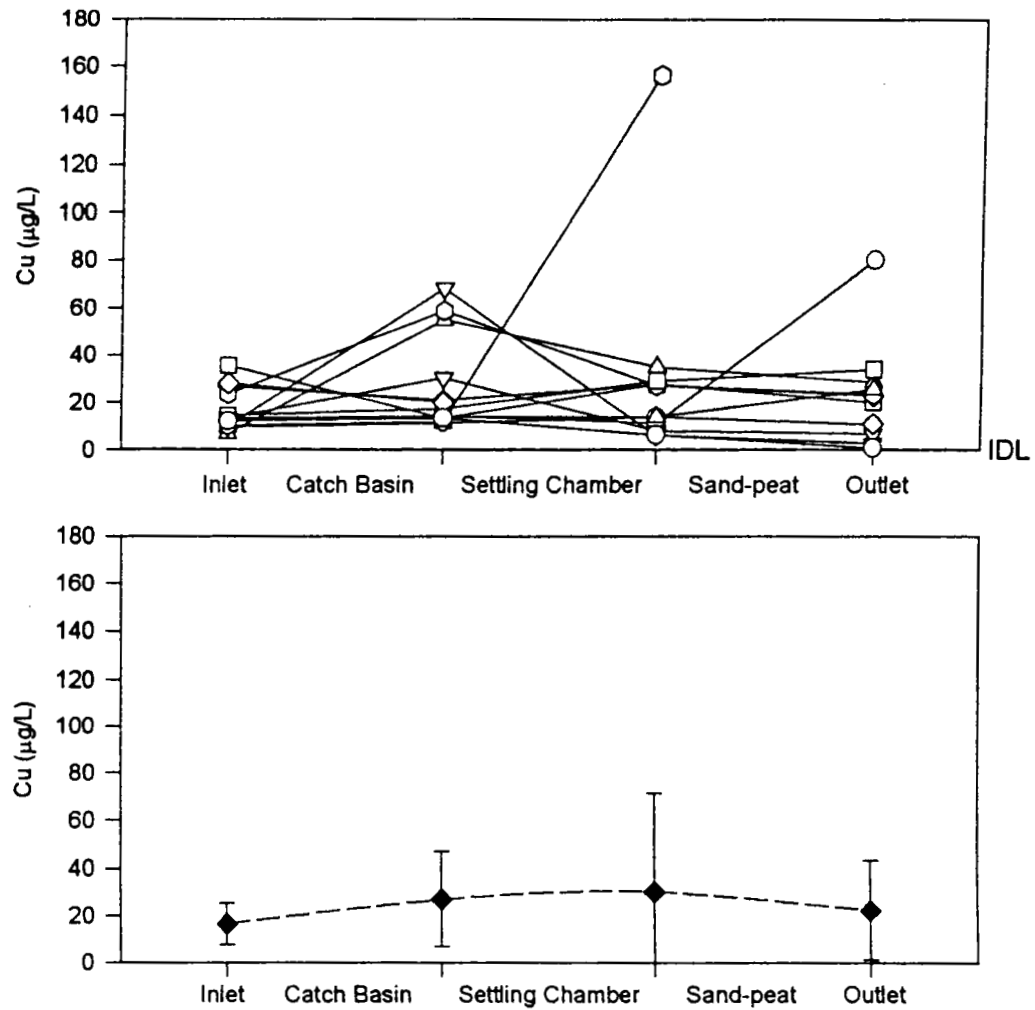
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.0203	0.2148	-0.1055	0.1602
Min. Percent Reduction	-63	-240	-250	-155
Max. Percent Reduction	100	26	100	75
Median Percent Reduction	21	0	-21	16
Std. Dev. of Percent Reduction	67	94	97	69
COV of Percent Reduction	1.9	-2.2	-4.5	-3.6

TABLE A-34.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Copper



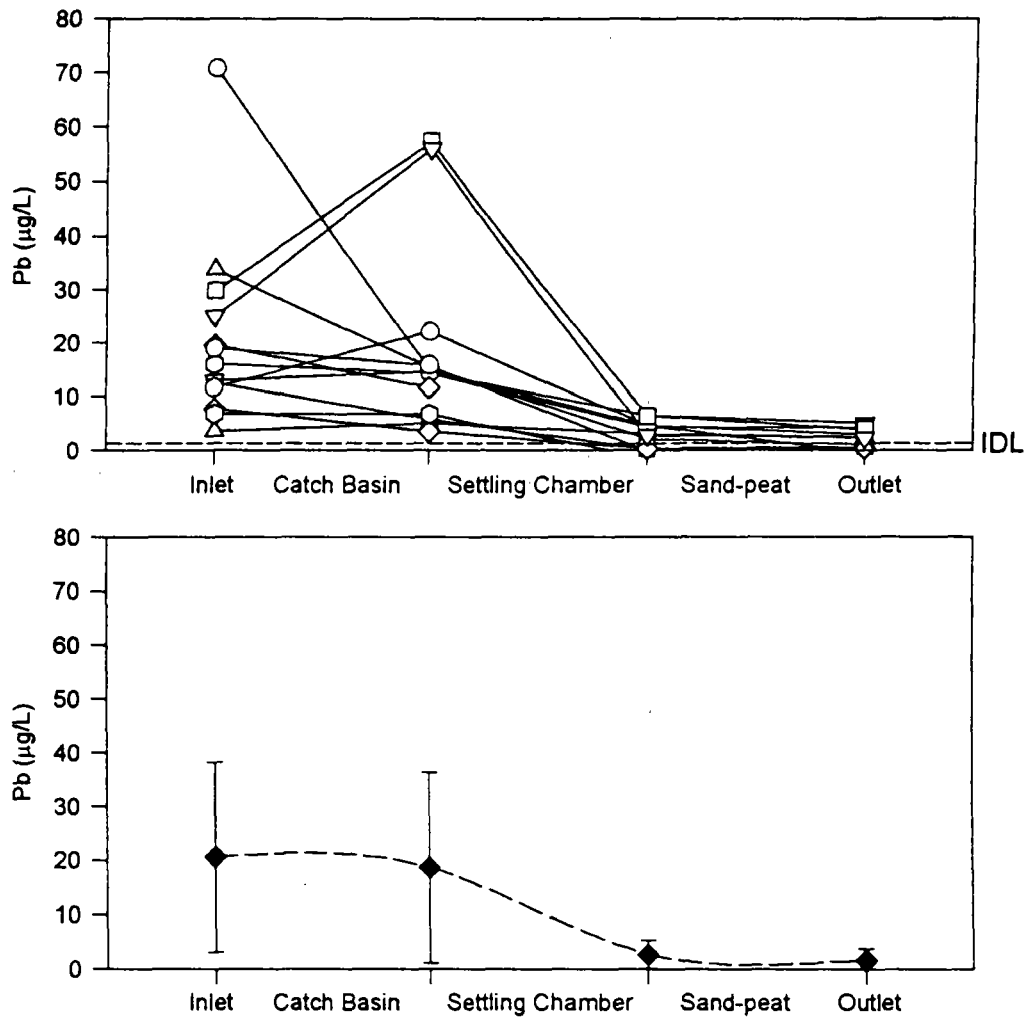
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.3424	0.0320	0.3823	0.2119
Min. Percent Reduction	-85	-49	-322	-159
Max. Percent Reduction	100	71	49	100
Median Percent Reduction	-19	23	25	22
Std. Dev. of Percent Reduction	335	34	107	566
COV of Percent Reduction	4.1	1.7	-4.3	3.3

TABLE A-35.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Copper



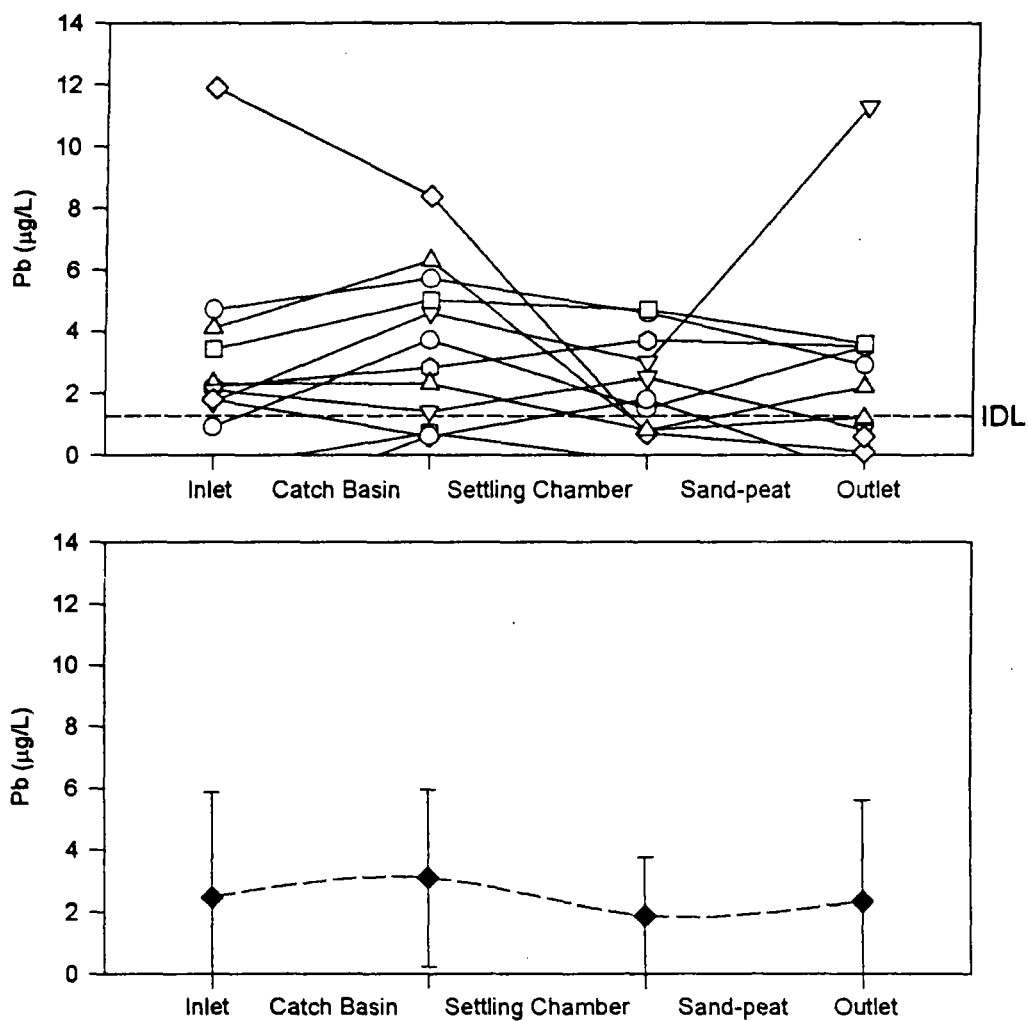
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.0839	0.2847	0.3188	-0.4250
Min. Percent Reduction	-712	-1224	-617	-558
Max. Percent Reduction	62	91	86	93
Median Percent Reduction	-18	13	18	17
Std. Dev. of Percent Reduction	245	361	196	197
COV of Percent Reduction	-2.0	-3.9	-4.7	-2.8

TABLE A-36.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Lead



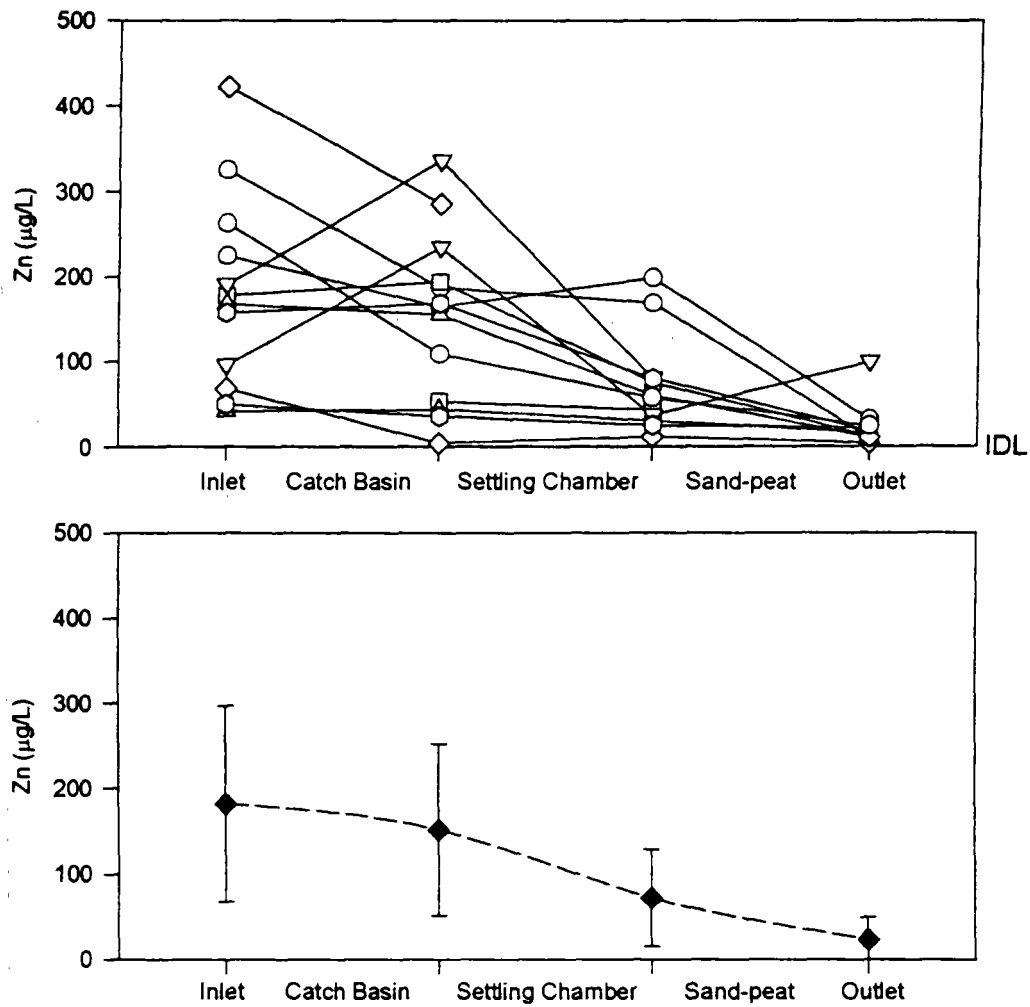
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.3386	0.0002	0.0078	0.0002
Min. Percent Reduction	-124	40	-133	29
Max. Percent Reduction	79	100	100	100
Median Percent Reduction	10	88	18	93
Std. Dev. of Percent Reduction	65	21	60	22
COV of Percent Reduction	-16	0.26	5.2	0.26

TABLE A-37.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Lead



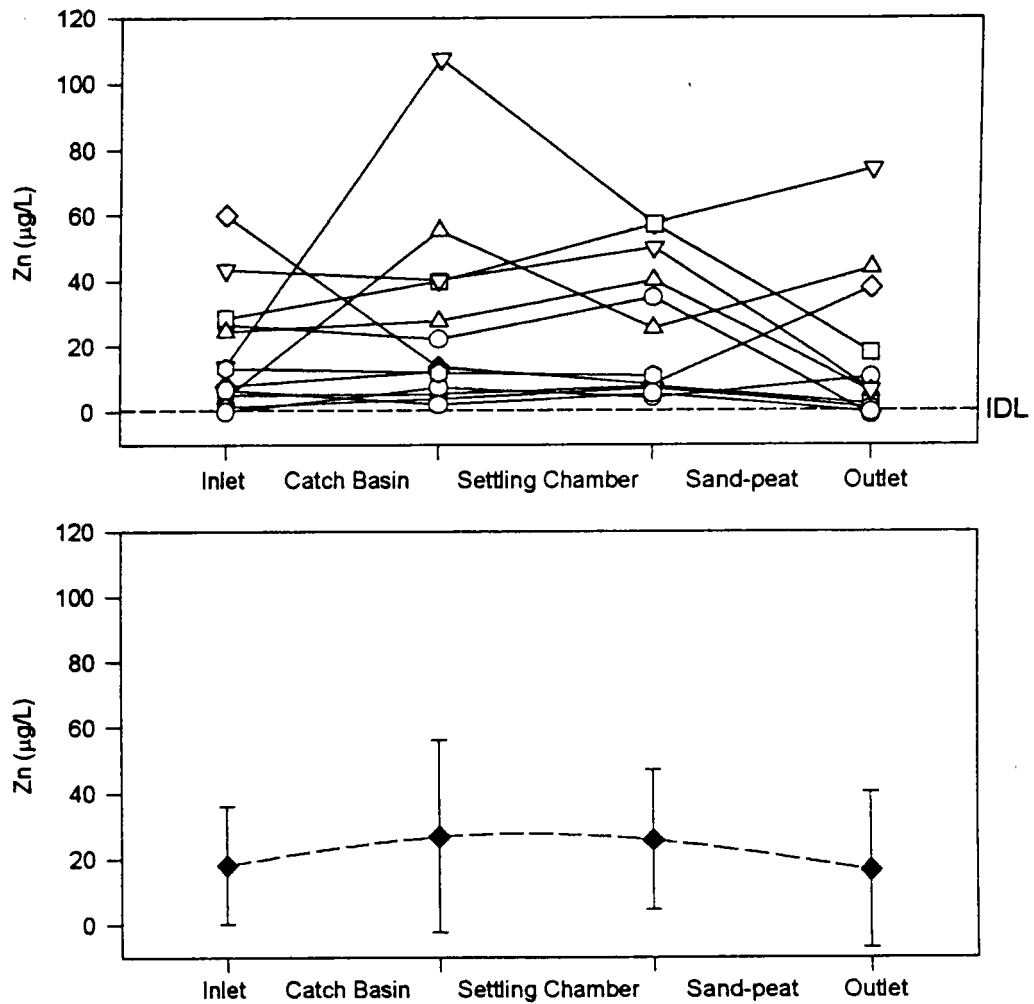
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.1462	0.0535	0.3408	0.3345
Min. Percent Reduction	-311	-200	-400	-565
Max. Percent Reduction	100	100	100	99
Median Percent Reduction	-21	33	5	42
Std. Dev. of Percent Reduction	146	89	167	196
COV of Percent Reduction	-7.1	5.0	-2.7	-3.6

TABLE A-38.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Zinc



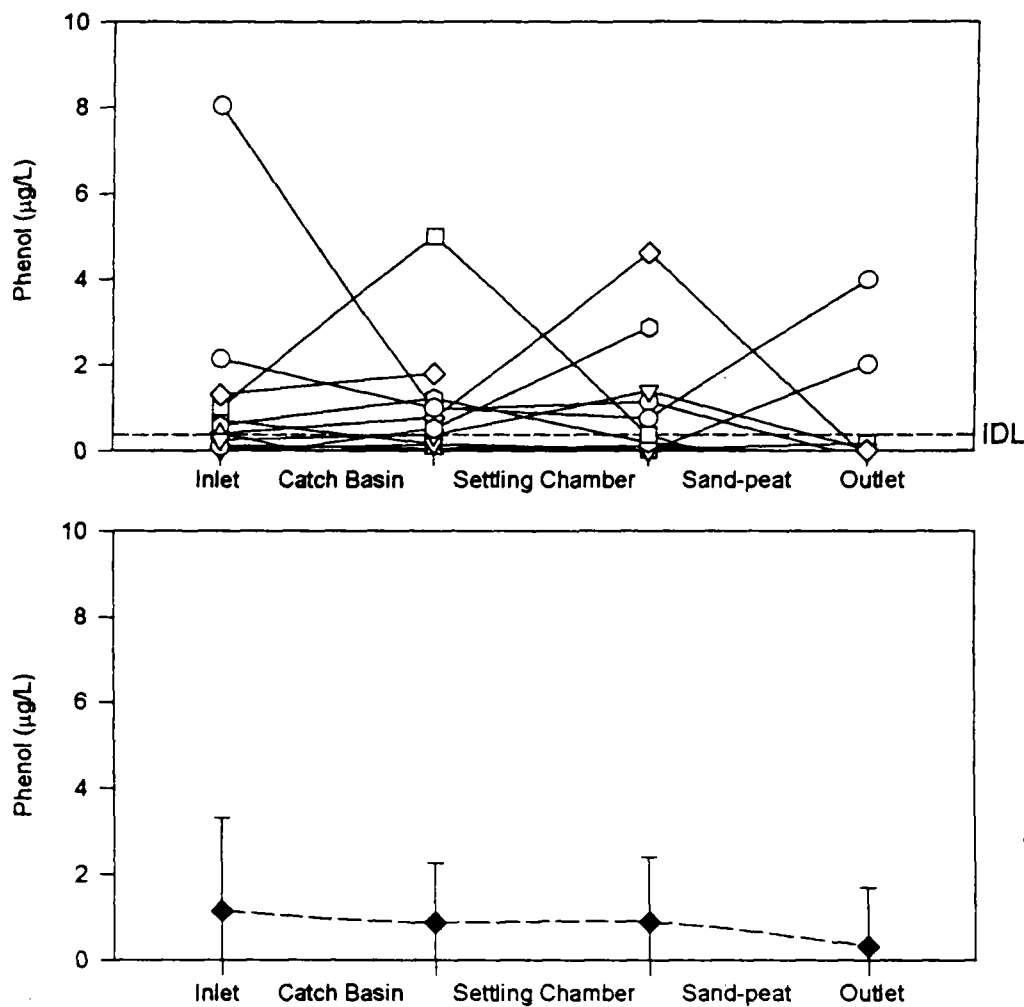
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.1219	0.0046	0.0874	0.0005
Min. Percent Reduction	-144	-171	-5908	-3
Max. Percent Reduction	99	84	94	97
Median Percent Reduction	27	39	62	91
Std. Dev. of Percent Reduction	65	68	1796	31
COV of Percent Reduction	5.7	2.9	-3.6	0.42

TABLE A-39.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Zinc



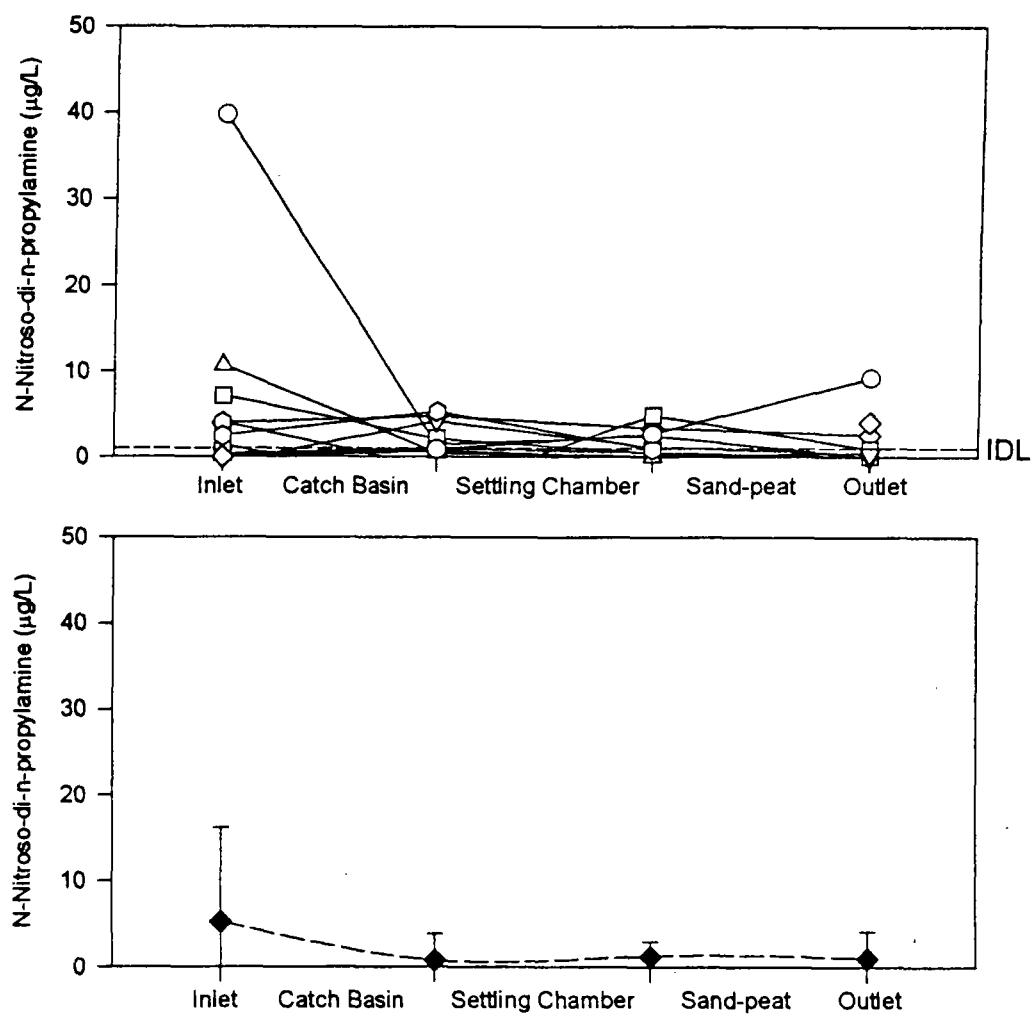
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.1736	-0.3386	0.1826	0.2119
Min. Percent Reduction	-1188	-155	-352	-923
Max. Percent Reduction	77	54	100	100
Median Percent Reduction	-8	-34	69	54
Std. Dev. of Percent Reduction	381	62	142	323
COV of Percent Reduction	-2.3	-2.8	322	-4.7

TABLE A-40.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Phenol



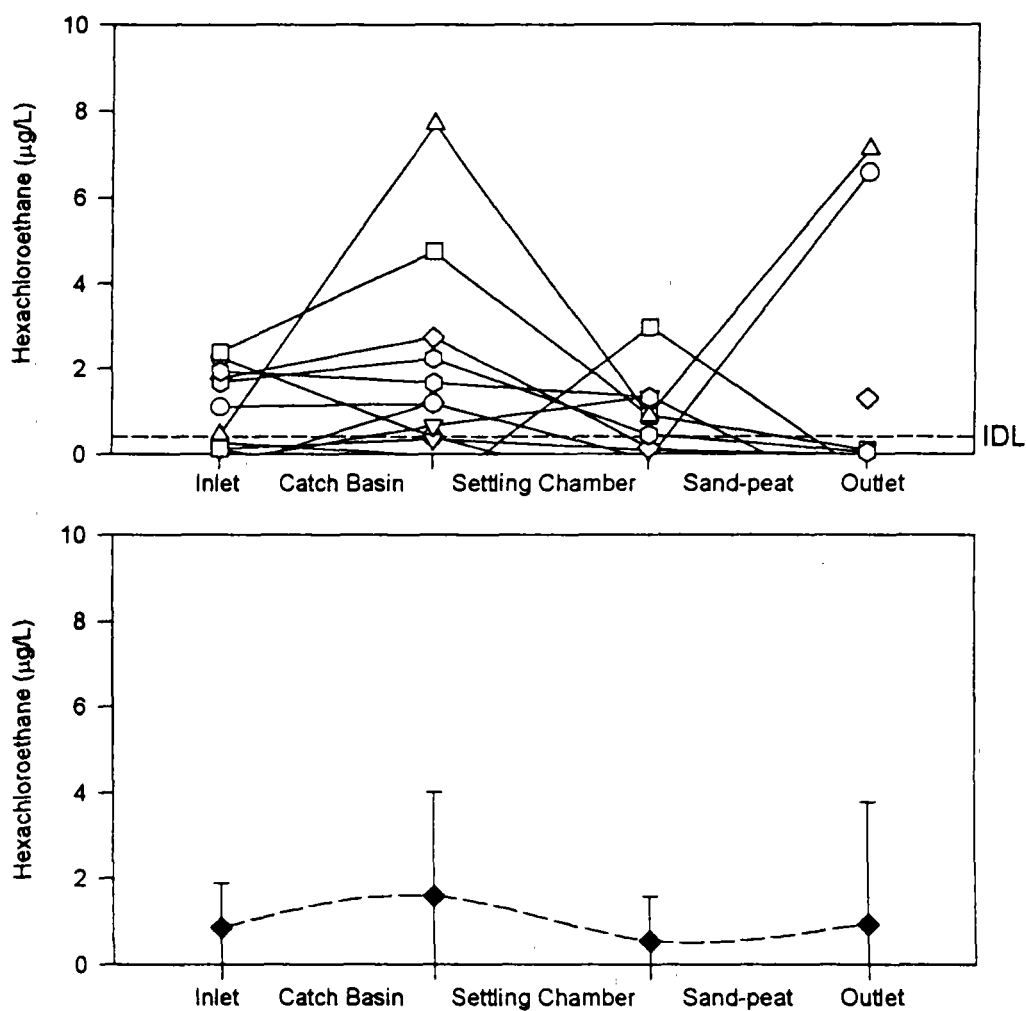
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.5000	0.3125	0.2188	0.1094
Min. Percent Reduction	-395	-500	-500	-1910
Max. Percent Reduction	100	94	100	100
Median Percent Reduction	53	3	100	100
Std. Dev. of Percent Reduction	214	214	3064	589
COV of Percent Reduction	16	-2.7	3.2	-10

TABLE A-41.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
N-Nitroso-di-n-propylamine



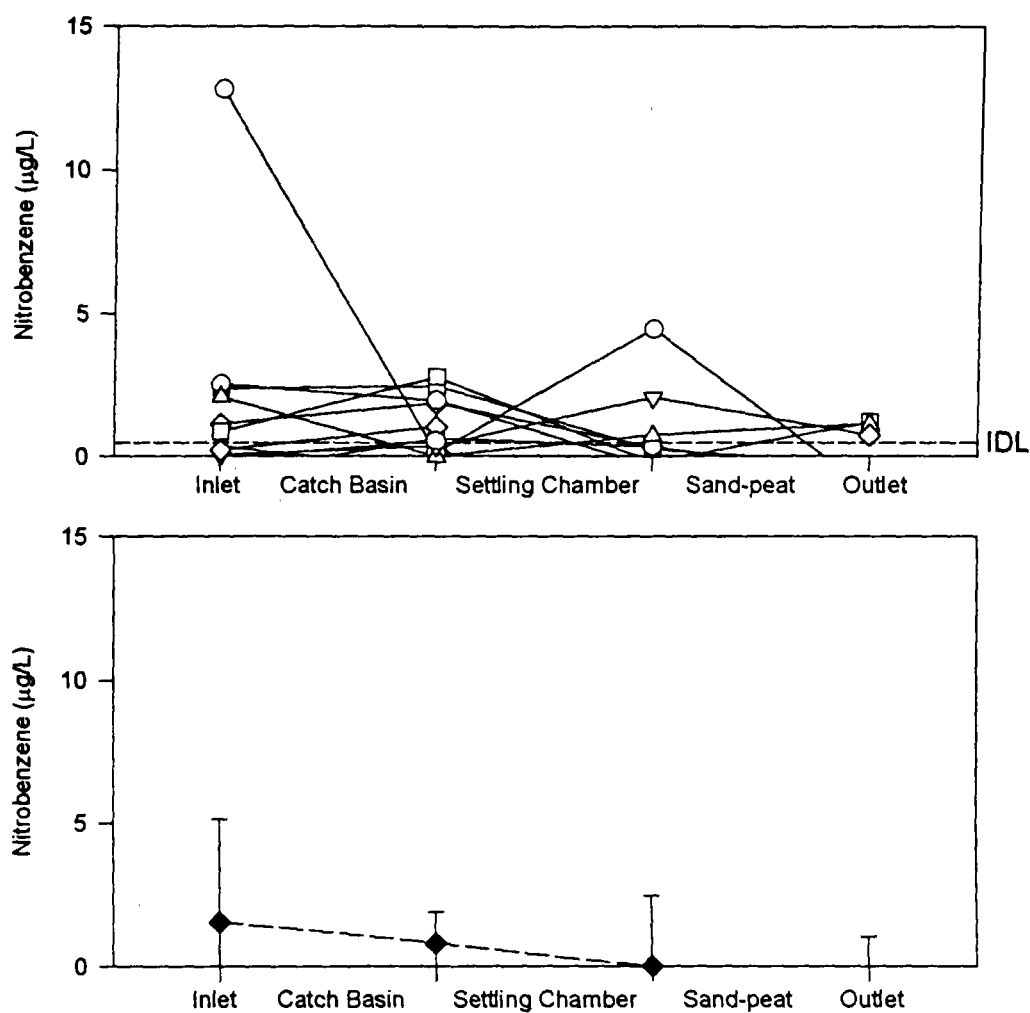
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.1563	0.0938	0.0625	0.0625
Min. Percent Reduction	-3019	-208	-5400	-969
Max. Percent Reduction	100	100	100	100
Median Percent Reduction	83	81	64	99
Std. Dev. of Percent Reduction	943	106	2236	918
COV of Percent Reduction	-5.8	2.1	-23	4.3

TABLE A-42.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Hexachloroethane



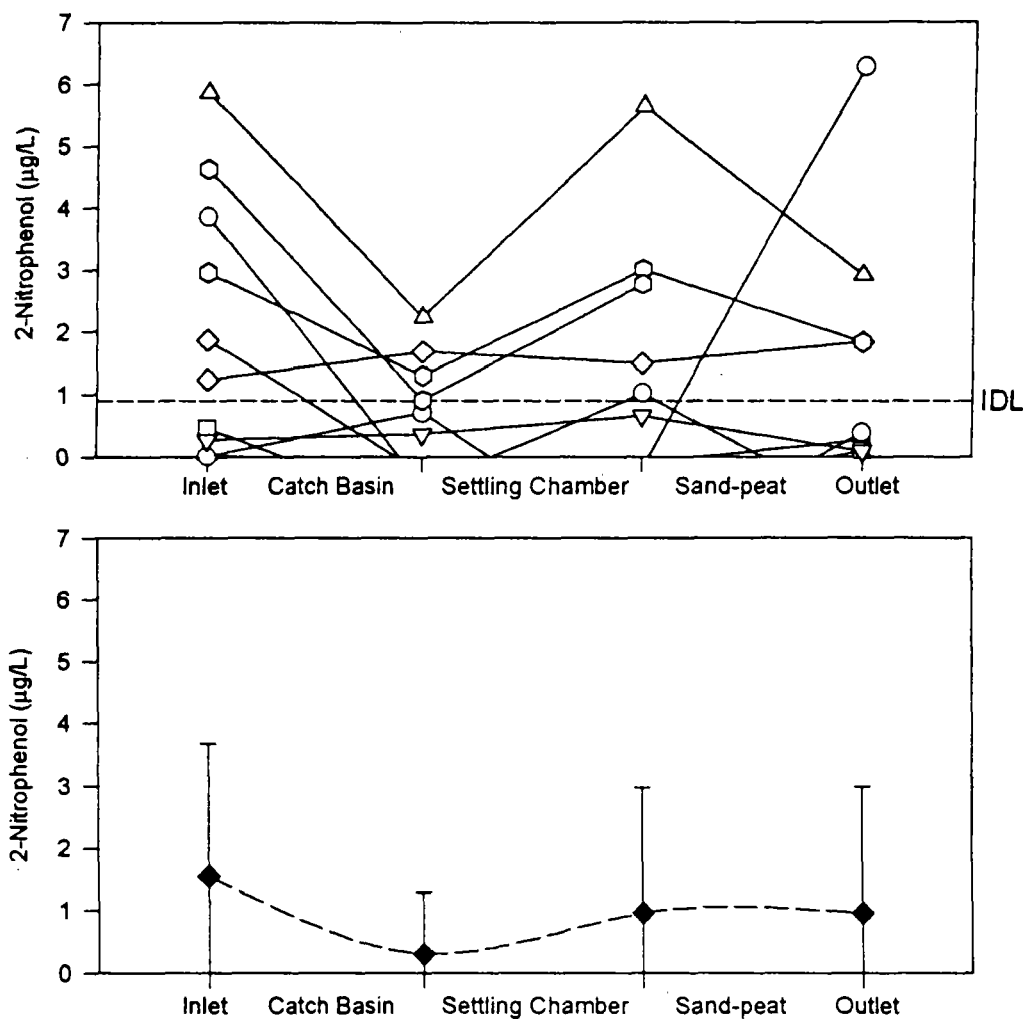
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.1484	0.0078	-0.4063	-0.5000
Min. Percent Reduction	-1611	-933	-700	-1482
Max. Percent Reduction	100	100	100	100
Median Percent Reduction	-7	82	89	100
Std. Dev. of Percent Reduction	560	331	1578	541
COV of Percent Reduction	-28	12	3.3	-6.6

TABLE A-43.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Nitrobenzene



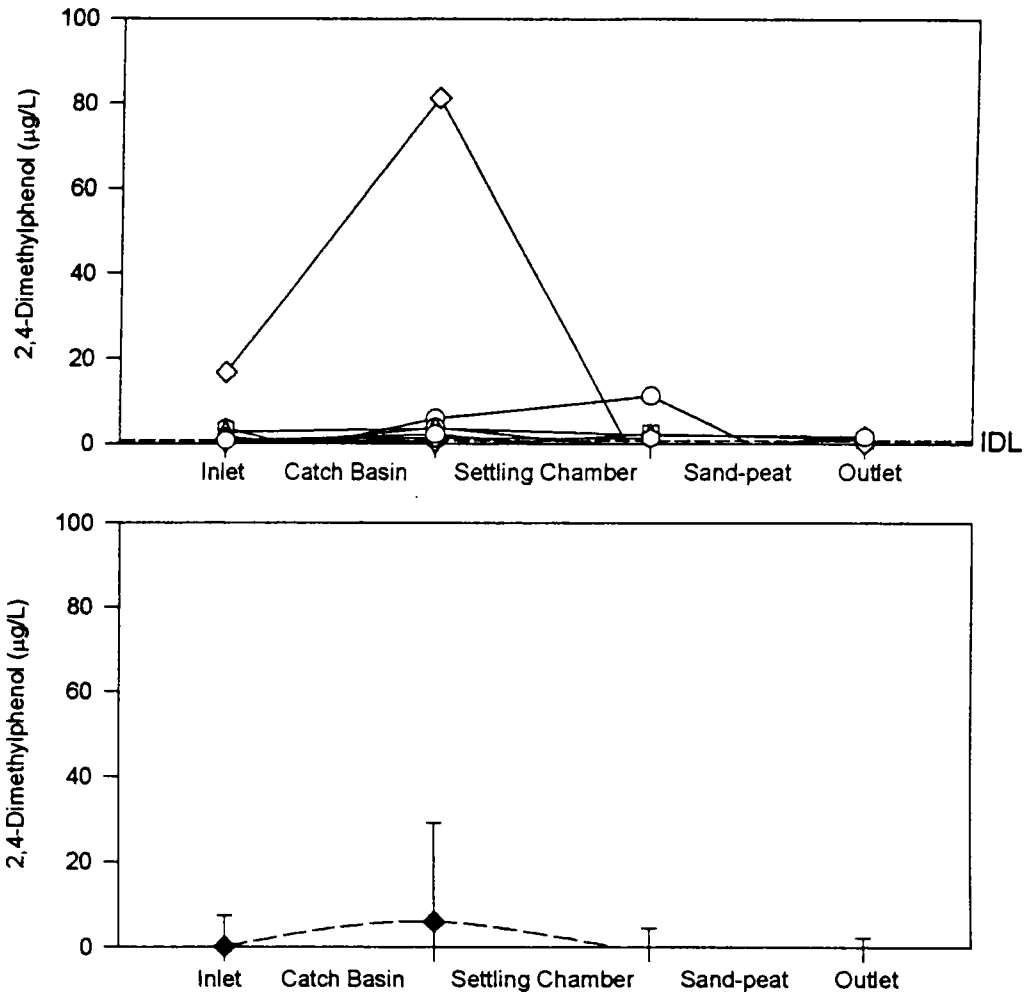
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.1875	0.0625	0.5000	0.1250
Min. Percent Reduction	-517	-3086	-152	-5557
Max. Percent Reduction	100	100	100	100
Median Percent Reduction	34	44	70	18
Std. Dev. of Percent Reduction	332	1052	225	1625
COV of Percent Reduction	8.7	-6.1	1.5	-3.1

TABLE A-44.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
2-Nitrophenol



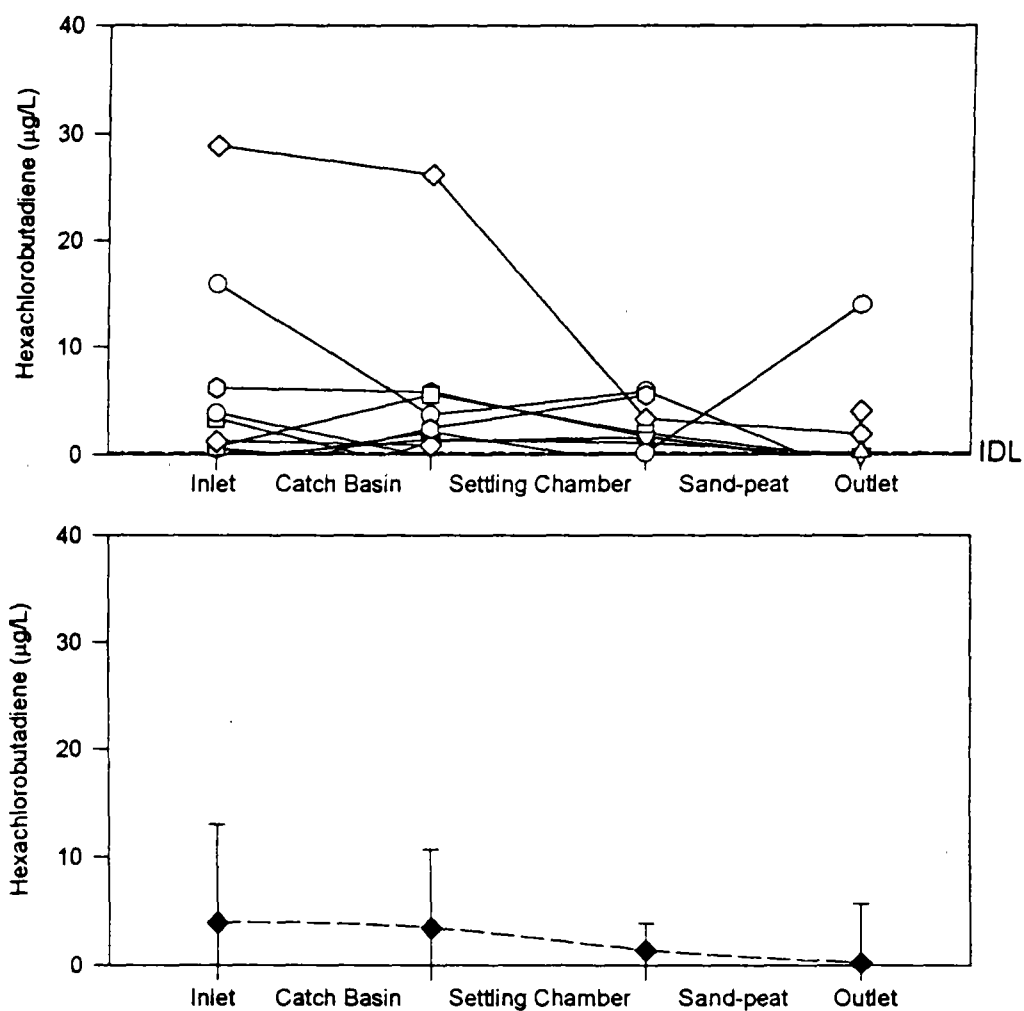
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.1250	0.1250	0.2500	0.2500
Min. Percent Reduction	-7000	-204	-55	-3800
Max. Percent Reduction	100	100	100	100
Median Percent Reduction	56	6	86	40
Std. Dev. of Percent Reduction	1978	165	869	1111
COV of Percent Reduction	-4.4	8.4	2.4	-3.9

TABLE A-45.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
2,4-Dimethylphenol



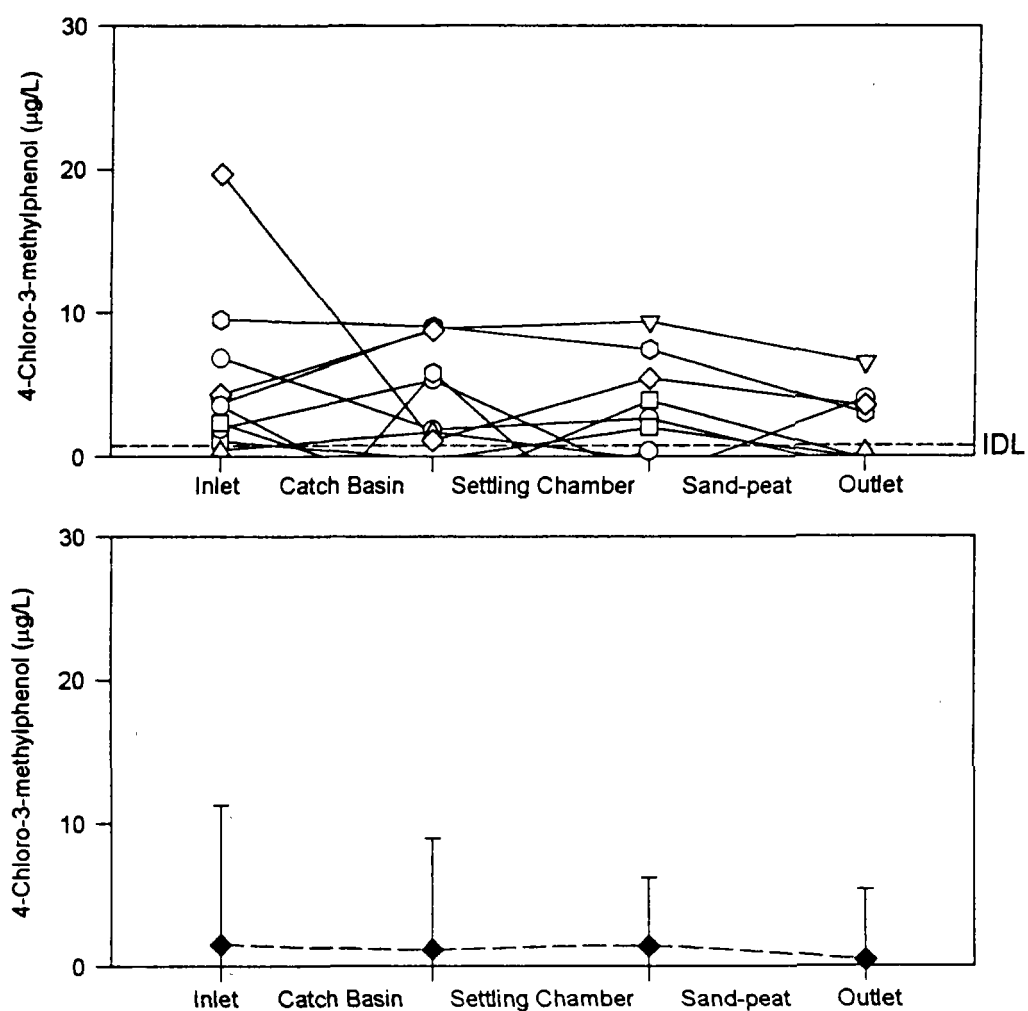
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.0625	0.0313	0.4375	0.1250
Min. Percent Reduction	-385	-141	-155	-182
Max. Percent Reduction	100	100	100	100
Median Percent Reduction	57	53	41	100
Std. Dev. of Percent Reduction	237	207	119	141
COV of Percent Reduction	3.0	1.9	2.8	1.6

TABLE A-46.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Hexachlorobutadiene



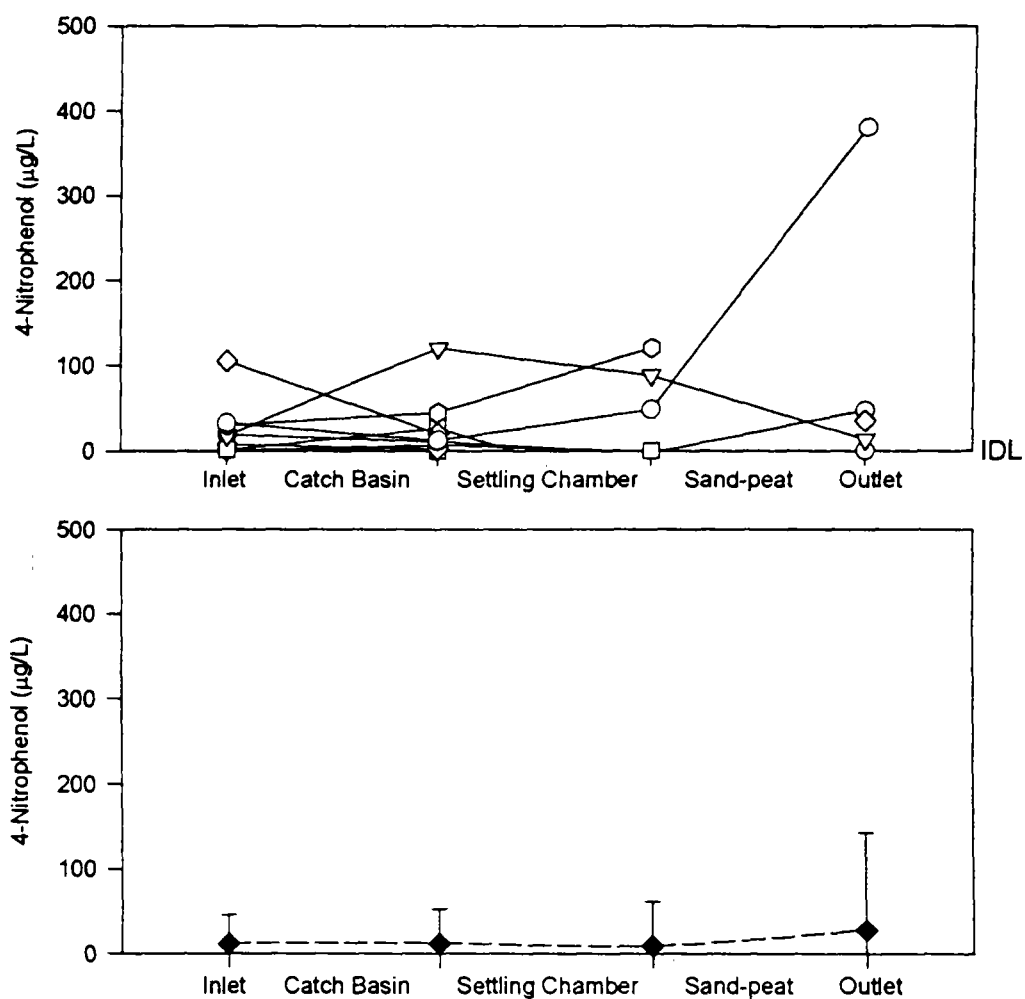
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.2188	0.1250	0.0625	0.0938
Min. Percent Reduction	-683	-129	-6855	-548
Max. Percent Reduction	100	100	100	100
Median Percent Reduction	100	29	97	100
Std. Dev. of Percent Reduction	302	88	2089	609
COV of Percent Reduction	4.8	2.8	-3.3	3.9

TABLE A-47.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
4-Chloro-3-methylphenol



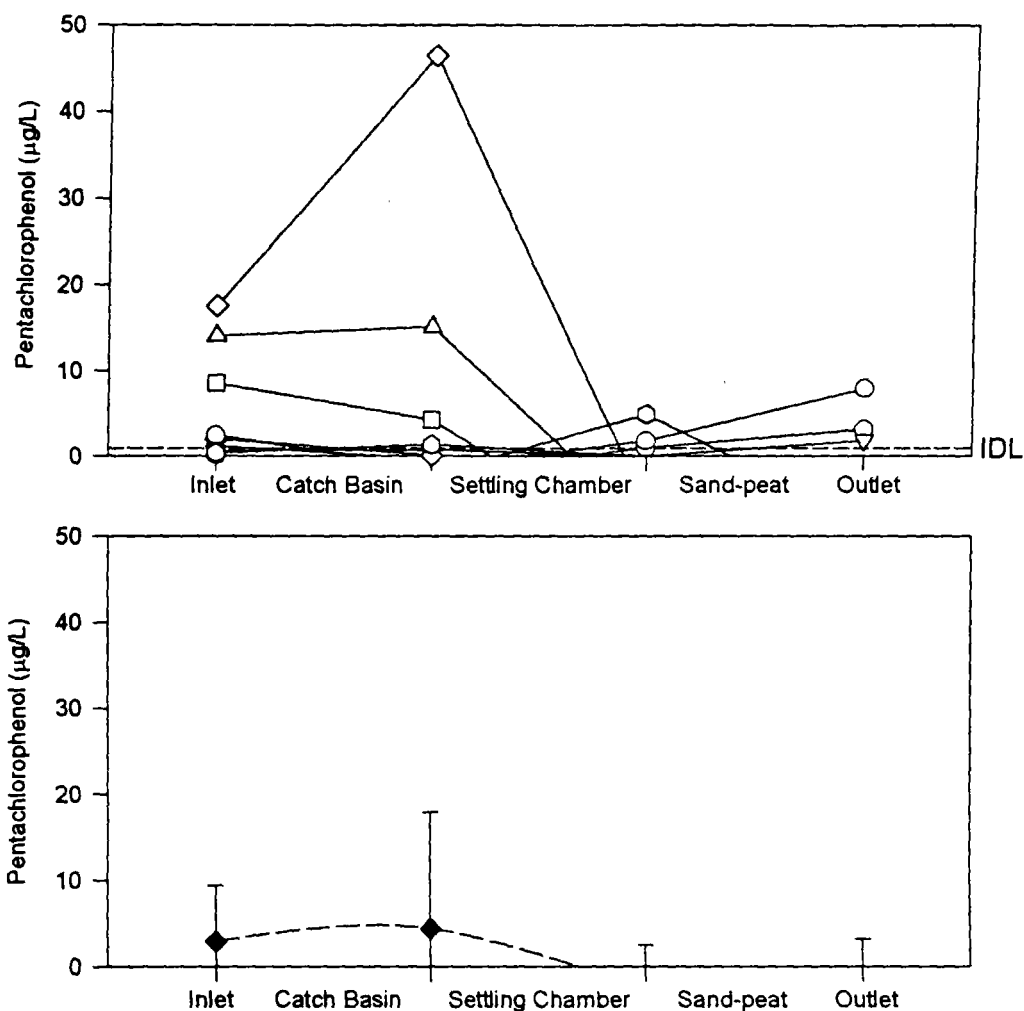
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.5000	0.2813	0.2501	0.1563
Min. Percent Reduction	-284	-500	-154	-106
Max. Percent Reduction	100	100	100	100
Median Percent Reduction	73	93	100	92
Std. Dev. of Percent Reduction	154	370	1023	147
COV of Percent Reduction	7.6	4.5	2.8	1.6

TABLE A-48.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
4-Nitrophenol



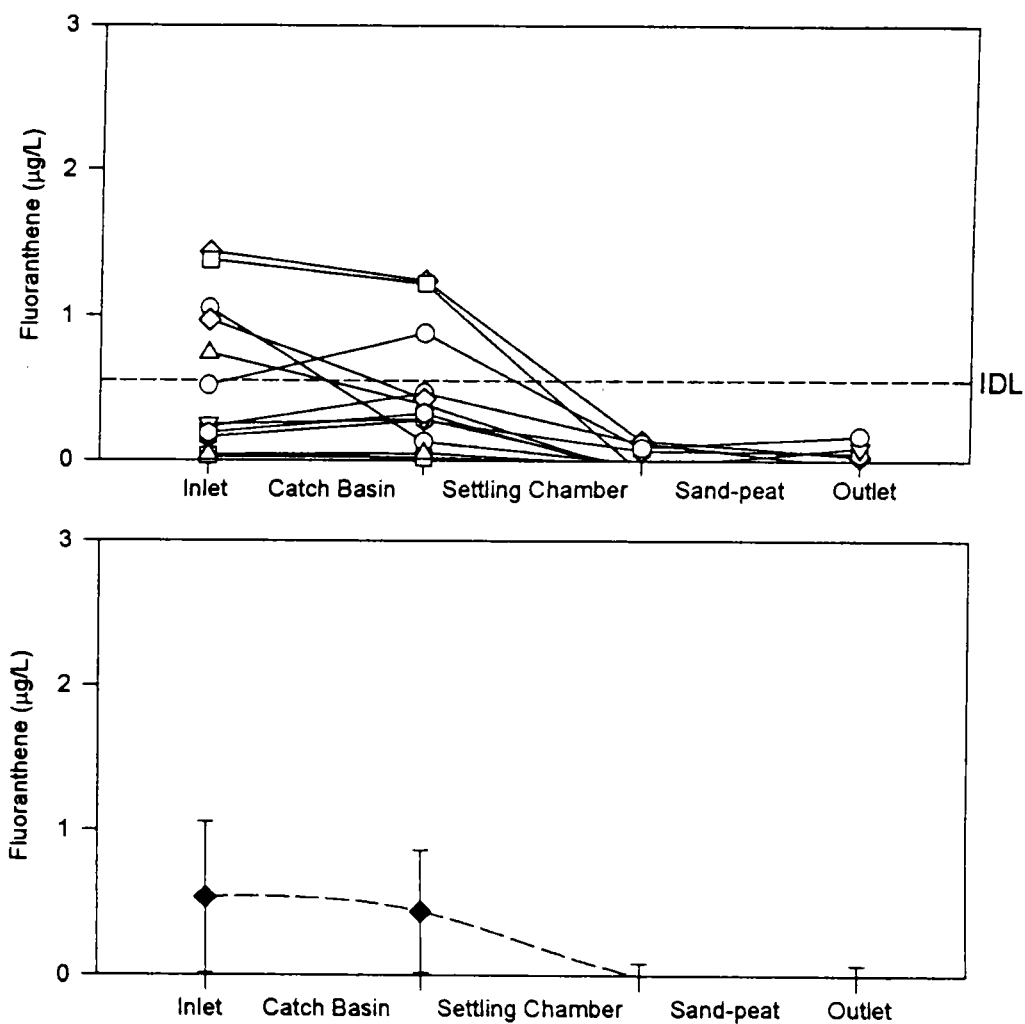
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.4688	-0.5000	-0.2188	0.4219
Min. Percent Reduction	-2279	-287	-683	-1069
Max. Percent Reduction	95	100	100	100
Median Percent Reduction	-49	50	13	-4
Std. Dev. of Percent Reduction	802	474	913	1042
COV of Percent Reduction	-1.9	3.2	4.0	5.7

TABLE A-49.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Pentachlorophenol



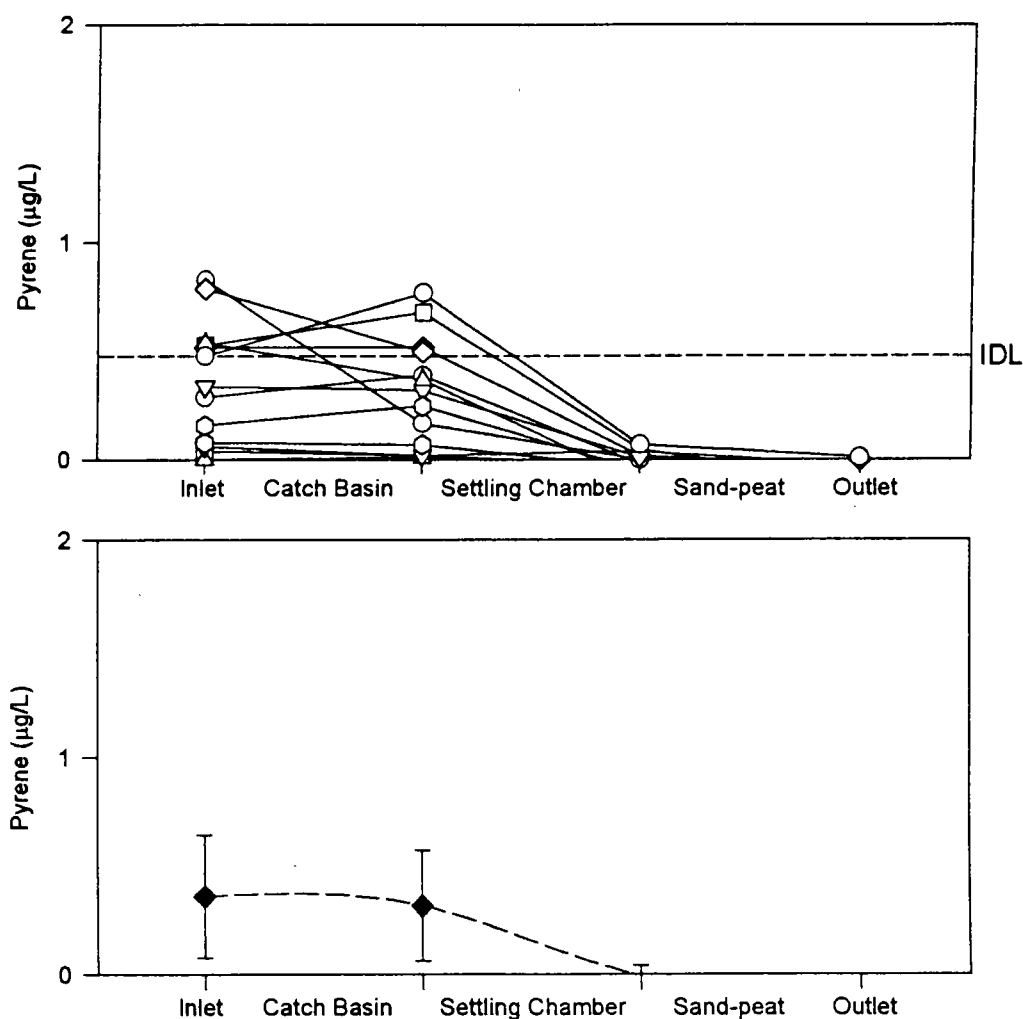
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.3750	0.1250	0.3750	0.1250
Min. Percent Reduction	-238	-282	-340	-1850
Max. Percent Reduction	100	100	100	100
Median Percent Reduction	36	100	-36	11
Std. Dev. of Percent Reduction	426	175	2801	563
COV of Percent Reduction	3.72	1.72	3.64	-4.05

TABLE A-50
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Fluoranthene



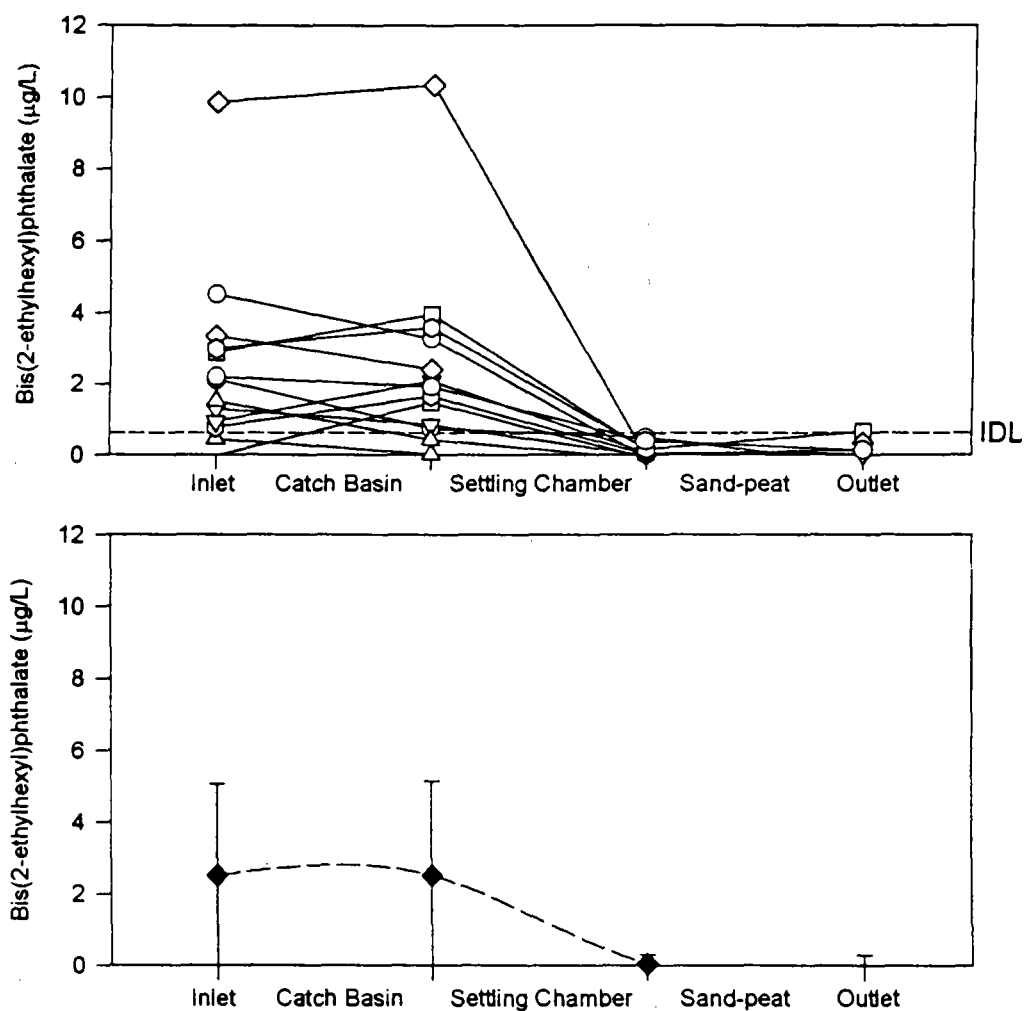
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.6250	0.1250	0.3750	0.1250
Min. Percent Reduction	-104	-300	-89	-233
Max. Percent Reduction	88	100	100	100
Median Percent Reduction	12	100	0	100
Std. Dev. of Percent Reduction	60	125	103	107
COV of Percent Reduction	-9.6	1.5	3.7	1.3

TABLE A-51.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Pyrene



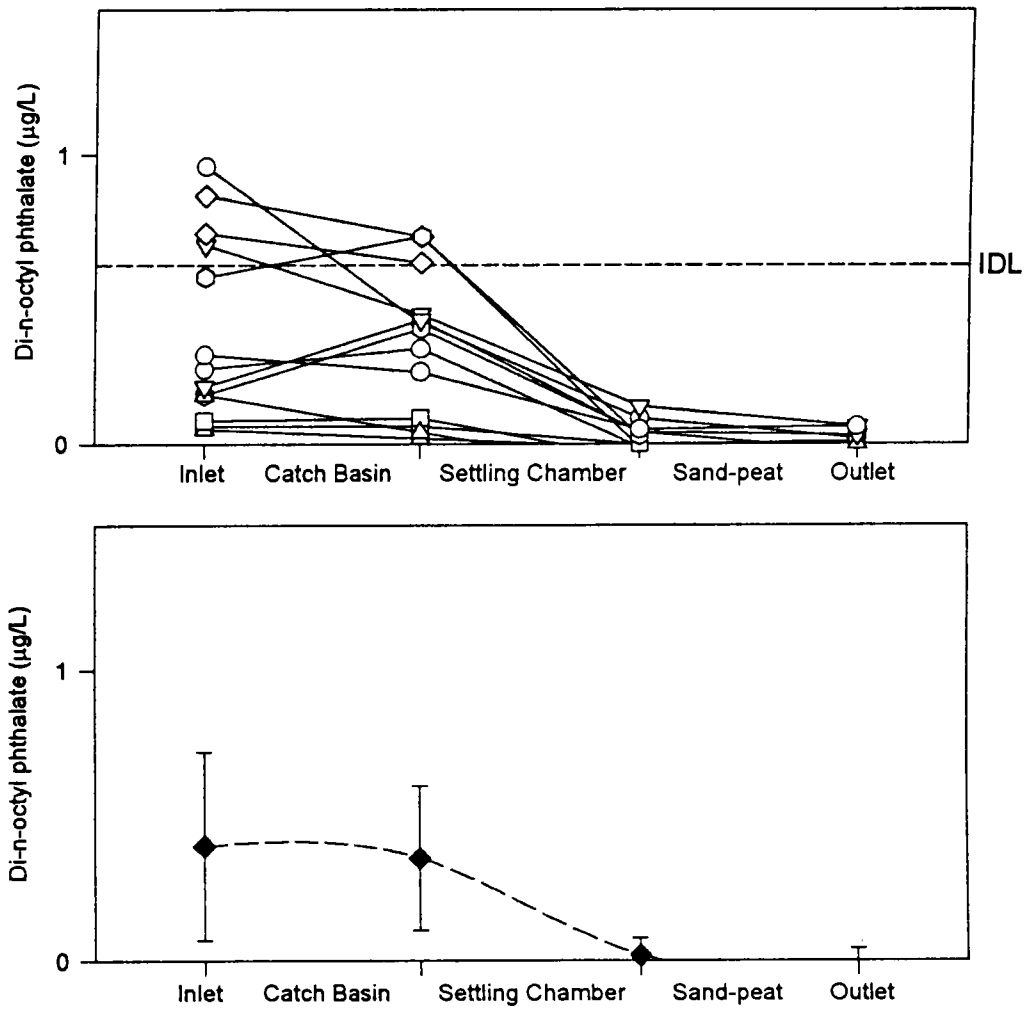
	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	-0.5000	0.1250	0.1250	0.0625
Min. Percent Reduction	-60	-100	-100	98
Max. Percent Reduction	80	100	100	100
Median Percent Reduction	9	100	55	100
Std. Dev. of Percent Reduction	46	116	155	24
COV of Percent Reduction	5.4	0.91	1.4	0.20

TABLE A-52.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Bis(2-ethylhexyl)phthalate



	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.5000	0.0020	0.1563	0.0020
Min. Percent Reduction	-121	34	-650	-667
Max. Percent Reduction	100	100	100	100
Median Percent Reduction	28	99	-188	99
Std. Dev. of Percent Reduction	1397	454	300	226
COV of Percent Reduction	3.6	2.0	-1.7	5.2

TABLE A-53.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Di-n-octylphthalate



	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.2500	N/A	N/A	0.2500
Min. Percent Reduction	-135	71	-100	81
Max. Percent Reduction	76	100	100	100
Median Percent Reduction	14	98	13	100
Std. Dev. of Percent Reduction	63	63	75	34
COV of Percent Reduction	-22	0.53	3.3	0.31

Table A-54 Particle Size Distributions of MCTT Treated Water – UAB Remote Parking Lot, Birmingham, AL Storm Event #1

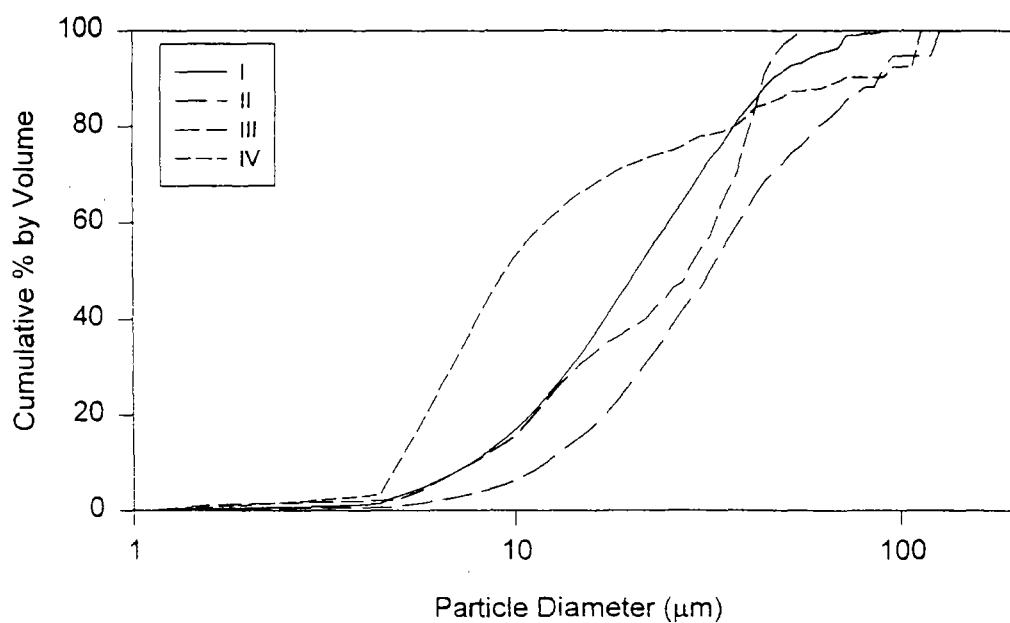
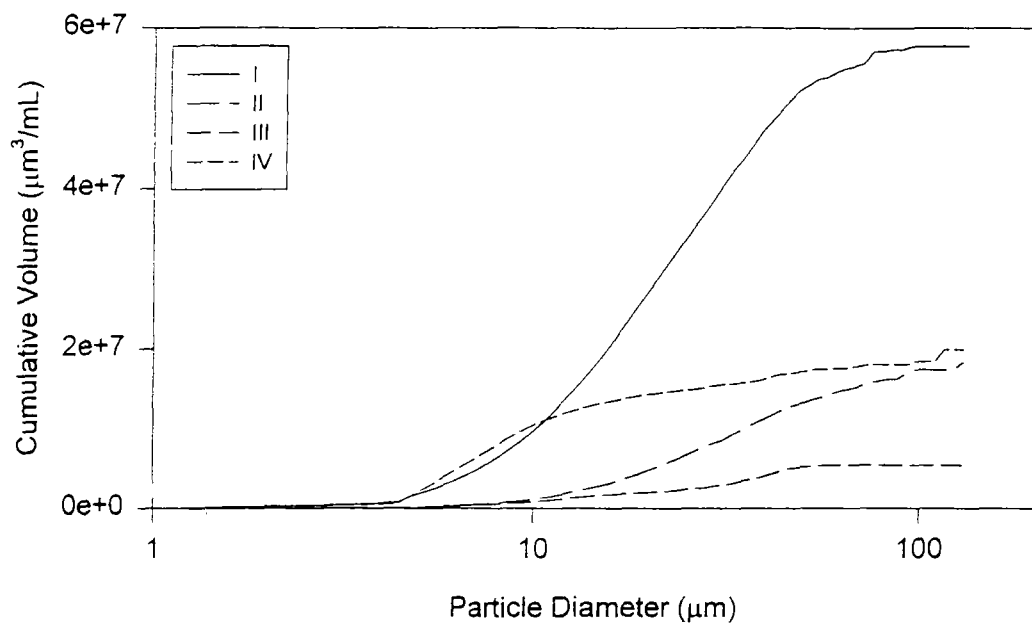


Table A-55 Particle Size Distributions of MCTT Treated Water – UAB Remote Parking Lot, Birmingham, AL Storm Event #2

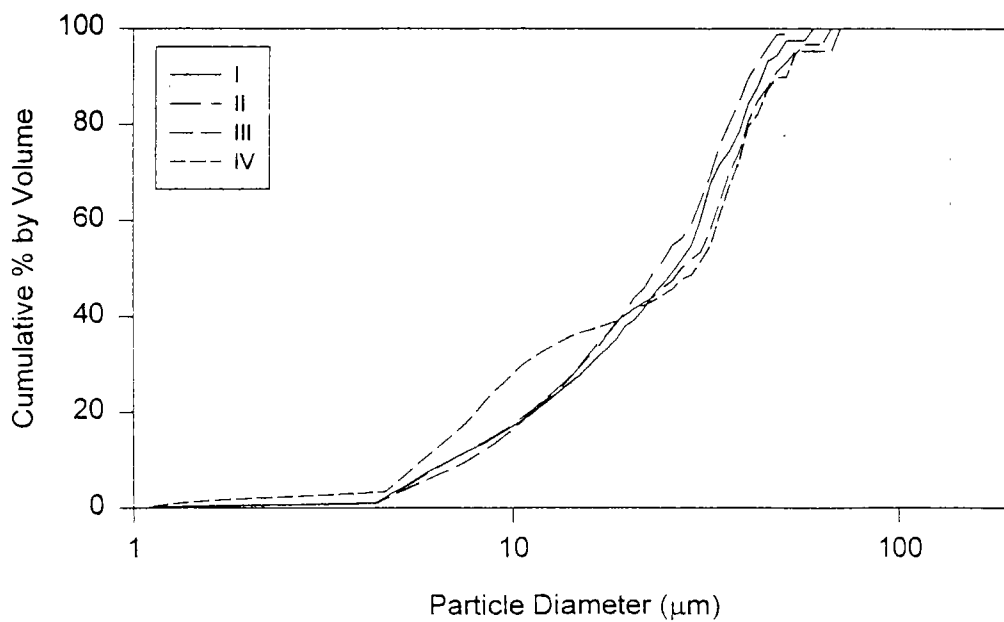
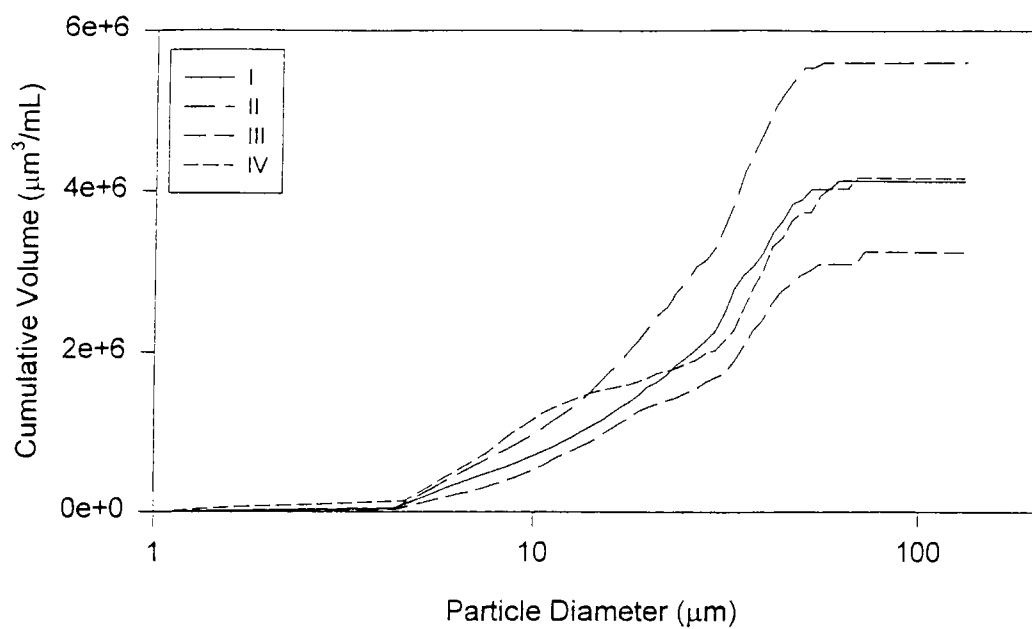


Table A-56 Particle Size Distributions of MCTT Treated Water – UAB Remote Parking Lot, Birmingham, AL Storm Event #3

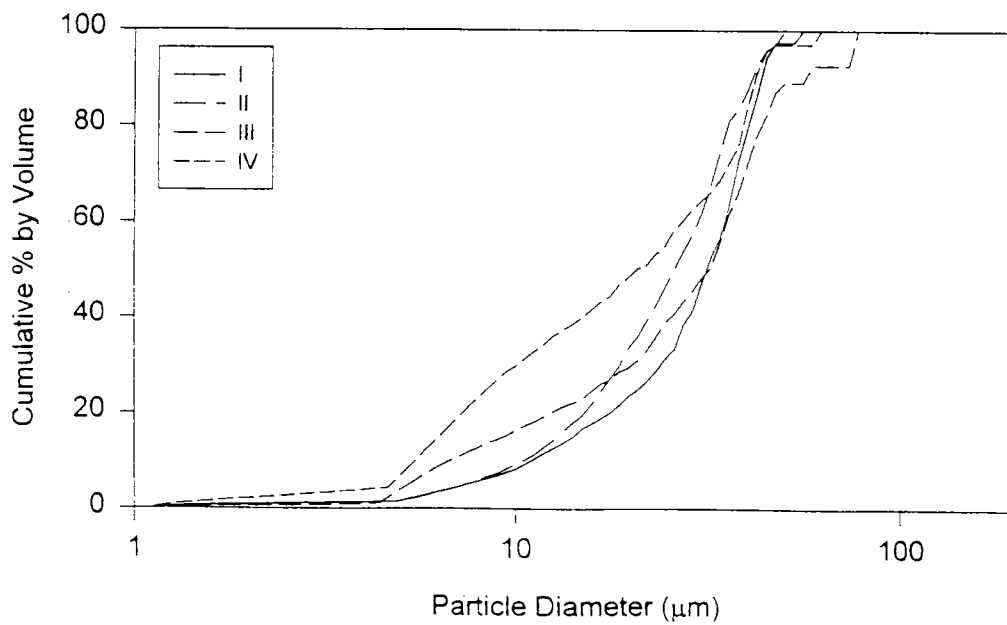
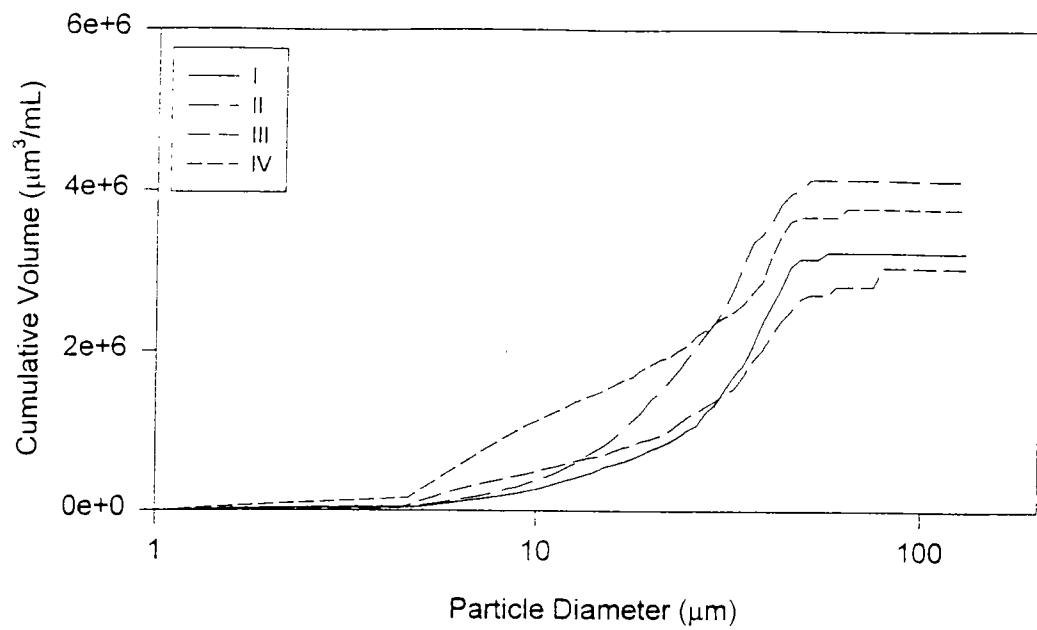


Table A-57 Particle Size Distributions of MCTT Treated Water – UAB Remote Parking Lot, Birmingham, AL Storm Event #4

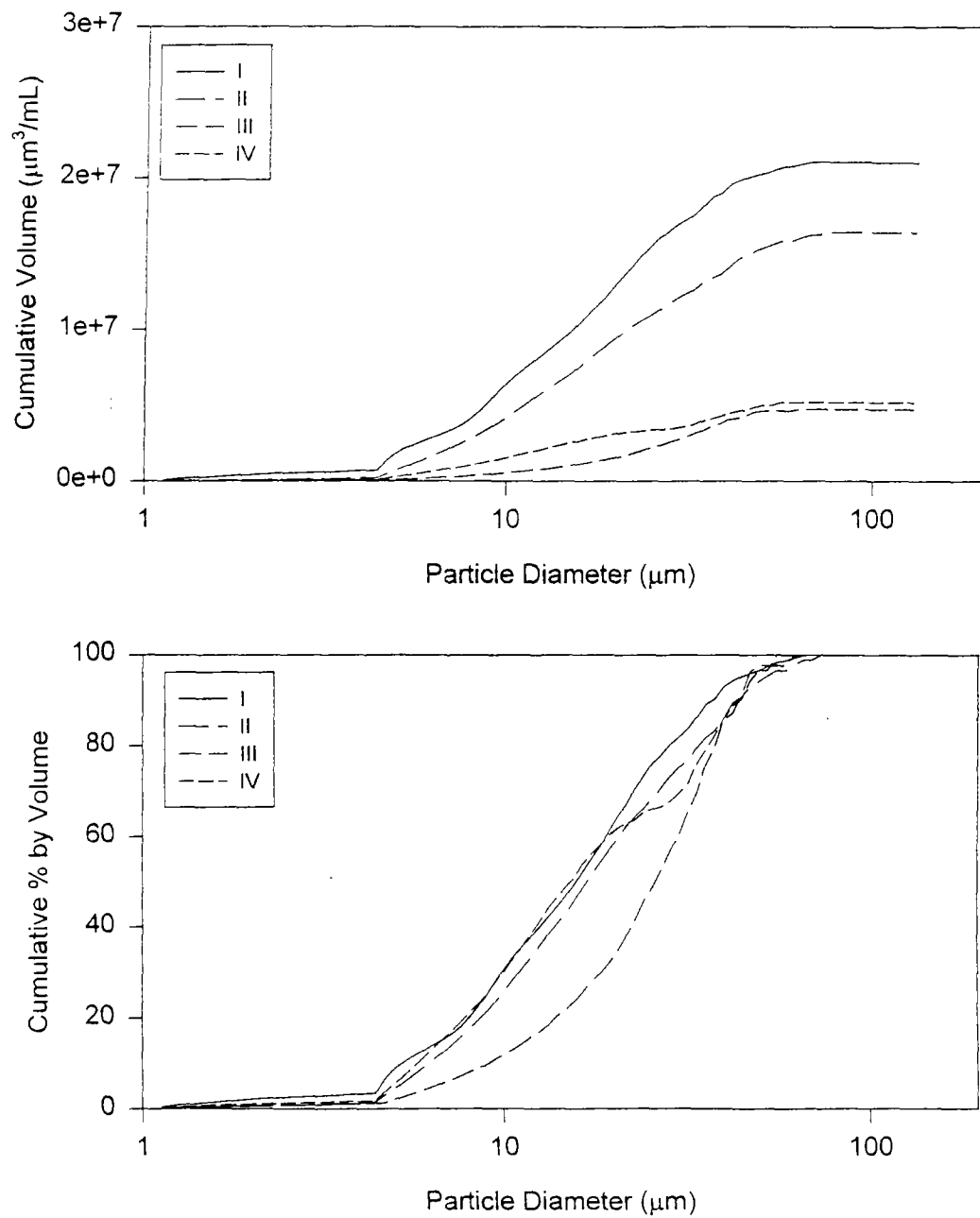


Table A-58 Particle Size Distributions of MCTT Treated Water – UAB Remote Parking Lot, Birmingham, AL Storm Event #5

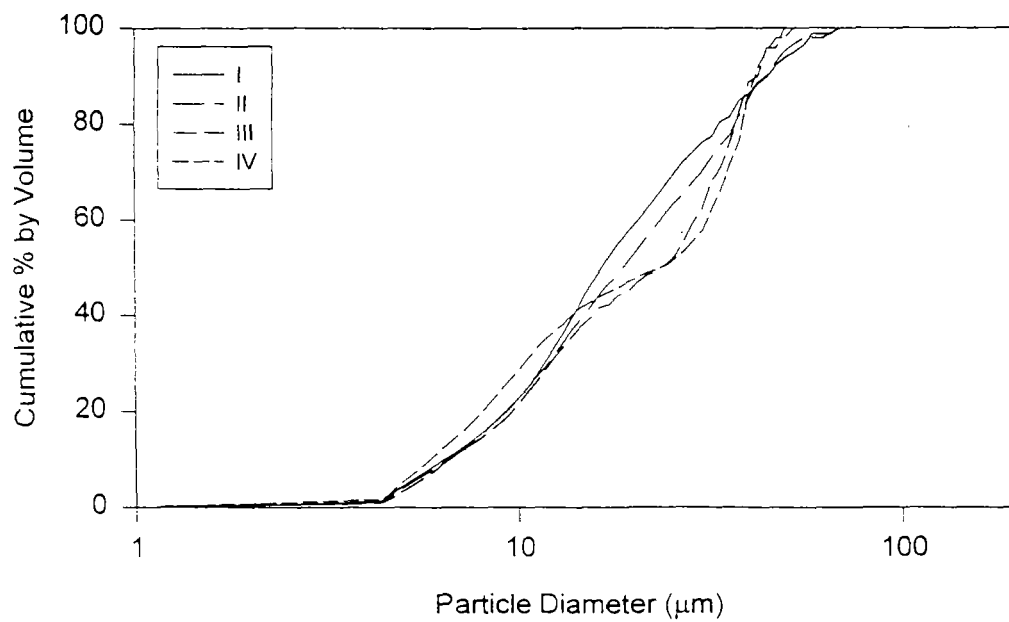
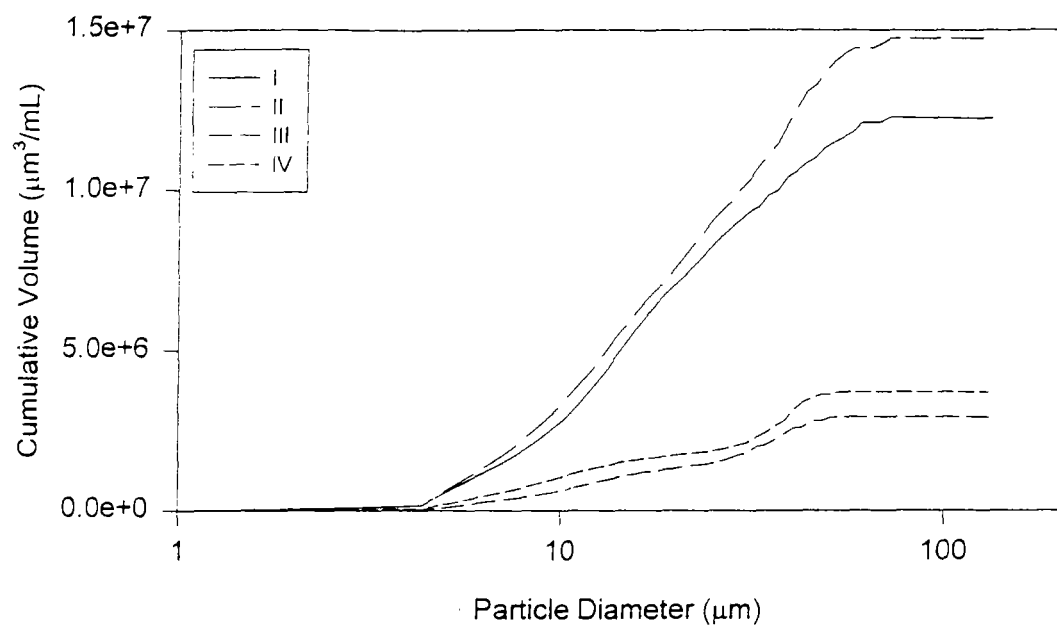


Table A-59 Particle Size Distributions of MCTT Treated Water – UAB Remote Parking Lot, Birmingham, AL Storm Event #6

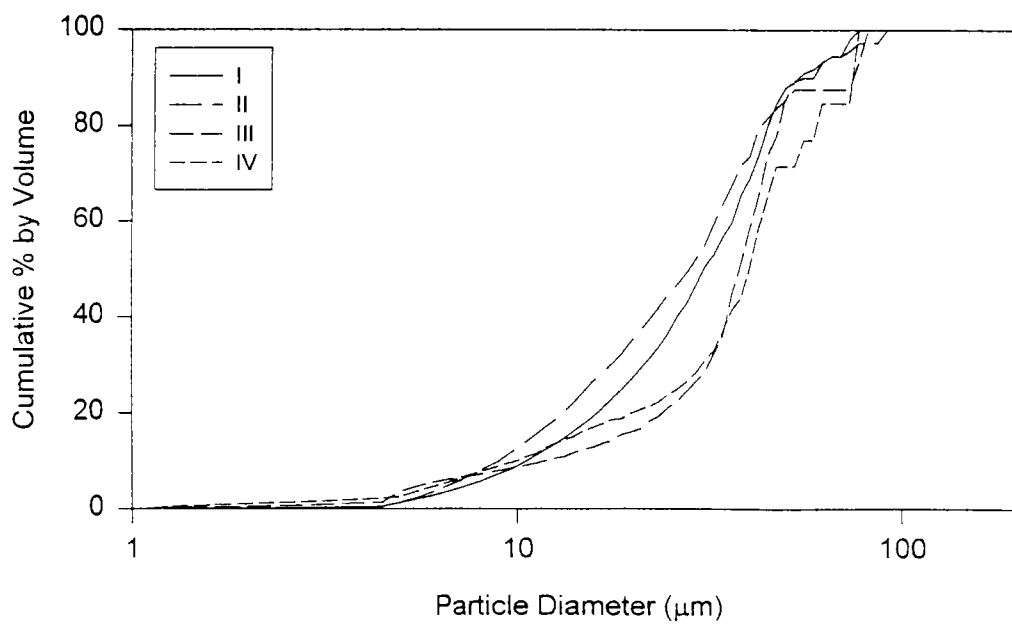
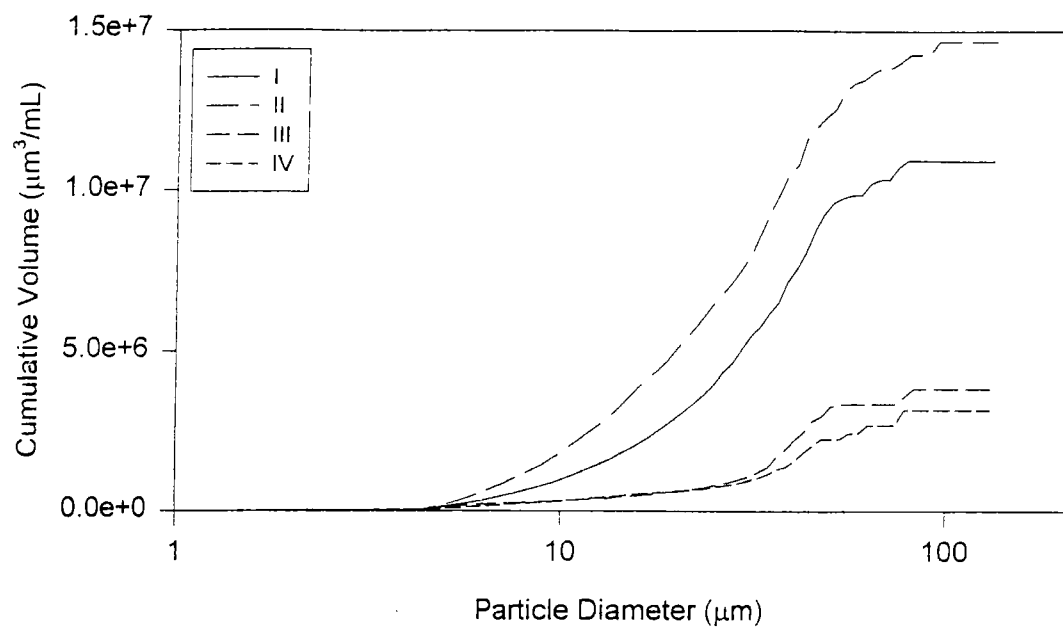


Table A-60 Particle Size Distributions of MCTT Treated Water – UAB Remote Parking Lot, Birmingham, AL Storm Event #7

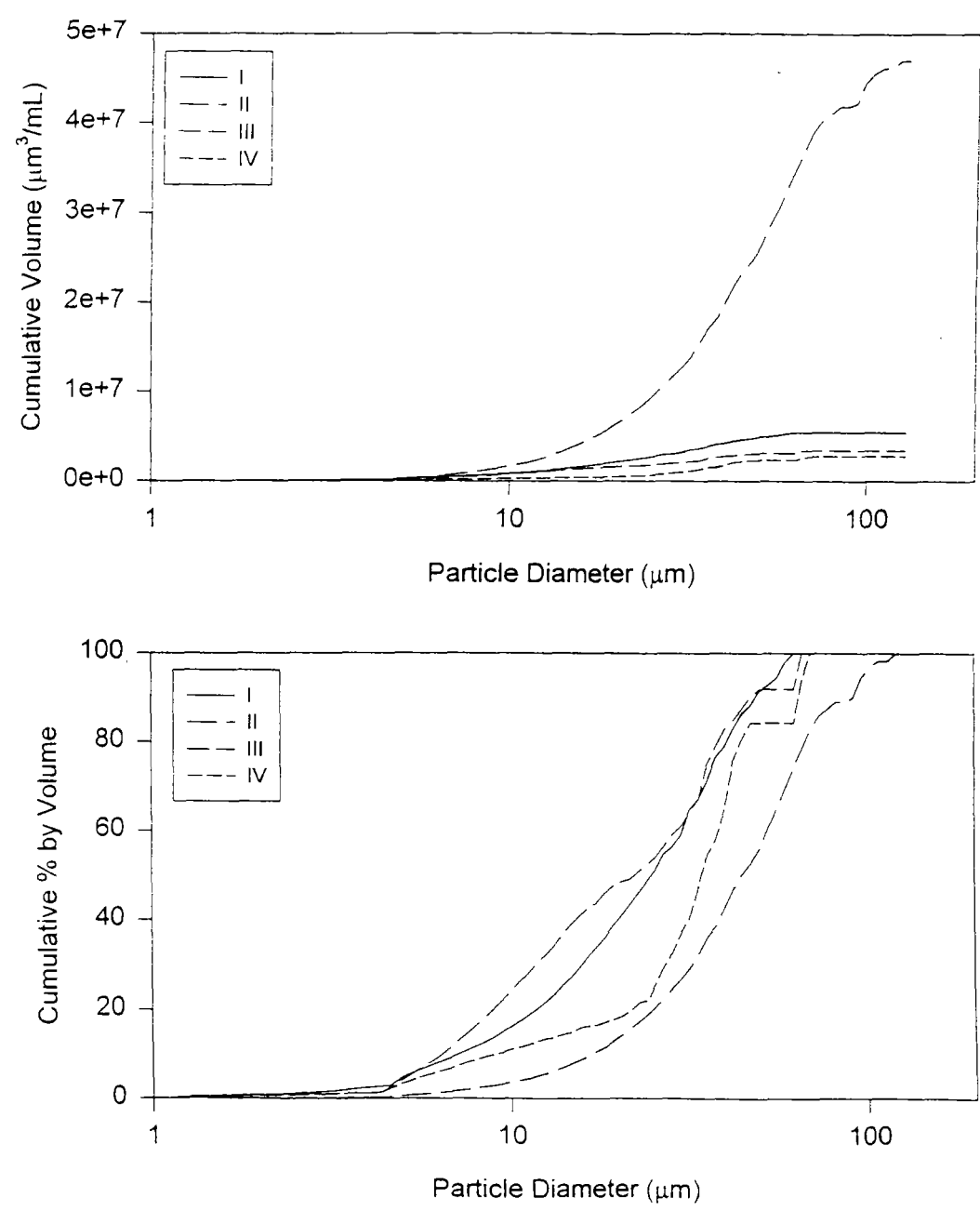


Table A-61 Particle Size Distributions of MCTT Treated Water – UAB Remote Parking Lot, Birmingham, AL Storm Event #8

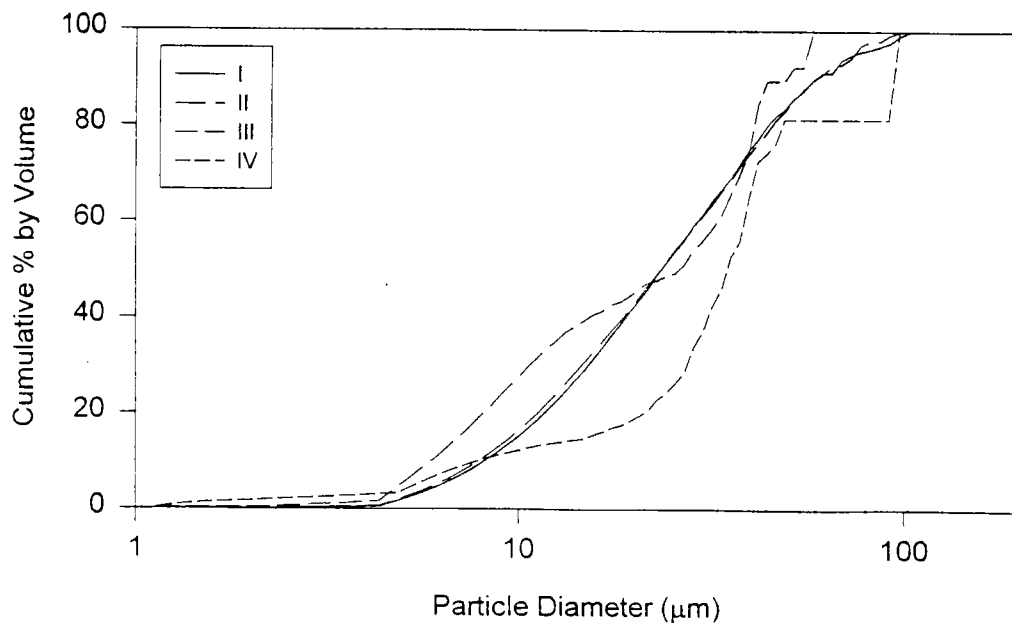
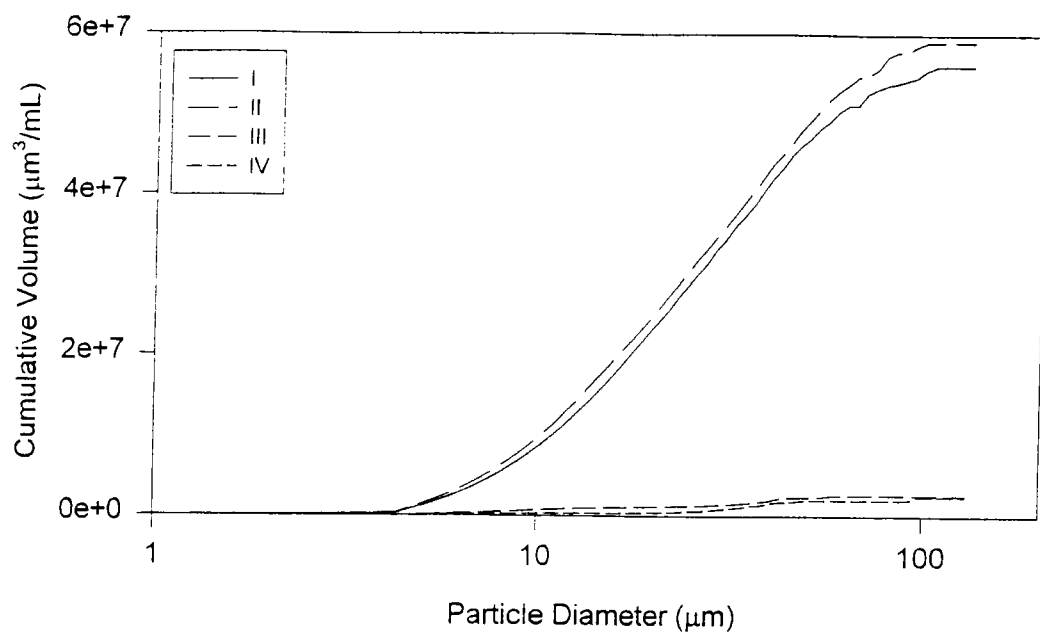


Table A-62 Particle Size Distributions of MCTT Treated Water – UAB Remote Parking Lot, Birmingham, AL Storm Event #9

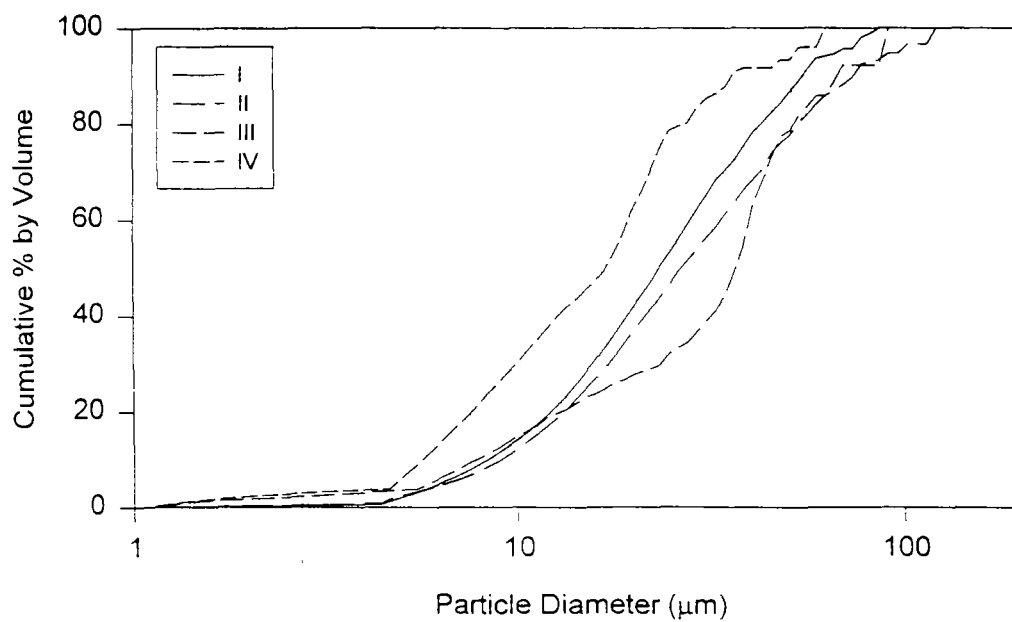
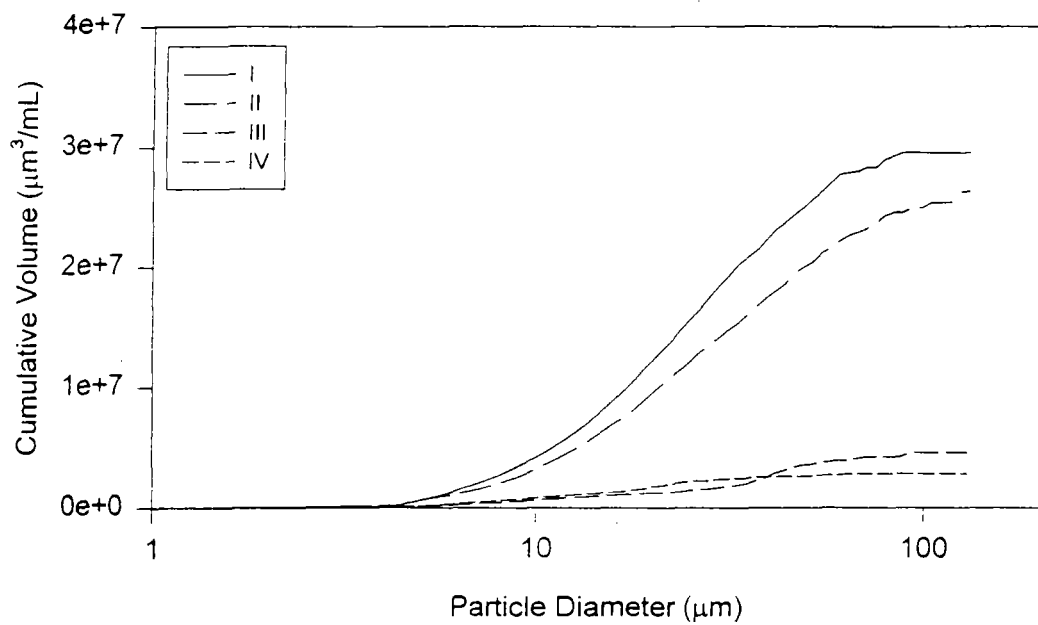


Table A-63 Particle Size Distributions of MCTT Treated Water – UAB Remote Parking Lot, Birmingham, AL Storm Event #10

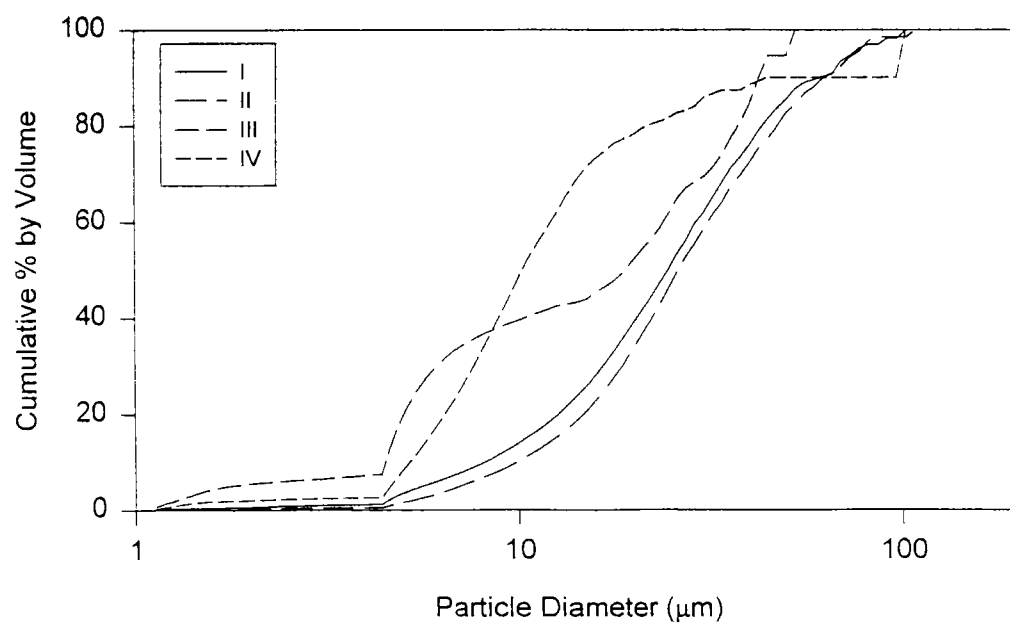
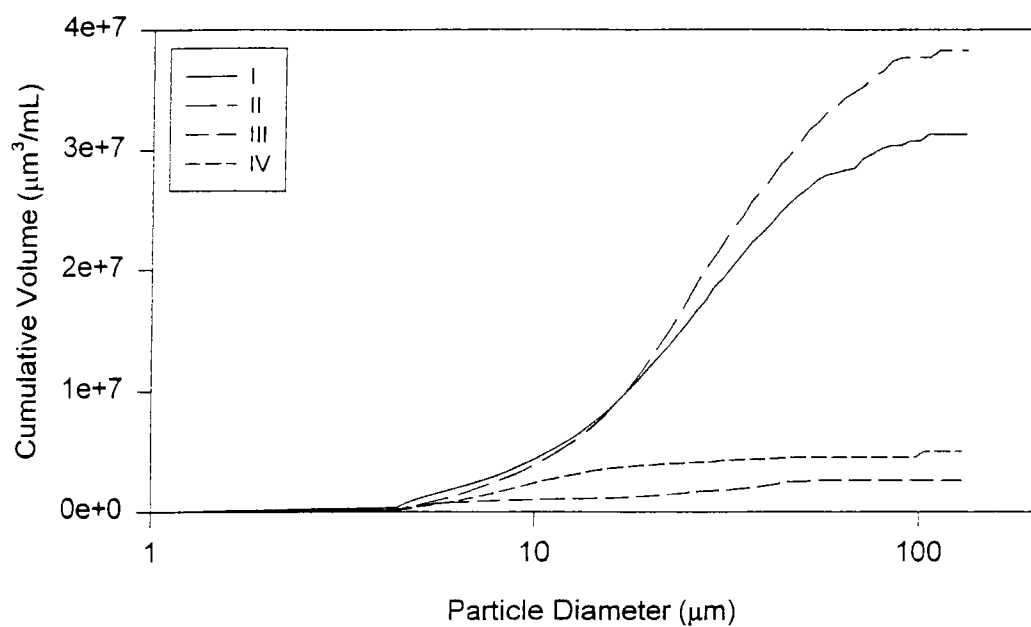


Table A-64 Particle Size Distributions of MCTT Treated Water – UAB Remote Parking Lot, Birmingham, AL Storm Event #11

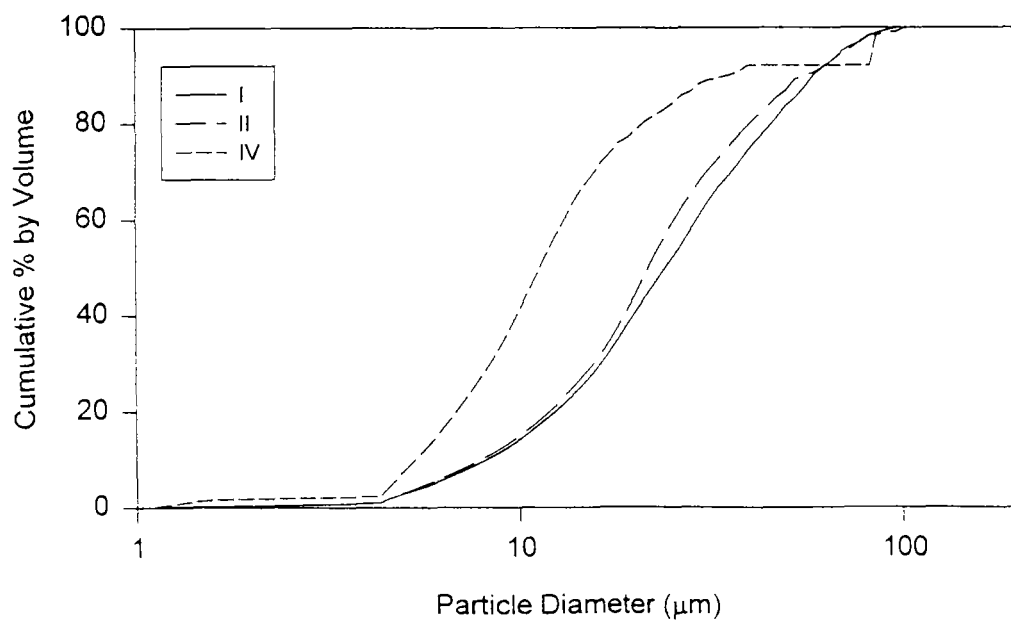
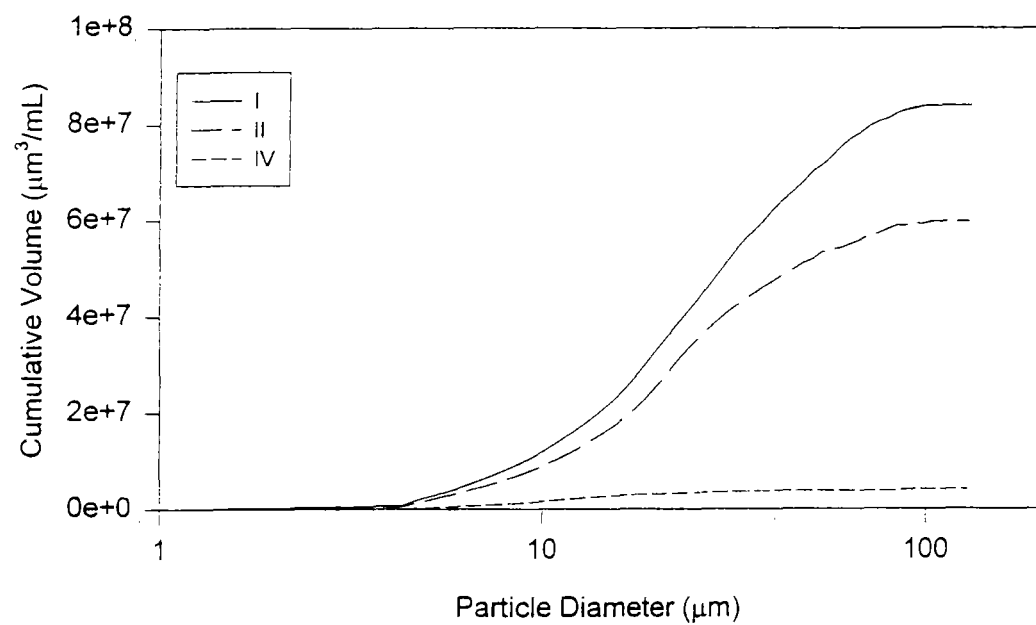


Table A-65 Particle Size Distributions of MCTT Treated Water – UAB Remote Parking Lot, Birmingham, AL Storm Event #12

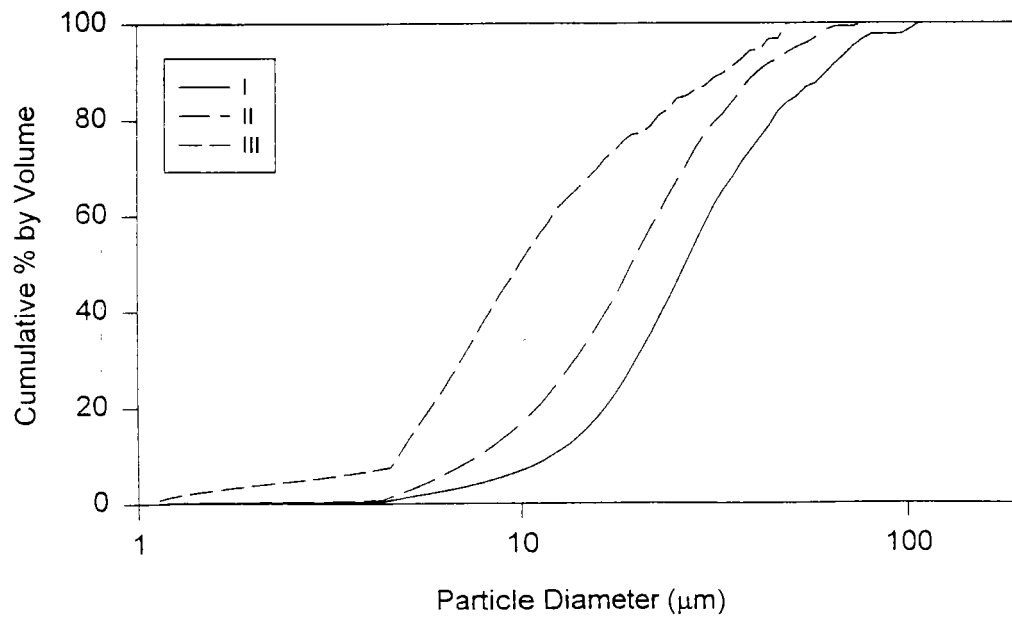
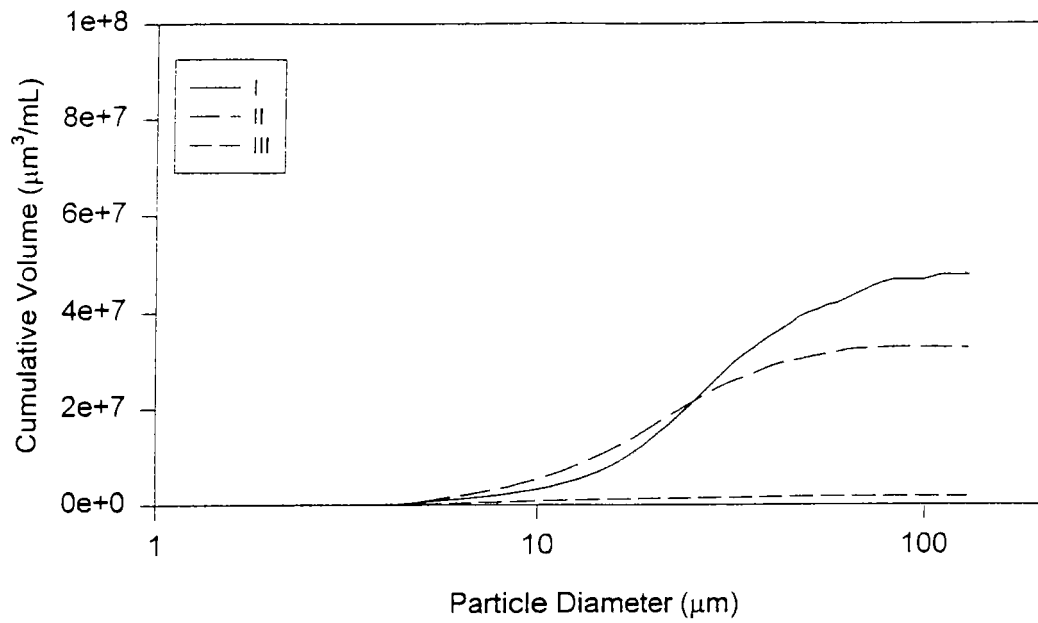
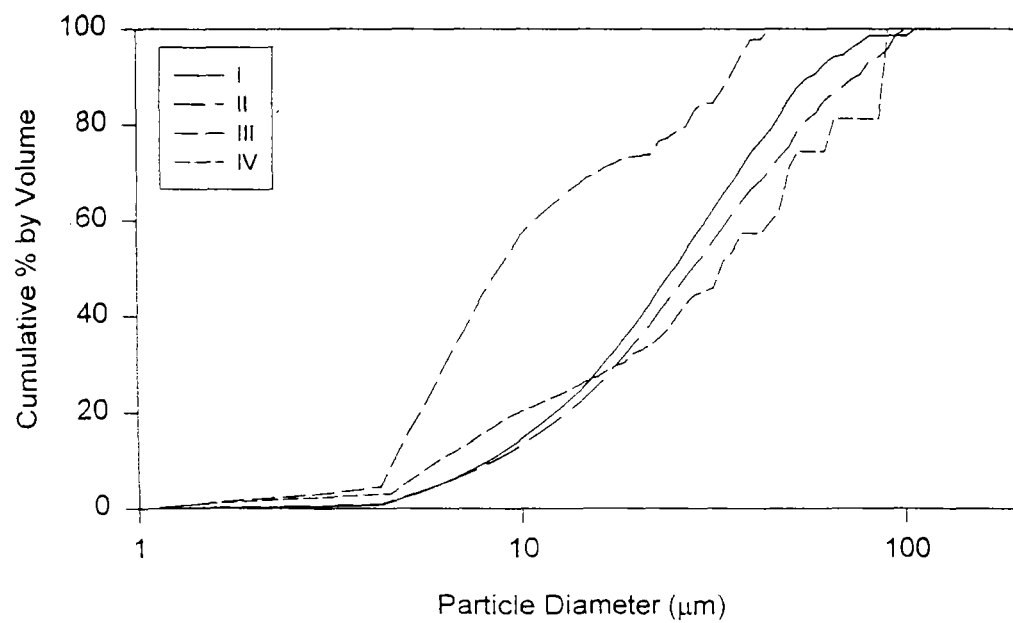
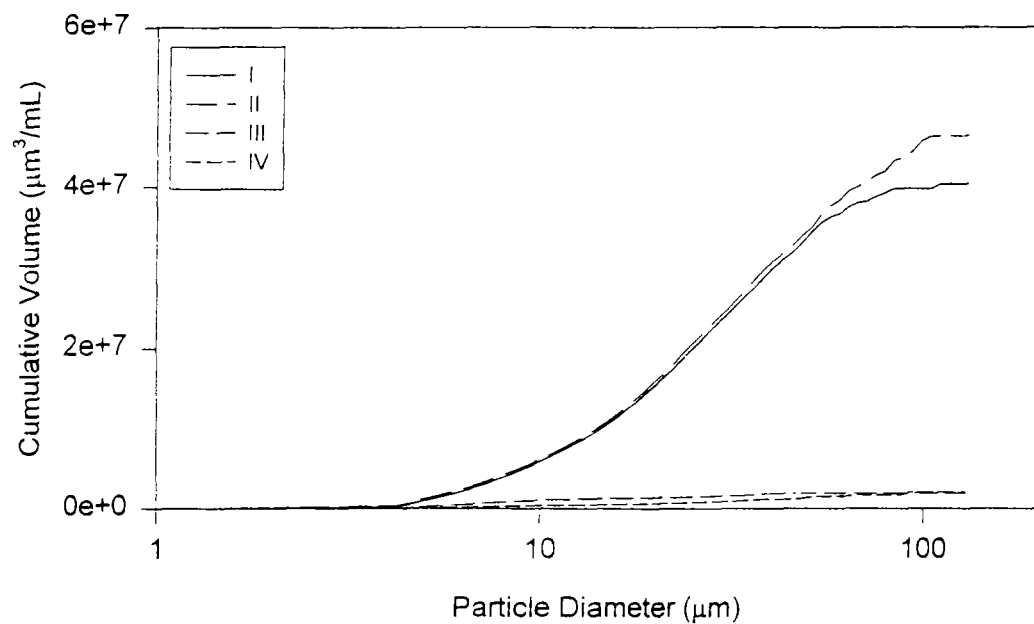


Table A-66 Particle Size Distributions of MCTT Treated Water – UAB Remote Parking Lot, Birmingham, AL Storm Event #13



Appendix B
Tabular MCTT Performance Data

TABLE B-1.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Total Solids (mg/L)
IDL = 2.5 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	255	110	111	168
2	55	47	43	44
3	58	47	54	41
4	190	142	99	78
5	58	70	53	52
6	29	34	21	31
7	91	132	66	64
8	154	163	87	75
9	134	83	65	62
10	105	114	77	75
11	229	202	NS *	107
12	136	162	90	NS *
13	78	72	37	38
Min. Concentration	29	34	21	31
Max. Concentration	255	202	111	168
Median Concentration	105	110	66	63
Standard Deviation	70	52	27	38
COV	0.58	0.49	0.40	0.54

*No sample available for analysis.

TABLE B-2.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Volatile Total Solids (mg/L)
IDL = 2.5 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	80	51	54	78
2	20	20	20	26
3	25	18	23	26
4	94	81	48	42
5	28	38	21	28
6	10	12	10	14
7	40	53	27	30
8	64	67	38	38
9	43	28	21	24
10	43	51	26	37
11	105	77	NS *	65
12	56	63	43	NS *
13	33	30	14	19
Min. Concentration	10	12	10	14
Max. Concentration	105	81	54	78
Median Concentration	43	51	25	29
Standard Deviation	29	23	14	19
COV	0.59	0.50	0.48	0.53

*No sample available for analysis.

TABLE B-3.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
Total Suspended Solids (mg/L)
IDL = 2.5 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	137	18	10	55
2	7	7	<IDL	3
3	8	<IDL ^b	9	6
4	38	31	6	8
5	17	26	<IDL	6
6	16	16	<IDL	4
7	23	59	<IDL	<IDL
8	75	77	11	6
9	77	25	<IDL	<IDL
10	41	34	<IDL	5
11	103	81	NS ^a	8
12	47	59	<IDL	NS
13	41	19	3	<IDL
Min. Concentration	7	<IDL	<IDL	<IDL
Max. Concentration	137	81	11	55
Median Concentration	41	26	<IDL	6
Standard Deviation	39	26	4	15
COV	0.81	0.74	1.1	1.7

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-4.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
Volatile Suspended Solids (mg/L)
IDL = 2.5 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	29	8	6	19
2	3	12	5	5
3	<IDL ^b	4	11	6
4	28	28	<IDL	<IDL
5	11	15	4	10
6	5	<IDL	<IDL	<IDL
7	13	23	<IDL	<IDL
8	29	26	8	8
9	17	6	<IDL	<IDL
10	13	21	<IDL	9
11	46	30	NS ^a	19
12	19	14	9	NS
13	24	17	9	6
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	46	30	11	19
Median Concentration	17	15	5	6
Standard Deviation	13	9	5	7
COV	0.69	0.59	1.1	1.0

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-5.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Dissolved Solids (mg/L)
IDL = 2.5 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	118	92	101	113
2	48	40	41	41
3	50	46	45	35
4	152	111	93	70
5	41	44	52	46
6	13	18	21	27
7	68	73	74	62
8	79	86	76	69
9	57	58	67	62
10	64	80	76	70
11	126	121	NS *	107
12	89	103	89	NS *
13	37	53	34	36
Min. Concentration	13	18	21	27
Max. Concentration	152	121	101	113
Median Concentration	64	73	71	62
Standard Deviation	40	31	25	27
COV	0.55	0.43	0.39	0.44

*No sample available for analysis.

TABLE B-6.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Volatile Dissolved Solids (mg/L)
IDL = 2.5 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	51	43	48	59
2	17	8	15	21
3	23	14	12	20
4	66	53	46	40
5	17	23	17	18
6	5	10	9	14
7	27	30	29	32
8	35	41	30	30
9	26	22	22	22
10	30	30	28	28
11	59	47	NS *	46
12	37	49	34	NS *
13	9	13	5	13
Min. Concentration	5	8	5	13
Max. Concentration	66	53	48	59
Median Concentration	27	30	25	25
Standard Deviation	19	16	14	14
COV	0.60	0.54	0.56	0.49

*No sample available for analysis.

TABLE B-7.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Turbidity (NTU)
IDL = 0.75 NTU

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	6.3	1.9	1.7	2.4
2	2.2	1.4	0.8	5.2
3	2.0	2.1	1.1	6.9
4	16.0	5.7	3.6	7.7
5	6.3	6.1	0.8	4.0
6	3.5	2.7	1.5	6.0
7	8.2	9.1	1.9	3.6
8	7.8	7.4	1.9	3.1
9	6.2	3.3	1.4	3.5
10	2.6	1.8	1.9	4.8
11	4.0	3.8	NS *	4.8
12	4.6	3.1	1.5	NS *
13	5.5	6.3	2.3	2.4
Min. Concentration	2.0	1.4	0.8	2.4
Max. Concentration	16.0	9.1	3.6	7.7
Median Concentration	5.5	3.3	1.6	4.4
Standard Deviation	3.7	2.5	0.8	1.7
COV	0.64	0.58	0.44	0.37

*No sample available for analysis.

TABLE B-8.
MCTT PERFORMANCE DATA – FILTERED SAMPLES
Turbidity (NTU)
IDL = 0.75 NTU

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	<IDL ^b	<IDL	<IDL	1.80
2	<IDL	<IDL	<IDL	<IDL
3	<IDL	<IDL	<IDL	<IDL
4	1.60	<IDL	<IDL	0.93
5	<IDL	<IDL	<IDL	<IDL
6	<IDL	<IDL	<IDL	0.85
7	<IDL	<IDL	<IDL	<IDL
8	<IDL	<IDL	<IDL	<IDL
9	<IDL	<IDL	<IDL	<IDL
10	<IDL	<IDL	<IDL	<IDL
11	<IDL	<IDL	NS ^a	0.90
12	1.00	1.50	2.10	NS
13	<IDL	1.50	<IDL	1.30
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	1.60	1.50	2.10	1.80
Median Concentration	<IDL	<IDL	<IDL	<IDL
Standard Deviation	0.38	0.43	0.52	0.39
COV	0.70	0.75	1.15	0.47

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-9.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Apparent Color (Hach® color units)

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	44	37	34	100
2	24	19	19	46
3	27	29	16	44
4	58	36	25	62
5	26	24	20	35
6	16	15	13	47
7	26	32	26	38
8	20	43	36	40
9	20	23	27	42
10	38	38	30	50
11	55	55	NS *	73
12	54	58	41	NS *
13	34	32	30	30
Min. Concentration	16	15	13	30
Max. Concentration	58	58	41	100
Median Concentration	27	32	27	45
Standard Deviation	15	13	8	19
COV	0.43	0.38	0.32	0.38

*No sample available for analysis.

TABLE B-10.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Color (HACH® color units)

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	39	32	31	100
2	22	23	16	33
3	18	17	12	27
4	45	35	27	39
5	20	21	18	33
6	4	9	9	38
7	19	19	14	28
8	40	35	27	35
9	32	38	23	47
10	40	38	26	48
11	55	55	NS *	50
12	47	52	41	NS *
13	22	20	22	40
Min. Concentration	4	9	9	27
Max. Concentration	55	55	41	100
Median Concentration	32	32	23	39
Standard Deviation	15	14	9	19
COV	0.47	0.45	0.41	0.45

*No sample available for analysis.

TABLE B-11.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Conductivity (uS/cm²)

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	89	76	92	73
2	52	42	45	31
3	48	40	51	25
4	124	92	86	52
5	41	41	50	39
6	14	19	29	22
7	79	81	66	54
8	55	62	70	57
9	64	61	72	61
10	52	61	71	56
11	90	90	NS *	73
12	80	101	92	NS *
13	38	38	42	39
Min. Concentration	14	19	29	22
Max. Concentration	124	101	92	73
Median Concentration	55	61	68	53
Standard Deviation	28	25	21	17
COV	0.45	0.40	0.32	0.36

*No sample available for analysis.

TABLE B-12.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
pH

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	7.22	6.86	6.95	6.37
2	7.04	6.96	7.10	6.26
3	7.44	7.32	7.27	5.93
4	7.11	7.12	6.95	6.05
5	6.87	6.98	6.93	6.45
6	6.82	6.80	7.07	6.78
7	6.94	6.91	6.29	6.34
8	6.34	6.52	6.75	6.47
9	6.53	6.54	6.98	6.62
10	6.58	6.60	6.97	6.50
11	7.16	7.21	NS *	5.97
12	7.12	7.13	7.03	NS *
13	7.15	7.20	7.03	6.64
Min. Concentration	6.34	6.52	6.29	5.93
Max. Concentration	7.44	7.32	7.27	6.78
Median Concentration	7.04	6.96	6.98	6.41
Standard Deviation	0.31	0.26	0.24	0.27
COV	0.045	0.038	0.034	0.043

*No sample available for analysis.

TABLE B-13.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
Chemical Oxygen Demand (mg/L)
IDL = 1.1 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	107	41	31	69
2	31	27	19	16
3	2	6	<IDL	<IDL
4	114	55	44	18
5	2	18	5	<IDL
6	<IDL ^b	<IDL	<IDL	14
7	42	98	49	45
8	48	92	31	67
9	48	23	53	<IDL
10	26	25	11	17
11	197	82	NS ^a	62
12	63	101	42	NS
13	42	54	11	17
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	197	101	53	69
Median Concentration	42	41	25	17
Standard Deviation	55	35	19	26
COV	1.0	0.74	0.79	0.98

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-14.
MCTT PERFORMANCE DATA – FILTERED SAMPLES
Chemical Oxygen Demand (mg/L)
IDL = 1.1 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	70	75	35	71
2	23	26	22	23
3	5	3	<IDL	<IDL
4	110	59	25	10
5	7	4	<IDL	<IDL
6	5	8	<IDL	4
7	55	62	38	37
8	24	55	45	39
9	<IDL ^b	56	23	<IDL
10	<IDL	23	<IDL	15
11	85	74	NS ^a	59
12	58	67	34	NS
13	11	3	9	14
Min. Concentration	<IDL	3	<IDL	<IDL
Max. Concentration	110	75	45	71
Median Concentration	23	55	23	15
Standard Deviation	37	29	17	24
COV	1.05	0.73	0.88	1.06

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-15.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
Relative Toxicity (I 25% reduction)
IDL = I₂₀ of 5%

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	24	27	23	7
2	25	24	24	<IDL
3	12	<IDL	10	<IDL
4	70	28	13	6
5	13	15	<IDL	<IDL
6	<IDL ^b	<IDL	<IDL	<IDL
7	37	42	33	<IDL
8	33	39	<IDL	8
9	<IDL	16	10	18
10	31	27	13	9
11	50	42	NS ^a	<IDL
12	12	<IDL	8	NS
13	7	12	16	<IDL
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	70	42	33	18
Median Concentration	24	24	12	<IDL
Standard Deviation	21	15	10	9
COV	0.88	0.73	0.82	11.82

^aNo sample available for analysis.

^bData below instrument detection limit (IDL).

TABLE B-16.
MCTT PERFORMANCE DATA – FILTERED SAMPLES
Relative Toxicity (1 25% reduction)
IDL = I₂₀ of 5%

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	32	40	24	16
2	9	27	<IDL	<IDL
3	10	23	<IDL	<IDL
4	61	32	21	11
5	12	22	11	<IDL
6	<IDL ^b	<IDL	<IDL	9
7	39	37	18	<IDL
8	35	35	<IDL	<IDL
9	13	7	23	13
10	42	41	9	<IDL
11	36	41	NS ^a	<IDL
12	8	11	<IDL	NS
13	16	16	<IDL	5
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	61	41	24	16
Median Concentration	16	27	7	<IDL
Standard Deviation	18	14	10	8
COV	0.73	0.57	1.0	2.5

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-17.
MCTT PERFORMANCE DATA – FILTERED SAMPLES
Ammonium (mg/L)
IDL = 0.25 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	0.38	0.34	0.63	2.25
2	<IDL ^b	<IDL	<IDL	0.30
3	<IDL	<IDL	<IDL	0.29
4	<IDL	<IDL	0.47	0.46
5	<IDL	<IDL	0.39	0.42
6	<IDL	<IDL	<IDL	<IDL
7	0.46	0.27	<IDL	0.32
8	0.25	<IDL	<IDL	<IDL
9	0.34	<IDL	0.93	0.74
10	<IDL	<IDL	<IDL	<IDL
11	<IDL	<IDL	NS ^a	0.40
12	<IDL	<IDL	<IDL	NS
13	<IDL	<IDL	<IDL	<IDL
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	0.46	0.34	0.93	2.25
Median Concentration	<IDL	<IDL	<IDL	0.31
Standard Deviation	0.16	0.11	0.26	0.58
COV	1.10	0.88	0.88	1.20

^aNo sample available for analysis.

^bData below instrument detection limit (IDL).

TABLE B-18.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Calcium (mg/L)
IDL = 0.25 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	15.35	10.10	16.10	7.92
2	8.43	6.68	6.63	2.79
3	9.27	7.50	7.92	1.85
4	11.13	10.65	10.32	2.96
5	5.64	6.01	5.76	2.78
6	1.17	1.63	2.85	2.33
7	9.03	9.26	9.70	6.37
8	8.75	9.93	8.73	7.16
9	7.27	6.92	10.22	6.54
10	6.75	8.74	9.67	6.04
11	13.54	15.11	NS *	8.48
12	10.97	13.29	11.77	NS *
13	4.23	5.86	6.29	4.05
Min. Concentration	1.17	1.63	2.85	1.85
Max. Concentration	15.35	15.11	16.10	8.48
Median Concentration	8.75	8.74	9.20	5.05
Standard Deviation	3.77	3.46	3.36	2.38
COV	0.44	0.40	0.38	0.48

*No sample available for analysis.

TABLE B-19.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Lithium (mg/L)
IDL = 0.025 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	0.003 ^b	0.000 ^b	0.003 ^b	0.002 ^b
2	0.000 ^b	0.000 ^b	0.000 ^b	0.000 ^b
3	0.000 ^b	0.000 ^b	0.000 ^b	0.000 ^b
4	0.002 ^b	0.003 ^b	0.002 ^b	0.002 ^b
5	0.000 ^b	0.000 ^b	0.000 ^b	0.001 ^b
6	0.000 ^b	0.000 ^b	0.001 ^b	0.000 ^b
7	0.005 ^b	0.000 ^b	0.002 ^b	0.002 ^b
8	0.000 ^b	0.000 ^b	0.000 ^b	0.001 ^b
9	0.000 ^b	0.001 ^b	0.000 ^b	0.001 ^b
10	0.000 ^b	0.000 ^b	0.000 ^b	0.000 ^b
11	0.000 ^b	0.000 ^b	NS ^a	0.000 ^b
12	0.000 ^b	0.000 ^b	0.000 ^b	NS ^a
13	0.004 ^b	0.000 ^b	0.000 ^b	0.000 ^b
Min. Concentration	0.000 ^b	0.000 ^b	0.000 ^b	0.000 ^b
Max. Concentration	0.005 ^b	0.003 ^b	0.003 ^b	0.002 ^b
Median Concentration	0.000 ^b	0.000 ^b	0.000 ^b	0.001 ^b
Standard Deviation	0.002	0.001	0.001	0.001
COV	1.672	2.778	1.610	1.155

^aNo sample available for analysis.

^bData below instrument detection limit (IDL).

TABLE B-21.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Potassium (mg/L)
IDL = 0.062 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	0.73	0.55	1.04	1.84
2	0.36	0.40	0.43	0.56
3	0.54	0.49	0.39	0.64
4	1.67	1.21	1.19	0.96
5	0.51	0.54	0.57	0.65
6	0.25	0.36	0.39	0.45
7	0.46	0.27	0.24	0.32
8	0.95	1.01	0.81	0.97
9				

TABLE B-25.
MCTT PERFORMANCE DATA – FILTERED SAMPLES
Fluoride (mg/L)
IDL = 0.025 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	0.11	0.09	0.11	0.03
2	0.07	0.03	0.05	<IDL
3	0.04	0.03	0.05	<IDL
4	<IDL ^b	0.08	0.05	0.04
5	0.03	0.05	<IDL	<IDL
6	<IDL	<IDL	<IDL	<IDL
7	<IDL	<IDL	0.03	<IDL
8	<IDL	<IDL	<IDL	<IDL
9	<IDL	<IDL	0.04	<IDL
10	<IDL	<IDL	0.03	<IDL
11	<IDL	0.04	NS ^a	<IDL
12	0.03	0.04	<IDL	NS
13	<IDL	<IDL	<IDL	<IDL
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	0.11	0.09	0.11	0.04
Median Concentration	<IDL	0.03	0.03	<IDL
Standard Deviation	0.03	0.03	0.03	0.01
COV	1.04	0.81	0.93	0.65

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-26.
MCTT PERFORMANCE DATA – FILTERED SAMPLES
Nitrate (mg/L)
IDL = 0.25 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	5.81	5.69	4.89	5.15
2	1.22	1.17	1.24	1.58
3	1.88	1.80	1.46	0.77
4	1.52	2.06	1.39	1.34
5	1.40	1.28	1.44	1.47
6	<IDL ^b	<IDL	<IDL	<IDL
7	7.40	7.84	4.22	3.82
8	4.26	4.52	2.74	2.83
9	3.90	3.44	1.60	1.71
10	2.63	2.79	<IDL	0.85
11	4.24	4.41	NS ^a	1.93
12	1.89	2.39	1.88	NS
13	1.28	1.24	1.24	1.35
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	7.40	7.84	4.89	5.15
Median Concentration	1.89	2.39	1.45	1.53
Standard Deviation	2.09	2.15	1.46	1.40
COV	0.72	0.72	0.78	0.73

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-27.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Nitrite (mg/L)
IDL = 0.25 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	0.24 ^b	0.15 ^b	0.84 ^b	0.35 ^b
2	0.04 ^b	0.04 ^b	0.06 ^b	0.00 ^b
3	0.05 ^b	0.06 ^b	0.00 ^b	0.18 ^b
4	0.00 ^b	0.00 ^b	0.15 ^b	0.00 ^b
5	0.00 ^b	0.00 ^b	0.05 ^b	0.01 ^b
6	0.00 ^b	0.00 ^b	0.00 ^b	0.00 ^b
7	0.01 ^b	0.08 ^b	0.60	0.34
8	0.01 ^b	0.06 ^b	0.15 ^b	0.09 ^b
9	0.05 ^b	0.07 ^b	0.14 ^b	0.07 ^b
10	0.08 ^b	0.00 ^b	0.04 ^b	0.00 ^b
11	0.00 ^b	0.00 ^b	NS ^a	0.00 ^b
12	0.00 ^b	0.03 ^b	0.05 ^b	NS ^a
13	0.04 ^b	0.06 ^b	0.05 ^b	0.00 ^b
Min. Concentration	0.00 ^b	0.00 ^b	0.00 ^b	0.00 ^b
Max. Concentration	0.24 ^b	0.15 ^b	0.84	0.35
Median Concentration	0.01 ^b	0.04 ^b	0.06 ^b	0.01 ^b
Standard Deviation	0.07	0.04	0.26	0.13
COV	1.61	1.02	1.48	1.51

^aNo sample available for analysis.

^bData below instrument detection limit (IDL).

TABLE B-28.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Phosphate (mg/L)
IDL = 0.25 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	0.63	0.00 ^b	0.23	0.00 ^b
2	0.00 ^b	0.00 ^b	0.00 ^b	0.00 ^b
3	0.00 ^b	0.00 ^b	0.00 ^b	1.31
4	0.00 ^b	0.68	0.89	0.52
5	0.00 ^b	0.00 ^b	0.00 ^b	0.00 ^b
6	0.00 ^b	0.00 ^b	0.00 ^b	0.00 ^b
7	0.00 ^b	0.00 ^b	0.00 ^b	0.00 ^b
8	0.00 ^b	0.00 ^b	0.00 ^b	0.00 ^b
9	0.00 ^b	0.00 ^b	0.00 ^b	0.00 ^b
10	0.00 ^b	0.00 ^b	0.00 ^b	0.00 ^b
11	0.00 ^b	0.00 ^b	NS ^a	0.00 ^b
12	0.45	0.56	0.00 ^b	NS ^a
13	0.00 ^b	0.30	0.00 ^b	0.67
Min. Concentration	0.00 ^b	0.00 ^b	0.00 ^b	0.00 ^b
Max. Concentration	0.63	0.68	0.89	1.31
Median Concentration	0.00 ^b	0.00 ^b	0.00 ^b	0.00 ^b
Standard Deviation	0.21	0.24	0.26	0.42
COV	2.48	2.02	2.78	2.01

^aNo sample available for analysis.

^bData below instrument detection limit (IDL).

TABLE B-29.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Sulfate (mg/L)
IDL = 0.25 mg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	20.09	18.13	21.69	19.93
2	2.90	2.74	3.07	4.75
3	3.91	3.54	3.18	12.89
4	3.51	10.75	10.04	8.33
5	4.11	3.81	5.47	6.03
6	1.02	1.51	1.34	1.93
7	14.49	15.41	14.82	12.34
8	12.70	13.86	12.64	12.98
9	11.51	11.53	12.08	12.78
10	10.42	11.92	12.33	13.82
11	23.90	23.67	NS ^a	24.71
12	15.65	17.46	15.55	NS ^a
13	6.66	6.80	7.31	8.13
Min. Concentration	1.02	1.51	1.34	1.93
Max. Concentration	23.90	23.67	21.69	24.71
Median Concentration	10.42	11.53	11.06	12.56
Standard Deviation	7.15	6.86	6.06	6.37
COV	0.71	0.63	0.61	0.55

^aNo sample available for analysis.

TABLE B-30.
MCTT PERFORMANCE DATA -UNFILTERED SAMPLES
Bicarbonate (mg/L)

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	61.05	29.60	35.73	14.91
2	41.66	34.58	34.24	8.91
3	44.92	37.21	39.89	5.74
4	80.33	47.89	50.66	13.66
5	22.95	25.63	32.28	12.87
6	12.37	15.84	27.41	17.61
7	21.28	20.29	33.16	17.62
8	36.62	40.68	37.91	21.18
9	27.22	25.24	42.16	21.58
10	26.63	33.16	50.28	19.40
11	46.30	45.12	NS *	13.86
12	43.71	46.08	50.23	NS *
13	23.74	23.94	35.45	16.23
Min. Concentration	12.37	15.84	27.41	5.74
Max. Concentration	80.33	47.89	50.66	21.58
Median Concentration	36.62	33.16	36.82	15.57
Standard Deviation	18.48	10.34	7.75	4.72
COV	0.49	0.32	0.20	0.31

*No sample available for analysis.

TABLE B-31.
MCTT PERFORMANCE DATA -UNFILTERED SAMPLES
Carbonate (mg/L)

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	0.03	0.00	0.01	0.00
2	0.02	0.01	0.01	0.00
3	0.02	0.01	0.01	0.00
4	0.06	0.03	0.03	0.00
5	0.01	0.01	0.01	0.00
6	0.00	0.00	0.01	0.01
7	0.01	0.01	0.01	0.00
8	0.01	0.01	0.01	0.00
9	0.00	0.00	0.01	0.00
10	0.01	0.01	0.02	0.01
11	0.03	0.02	NS ^a	0.00
12	0.05	0.05	0.05	NS ^a
13	0.02	0.02	0.02	0.00
Min. Concentration	0.00	0.00	0.01	0.00
Max. Concentration	0.06	0.05	0.05	0.01
Median Concentration	0.02	0.01	0.01	0.00
Standard Deviation	0.02	0.01	0.01	0.00
COV	0.88	0.89	0.82	0.69

^aNo sample available for analysis.

TABLE B-32.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
Cadmium (µg/L)
IDL = 1 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	2.9	11.8	8.8	2.2
2	2.0	7.0	4.2	6.3
3	<IDL ^b	<IDL	<IDL	<IDL
4	<IDL	<IDL	<IDL	<IDL
5	<IDL	1.1	1.1	<IDL
6	<IDL	<IDL	<IDL	<IDL
7	2.1	2.3	1.7	2.3
8	2.4	2.5	2.1	2.1
9	<IDL	<IDL	<IDL	<IDL
10	<IDL	1.0	<IDL	<IDL
11	2.0	<IDL	NS ^a	<IDL
12	<IDL	<IDL	<IDL	NS
13	<IDL	<IDL	<IDL	<IDL
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	2.9	11.8	8.8	6.3
Median Concentration	<IDL	<IDL	<IDL	<IDL
Standard Deviation	1.3	3.6	2.8	2.2
COV	1.4	1.9	2.2	2.5

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-33.
MCTT PERFORMANCE DATA – FILTERED SAMPLES
Cadmium (µg/L)
IDL = 1 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	2.0	1.9	1.4	1.7
2	2.0	1.0	3.4	5.1
3	<IDL ^b	<IDL	<IDL	<IDL
4	<IDL	<IDL	<IDL	<IDL
5	<IDL	<IDL	<IDL	<IDL
6	1.0	<IDL	<IDL	<IDL
7	2.5	1.7	1.7	2.1
8	2.1	1.8	1.7	1.7
9	<IDL	<IDL	<IDL	<IDL
10	<IDL	<IDL	<IDL	<IDL
11	1.2	<IDL	NS ^a	<IDL
12	<IDL	<IDL	<IDL	NS
13	<IDL	<IDL	<IDL	<IDL
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	2.5	1.9	3.4	5.1
Median Concentration	<IDL	<IDL	<IDL	<IDL
Standard Deviation	1.3	1.1	1.4	1.8
COV	2.2	3.5	2.9	2.5

^aNo sample available for analysis.

^bData below instrument detection limit (IDL).

TABLE B-34.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
Copper (µg/L)
IDL = 0.25 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	96.7	18.0	22.3	13.1
2	11.9	16.5	7.3	30.8
3	<IDL ^b	6.5	6.1	11.1
4	32.9	47.6	23.7	38.3
5	23.0	27.3	40.6	25.4
6	25.9	24.6	22.9	22.7
7	12.7	20.0	14.4	10.8
8	23.7	36.1	23.5	16.6
9	32.6	15.6	12.7	6.5
10	25.1	33.7	9.9	7.0
11	65.0	25.3	NS ^a	4.8
12	20.8	19.4	12.5	NS
13	12.9	23.9	22.6	27.7
Min. Concentration	<IDL	6.5	6.1	4.8
Max. Concentration	96.7	47.6	40.6	38.3
Median Concentration	23.7	23.9	18.4	14.9
Standard Deviation	25.4	10.5	9.7	10.9
COV	0.86	0.43	0.53	0.61

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-35.
MCTT PERFORMANCE DATA - FILTERED SAMPLES
Copper (µg/L)
IDL = 0.25 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	13.5	14.3	13.9	10.8
2	35.6	13.4	27.8	20.2
3	6.8	55.2	35.2	28.8
4	9.8	68.4	6.3	2.6
5	26.8	21.1	27.6	23.0
6	23.5	58.9	27.3	23.7
7	12.2	14.4	11.2	80.3
8	14.4	17.4	29.3	34.1
9	9.5	11.4	13.9	25.7
10	13.3	30.6	8.1	6.6
11	28.1	20.2	NS *	11.1
12	10.3	11.8	156.2	NS *
13	12.1	13.5	6.3	0.9
Min. Concentration	6.8	11.4	6.3	0.9
Max. Concentration	35.6	68.4	156.2	80.3
Median Concentration	13.3	17.4	20.6	21.6
Standard Deviation	8.9	20.2	40.9	21.1
COV	0.53	0.75	1.4	0.95

*No sample available for analysis.

TABLE B-36.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
Lead (µg/L)
IDL = 1.25 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	70.8	15.1	4.6	<IDL
2	12.5	5.7	<IDL ^b	<IDL
3	3.5	5.0	3.0	2.5
4	12.9	14.6	6.4	5.0
5	7.6	3.5	<IDL	<IDL
6	16.0	14.4	4.2	4.2
7	11.6	22.1	4.6	2.9
8	29.8	57.3	6.3	3.9
9	33.8	15.4	2.1	<IDL
10	25.0	56.0	2.8	2.3
11	19.5	11.6	NS ^a	<IDL
12	6.7	6.7	<IDL	NS
13	18.9	15.8	<IDL	<IDL
Min. Concentration	3.5	3.5	<IDL	<IDL
Max. Concentration	70.8	57.3	6.4	5.0
Median Concentration	16.0	14.6	2.9	1.7
Standard Deviation	17.5	17.7	2.6	2.1
COV	0.85	0.94	0.92	1.2

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-37.
MCTT PERFORMANCE DATA – FILTERED SAMPLES
Lead (µg/L)
IDL = 1.25 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	<IDL ^b	3.7	1.5	3.5
2	<IDL	<IDL	<IDL	<IDL
3	4.1	6.3	<IDL	2.2
4	1.7	4.6	3.0	11.3
5	11.9	8.4	<IDL	<IDL
6	2.2	2.8	3.7	3.5
7	4.7	5.7	4.6	2.9
8	3.4	5.0	4.7	3.6
9	2.3	2.3	<IDL	1.2
10	2.1	1.4	2.5	<IDL
11	1.8	<IDL	NS ^a	<IDL
12	<IDL	<IDL	<IDL	NS
13	<IDL	<IDL	1.8	<IDL
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	11.9	8.4	4.7	11.3
Median Concentration	2.1	2.8	1.7	1.7
Standard Deviation	3.4	2.9	1.9	3.3
COV	1.4	0.93	0.99	1.4

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-38.
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Zinc (µg/L)
IDL = 0.5 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	225	164	198	31
2	4022	53	43	2578
3	42	44	31	17
4	96	235	37	99
5	68	4.5	12	4.6
6	50	36	26	23
7	326	187	168	11
8	178	194	76	12
9	168	155	60	11
10	191	337	80	18
11	422	286	NS *	11
12	157	169	80	NS *
13	263	109	58	24
Min. Concentration	42	4.5	12	4.6
Max. Concentration	4022	337	198	2578
Median Concentration	178	164	59	18
Standard Deviation	1071	100	57	738
COV	2.2	0.66	0.78	3.1

*No sample available for analysis.

TABLE B-39.
MCTT PERFORMANCE DATA – FILTERED SAMPLES
Zinc (µg/L)
IDL = 0.5 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	26.6	22.1	34.9	<IDL
2	5.2	5.4	7.8	2.4
3	4.3	55.4	25.5	44.0
4	13.8	107.5	57.6	74.4
5	60.2	13.6	8.4	38.0
6	1.4	4.0	7.2	1.3
7	<IDL ^b	7.5	4.4	10.5
8	28.6	39.9	57.3	18.0
9	24.5	27.7	40.2	6.1
10	43.5	40.3	50.2	6.6
11	7.8	12.3	NS ^a	<IDL
12	13.3	11.8	11.0	NS
13	6.7	2.2	5.6	<IDL
Min. Concentration	<IDL	2.2	4.4	<IDL
Max. Concentration	60.2	107.5	57.6	74.4
Median Concentration	13.3	13.6	18.3	6.4
Standard Deviation	18.0	29.3	21.2	23.6
COV	0.99	1.1	0.82	1.4

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B- 40.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
Phenol (µg/L)
IDL = 0.38 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	8.04	0.97	1.15	<IDL
2	0.71	<IDL	<IDL	<IDL
3	<IDL ^b	<IDL	<IDL	<IDL
4	<IDL	<IDL	<IDL	<IDL
5	0.40	0.77	4.62	<IDL
6	0.59	1.22	<IDL	<IDL
7	<IDL	<IDL	<IDL	2.01
8	1.01	5.00	0.38	<IDL
9	0.40	<IDL	<IDL	<IDL
10	<IDL	0.38	1.39	<IDL
11	1.31	1.80	NS ^a	<IDL
12	<IDL	0.53	2.88	NS
13	2.14	1.00	0.76	3.98
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	8.04	5.00	4.62	3.98
Median Concentration	0.40	0.53	<IDL	<IDL
Standard Deviation	2.16	1.39	1.50	1.36
COV	1.88	1.39	1.69	4.12

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-41.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
N-Nitroso-di-n-propylamine (µg/L)
IDL = 1.0 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	39.75	1.39	2.45	<IDL
2	7.11	2.12	<IDL	<IDL
3	<IDL ^b	<IDL	<IDL	<IDL
4	0.36	1.01	<IDL	<IDL
5	3.94	4.78	3.38	2.51
6	3.99	<IDL	<IDL	<IDL
7	<IDL	<IDL	-0.88	<IDL
8	1.45	<IDL	4.83	<IDL
9	10.65	<IDL	<IDL	<IDL
10	<IDL	4.13	1.11	<IDL
11	<IDL	<IDL	NS ^a	4.03
12	2.42	5.26	<IDL	NS
13	<IDL	<IDL	2.68	9.17
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	39.75	5.26	4.83	9.17
Median Concentration	1.45	<IDL	<IDL	<IDL
Standard Deviation	10.89	3.02	1.68	3.06
COV	2.06	3.77	1.30	2.88

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-42.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
Hexachloroethane (µg/L)
IDL = 0.40 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	2.26	0.40	<IDL	<IDL
2	2.38	4.74	0.89	<IDL
3	<IDL ^b	<IDL	<IDL	<IDL
4	<IDL	<IDL	<IDL	<IDL
5	1.76	2.72	<IDL	<IDL
6	1.67	2.23	0.45	<IDL
7	<IDL	<IDL	<IDL	<IDL
8	<IDL	<IDL	2.96	<IDL
9	0.45	7.70	0.89	7.12
10	<IDL	0.66	1.33	<IDL
11	<IDL	1.20	NS ^a	1.30
12	1.93	1.66	1.32	NS
13	1.10	1.18	<IDL	6.58
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	2.38	7.70	2.96	7.12
Median Concentration	0.45	1.18	<IDL	<IDL
Standard Deviation	1.03	2.42	1.02	2.83
COV	1.21	1.53	1.86	3.01

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-43.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
Nitrobenzene (µg/L)
IDL = 0.48 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	12.81	<IDL	4.46	<IDL
2	2.36	2.44	<IDL	<IDL
3	<IDL ^b	<IDL	<IDL	<IDL
4	<IDL	<IDL	<IDL	<IDL
5	1.13	1.84	<IDL	<IDL
6	<IDL	0.63	<IDL	<IDL
7	2.52	1.94	<IDL	<IDL
8	0.86	2.76	<IDL	1.19
9	2.07	<IDL	0.73	1.13
10	<IDL	<IDL	2.04	0.75
11	<IDL	1.02	NS ^a	0.74
12	<IDL	<IDL	<IDL	NS
13	<IDL	0.54	<IDL	<IDL
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	12.81	2.76	4.46	1.19
Median Concentration	<IDL	0.54	<IDL	<IDL
Standard Deviation	3.56	1.08	2.44	1.39
COV	2.28	1.31	97.61	-3.97

^aNo sample available for analysis.

^bData below instrument detection limit (IDL).

TABLE B-44.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
2-Nitrophenol (µg/L)
IDL = 0.90 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	<IDL ^b	<IDL	1.02	<IDL
2	<IDL	<IDL	<IDL	<IDL
3	<IDL	<IDL	<IDL	<IDL
4	<IDL	<IDL	<IDL	<IDL
5	1.24	1.69	1.50	1.84
6	2.96	1.30	3.01	1.83
7	<IDL	<IDL	<IDL	<IDL
8	<IDL	<IDL	<IDL	<IDL
9	5.87	2.24	5.65	2.92
10	<IDL	<IDL	<IDL	<IDL
11	1.87	<IDL	NS ^a	<IDL
12	4.96	0.91	2.77	NS
13	3.89	<IDL	<IDL	6.28
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	5.87	2.24	5.65	6.28
Median Concentration	<IDL	<IDL	<IDL	<IDL
Standard Deviation	2.12	0.98	2.01	2.03
COV	1.37	3.22	2.09	2.11

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-45.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
2,4 Dimethyphenol (µg/L)
IDL = 0.68 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	<IDL ^b	5.82	11.23	<IDL
2	<IDL	<IDL	<IDL	<IDL
3	1.76	<IDL	<IDL	<IDL
4	<IDL	<IDL	<IDL	<IDL
5	16.74	81.25	<IDL	<IDL
6	3.60	<IDL	<IDL	<IDL
7	<IDL	3.73	<IDL	1.10
8	<IDL	<IDL	2.34	0.93
9	2.65	3.52	2.06	1.70
10	<IDL	<IDL	<IDL	<IDL
11	1.11	<IDL	NS ^a	<IDL
12	0.95	1.46	1.34	NS
13	0.69	2.12	<IDL	1.56
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	16.74	81.25	11.23	1.70
Median Concentration	0.69	<IDL	<IDL	<IDL
Standard Deviation	7.20	22.97	5.38	4.72
COV	41.98	3.81	-5.53	-1.95

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-46.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
Hexachlorobutadiene (µg/L)
IDL = 0.22 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	15.95	3.70	5.90	<IDL
2	3.31	<IDL	<IDL	<IDL
3	<IDL ^b	<IDL	<IDL	<IDL
4	<IDL	1.44	1.08	<IDL
5	28.91	26.19	3.34	1.90
6	6.20	5.82	1.66	<IDL
7	0.56	<IDL	<IDL	<IDL
8	0.71	5.56	2.00	<IDL
9	<IDL	2.10	<IDL	0.29
10	<IDL	1.24	1.62	<IDL
11	1.25	0.91	NS ^a	4.05
12	<IDL	2.42	5.54	NS
13	3.85	<IDL	<IDL	13.91
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	28.91	26.19	5.90	13.91
Median Concentration	0.71	1.44	1.35	<IDL
Standard Deviation	9.07	7.20	2.46	5.48
COV	2.28	2.05	1.70	19.97

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-47.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
4-Chloro-3-methyphenol (µg/L)
IDL = 0.75 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	6.83	1.87	2.65	<IDL
2	1.09	<IDL	2.01	<IDL
3	<IDL ^b	1.69	<IDL	<IDL
4	<IDL	<IDL	<IDL	<IDL
5	19.67	1.11	5.43	3.52
6	9.51	9.03	7.44	3.01
7	1.95	5.31	<IDL	4.01
8	2.32	<IDL	3.89	<IDL
9	<IDL	<IDL	<IDL	<IDL
10	3.70	8.87	9.37	6.51
11	4.32	8.75	NS ^a	3.56
12	<IDL	5.79	<IDL	NS
13	3.54	<IDL	<IDL	<IDL
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	19.67	9.03	9.37	6.51
Median Concentration	2.32	1.69	1.21	<IDL
Standard Deviation	9.68	7.76	4.78	4.94
COV	6.30	6.56	3.33	11.09

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-48.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
4-Nitrophenol (µg/L)
IDL = 0.60 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	<IDL ^b	6.90	<IDL	0.69
2	2.04	<IDL	<IDL	<IDL
3	<IDL	<IDL	<IDL	<IDL
4	<IDL	0.61	<IDL	<IDL
5	7.68	2.72	<IDL	<IDL
6	<IDL	<IDL	<IDL	<IDL
7	18.78	11.24	<IDL	47.63
8	1.26	27.00	<IDL	<IDL
9	<IDL	<IDL	<IDL	<IDL
10	17.81	119.95	88.2	13.83
11	105.28	20.69	NS ^a	35.99
12	29.80	44.40	120.98	NS
13	32.57	12.55	48.63	380.74
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	105.28	119.95	120.98	380.74
Median Concentration	2.04	6.90	<IDL	<IDL
Standard Deviation	33.45	40.43	51.57	114.60
COV	2.74	3.29	5.30	4.05

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-49.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
Pentachlorophenol (µg/L)
IDL = 0.90 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	<IDL ^b	<IDL	0.99	3.12
2	1.21	<IDL	<IDL	<IDL
3	<IDL	<IDL	<IDL	<IDL
4	<IDL	<IDL	<IDL	<IDL
5	17.55	46.46	<IDL	<IDL
6	<IDL	<IDL	4.91	<IDL
7	<IDL	<IDL	<IDL	<IDL
8	8.54	4.23	<IDL	<IDL
9	14.07	15.10	<IDL	<IDL
10	<IDL	<IDL	<IDL	1.82
11	2.01	<IDL	NS ^a	<IDL
12	<IDL	1.35	<IDL	NS
13	2.44	<IDL	1.79	7.88
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	17.55	46.46	4.91	7.88
Median Concentration	<IDL	<IDL	<IDL	<IDL
Standard Deviation	6.47	13.44	4.41	5.83
COV	2.20	3.02	-2.35	-2.20

^a No sample available for analysis.

^b Data below instrument detection limit (IDL).

TABLE B-50.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
Fluoranthene (µg/L)
IDL = 0.55 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	1.05	<IDL	<IDL	<IDL
2	<IDL ^b	<IDL	<IDL	<IDL
3	<IDL	<IDL	<IDL	<IDL
4	<IDL	<IDL	<IDL	<IDL
5	1.44	1.24	<IDL	<IDL
6	<IDL	<IDL	<IDL	<IDL
7	<IDL	<IDL	<IDL	<IDL
8	1.38	1.22	<IDL	<IDL
9	0.74	<IDL	<IDL	<IDL
10	<IDL	<IDL	<IDL	<IDL
11	0.97	<IDL	NS ^a	<IDL
12	<IDL	<IDL	<IDL	NS
13	<IDL	0.88	<IDL	<IDL
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	1.44	1.24	<IDL	<IDL
Median Concentration	<IDL	<IDL	<IDL	<IDL
Standard Deviation	0.52	0.42	0.09	0.08
COV	0.98	0.96	-25.6	-6.70

^aNo sample available for analysis.

^bData below instrument detection limit (IDL).

TABLE B-51.
MCTT PERFORMANCE DATA – FILTERED SAMPLES
Pyrene (µg/L)
IDL = 0.48 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	0.83	<IDL	<IDL	<IDL
2	<IDL ^b	<IDL	<IDL	<IDL
3	<IDL	<IDL	<IDL	<IDL
4	<IDL	<IDL	<IDL	<IDL
5	0.52	0.52	<IDL	<IDL
6	<IDL	<IDL	<IDL	<IDL
7	<IDL	<IDL	<IDL	<IDL
8	0.53	0.68	<IDL	<IDL
9	0.54	<IDL	<IDL	<IDL
10	<IDL	<IDL	<IDL	<IDL
11	0.79	0.50	NS ^a	<IDL
12	<IDL	<IDL	<IDL	NS
13	0.48	0.77	<IDL	<IDL
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	0.83	0.77	<IDL	<IDL
Median Concentration	<IDL	<IDL	<IDL	<IDL
Standard Deviation	0.28	0.25	0.05	0.03
COV	0.79	0.81	-7.19	-0.87

^aNo sample available for analysis.

^bData below instrument detection limit (IDL).

TABLE B-52.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
Bis(2-ethylhexyl) phthalate (µg/L)
IDL = 0.62 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	2.11	0.76	<IDL	<IDL
2	<IDL ^b	1.48	<IDL	<IDL
3	<IDL	<IDL	<IDL	<IDL
4	1.30	0.86	<IDL	<IDL
5	9.85	10.34	<IDL	<IDL
6	0.78	1.66	<IDL	<IDL
7	4.51	3.26	<IDL	<IDL
8	2.88	3.94	<IDL	0.66
9	1.52	<IDL	<IDL	<IDL
10	0.94	2.08	<IDL	<IDL
11	3.35	2.40	NS ^a	<IDL
12	2.98	3.58	<IDL	NS
13	2.19	1.92	<IDL	<IDL
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	9.85	10.34	<IDL	0.66
Median Concentration	2.11	1.92	<IDL	<IDL
Standard Deviation	2.55	2.64	0.25	0.32
COV	1.01	1.05	4.73	-8.93

^aNo sample available for analysis.

^bData below instrument detection limit (IDL).

TABLE B-53.
MCTT PERFORMANCE DATA – UNFILTERED SAMPLES
Di-n-octylphthalate (µg/L)
IDL = 0.62 µg/L

Storm Event Number	MCTT and Catch Basin Inlet	Catch Basin to Settling Chamber	Settling Chamber to Peat-sand	MCTT and Peat-sand Outlet
1	0.96	<IDL	<IDL	<IDL
2	<IDL ^b	<IDL	<IDL	<IDL
3	<IDL	<IDL	<IDL	<IDL
4	0.69	<IDL	<IDL	<IDL
5	0.86	0.72	<IDL	<IDL
6	<IDL	<IDL	<IDL	<IDL
7	<IDL	<IDL	<IDL	<IDL
8	<IDL	<IDL	<IDL	<IDL
9	<IDL	<IDL	<IDL	<IDL
10	<IDL	<IDL	<IDL	<IDL
11	0.73	0.63	NS ^a	<IDL
12	<IDL	0.72	<IDL	NS
13	<IDL	<IDL	<IDL	<IDL
Min. Concentration	<IDL	<IDL	<IDL	<IDL
Max. Concentration	0.96	0.72	<IDL	<IDL
Median Concentration	<IDL	<IDL	<IDL	<IDL
Standard Deviation	0.32	0.25	0.06	0.04
COV	0.82	0.71	3.15	-13.50

^aNo sample available for analysis.

^bData below instrument detection limit (IDL).

Table B-54. Observed MCTT Influent Pesticide Concentrations (µg/L)

Sample	Storm Event	Chamber	Filtered	alpha-BHC	gamma-BHC	heptachlor	beta-BHC	delta-BHC	aldrin	heptachlor epoxide	endosulfan I	4,4'-DDE
estimated MDL (ng/L)				8	3	7	2	9	48	11	15	26
874	1	I	N						530	20		
908	2	I	N				12		197			
936	3	I	N				17		82			
964	4	I	N				24		96			
992	5	I	N		18		31		133			
1020	6	I	N				6		49			
1048	7	I	N				35	17	941			
1097	8	I	N				12		140			
1287	9	I	N		23		12		284			
1315	10	I	N			11			656	15		
1403	11	I	N				11		181			
1512	12	I	N				10		59			
1621	13	I	N				3		105			
876	1	I	F	14			17		626		37	
910	2	I	F				9		146			
938	3	I	F				10		85			
966	4	I	F				11		68			
994	5	I	F				18		97			
1022	6	I	F				5					
1050	7	I	F				29		838			
1099	8	I	F				8		102			
1289	9	I	F						512			
1317	10	I	F						979			
1405	11	I	F				5		89			
1514	12	I	F			9	7		33			
1623	13	I	F				4		65			

Continued

Table B-54. Continued

Sample	Storm Event	Chamber	Filtered	dieldrin	endrin	4,4'-DDD	endosulfan II	4,4'-DDT	endrin aldehyde	endosulfan sulfate	methoxychlor	endrin ketone
estimated MDL (ng/L)				12	26	7	5	31	47	8	39	7
874	1 I	N		169		142		139		47	170	11
908	2 I	N		140		52				28	51	
936	3 I	N		49		21				9	41	
964	4 I	N		23	39	45		152		35	138	8
992	5 I	N		121		32		60		44	186	25
1020	6 I	N								12		
1048	7 I	N		170	42	139		51		75	296	11
1097	8 I	N		55	46	104		113		83	330	17
1287	9 I	N		112	48	95				104		19
1315	10 I	N		154	37	185				85	335	17
1403	11 I	N		26	67	103	6	68		98		18
1512	12 I	N			36	49		35		27	251	15
1621	13 I	N			26	20				29	181	17
876	1 I	F		171		143				16		10
910	2 I	F		103		45				11		
938	3 I	F		56		26				36		7
968	4 I	F			35	49				11		88
994	5 I	F		72		28				20		20
1022	6 I	F										
1050	7 I	F		35	29	114					92	9
1099	8 I	F		61	32	94		66		13		37
1289	9 I	F		103	37	91		108		13	113	7
1317	10 I	F		110	40	201				11	40	17
1405	11 I	F		35	50	89	8	61		15	121	72
1514	12 I	F			29	48		31		10	92	40
1623	13 I	F				15		39		12		28

Table B-55. Observed Pesticide Concentrations after Grit Chamber and before Main Settling Chamber (µg/L)

Sample	Storm Event	Chamber	Filtered	alpha-BHC	gamma-BHC	heptachlor	beta-BHC	delta-BHC	aldrin	heptachlor epoxide	endosulfan I	4,4'-DDE
estimated MDL (ng/L)				8	3	7	2	9	48	11	15	26
877	1 II	N		13					515			
911	2 II	N					8		165			
939	3 II	N					10		104			
987	4 II	N					13		98		15	
995	5 II	N					22		113			
1023	6 II	N					7		83			
1051	7 II	N					31		843			
1100	8 II	N					9		84			
1290	9 II	N			24				299			
1318	10 II	N				8			148			
1406	11 II	N					5		108			
1515	12 II	N					4		53			
1624	13 II	N			4		6		138			
900	1 II	F		17					832			
913	2 II	F					12		184			
941	3 II	F					11		100			
989	4 II	F					12		80			
997	5 II	F					25		111			
1025	6 II	F					3					
1053	7 II	F					31		841			
1102	8 II	F		8			8					
1292	9 II	F					16		611			
1320	10 II	F				12			747			
1408	11 II	F		11					117			
1517	12 II	F				8	3					
1626	13 II	F					4		60			

Continued

Table B-55. Continued

Sample	Storm Event	Chamber	Filtered	dieldrin	endrin	4,4'-DDD	endosulfan II	4,4'-DDT	endrin aldehyde	endosulfan sulfate	methoxychlor	endrin ketone
estimated MDL (ng/L)				12	26	7	5	31	47	8	39	7
877	1 II	N		203		112				77	337	16
911	2 II	N		92		37				27	48	11
939	3 II	N		60		27						8
967	4 II	N		25	41	49				24		94
995	5 II	N		63		28				47	225	
1023	6 II	N								8		
1051	7 II	N		156	37	129		99		75	303	11
1100	8 II	N		50	57	108		79		83	326	21
1290	9 II	N			44	108				103	438	7
1318	10 II	N		107	49	208				102	95	18
1406	11 II	N		26	38	114				100	225	23
1515	12 II	N			39	41				26	78	15
1624	13 II	N				22				37	40	14
900	1 II	F		232		125				8		18
913	2 II	F		131		52				10		10
941	3 II	F		66		29				41		9
969	4 II	F		27	41	47				11		79
997	5 II	F		112		31				21		17
1025	6 II	F										
1053	7 II	F		115	39	133		92			108	10
1102	8 II	F		53	35	100		73		15		44
1292	9 II	F		136	41	105		93		17	109	
1320	10 II	F		117	50	234				50	218	19
1408	11 II	F		38	56	105		56		19		79
1517	12 II	F			37	42				11	126	41
1626	13 II	F				17				11		28

Table B-56. Observed Pesticide Concentrations after Main Settling Chamber and before Final MCTT Chamber ($\mu\text{g/L}$)

Sample	Storm Event	Chamber	Filtered	alpha-BHC	gamma-BHC	heptachlor	beta-BHC	delta-BHC	aldrin	heptachlor epoxide	endosulfan I	4,4'-DDE
estimated MDL (ng/L)				8	3	7	2	9	48	11	15	28
879	1	III	N	16			15		501			
914	2	III	N				9		60			
950	3	III	N				10		66			
970	4	III	N				22		52			
998	5	III	N				5					
1026	6	III	N	667	1938	1710	1927	1250	2672	4633	4147	7448
1026	6	III	N	785	2305	1828	2092	1451	3122	5339	5173	8288
1054	7	III	N						131			
1103	8	III	N				10					
1293	9	III	N				9		72			
1321	10	III	N				7		60			
1518	12	III	N									
1627	13	III	N				9					
881	1	III	F	14			15		600			
916	2	III	F				7		58			
952	3	III	F				9		53			
972	4	III	F				17		51			
1000	5	III	F				6		70			
1028	6	III	F	14	48	44	39	46	117	119	129	135
1028	6	III	F	18	54	46	40	48	133	123	132	142
1056	7	III	F						170			
1105	8	III	F	16			7		30			
1295	9	III	F						101			
1323	10	III	F				8		80			
1520	12	III	F				3					
1629	13	III	F				9					

Continued

Table B-57. Observed Pesticide Concentrations in MCTT Effluent (µg/L)

Sample	Storm Event	Chamber	Filtered	alpha-BHC	gamma-BHC	heptachlor	beta-BHC	delta-BHC	aldrin	heptachlor epoxide	endosulfan I	4,4'-DDE
estimated MDL (ng/L)				8	3	7	2	9	48	11	15	26
882	1	IV	N	9			10					
917	2	IV	N				9					
953	3	IV	N				9					
973	4	IV	N				18					
1001	5	IV	N				5					
1029	6	IV	N	13	58	49	46	65	135	222	249	308
1029	6	IV	N	15	68	57	55	76	163	265	296	386
1057	7	IV	N	10			9		66			
1106	8	IV	N				6					
1296	9	IV	N				6					
1324	10	IV	N				8					
1412	11	IV	N				15					
1630	13	IV	N				7					
901	1	IV	F				10					
919	2	IV	F				10					
955	3	IV	F				11					
975	4	IV	F				22					
1003	5	IV	F				6					
1031	6	IV	F	23	75	66	56	63	145	177	191	218
1031	6	IV	F	23	76	63	55	65	152	177	193	215
1059	7	IV	F	12			10		68			
1108	8	IV	F				8					
1298	9	IV	F				6					
1326	10	IV	F				9					
1414	11	IV	F				9					
1632	13	IV	F				8					

Continued

Table B-57. Continued

Sample	Storm Event	Chamber	Filtered	dieldrin	endrin	4,4'-DDD	endosulfan II	4,4'-DDT	endrin aldehyde	endosulfan sulfate	methoxychlor	endrin ketone
estimated MDL (ng/L)				12	26	7	5	31	47	8	39	7
882	1 IV	N				24						19
917	2 IV	N				14						
953	3 IV	N				9					63	
973	4 IV	N			29	28						62
1001	5 IV	N				10						
1029	6 IV	N		293	388	309	287	247	188	297	350	326
1029	6 IV	N		383	32	370	336	274	226	349	378	362
1057	7 IV	N			492	63				18		41
1106	8 IV	N			32	23				12	68	43
1296	9 IV	N			35	17				38	164	41
1324	10 IV	N				24				20	37	21
1412	11 IV	N			32	30				14	77	20
1630	13 IV	N				9				9		33
901	1 IV	F				28						
919	2 IV	F				14						
955	3 IV	F				7					62	
975	4 IV	F			40	30		39		10		37
1003	5 IV	F				12						
1031	6 IV	F		238	283	224	221	192	155	228	234	247
1031	6 IV	F		254	31	228	225	163	164	220	184	240
1059	7 IV	F		23	283	70				18		7
1108	8 IV	F			32	66				9		17
1298	9 IV	F				52				9	65	11
1326	10 IV	F				76						11
1414	11 IV	F			32	43		37		8	76	12
1632	13 IV	F				11				8		7

Appendix C
Source Area Pollutant Observations

Table C-6. Vehicle Service Area Runoff Sheetflow Quality Observations (Continued)

	S4-Car Service	
	Non-filtered	Filtered
Microtox Toxicity		
I10 (% light decrease)	44	45
I35 (% light decrease)	49	50
EC50 (fraction)		
Other Constituents		
pH	5.3	
Suspended solids (mg/L)	20	
Turbidity (NTU)	21	
Particle Size		
10% larger (by vol.) than:	66	
25	63	
50	60	
75	57	
85	55	
90	54	
95	52	
99	47	
Base Neutrals Detected ($\mu\text{g/L}$)		
Bis(2-chloroethyl) ether		
1,3-Dichlorobenzene		
Bis(chloroisopropyl) ether		
Hexachloroethane		
Naphthalene		
Acenaphylene		
Fluorene		
Phenanthrene		
Anthracene		
Benzyl butyl phthalate		
Fluoranthene		
Pyrene		
Benzo(a) anthracene		
Chrysene		
Benzo(b) fluoranthene		
Benzo(k) fluoranthene		
Benzo(a) pyrene		
Pesticides Detected		
Chlordane		
Methoxychlor	0.3	
Heavy Metals Detected		
Aluminum	93	<5
Cadmium	2.4	0.50
Chromium	11	2.5
Copper	76	24
Lead	27	3.4
Nickel	62	31
Zinc	234	234

Appendix D

Receiving Water Impacts

The main purpose of treating stormwater is to reduce its adverse impacts on receiving water beneficial uses. Therefore, it is important in any urban stormwater runoff study to assess the detrimental effects that runoff is actually having on a receiving water. Urban receiving waters may have many beneficial use goals, including:

- stormwater conveyance (flood prevention)
- biological uses (warm water fishery, biological integrity, etc.)
- non-contact recreation (linear parks, aesthetics, boating, etc.)
- contact recreation (swimming)
- water supply

With full development in an urban watershed and with no stormwater controls, it is unlikely that any of these uses can be obtained. With less development and with the application of stormwater controls, some uses may be possible. It is important that unreasonable expectations not be placed on urban waters, as the cost to obtain these uses may be prohibitive. With full-scale development and lack of adequate stormwater controls, severely degraded streams will be common. However, stormwater conveyance and aesthetics should be the basic beneficial use goals for all urban waters. Biological integrity should also be a goal, but with the realization that the natural stream ecosystem will be severely modified with urbanization. Certain basic controls, installed at the time of development, plus protection of stream habitat, may enable partial use of some of these basic goals in urbanized watersheds. Careful planning and optimal utilization of stormwater controls are necessary to obtain these basic goals in most watersheds. Water contact recreation, consumptive fisheries, and water supplies are not appropriate goals for most urbanized watersheds. These higher uses may be possible in urban areas where the receiving waters are large and drain mostly undeveloped areas.

In general, monitoring of urban stormwater runoff has indicated that the biological beneficial uses of urban receiving waters are most likely affected by habitat destruction and long-term pollutant exposures (especially to macroinvertebrates via contaminated sediment), while documented effects associated from acute exposures of toxicants in the water column are rare (Field and Pitt 1990; Pitt 1994; Pitt 1995). Receiving water pollutant concentrations resulting from runoff events and typical laboratory bioassay test results have not indicated many significant short-term receiving water problems. As an example, Lee and Jones-Lee (1993) state that exceedences of numeric criteria by short-term discharges do not necessarily imply that a beneficial use impairment exists. Many toxicologists and water quality experts have concluded that the relatively short periods of exposures to the toxicant concentrations in stormwater are not sufficient to produce the receiving water effects that are evident in urban receiving waters, especially considering the relatively large portion of the toxicants that are associated with particulates (Lee and Jones-Lee 1995). Lee and Jones-Lee (1995) conclude that the biological problems evident in urban receiving waters are mostly associated with illegal discharges and that the sediment bound toxicants are of little risk. Mancini and Plummer (1986) have long been advocates of numeric water quality standards for stormwater that reflect the partitioning of the toxicants and the short periods of exposure during rains. Unfortunately, this approach attempts to isolate individual runoff events and does not consider the accumulative adverse effects caused by the frequent exposures of receiving water organisms to stormwater (Davies 1995; Herricks, *et al.* 1996a and 1996b). Recent investigations have identified acute toxicity problems associated with short-term (about 10 to 20 day) exposures to adverse toxicant concentrations in urban receiving streams (Crunkilton, *et al.*

Cedar swamps in the New Jersey Pine Barrens were studied by Ehrenfeld and Schneider (1983). They examined nineteen wetlands subjected to varying amounts of urbanization. Typical plant species were lost and replaced by weeds and exotic plants in urban runoff affected wetlands. Increased uptakes of phosphorus and lead in the plants were found. It was concluded that the presence of stormwater runoff to the cedar swamps caused marked changes in community structure, vegetation dynamics, and plant tissue element concentrations.

Medeiros and Coler (1982) and Medeiros, *et al.* (1984) used a combination of laboratory and field studies to investigate the effects of urban runoff on fathead minnows. Hatchability, survival, and growth were assessed in the laboratory in flow-through and static bioassay tests. Growth was reduced to one half of the control growth rates at 60 percent dilutions of urban runoff. The observed effects were believed to be associated with a combination of toxicants.

The University of Washington (Pederson 1981; Richey, *et al.* 1981; Perkins 1982; Richey 1982; Scott, *et al.* 1982; Ebbert, *et al.* 1983; Pitt and Bissonnette 1984; and Prych and Ebbert undated) conducted a series of studies to contrast the biological and chemical conditions in urban Kelsey Creek with rural Bear Creek in Bellevue, Washington. The urban creek was significantly degraded when compared to the rural creek, but still supported a productive, but limited and unhealthy salmonid fishery. Many of the fish in the urban creek, however, had respiratory anomalies. The urban creek was not grossly polluted, but flooding from urban developments had increased dramatically in recent years. These increased flows dramatically changed the urban stream's channel, by causing unstable conditions with increased stream bed movement, and by altering the availability of food for the aquatic organisms. The aquatic organisms were very dependent on the few relatively undisturbed reaches. Dissolved oxygen concentrations in the sediments depressed embryo salmon survival in the urban creek. Various organic and metallic priority pollutants were discharged to the urban creek, but most of them were apparently carried through the creek system by the high storm flows to Lake Washington. The urbanized Kelsey Creek also had higher water temperatures (probably due to reduced shading) than Bear Creek. This probably caused the faster fish growth in Kelsey Creek.

The fish population in the urbanized Kelsey Creek had adapted to its degrading environment by shifting the species composition from coho salmon to less sensitive cutthroat trout and by making extensive use of less disturbed refuge areas. Studies of damaged gills found that up to three-fourths of the fish in Kelsey Creek were affected with respiratory anomalies, while no cutthroat trout and only two of the coho salmon sampled in the forested Bear Creek had damaged gills. Massive fish kills in Kelsey Creek and its tributaries were also observed on several occasions during the project due to the dumping of toxic materials down the storm drains.

There were also significant differences in the numbers and types of benthic organisms found in urban and forested creeks during the Bellevue research. Mayflies, stoneflies, caddisflies, and beetles were rarely observed in the urban Kelsey Creek, but were quite abundant in the forested Bear Creek. These organisms are commonly regarded as sensitive indicators of environmental degradation. One example of degraded conditions in Kelsey Creek was shown by a species of clams (*Unionidae*) that was not found in Kelsey Creek, but was commonly found in Bear Creek. These clams are very sensitive to heavy siltation and unstable sediments. Empty clam shells, however, were found buried in the Kelsey Creek sediments indicating their previous presence in the creek and their inability to adjust to the changing conditions. The benthic organism composition in Kelsey Creek varied radically with time and place while the organisms were much more stable in Bear Creek.

Urban runoff impact studies were conducted in the Hillsborough River near Tampa Bay, Florida, as part of the U.S. EPA's Nationwide Urban Runoff Program (NURP) (Mote Marine Laboratory 1984). Plants, animals, sediment, and water quality were all studied in the field and supplemented by laboratory bioassay tests. Effects of salt water intrusion and urban runoff were both measured because of the estuarine environment. During wet weather, freshwater species were found closer to the Bay than during dry weather. In coastal areas, these additional natural factors made it even more difficult to identify the cause and effect relationships for aquatic life problems. During another NURP project, Striegl (1985) found that

the effects of accumulated pollutants in Lake Ellyn (Glen Ellyn, Ill.) inhibited desirable benthic invertebrates and fish and increased undesirable phytoplankton blooms.

The number of benthic organism taxa in Shabakunk Creek in Mercer County, New Jersey, declined from 13 in relatively undeveloped areas to four below heavily urbanized areas (Garie and McIntosh 1986 and 1990). Periphyton samples were also analyzed for heavy metals with significantly higher metal concentrations found below the heavily urbanized area than above.

Many of the above noted biological effects associated with urban runoff are likely caused by polluted sediments and benthic organism impacts. Examples of heavy metal and nutrient accumulations in sediments are numerous. In addition to the studies noted above, DePinto, *et al.* (1980) found that the cadmium content of river sediments can be more than 1,000 times greater than the overlying water concentrations and the accumulation factors in sediments are closely correlated with sediment organic content. Another comprehensive study on polluted sediment was conducted by Wilber and Hunter (1980) along the Saddle River in New Jersey where they found significant increases in sediment contamination with increasing urbanization.

The effects of urban runoff on receiving water aquatic organisms or other beneficial uses is very site specific. Different land development practices create substantially different runoff flow characteristics. Different rain patterns cause different particulate washoff, transport and dilution conditions. Local attitudes also define specific beneficial uses and, therefore, current problems. There is also a wide variety of water types receiving urban runoff, and these waters all have watersheds that are urbanized to various degrees. Therefore, it is not surprising that urban runoff effects, though generally dramatic, are also quite variable and site specific. Claytor (1996a) summarized the approach developed by the Center for Watershed Protection as part of their EPA sponsored research on stormwater indicators (Claytor and Brown 1996). The 26 stormwater indicators used for assessing receiving water conditions were divided into six broad categories: water quality, physical/hydrological, biological, social, programmatic, and site. These were presented as tools to measure stress (impacting receiving waters), to assess the resource itself, and to indicate stormwater control program implementation effectiveness. The biological communities in Delaware's Piedmont streams have been severely impacted by stormwater, after the extent of imperviousness in the watersheds exceeds about 8 to 15%, according to a review article by Claytor (1996c). If just conventional water quality measures are used, almost all (87%) of the state's non-tidal streams supported their designated biological uses. However, when biological assessments are included, only 13% of the streams were satisfactory.

Changes in physical stream channel characteristics can have a significant effect on the biological health of the stream. Schueler (1996) stated that channel geometry stability can be a good indicator of the effectiveness of stormwater control practices. He also found that once a watershed area has more than about 10 to 15% effective impervious cover, noticeable changes in channel morphology occur, along with quantifiable impacts on water quality, and biological conditions. Stephenson (1996) studied changes in streamflow volumes in South Africa during urbanization. He found increased stormwater runoff, decreases in the groundwater table, and dramatically decreased times of concentration. The peak flow rates increased by about two-fold, about half caused by increased pavement (in an area having only about 5% effective impervious cover), with the remainder caused by decreased times of concentration.

Fates of Stormwater Pollutants in Surface Waters

Many processes may affect urban runoff pollutants after discharge. Sedimentation in the receiving water is the most common fate mechanism because many of the pollutants investigated are mostly associated with settleable particulate matter and have relatively low filterable concentration components. Exceptions include zinc and 1,3-dichlorobenzene which are mostly associated with the filtered sample portions. Particulate reduction can occur in many stormwater runoff and combined sewer overflow (SCSO) control facilities, including (but not limited to) catchbasins, swirl concentrators, fine mesh screens, sand or other filters, drainage systems, and detention ponds. These control facilities (with the possible exception of drainage systems) allow reduction of the accumulated polluted sediment for final disposal in an appropriate manner. Uncontrolled sedimentation will occur in relatively quiescent receiving waters, such as lakes,

reservoirs, or slow moving rivers or streams. In these cases, the wide dispersal of the contaminated sediment is difficult to remove and can cause significant detrimental effects on biological processes.

Biological or chemical degradation of the sediment toxicants may occur in the typically anaerobic environment of the sediment, but the degradation is quite slow for many of the pollutants. Degradation by photochemical reaction and volatilization (evaporation) of the soluble pollutants may also occur, especially when these pollutants are near the surface of aerated waters (Callahan, *et al.* 1979; Parmer 1993). Increased turbulence and aeration encourages these degradation processes, which in turn may significantly reduce toxicant concentrations. In contrast, quiescent waters would encourage sedimentation that would also reduce water column toxicant concentrations, but increase sediment toxicant concentrations. Metal precipitation and sorption of pollutants onto suspended solids increases the sedimentation and/or floatation potential of the pollutants and also encourages more efficient bonding of the pollutants to soil particles, preventing their leaching to surrounding waters.

Receiving waters have a natural capacity to treat and/or assimilate polluted discharges. This capacity will be exceeded sooner (assuming equal inputs), resulting in more degradation, in smaller urban creeks and streams, than in larger receiving waters. Larger receiving waters may still have ecosystem problems from the long-term build up of toxicants in the sediment and repeated exposures to high flowrates, but these problems will be harder to identify using chemical analyses of the water alone, because of increased dilution (Pitt and Bissonnette 1984).

In-stream receiving water investigations of urban runoff effects need a multi-tiered monitoring approach, including habitat evaluations, water and sediment quality monitoring, flow monitoring, and biological investigations, conducted over long periods of time (Pitt 1991). In-stream taxonomic (biological community structure) investigations are needed to help identify actual toxicity problems. Laboratory bioassay tests can be useful to determine the major sources of toxicants and to investigate toxicity reduction through treatment, but they are not a substitute for actual in-stream investigations of receiving water effects. In order to identify the sources and treatability of the problem pollutants, detailed watershed investigations are needed, including both dry and wet weather urban drainage monitoring and source area monitoring.

An estimate of the actual pollutant loads (calculated from the runoff volumes and pollutant concentrations) from different watershed areas is needed for the selection and design of most treatment devices. Several characteristics of a source area are significant influences on the pollutant concentrations and stormwater runoff volumes. The washoff of debris, soil, and pollutants depends on the intensity of the rain, the properties of the material removed, and the surface characteristics where the material resides. The potential mass of pollutants available to be washed off will be directly related to the time interval between runoff events during which the pollutants can accumulate.

Human Health Effects of Stormwater

Water Environment & Technology (1996b) reported on an epidemiology study conducted at Santa Monica Bay, CA, that found that swimmers who swam in front of stormwater outfalls were 50% more likely to develop a variety of symptoms than those who swam 400 m from the same outfalls (Haile, *et al.* 1996). This was a follow-up study after previous investigations found that human fecal waste was present in the stormwater collection systems. *Environmental Science & Technology* (1996b) also reported on this Santa Monica Bay study. They reported that more than 1% of the swimmers who swam in front of the outfalls were affected by fevers, chills, ear discharges, vomiting and coughing, based on surveys of more than 15,000 swimmers. The health effects were also more common for swimmers who were exposed on days when viruses were found in the outfall water samples.

Water Environment & Technology (1996a) reported that the fecal coliform counts decreased from about 500 counts/100 mL to about 150 counts/100 mL in the Mississippi River after the sewer separation program in the Minneapolis and St. Paul area of Minnesota. Combined sewers in 8,500 ha were separated during this 10-year, \$332 million program.

in percolation loss. Organophosphate pesticides are less persistent than organochlorine pesticides, but they also are not strongly adsorbed by the sediment and are likely to leach into the vadose zone, and the groundwater.

Other Organics

The most commonly occurring organic compounds that have been found in urban groundwaters include phthalate esters (especially bis(2-ethylhexyl)phthalate) and phenolic compounds. Other organics more rarely found, possibly due to losses during sample collection, have included the volatiles: benzene, chloroform, methylene chloride, trichloroethylene, tetrachloroethylene, toluene, and xylene. PAHs (especially benzo(a)anthracene, chrysene, anthracene and benzo(b)fluoranthene) have also been found in groundwaters near industrial sites.

Groundwater contamination from organics, like from other pollutants, occurs more readily in areas with sandy soils and where the water table is near the land surface. Removal of organics from the soil and recharge water can occur by one of three methods: volatilization, sorption, and degradation. Volatilization can significantly reduce the concentrations of the most volatile compounds in groundwater, but the rate of gas transfer from the soil to the air is usually limited by the presence of soil water. Hydrophobic sorption onto soil organic matter limits the mobility of less soluble base/neutral and acid extractable compounds through organic soils and the vadose zone. Sorption is not always a permanent removal mechanism, however. Organic re-solubilization can occur during wet periods following dry periods. Many organics can be at least partially degraded by microorganisms, but others cannot. Temperature, pH, moisture content, ion exchange capacity of soil, and air availability may limit the microbial degradation potential for even the most degradable organic.

Pathogenic Microorganisms

Viruses have been detected in groundwater where stormwater recharge basins were located short distances above the aquifer. Enteric viruses are more resistant to environmental factors than enteric bacteria and they exhibit longer survival times in natural waters. They can occur in potable and marine waters in the absence of fecal coliforms. Enteroviruses are also more resistant to commonly used disinfectants than are indicator bacteria, and can occur in groundwater in the absence of indicator bacteria.

The factors that affect the survival of enteric bacteria and viruses in the soil include pH, antagonism from soil microflora, moisture content, temperature, sunlight, and organic matter. The two most important attributes of viruses that permit their long-term survival in the environment are their structure and very small size. These characteristics permit virus occlusion and protection within colloid-size particles. Viral adsorption is promoted by increasing cation concentration, decreasing pH and decreasing soluble organics. Since the movement of viruses through soil to groundwater occurs in the liquid phase and involves water movement and associated suspended virus particles, the distribution of viruses between the adsorbed and liquid phases determines the viral mass available for movement. Once the virus reaches the groundwater, it can travel laterally through the aquifer until it is either adsorbed or inactivated.

The major bacterial removal mechanisms in soil are straining at the soil surface and at intergrain contacts, sedimentation, sorption by soil particles, and inactivation. Because of their larger size than for viruses, most bacteria are therefore retained near the soil surface due to this straining effect. In general, enteric bacteria survive in soil between two and three months, although survival times up to five years have been documented.

Heavy Metals and Other Inorganic Compounds

Heavy metals and other inorganic compounds in stormwater of most environmental concern, from a groundwater pollution standpoint, are aluminum, arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, and zinc. However, the majority of these compounds, with the consistent exception of zinc, are mostly found associated with the particulate solids in stormwaters and are thus relatively easily removed through sedimentation practices. Filterable forms of the metals may also be removed by either sediment adsorption or are organically complexed with other particulates.

In general, studies of recharge basins receiving large metal loads found that most of the heavy metals are removed either in the basin sediment or in the vadose zone. Dissolved metal ions are removed from stormwater during infiltration mostly by adsorption onto the near-surface particles in the vadose zone, while the particulate metals are filtered out at the soil surface. Studies at recharge basins found that lead, zinc, cadmium, and copper accumulated at the soil surface with little downward movement over many years. However, nickel, chromium, and zinc concentrations have exceeded regulatory limits in the soils below a recharge area at a commercial site. Elevated groundwater heavy metal concentrations of aluminum, cadmium, copper, chromium, lead, and zinc have been found below stormwater infiltration devices where the groundwater pH has been acidic. Allowing percolation ponds to go dry between storms can be counterproductive to the removal of lead from the water during recharge. Apparently, the adsorption bonds between the sediment and the metals can be weakened during the drying period.

Similarities in water quality between runoff water and groundwater has shown that there is significant downward movement of copper and iron in sandy and loamy soils. However, arsenic, nickel, and lead did not significantly move downward through the soil to the groundwater. The exception to this was some downward movement of lead with the percolation water in sandy soils beneath stormwater recharge basins. Zinc, which is more soluble than iron, has been found in higher concentrations in groundwater than iron. The order of attenuation in the vadose zone from infiltrating stormwater is: zinc (most mobile) > lead > cadmium > manganese > copper > iron > chromium > nickel > aluminum (least mobile).

Salts

Salt applications for winter traffic safety is a common practice in many northern areas and the sodium and chloride, which are collected in the snowmelt, travel down through the vadose zone to the groundwater with little attenuation. Soil is not very effective at removing salts. Salts that are still in the percolation water after it travels through the vadose zone will contaminate the groundwater. Infiltration of stormwater has led to increases in sodium and chloride concentrations above background concentrations. Fertilizer and pesticide salts also accumulate in urban areas and can leach through the soil to the groundwater.

Studies of depth of pollutant penetration in soil have shown that sulfate and potassium concentrations decrease with depth, while sodium, calcium, bicarbonate, and chloride concentrations increase with depth. Once contamination with salts begin, the movement of salts into the groundwater can be rapid. The salt concentration may not decrease until the source of the salts is removed.

Recommendations to Protect Groundwater During Stormwater Infiltration

Table D-1 is a summary of the pollutants found in stormwater that may cause groundwater contamination problems for various reasons. This table does not consider the risk associated with using groundwater contaminated with these pollutants. Causes of concern include high mobility (low sorption potential) in the vadose zone, high abundance (high concentrations and high detection frequencies) in stormwater, and high soluble fractions (small fraction associated with particulates which would have little removal potential using conventional stormwater sedimentation controls) in the stormwater. The contamination potential is the lowest rating of the influencing factors. As an example, if no pretreatment was to be used before percolation through surface soils, the mobility and abundance criteria are most important. If a compound was mobile, but was in low abundance (such as for VOCs), then the groundwater contamination potential would be low. However, if the compound was mobile and was also in high abundance (such as for sodium chloride, in certain conditions), then the groundwater contamination would be high. If sedimentation pretreatment was to be used before infiltration, then much of the pollutants will likely be removed before infiltration. In this case, all three influencing factors (mobility, abundance in stormwater, and soluble fraction) would be considered important. As an example, chlordane would have a low contamination potential with sedimentation pretreatment, while it would have a moderate contamination potential if no pretreatment was used. In addition, if subsurface infiltration/injection was used instead of surface percolation, the compounds would most likely be more mobile, making the abundance criteria the most important, with some regard given to the filterable fraction information for operational considerations.

This table is only appropriate for initial estimates of contamination potential because of the simplifying assumptions made, such as the likely worst case mobility measures for sandy soils having low organic

in most stormwaters. However, if the stormwater nitrate concentration was high, then the groundwater contamination potential would also likely be high.

- pesticides: lindane and chlordane have moderate groundwater contamination potentials for surface percolation practices (with no pretreatment) and for subsurface injection (with minimal pretreatment). The groundwater contamination potentials for both of these compounds would likely be substantially reduced with adequate sedimentation pretreatment. Pesticides have been mostly found in urban runoff from residential areas, especially in dry-weather flows associated with landscaping irrigation runoff.

- other organics: 1,3-dichlorobenzene may have a high groundwater contamination potential for subsurface infiltration/injection (with minimal pretreatment). However, it would likely have a lower groundwater contamination potential for most surface percolation practices because of its relatively strong sorption to vadose zone soils. Both pyrene and fluoranthene would also likely have high groundwater contamination potentials for subsurface infiltration/injection practices, but lower contamination potentials for surface percolation practices because of their more limited mobility through the unsaturated zone (vadose zone). Others (including benzo(a)anthracene, bis (2-ethylhexyl) phthalate, pentachlorophenol, and phenanthrene) may also have moderate groundwater contamination potentials, if surface percolation with no pretreatment, or subsurface injection/infiltration is used. These compounds would have low groundwater contamination potentials if surface infiltration was used with sedimentation pretreatment. Volatile organic compounds (VOCs) may also have high groundwater contamination potentials if present in the stormwater (likely for some industrial and commercial facilities and vehicle service establishments). The other organics, especially the volatiles, are mostly found in industrial areas. The phthalates are found in all areas. The PAHs are also found in runoff from all areas, but they are in higher concentrations and occur more frequently in industrial areas.

- pathogens: enteroviruses likely have a high groundwater contamination potential for all percolation practices and subsurface infiltration/injection practices, depending on their presence in stormwater (likely if contaminated with sanitary sewage). Other pathogens, including *Shigella*, *Pseudomonas aeruginosa*, and various protozoa, would also have high groundwater contamination potentials if subsurface infiltration/injection practices are used without disinfection. If disinfection (especially by chlorine or ozone) is used, then disinfection byproducts (such as trihalomethanes or ozonated bromides) would have high groundwater contamination potentials. Pathogens are most likely associated with sanitary sewage contamination of storm drainage systems, but several bacterial pathogens are commonly found in surface runoff in residential areas.

- heavy metals: nickel and zinc would likely have high groundwater contamination potentials if subsurface infiltration/injection was used. Chromium and lead would have moderate groundwater contamination potentials for subsurface infiltration/injection practices. All metals would likely have low groundwater contamination potentials if surface infiltration was used with sedimentation pretreatment. Zinc is mostly found in roof runoff and other areas where galvanized metal comes into contact with rainwater.

- salts: chloride would likely have a high groundwater contamination potential in northern areas where road salts are used for traffic safety, irrespective of the pretreatment, infiltration or percolation practice used. Salts are at their greatest concentrations in snowmelt and early spring runoff in northern areas.

It has been suggested that, with a reasonable degree of site-specific design considerations to compensate for soil characteristics, infiltration can be very effective in controlling both urban runoff quality and quantity problems (EPA 1983a). This strategy encourages infiltration of urban runoff to replace the natural infiltration capacity lost through urbanization and to use the natural filtering and sorption capacity of soils to remove pollutants. However, potential groundwater contamination through infiltration of some types of urban runoff requires some restrictions. Infiltration of urban runoff having potentially high concentrations of pollutants that may pollute groundwater requires adequate pretreatment, or the diversion of these waters

away from infiltration devices. The following general guidelines for the infiltration of stormwater and other storm drainage effluent are recommended in the absence of comprehensive site-specific evaluations:

- Dry-weather storm drainage effluent should be diverted from infiltration devices because of their probable high concentrations of soluble heavy metals, pesticides, and pathogenic microorganisms.
- Combined sewage overflows should be diverted from infiltration devices because of their poor water quality, especially high pathogenic microorganism concentrations, and high clogging potential.
- Snowmelt runoff should also be diverted from infiltration devices because of its potential for having high concentrations of soluble salts.
- Runoff from manufacturing industrial areas should also be diverted from infiltration devices because of its potential for having high concentrations of soluble toxicants.
- Construction site runoff must be diverted from stormwater infiltration devices (especially subsurface devices) because of its high SS concentrations which would quickly clog infiltration devices.
- Runoff from other critical source areas, such as vehicle service facilities and large parking areas, should at least receive adequate pretreatment to eliminate their groundwater contamination potential before infiltration.
- Runoff from residential areas (the largest component of urban runoff from most cities) is generally the least polluted urban runoff flow and should be considered for infiltration. Very little treatment of residential area stormwater runoff should be needed before infiltration, especially if surface infiltration is through the use of grass swales. If subsurface infiltration (French drains, infiltration trenches, dry wells, etc.) is used, then some pretreatment may be needed, such as by using grass filter strips, or other surface filtration devices.

All other runoff should include pretreatment using sedimentation processes before infiltration, to both minimize groundwater contamination and to prolong the life of the infiltration device (if needed). This pretreatment can take the form of grass filters, sediment sumps, wet detention ponds, etc., depending on the runoff volume to be treated and other site specific factors. Pollution prevention can also play an important role in minimizing groundwater contamination problems, including reducing the use of galvanized metals, pesticides, and fertilizers in critical areas. The use of specialized treatment devices can also play an important role in treating runoff from critical source areas before these more contaminated flows commingle with cleaner runoff from other areas. Sophisticated treatment schemes, especially the use of chemical processes or disinfection, may not be warranted, except in special cases, especially considering the potential of forming harmful treatment by-products (such as THMs and soluble aluminum).

Most past stormwater quality monitoring has not been adequate to completely evaluate groundwater contamination potential. The following list shows the parameters that are recommended to be monitored if stormwater contamination potential needs to be considered, or infiltration devices are to be used. Other analyses are appropriate for additional monitoring objectives (such as evaluating surface water problems). In addition, all phases of urban runoff should be sampled, including stormwater runoff, dry-weather flows, and snowmelt.

- Contamination potential:
 - Nutrients (especially nitrates)
 - Salts (especially chloride)
 - VOCs (if expected in the runoff, such as from manufacturing industrial or vehicle service areas, could screen for VOCs with purgable organic carbon, POC, analyses)
 - Pathogens (especially enteroviruses, if possible, along with other pathogens such as *Pseudomonas aeruginosa*, *Shigella*, and pathogenic protozoa)

- Bromide and total organic carbon, TOC (to estimate disinfection by-product generation potential, if disinfection by either chlorination or ozone is being considered)
- Pesticides, in both filterable and total sample components (especially lindane and chlordane)
- Other organics, in both filterable and total sample components (especially 1,3 dichlorobenzene, pyrene, fluoranthene, benzo (a) anthracene, bis (2-ethylhexyl) phthalate, pentachlorophenol, and phenanthrene)
- Heavy metals, in both filterable and total sample components (especially chromium, lead, nickel, and zinc)
- Operational considerations:
 - Sodium, calcium, and magnesium (in order to calculate the sodium adsorption ratio to predict clogging of clay soils)
 - Suspended solids (to determine the need for sedimentation pretreatment to prevent clogging)

The Technical University of Denmark (Mikkelsen, *et al.* 1996a and 1996b) has been involved in a series of tests to examine the effects of stormwater infiltration on soil and groundwater quality. They found that heavy metals and PAHs present little groundwater contamination threat, if surface infiltration systems are used. However, they express concern about pesticides which are much more mobile. Squillace, *et al.* (1996) along with Zogorski, *et al.* (1996) presented information concerning stormwater and its potential as a source of groundwater MTBE contamination. Mull (1996) stated that traffic areas are the third most important source of groundwater contamination in Germany (after abandoned industrial sites and leaky sewers). The most important contaminants are chlorinated hydrocarbons, sulfate, organic compounds, and nitrates. Heavy metals are generally not an important groundwater contaminant because of their affinity for soils. Trauth and Xanthopoulos (1996) examined the long-term trends in groundwater quality at Karlsruhe, Germany. They found that the urban landuse is having a long-term influence on the groundwater quality. The concentration of many pollutants have increased by about 30 to 40% over 20 years. Hütter and Remmler (1996) describe a groundwater monitoring plan, including monitoring wells that were established during the construction of an infiltration trench for stormwater disposal in Dortmund, Germany. The worst case problem expected is with zinc, if the infiltration water has a pH value of 4.

Appendix E
Laboratory Procedures Used For MCTT Pilot-Scale Evaluations

