United States
Environmental Protection
Agency

Risk Reduction
Engineering Laboratory
Cincinnati OH 45268

EPA/600/8-89/054
January 1990

Research and Development

EPA

Storm and Combined Sewer Overflow:

An Overview of EPA's Research Program

EPA/600/8-89/054
January 1990

STORM AND COMBINED SEWER OVERFLOW:

AN OVERVIEW OF EPA's RESEARCH PROGRAM

by

Richard Field

Storm and Combined Sewer Pollution Control Program
Risk Reduction Engineering Laboratory--Cincinnati
Edison, New Jersey 08837

RISK REDUCTION ENGINEERING LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

This report has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency is charged by the Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural system to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

It covers the gamut of urban storm-induced pollution environmental engineering requirements from pollution-problem assessment and associated tools to management and control planning and design. This report represents an overview of the agency's Storm & Combined Sewer Pollution Control Research Program (SCSP) performed over a 20-year period, beginning with the mid-1960s. As controls to reduce water pollution from traditional point sources have been implemented, it became more evident that diffuse sources of pollutants, including discharges from separate storm drainage systems and combined sewer overflows (CSO) are major causes of water quality problems. In response to this situation Congress required the EPA, by adding Section 402 (p) to the Clean Water Act (CWA) of 1987, to regulate stormwater discharges to protect water quality by establishing comprehensive programs for permit applications, guidance, and management and treatment requirements. In addition, Section 319 was added to the CWA requiring States to develop nonpoint source assessment and management programs. EPA has also recently implemented a "National CSO Control Strategy" to ensure that CSO meet the technology and water quality-based requirements of the CWA. It is a handy reference for the user community faced with the challenges and mandates to combat urban wet-weather-induced water pollution.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

This report represents an overview of the EPA's Storm & Combined Sewer Pollution control Research Program performed over a 20-year period beginning with the mid-1960s. It covers Program involvements in the development of a diverse technology including pollution-problem assessment/solution methodology and associated instrumentation and stormwater management models, best management practices (BMPs) erosion control, infiltration/inflow (I/I) control, control-treatment technology and the associated sludge and solids residuals handling and many others.

The report is a handy reference for the user community faced with the challenges and mandates to combat urban wet-weather-induced water pollution. It comprises the gamut of environmental engineering requirements from pollution problem assessment to management and control planning and design.

CONTENTS

FIGURES

TABLES

INTRODUCTION

The Storm and Combined Sewer Pollution Control Research, Development, and Demonstration Program (SCSP) was initiated back in 1964. Congress acknowledged the problem 23 years ago by authorizing funds under the Water Quality Act of 1965 for researching ways of stormwater pollution management. The research effort was directed by the Storm and Combined Sewer Technology Program (SCSP) located in Edison, New Jersey until 1983 when it was disestablished. About 300 projects totaling approximately $150 million have been awarded under the U. S. Environmental Protection Agency (EPA) Research Program which resulted in approximately 320 final reports. More than 100 conference papers and over 100 articles and in-house reports have been presented and published, respectively by the Program. The goal has been user assistance with emphasis on planning and design oriented material.

Many in-house papers and reports have been published on Program overviews, state-of-the-arts (SOTA), and special topics. These are important management tools having been read and used internationally. The Program paper, appearing in the American Society of Civil Engineers (ASCE) Journal, of the Environment Engineering Division, won the ASCE SOTA of Civil Engineering Award; and a paper presentation on the swirl regulator won a New York Water Pollution Control Association award for excellence and a similar Journal of the Water Pollution Control Federation paper won the Level-1 EPA Award for Scientific and Technological Achievement.

The mission of the SCSP was to develop methods for controlling pollution from urban stormwater discharges and combined sewer overflows (CSO), and excessive inflow and infiltration (I/I).

The Program had two facets. The first was problem definition that led to the second -- development of effective control alternatives.

The Program has been involved in the development of a diverse technology including pollution-problem assessments/solution methodology and associated instrumentation and stormwater management models, best management practices (BMP), erosion control, infiltration/inflow (I/I) control, CSO and Stormwater control-Treatment Technology and associated sludge and solids residue handling and disposal methods, and many others. This report covers SCSP products and accomplishments in these areas covering 18 years of efforts. The vastness of the Program makes it difficult to allow complete coverage. Therefore SCSP outputs and developments will be selectively emphasized.

CONCLUSIONS

In general, on a mass basis, toxics, bacteria, oxygen demanding, suspended, and visual matter in CSO and urban stormwater are significant. Ignoring the problem because it seems to be too costly to solve, will not make the problem go away. The integrated approach to wet-weather pollution control is the only way which is going to be feasible, economical and, therefore, acceptable. Potentially tremendous "bangs-for-the-bucks" can be derived from wet-weather pollution control research fostering integrated solutions. As you can see, the SCSP has investigated a problem, proven its significance, and developed a gamut of design and control techniques that has led our nation and been accepted internationally. Better advantage needs to be taken of proven technology.

An extremely important area where the SCSP can provide valuable assistance to the operating programs and the user community is through increased availability for consulting services and for dissemination/technology transfer of its products.

And as was discussed and because of the hundreds of millions of dollars being spent annually, much more research still needs to be done.

RECOMMENDATIONS FOR THE FUTURE

RECEIVING WATER IMPACTS

Ties between receiving water quality and storm flow discharges must be clearly established and delineated. Quantification of the impairment of beneficial uses and water quality by such discharges is a major goal. Project results indicate the potential for significant impact to receiving waters of wet-weather flows. Control of runoff pollution can be a viable alternative for maintaining receiving water quality standards. However, the problems found seem to be site-sepcific in nature. Therefore, site-specific surveys are required that must consider the effects of larger materials and floatables near the outfalls (the nearfield). Based on results from these surveys, control may be warranted.

INDICATOR MICROORGANISMS/DISINFECTION REQUIREMENTS AND TECHNOLOGY

As discussed earlier, research is warranted for finding better indicator microorganisms for the disease causing potential of CSO and stormwater, associated disinfection requirements, and disinfection technology since disinfection costs will be great for the high storm flows encountered.

TOXICS CHARACTERIZATION/PROBLEM ASSESSMENT/CONTROL-TREATMENT

Results from a limited in-house effort, and EPA OWRS studies (including the Nationwide Urban Runoff Program (NURP) study) indicate that urban stormwater runoff and CSO contain significant quantities of toxic substances (priority pollutants). Without toxic and industrial runoff problem assessment and control, our various hazardous substances cleanup and control programs (under CERCLA/SARA, R RA, TSCA, etc.) may be done in vain. Additional investigation of the significance of concentrations and quantities of toxic pollutants with regard to their health effects or potential health effects and ecosystem effects is required. A need exists to evaluate the removal capacity of conventional and alternative treatment technologies and BMP's for these toxics and to compare their effectiveness with estimated removal needs to meet water quality goals. From this comparison further advanced treatment and control for toxic substances will need to be developed.

INDUSTRIAL STORMWATER RUNOFF PROBLEM ASSESSMENT/CONTROL

Permitting for industrial stormwater runoff along with follow-up compliance and control is now a mandated requirement (WQA Section405 and CWA Section 402 (p)). There are thousands of industrial sites in the country with pollutants and toxicants in their runoff. Research and development for problem assessment and control of industrial stormwater runoff is needed to support these mandates; especially because research has never been done in this area.

MORATORIUM SOURCES RUNOFF PROBLEM ASSESSMENT/CONTROL

Research support is required for the assessment and control of stormwater runoff from all moratorium sources (i.e., municipalities with populations less than 100,000 and commercial/institutional areas) as mandated by the WQA Section 405.

SEWER SYSTEM CROSS-CONNECTIONS

Investigations have shown that sanitary and industrial contamination of separate storm sewers (by cross-connections) is a nationwide problem. In other words, a significant number of separate stormwater drainage systems function as combined sewer systems. Therefore, a nationwide effort on both federal and local levels to alleviate the pollution impacts from discharges of these systems is required. It may be better to classify such bastardized drainage systems as combined systems for pollution control purposes and priorities. More research on detection and control is needed because of large sums of money that will be spent on corrective action.

LEAKING UNDERGROUND STORAGE TANKS (UST)

Many leaks from UST enter utility trenches and lines, e.g., sewer networks. Pollution abatement costs would be significantly lower if methodologies are developed to enable municipalities to detect and control UST leaks via these utility systems.

INTEGRATED STORMWATER MANAGEMENT

The most effective solution methodology for wet-weather pollution problems must consider: (1) wet-weather pollution impacts in lieu of blindly upgrading existing municipal plants, (2) structural vs. non-structural techniques, (3) integrating dry- and wet-weather flow systems/control to make maximum use of the previously existing sewerage/drainage systems during wet conditions and maximum use of wet-weather control/treatment facilities during dry weather, and (4) the segment or bend on the percent pollutant control vs. cost curve in which cost differences accelerate at much higher rates than pollutant control increases, although load discharge or receiving water requirements will dictate, ultimately, the degree of control/treatment required.

Flood and erosion control technology must be integrated with pollution control, so that the retention and drainage facilities required for flood and erosion control can be simultaneously designed or retrofitted for pollution control. Upstream storage should also be designed to lessen size and cost requirements for downstream drainage. If land management and non-structural/low-structurally intensive techniques are maximized and integrated, there will be less to pay for the extraction of pollutants from storm flows in the potentially more costly downstream plants. There is a significant need to further develop and demonstrate various forms of integrated stormwater management.

NEW AND INNOVATIVE STORMWATER CONTROL

New research and development must be devoted to the low-cost separate stormwater pollution control concepts, e.g., swirls and smaller storage units for bleed back to the existing dry-weather plant.

SURFACE AND GROUNDWATER INTERFACING

Surface and groundwater have never been interfaced in the area of pollutant routing. Runoff problems cannot be adequately assessed without this interface. For example, enhancing surface runoff infiltration to groundwater by applying certain BMP's, i.e., porous pavement may cause a groundwater pollution problem that in turn may create a surface water pollution problem later.

LANDFILL AND WASTE SITE RUNOFF CONTROL

Landfill and waste site runoff/leachate conveys vast quantities of toxic and other pollution substances to surface and groundwater. Pollutant routing and control technologies should be developed.

INSTITUTIONAL/SOCIO/ECONOMIC CONFLICTS

Some of the most promising opportunities for cost-effect environmental control are multipurpose in nature. However, there are institutional problems that hinder their implementation. First, the autonomous Federal and local agencies and professions involved in flood and erosion control, pollution control, and land management and environmental planning must be integrated at both the planning and operation levels. Multi-agency incentives (e.g., grant coverage) and rules must be adequate to stimulate such an approach. For example, the EPA would have to join with the Corps of Engineers, Soil Conservation Service, Department of Transportation, and perhaps other Federal agencies as well as departments of pollution control, sanitation, planning, and flood control at the local level.

Another problem is that construction grant (and other) incentives are geared towards structurally intensive projects which may counter research findings in the area of optimal solutions. Optimized wet-weather pollution involves a city-wide approach including the integration of structural as well as low-structural controls. The low-structural measures are more labor intensive. Construction grant funding does not presently address this expense and accordingly, municipalities are discouraged from using them.

POLLUTION PROBLEM ASSESSMENT

BACKGROUND

The background of sewer construction led to the present urban runoff problem. Early drainage plans made no provisions for storm flow pollutional impacts. Untreated overflows occur from storm events giving rise to the storm flow pollution problem.

Simply stated the problem is: When a city takes a shower what do you do with the dirty water?

Three types of discharges are involved: combined sewer overflow (CSO), which is a mixture of storm drainage and municipal wastewater, which also includes dry-weather flow (DWF) discharged from a combined sewer due to clogged interceptors, inadequate interceptor capacity, or malfunctioning regulators; storm drainage from separate storm systems either sewered or unsewered; and another form of CSO, overflow from sanitary lines infiltrated with stormwater.

CHARACTERIZATION

The problem constituents in overflows are: visible matter, infect- ious (pathogenic) bacteria and viruses, organics and solids, and in addition include nutrients, and toxicants (e.g., heavy metals, pesticides and petroleum hydrocarbons).

The average five-day biochemical oxygen demand (BOD) concentration in CSO is approximately one-half the raw sanitary sewage BOD. But storm discharges must be considered in terms of their shockloading effect due to their relative magnitude. Urban runoff flow rates from an average storm intensity of 0.1 in./h are five to ten times greater than the DWF from the same area. Likewise a not uncommon rainfall intensity of 1.0 in./h will produce flow rates 50 to 100 times DWF. Even separate storm wastewaters are significant sources of pollution, typically characterized as having solids concentrations equal to or greater than those of untreated sanitary wastewater and BOD concentrations approximately equal to those of secondary effluent. The bacterial and viral pollution problem from wet-weather flow (WWF) is also severe.

The quality and quantity characterization of WWF is necessary for problem assessment, planning, and design. Summaries of characterization data from many research studies are available[1-3]. The average pollutant concentrations for urban runoff and CSO are compared to background pollution and sanitary sewage in Table 1[2].

Since 1974, the SCSP supported the urban rainfall-runoff-quality data base[4,5] for two important data requirements: characterization, and calibration and verification of models. This project was initiated to bring together the many widely scattered data sources.

Table 1. Comparison of Typical Values for Storm Flow Discharges

	TSS	VSS	BOD	COD	Kjeldahl nitrogen	Total nitrogen	PO_4-P	OPO_4-P	Lead	Fecal coliforms
Background levels	5-100	...	0.5-3	20	.....	0.05-0.5[b]	0.01-0.2[c]	....	<0.1	....
Stormwater runoff	415	90	20	115	1.4	3-10	0.6	0.4	0.35	14 500
Combined sewer overflow	370	140	115	375	3.8	9-10	1.9	1.0	0.37	670 000
Sanitary sewage	200	150	375	500	40	40	10	7	....	....

a. All values mg/L except fecal coliforms which are organisms/100 mL.

b. NO_3 as N.

c. Total phosphorus as P.

CASE STUDIES

A few municipal studies can serve to exemplify the problem. In Northampton, England it was found that the total mass of BOD emitted from CSO over a two year period was approximately equal to the mass of BOD emitted from the secondary sewage treatment plant effluent. And that the mass emission of suspended solids (SS) in CSO was three times that of the secondary effluent. In Buffalo, New York a study concluded that 20 to 30% of the DWF solids settled in the combined sewer which was subsequently flushed and bypassed during high-velocity storm flows.

A study in Durham, North Carolina has shown that after providing secondary treatment of municipal wastes, the largest single source of pollution from the 1.67 mi^2 watershed is separate urban runoff without the sanitary constituent. When compared to the raw municipal waste generated within the study area the annual urban runoff of chemical oxygen demand (COD) was equal to 91% the raw sewage yield; the BOD yield was equal to 67%; and the SS yield was 20 times that contained in the raw municipal wastes.

From an in-house project, preliminary screening of urban wet-weather discharges from 24 samples from nine urban areas found approximately one half of the 129 priority pollutants. The heavy metals were consistently found in all samples. Polynuclear aromatic hydrocarbons, from petroleum were the most frequently detected organics followed (in order) by phthalate esters, aromatic hydrocarbons, halogenated hydrocarbons, and phenols. A Nationwide Urban Runoff Program (NURP) and another EPA headquarters study also indicated that CSO and stormwater contain significant quantities of priority pollutants.

A project in Syracuse, New York used the Ames test to evaluate urban runoff and CSO mutagenicity[6,7]. Detectable responses have been obtained on 22% of the samples. It is significant that some mutagenic substances are present with a potential for entering the food chain.

Indicators such as fecal coliform have long been known to be present in stormwater discharges in densities sufficient to cause contravention of standards. A study in Baltimore, Maryland identified actual pathogens and enteroviruses in storm sewer discharges[8]. Cross-connections from sanitary sewers were strongly implicated as the major cause. Obviously, this problem is not isolated to Baltimore. For instances, two surveys in Canada found that 13 and 5% of the houses had illicit sanitary connections to separate storm sewers, respectively. At this juncture, because of the high expenses involved for disinfection it is important to mention that better indicator organisms of human disease potential are needed since the conventional indicators, e.g., coliform can come from animal fecal matter and soil in the runoff whereas in sanitary flow it is principally from human enteric origin. Perhaps direct pathogen measurement is best.

RECEIVING WATER IMPACTS

Knowledge of the receiving water impacts resulting from urban wet-weather discharges is a basis for determining the severity of problems and for justifying control. Program studies of receiving water impacts are described in a proceedings from a national conference[9] and in a journal paper[10].

Oxygen Demand Loads

Under certain conditions storm runoff can govern the quality of receiving waters regardless of the level of DWF treatment provided. Based on national annual mass balance determinations (Table 2), urban wet-weather oxygen demand loads are greater than the dry-weather (sanitary sewer) loads from the same areas and ten times greater during storm-flow periods[11,12]. Hence, control of storm runoff pollution is a viable alternative for maintaining receiving water quality standards.

Table 2 National Annual Urban Wet/Dry-Weather Flow (WWF/DWF) BOD_5 and COD Comparisons[11,12]

Type	Percent of Developed Area	Annual DWF		Annual WWF		Percent WWF	
		BOD_5 x 10^6 Lb	COD x 10^6 Lb	BOD_5 x 10^6 Lb	COD x 10^6 Lb	BOD_5	COD
Combined Sewer	14.3	340	910	880	2640	72	74
Storm Sewer	38.3	710	1890	440	2500	36	57
Unsewered	47.4	310	830	360	2250	54	73
Totals	100	1330	3630	1640	7390	55	67

Aesthetic Deterioration and Solids

Stormwater conveys debris and solids to receiving waterbodies. This material can either disperse, float, or wash ashore onto beaches or embankments, or eventually settle, creating such nuisances as: odors and toxic/corrosive atmospheres from bottom mud deposits, and aesthetic upsets either in general appearance (dirty, turbid, cloudy) or in the actual presence of specific, objectionable items (floating debris, oil films, sanitary discards/fecal matter, scum or slimes, tires, timber, etc.).

Coliform Bacteria and Pathogenic Microorganisms

Excess concentrations of bacterial indicator organisms in urban runoff will hinder water supply, recreational, and fishing/shell-fishing use of the receiving water[8-10].

Elevated coliform levels in Mamaroneck Harbor, New York and subsequent beach closings have been linked to stormwater runoff. Stormwater discharges from the City of Myrtle Beach, South Carolina, directly onto the beach showed high bacterial counts for short durations immediately after storm events. In many instances these counts violated EPA recommended water quality criteria for aquatic life and contact recreation. In Long Island, New York stormwater runoff was identified as the major source of bacterial loading to marine waters and the indirect cause of the closing of about one-fourth of the shellfishing area.

Biological Impacts

An investigation of aquatic and benthic organisms in Coyote Creek, San José, California found a diverse population of fish and benthic macroinvertebrates in the non-urbanized section of the creek as compared to the urbanized portion, which was completely dominated by pollution tolerant algae, mosquito fish, and tubificid worms[9,10,15,16]. In the State of Washington, similar results were found in a Lake Washington project[9,10,17], where bottom organisms (aquatic earthworms) near storm sewer outfalls were more pollution tolerant relative to those at a distance from these outfalls. Aquatic earthworm numbers and biomass were found to be enhanced within the zone of influence of the monitored storm drain in the Lake.

Toxicity

Toxicity problems can result from minute discharges of metals, pesticides, and persistent organics which may exhibit subtle long-term effects on the environment by gradually accumulating in sensitive areas. A large data base exists that identifies urban runoff as a significant source of toxic pollutants, e.g., New York Harbor receives metals from treatment plant effluents, CSO, separate storm sewer discharges, and untreated wastewater[9,10]. As seen in Table 3, urban runoff is the major contributor of heavy metals to the harbor.

Table 3. Metals Discharged in Harbor from New York City Sources[9,10]

Source	Copper	Chromium	Nickel	Zinc	Cadmium
Plant effluents	1,410	780	930	2,520	95
Runoff*†	1,990	690	650	6,920	110
Untreated wastewater	980	570	430	1,500	60
Total weight, lb/day	4,380	2,050	2,010	10,940	265
Average concentration, mg/L	0.25	0.12	0.11	0.62	0.015

* In reality, shockload discharges are much greater.

† Runoff data includes separate storm sewer drainage and wet-weather combined sewer overflows (CSO).

Table 4 shows the total annual mass of selected constituents from a storm overflow point in Seattle, Washington[9,10,17]. A high percentage of the heavy metals and toxic materials is associated with the SS or particulates which tend to concentrate in the sediment. This association is beneficial in terms of control and treatment since it is easier to separate pollutants attached to SS.

Table 4. Total Versus Particulate Mass from Storm Sewer Overflow Point; Lake Washington, Seattle, Washington[9]

Variable	Selected Storm Drain Point	
	Total mass, in pounds	Particulate mass, in pounds
Suspended Solids	4,924.	4,924.
Copper	2.55	1.64
Lead	13.29	11.7
Zinc	6.03	3.87
Aluminum	213.8	207.
Organic Carbon	658.	370.
Total Phororous	19.2	8.93
Oils and greases	249.	not applicable
Chlorinated Hydrocarbons	not determined	0.854G

Sediment samples were analyzed for metals, organic carbon, phosphorous, chlorinated hydrocarbons, and polychlorinated biphenyls (PCB). As can be seen from Figure 1, a composite index to assess wet-weather impacts was 16 times the minimum background control value. Also, pesticide levels in sediments along the Seattle shoreline of Lake Washington were up to 37 times background concentrations.

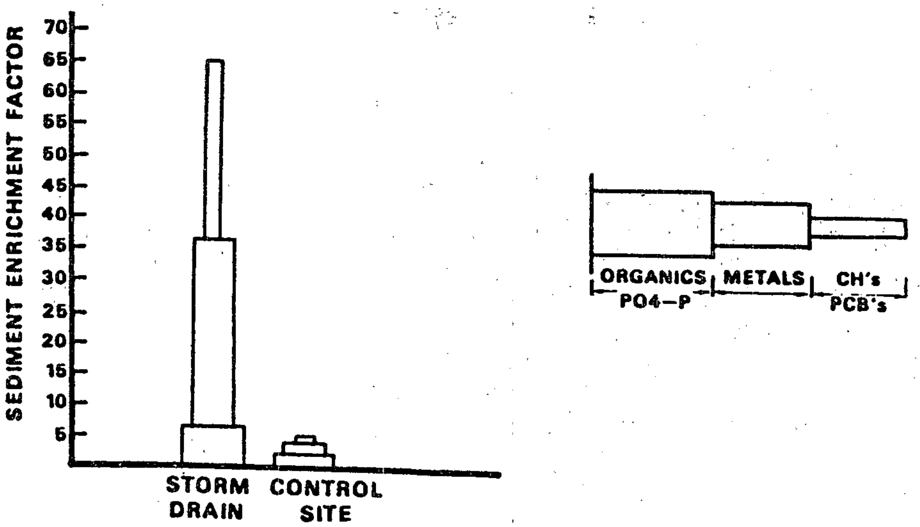


Figure 1. Urban Sediment Enrichment: Lake Washington, Seattle, Washington(9)

In the previously mentioned San Jose project(15,16), urban sediment compared to nonurban sediment from Coyote Creek contained higher peak concentrations of lead (up to 10 times greater) -- 400 mg/kg vs 40 mg/kg, arsenic (9 times greater) -- 13 mg/kg vs 1.5 mg/kg, BOD (up to 4 times greater) -- 1,900 mg/kg vs 925 mg/kg, and ortho phosphates (4 times greater) -- 6.7 mg/kg vs 1.8 mg/kg. Lead concentrations in urban samples of algae, crawfish, and cattails were two to three times greater than in nonurban samples, while zinc concentrations were about three times the nonurban concentrations. Bioaccumulation of lead and zinc in the organisms compared to water column concentrations was at least 100 to 500 times greater.

Petroleum hydrocarbons, particularly the polynuclear aromatics, are suspected carcinogens. At New York City's Newton Creek treatment plant, 24,000 gal of oil and grease, equivalent to a moderate spill were bypassed during one four hour storm(9). A study of Jamaica Bay, New York, found that 50% of the hexane extractable material contributed to the bay is due to wet-weather overflows(9). The major source of petroleum contamination in Jamaica Bay was shown to be waste crankcase oil(13). This is in agreement with studies of Delaware Bay(13). Petroleum hydrocarbons and associated aromatic hydrocarbons are a cause of ecosystem degradation in New York Bight(13). Accumulation of polynuclear aromatics in sediments eventually may prove harmful to benthic communities in the Bight. From Table 5 it is clear that urban runoff is the major factor to be considered once existing regulations for point sources are adequately enforced.

Table 5. Estimated Sources of Petroleum Hydrocarbons In Delaware Bay[13]

	Without efficient controls (lb/day)	With efficient controls (lb/day)
Spills	6,000	6,000
Municipal	7,700-15,700	2,000
Refineries	24,300	2,000
Other industrial	8,800	6,200
Urban runoff	10,600	10,600

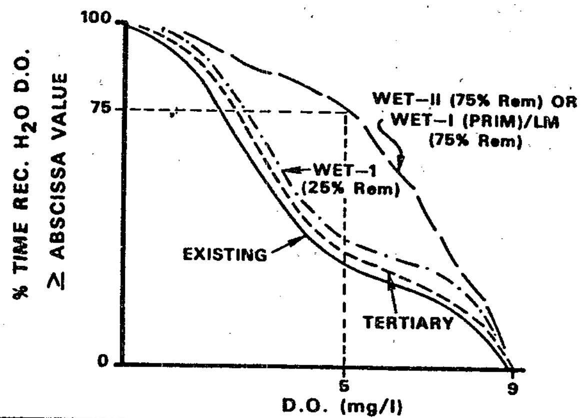
Over 86% of the total hydrocarbons in Philadelphia, Pennsylvania storm runoff[13] was associated with particulates, a distribution that probably is typical of most urban areas. Therefore, instream solids separation being designed and considered for separate stormwater systems will result in substantial lowering on non-point petroleum hydrocarbon inputs, provided the solids are disposed of elsewhere.

Sediment

Direct evidence has been obtained (from the Milwaukee River project[14]) of how a disturbed benthos depletes dissolved oxygen (DO) from the overlying waters. Previously mentioned and other studies have also shown that stormwater discharges and CSO's adversely affect sediment by toxics enrichment and resultant biological upsets[9,10,15-17]. Since particulate matter in untreated stormwater discharges and CSO's is larger, heavier, and in significant quantities when compared to treated sanitary effluent, more needs to be known about the fate and transport of settleable and separable materials. Hydrodynamic solids separation and sediment transport routines must be added to receiving water models to take care of the neglected or presently omitted significant particulate- and bed-flow fields.

SOLUTION METHODOLOGY

The concept of a simplified continuous receiving water quality model was developed in the nationwide evaluation of CSO's and urban stormwater discharges project[18,19] and refined into a user's manual during a subsequent project. This model, termed "Level III -- Receiving," permits preliminary planning and screening of area-wide wastewater treatment alternatives in terms of frequency of water quality violations based on time and distance varying DO profiles. Figure 2 represents a hypothetical example of the type of analysis facilitated by this model. This case is for DO; actual studies should include other parameters and should represent at least one year of continuous data.



CONTROL ALTERNATIVES	% BOD REMOVAL		COST ($×10[6])
	DRY WEATHER	WET WEATHER	
EXISTING	85	0	–
TERTIARY	95	0	6
WET–I (PRIMARY)	85	25	1
WET–II (ADV)	85	75	6
WET–I/LAND MGMT.	85	75	3

Figure 2. Hypothetical Example Solution Methodology

Using this analysis a truer cost-effectiveness comparison can be made based on the duration of the impact and associated abatement costs, e.g., if a 5 mg/l DO is desired in the receiving water 75% of the time, an advanced form of wet-weather treatment or primary wet-weather treatment integrated with land management is required. The latter is the most cost- effective at $3,000,000. This or similar tools will aid in setting cost- effective standards as well as the selection of alternatives.

Also, a general methodology has been developed for evaluating the impact of CSO's on receiving waters and for determining the abatement costs for various water quality goals[20]. It was developed from actual municipal pollution control (201) facility planning experience in Onondaga Lake in Syracuse, New York. An important goal of studies to determine the impact of waste discharges on a receiving water is to predict the waste loads that can be assimilated without violation of water quality standards so that a loading curve such as shown in Figure 3 can be defined.

This figure shows the potential effect storm loads may have in violating a 5 mg/l DO standard after dry-weather treatment is upgraded. It further implies that CSO pollution loads should be abated next, since they are the easiest of the storm loads to control and capture; and in this case would reduce loads to meet the water quality goal.

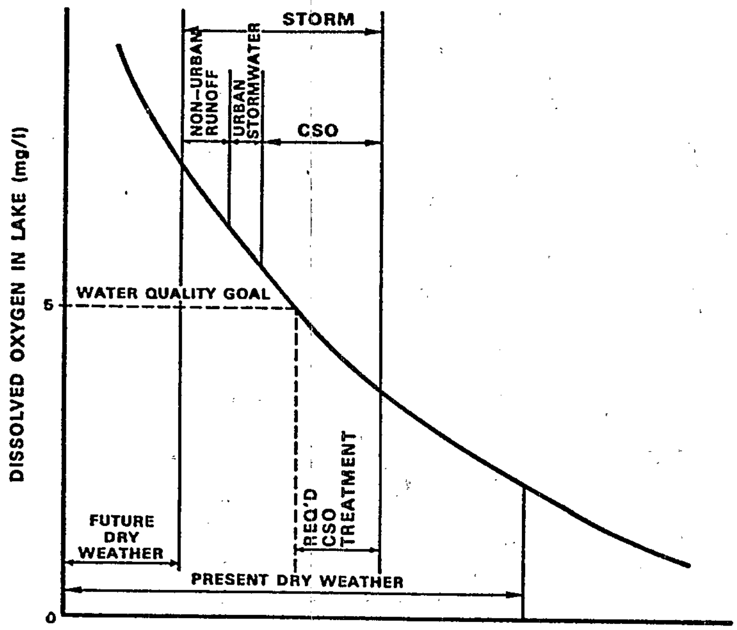


Figure 3. Typical Loading Curve Relating Pollutant Load to Water Quality Response

In addition, a methodology for defining criteria for wet-weather quality standards has been developed(21-23). In recognition of an important gap in the developed methodologies, the duration of water quality standards vs. species survival was taken into consideration.

USER'S ASSISTANCE TOOLS

User's assistance tools include instrumentation, stormwater management models, manuals of practice (MOP), methodologies, compendiums, and SOTA reports.

INSTRUMENTATION

Storm-flow measurement is essential for process planning, design, control, evaluation, and enforcement. Sampling devices do not provide representative aliquots. Conventional flowmeters apply to steady-state flows and not to the highly varying storm flows.

Flowmeters have been developed to overcome these adverse storm conditions(24,25). A prototype sampler for capturing representative solids in storm flow has also been developed and a design manual is available(26). This gave manufacturers the incentive to perfect samplers by increasing intake velocities and other ways. SOTA reports are available for flow measurement and sampling(27,28). Because storm-flow conditions are extremely adverse, the manuals and instruments developed are useful for monitoring all types of flow.

SIMULATION MODELS

The Program has fostered the development of models for assessment, planning, design, and control of urban stormwater pollution. Program thinking on urban water management analysis involves four levels of evaluation ranging from simple to complex that can be worked together.

The various levels of the stormwater management model, SWMM, are the most significant model products in terms of past resources and overall popularity. SWMM is one of the most widely used urban models and its benefits for planning and design have been demonstrated. It has been employed by consulting engineers to design sewers and to analyze pollution control alternatives.

There have been significant enhancements of SWMM. Probably the most significant is Version III[29-31], which includes a flexible physically based storage and treatment routine which provides estimates of treatment (by settling) in storage basins.

Documentation and user's manuals are available for all SWMM levels including three continuous stormwater planning models[32-37].

Operational models that have been implemented in Detroit, Michigan[38]; Minneapolis, Minnesota[39]; Seattle, Washington[40]; and San Francisco, California produce control decisions during storm events.

REPORTS

A major emphasis of the Program was solution methodology through developments of SOTA reports, MOP's, and user's manuals.

The SOTA texts, user's guide and the assessment on urban stormwater technology are excellent documents[41,]. Separate engineering manuals are available for storm flow-rate determination[43,44], porous pavement design[45-48], cost estimating[49-51], storm-sewer design[52-54], planning and design guidance[55], and for conducting stormwater studies[56]. Seminar proceedings with themes of "modeling, design, operation, and costs," have been published.

The SOTA document on particle size and settling velocity[57] offers significant information for solids treatability and their settlement in receiving waters, important areas overlooked in planning and design. An excellent film is being distributed by the General Services Administration (GSA) National Audio Visual Center which covers the EPA CSO Research Program, and in particular full-scale control technologies[58].

A report entitled, "Urban Stormwater Management and Technology: Case Histories,"[59] presents 12 case histories which represent the most promising approaches to CSO and stormwater control. The case histories were developed by evaluating operational facilities that have significant information for future guidance.

Three illustrative methodologies for conducting CSO facility planning have been published[60-62].

MANAGEMENT ALTERNATIVES

The next major Program area is management alternatives. First is the choice of where to attack the problem; at the source by land management, in the collection system, or off-line by storage. We can remove pollutants by treatment and by employing integrated systems combining control and treatment.

LAND MANAGEMENT

Land management includes structural, semi-structural, and non-structural measures for reducing urban and construction site stormwater runoff and pollutants before they enter the downstream drainage system. Various concepts have been fostered by the SCSP including:

Land Use Planning

Traditional urbanization upsets the natural hydrologic and ecological balance of a watershed. The degree of upset depends on the mix, location, and distribution of the proposed land use activities. As man urbanizes, the receiving waters are degraded by runoff from his activities. The goal of urban development resources planning is a macroscopic management concept to prevent problems from shortsighted planning. New variables of land usage and its perviousness, population density, and total runoff control must be considered and integrated with desired water quality.

Natural Drainage

Natural Drainage will reduce drainage costs and pollution, and enhance aesthetics, groundwater supplies, and flood protection. A project near Houston, Texas, focused on how a "natural-drainage system" integrates into a reuse scheme for recreation and aesthetics[59]. Runoff flows through vegetative swales and into a network of wet-weather ponds, strategically located in areas of porous soils. This system retards the flow of water downstream preventing floods by development, and enhances pollution abatement.

An interesting technological answer to the problem of preserving pervious areas is using an open-graded asphaltic-concrete as a paving material. This will be discussed later under the subsection "Porous Pavements" (pp. 14 and 15).

Dual-Purpose Detention/Retention

Dual-Purpose detention/retention and drainage facilities, and other management techniques required for flood and erosion control can be simultaneously designed or retrofitted for pollution control. Retention on-site or upstream can provide for the multi-benefits of aesthetics, recreation, recharge, irrigation, or other uses. An existing detention basin can be retrofitted to enhance pollution control by limiting or eliminating the bottom effluent orifice and by routing most or all of the effluent stormwaters through a surface overflow device, e.g., a weir or standpipe drain. This will induce solid-liquid separation by settling and enable entrapped solids and floatables to be disposed of at a later time without causing downstream receiving water pollution.

Major-Minor Flooding

By utilizing the less densely populated and less commercialized upstream, upland drainage areas for rainwater impoundment for the more intense storms, the relatively and significantly more costly and upsetting downtown downstream flooding can be eliminated or alleviated. The multi-benefits of pollution abatement and a reduced need for larger pipes downstream will also be gained. The "major-minor flooding" concept involves utilization of depression storage by brief flooding of curblines, right-of-ways, and lawn areas.

Controlled Stormwater Entry

A project in Cleveland, Ohio, demonstrated how controlling the rate at which stormwater stored upstream enters the sewerage system alleviates basement flooding and overflow pollution. The flow rate is regulated by a vortex internal-energy dissipator (Hydrobrake). This small device, which is located at the downstream end of a subsurface holding tank beneath the right-of-way, delivers a pre-designed virtually constant discharge rate, compatible with the downstream sewerage system capacities and water quality objectives, regardless of head variations. This is accomplished without the need of moving parts or external energy sources.

Porous Pavement

Porous pavements provide storage, enhancing soil infiltration that can be used to reduce runoff and CSO. Porous asphalt-concrete pavements can be underlain by a gravel base course with whatever storage capacity is desired (Figure 4).

Results from a study in Rochester, New York, indicate that peak runoff rates were reduced as much as 83%[63]. The structural integrity of the porous pavement was not impaired by heavy-load vehicles. Clogging did result from sediment from adjacent land areas during construction; however, it was relieved from cleaning by flushing. The construction cost of a porous pavement parking lot is about equal to that of a conventional paved lot with stormwater inlets and subsurface piping.

A project in Austin, Texas developed design criteria for porous pavements[46] and compared porous asphalt pavement to six other conventional and experimental pavements[47,48].

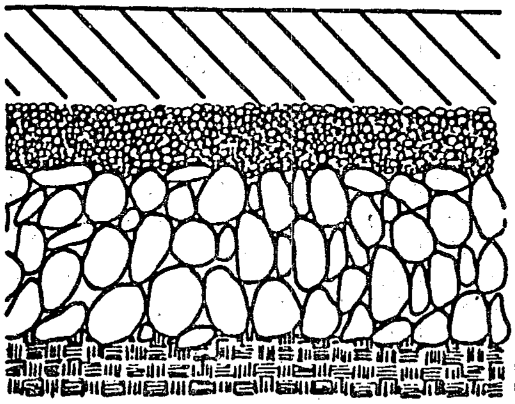


Figure 4. Porous Asphalt Paving Typical Section

Surface Sanitation

Maintaining and cleaning urban areas can have a significant impact on the quantity of pollutants washed off by stormwater with secondary benefits of a cleaner and healthier environment.

Litter Control

Spent containers from food and drink, cigarettes, newspapers, sidewalk sweepings, lawn trimmings, and a multitude of other materials carelessly discarded become street litter. Unless this material is prevented from reaching the street or is removed by street-cleaning, it often is found in stormwater discharges. Enforcement of anti-litter laws, convenient location of sidewalk waste disposal containers, and public education programs are just some of the source control measures that can be taken at the local level. While difficult to measure, the benefits include improved aesthetics and reduced pollution.

According to a recent California study[2], litter accumulates at a rate of approximately 4 lb/person-yr in urban areas. Of this total, about 1.8 lb/person-yr appears between the curb lines of streets. For example, the estimated annual litter deposition for a municipality having a population of 100,000 is 400,000 lb. It was reported that about 21% of the material picked up during mechanical street sweeping was litter.

Chemical Control

One of the most often overlooked measures for reducing the pollution from stormwater runoff is the reduction in the indiscriminate use and disposal of toxic substances such as fertilizers, pesticides, oil, gasoline, and detergents.

Operations such as tree spraying, weed control, and fertilization of parks and parkways by municipal agencies, and the use of pesticides and fertilizers by homeowners can be controlled by increasing public awareness of the potential hazards to receiving waters, and providing instruction as to proper use and application. In many cases over-application is the major problem, where use in moderation would achieve equal results. The use of less toxic formulations is another alternative to minimize potential pollution.

Pesticides have been detected in samples taken from several urban areas with typical loadings, including PCB, between 0.000136 to 0.012 lb /curb-mi [2]. Direct and indirect dumping and/or spills of chemicals, hazardous substances, crankcase oil, and debris into streets and gutters, catchbasins, inlets, and sewers are significant problems that may only be addressed through educational programs, ordinances, and enforcement.

Street Sweeping/Cleaning

Tests under real-world conditions in San Jose, California showed that street cleaning can remove up to 50% of the total solids (including litter) and heavy-metal yields in urban stormwater with once or twice a day cleaning [64]. Typical street cleaning programs of onceor twice a monthproved ineffective. Organics and nutrients that originate primarily from surfaces upstream of streets and may be dissolved or dissolved residue, could not be effectively controlled even with intensive cleaning.

In Bellevue, Washington, conventional street cleaning proved ineffective; however, a modified regenerative air Tymco street cleaner showed promise [65,66]. The main purpose of street sweeping is to enhance aesthetics by cleaning up litter and coarser solids. Street cleaning is no panacea for stormwater pollution control (and is site specific dependent upon rainfall/climatic conditions), but if integrated with other methods, could reduce city-wide costs for pollution control and in general. When considering that street sweeping is used in many locations for aesthetic purposes only, it will also provide a dual benefit, i.e., low-level water pollution control, especially enhancement of receiving water aesthetics.

Deicing Practices

Effective management of street and highway deicing practices can lessen environmental and receiving water impacts, often without a substantial increase in costs. A 1973 assessment study concluded major adverse environmental effects come from sloppy salt storage and over-application, which resulted in MOP's for improvement in those areas. These manuals were recognized as highly significant. The Federal Highway Administration reprinted them and distributed approximately 10,000 copies. Recommended modifications to current deicing practices include: (a) judicious application of salt and abrasives; (b) reduced application rates (using sodium and calcium salt premixes: rates of 150 to 400 lb/lane-mi have been recommended)[(2)], (c) using better spreading and metering equipment and calibrating application rates; (d) prohibiting use of chemical additives; (e) providing improved (covered and/or properly drained) salt storage areas; and (f) educating the public and operators about the effects of deicing technology and the best management practices[(2)]. The SCSP work encouraged states (e.g., Wisconsin) and local governments to abate salt usage.

Use of chemical additives such as cyanide, phosphate, and chromium can result in polluted snowmelt. Chromium concentrations of 3.9 mg/L have been reported[(2)].

Costs associated with salting of roadways, both direct and indirect, were estimated on an annual basis for the snowbelt states[(2)]. A total annual cost of $3 billion was reported, of which only $200 million was associated with salt purchase and application. Other costs in the total estimate included: (a) loss and contamination of water supplies and damage to health, $150 million; (b) vegetation damage, $50 million; (c) damage to highway structures, $500 million; (d) vehicle corrosion damage, $2 billion; and (e) damage to utilities, $10 million.

COLLECTION SYSTEM CONTROLS

The next overall Program category, collection system controls, pertains to management alternatives for wastewater interception and transport. These include: sewer separation; improved maintenance and design of catchbasins, sewers, regulators, and tide gates; and remote flow monitoring and control. The emphasis with the exception of sewer separation is on optimum use of existing facilities and fully automated control.

Sewer Separation

The concept of constructing new sanitary sewers to replace existing combined sewers as a control alternative, has largely been abandoned due to enormous costs, limited abatement effectiveness, inconvenience to the public and extended time for implementation. Again separate stormwater is a significant pollutant and sewer separation wouldn't cope with this load.

Catchbasins

In a project conducted in Boston, Massachusetts catchbasins were shown to be potentially quite effective for solids reduction (60-97%)[67,68]. Removals of associated pollutants such as COD and BOD were also significant (10-56% and 54-88%, respectively). To maintain the effectiveness of catchbasins for pollutant removal requires a municipal commitment with cleaning probably twice a year depending upon conditions. The SCSP developed an optimal catchbasin configuration based on hydraulic modeling[2].

Sewers

Manuals on new sewer design to alleviate sedimentation and resultant first-flush pollution and premature bypassing[52], and sewer design for added CSO storage[54] are available.

Sewer Flushing

As a follow-up to an earlier study[69], providing simple equations for predicting dry-weather deposition in sewers, a report was published showing that sewer flushing flush waves can effectively convey sewer deposits including organic matter[70]. In another study[71], it was concluded that sewer flushing could reduce CSO control costs 7% when compared to a CSO storage/treatment and disinfection facility designed for a one-year storm.

Polymers to Increase Capacity

Research has shown that polymeric injection can greatly increase flow capacity (by reducing wall friction) and thus be used to correct pollution-causing conditions such as localized flooding and excessive overflows[72]. Direct cost savings are realized by eliminating relief-sewer construction.

In-Sewer Storage and Flow Routing

Another control method is in-sewer storage and routing to maximize use of existing sewer capacity. The general approach comprises remote monitoring of rainfall, flow levels, and sometimes quality, at selected locations in the network, together with a centrally computerized console for positive regulation. This concept has proven effective in New York, New York; Detroit, Michigan[38]; Seattle, Washington[40] (Figure 5).
Cleveland, Ohio and San Francisco, California have also implemented this concept. Other cities are considering its use. New York City used a simple static weir which impounded upstream CSO up to a level where flooding would not be encountered. It is not a remotely-controlled intelligent system; however, it provides ten million gallons of storage at practically no cost.

Although never tried, storm sewers and channels can also be retro-fitted with flow regulators (and sensing devices) for in-channel and in-pipe storage applying CSO in-sewer storage and routing technology and other storage facilities for ties into the existing sewage treatment system, thus making better use of facilities and lowering costs for overall water pollution control. Ties into the existing treatment system will be discussed in more detail under the subsections, "Swirl and Helical Flow Regulators/Solids Concentrators" and "Flow Regulators for Separate Stormwater Pollution Control" (pp. 24, 25, 27).

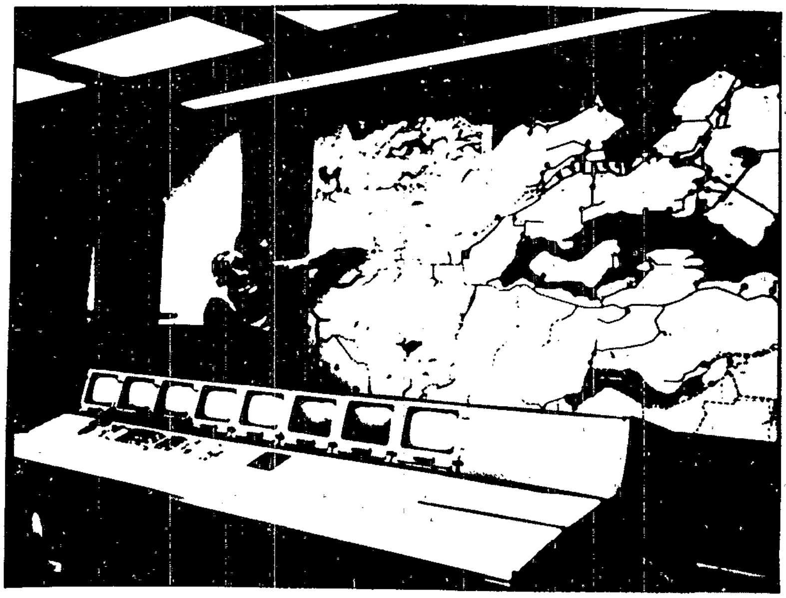


Figure 5. Computer Console for Augmented Flow Control System, Seattle, Washington.

Sewer System Cross-Connections

Research efforts have shown that sanitary and industrial contamination (by cross-connections) of separate storm sewers is a nationwide problem. One response to this problem includes simple methods of checking for cross-connections. Investigations should be made of the drainage network, using visual observation and screening/mass balance techniques, to determine the sources of sanitary or industrial contamination.

First, stormwater outfalls can be checked by eye for discharges during DWF conditions, and if flows are noticed, they should be observed further for clarity, odor, and sanitary matter. These dry-weather discharges should then be confirmed and quantified (for relative amounts of stormwater/groundwater/sanitary and industrial wastewater) by thermal (temperature), chemical (specific ions), and/or biochemical (BOD/COD/TOC) techniques and mass balances. Mass balances will depend on determined concentrations/values of parameters (i.e., pollutants and/or specific ions and/or temperatures) in the various potential sewer flows (i.e., stormwater/groundwater/sanitary and industrial wastewaters). If visual outfall observations cannot be made during low tides, then upstream observations or downstream sampling (during low-tide and non-tidal back-flow conditions) should be conducted. The drainage/sewer system flows as a branch and tree-trunk network which enables the investigators to strategically work upstream to isolate the sources of stormwater contamination or cross-connections.

Once the sources have been isolated, an analysis will have to be made to determine whether corrective action at the sources, i.e., eliminating the cross-connection(s), or downstream storage/treatment (dealing with the storm sewer/channel network as though it were a combined sewer network) is most feasible. This will depend on the amount, dispersion, and size of the cross-connections.

Flow Regulators and Tide Gates

Pace-setters in the area of CSO regulator technology were the Program's SOTA[73] and MOP[74].

Conventional regulators malfunction, lack flow-control ability, and cause excessive overflows. Devices such as the fluidic regulator, and the positive control gate regulator, have been demonstrated in Philadelphia, Pennsylvania[75], and Seattle, Washington[40] respectively.

Swirl and Helical Flow Regulators/Solids Concentrators

The dual functioning swirl flow regulator/solids concentrator has shown outstanding potential for simultaneous quality and quantity control[76,77].

The swirl has been demonstrated for CSO in Syracuse, New York, and Lancaster, Pennsylvania by the SCSP and elsewhere by others. The device (Figure 6) of eimple annular construction requires no moving parts. It controls flow by a central circular wire, while simultaneously treating combined wastewater by a "swirl" action which imparts liquid-solids separation. Tests indicate at least 50% removal for SS and BOD. Table 6 shows the Syracuse prototype results. Tankage is small compared to sedimentation making the device highly cost effective.

A helical type regulator/separator has also been developed based on principles similar to the swirl. A project in West Roxubry, Massachusetts represents the first trial on separate stormwater(78). There have been anumber of full-scale projects throughout the country using the swirl. A complete swirl/helical design textbook has been published(78).

Flow Regulators for Separate Stormwater Pollution Control

To protect receiving water from the effects of stormwater discharges, conventional static- or dynamic-flow regulators used for CSO control(78) can be installed in separate storm sewers to divert stormwater to either a sanitary interceptor and/or to a storage tank for coarse solids and floatables removal(77).

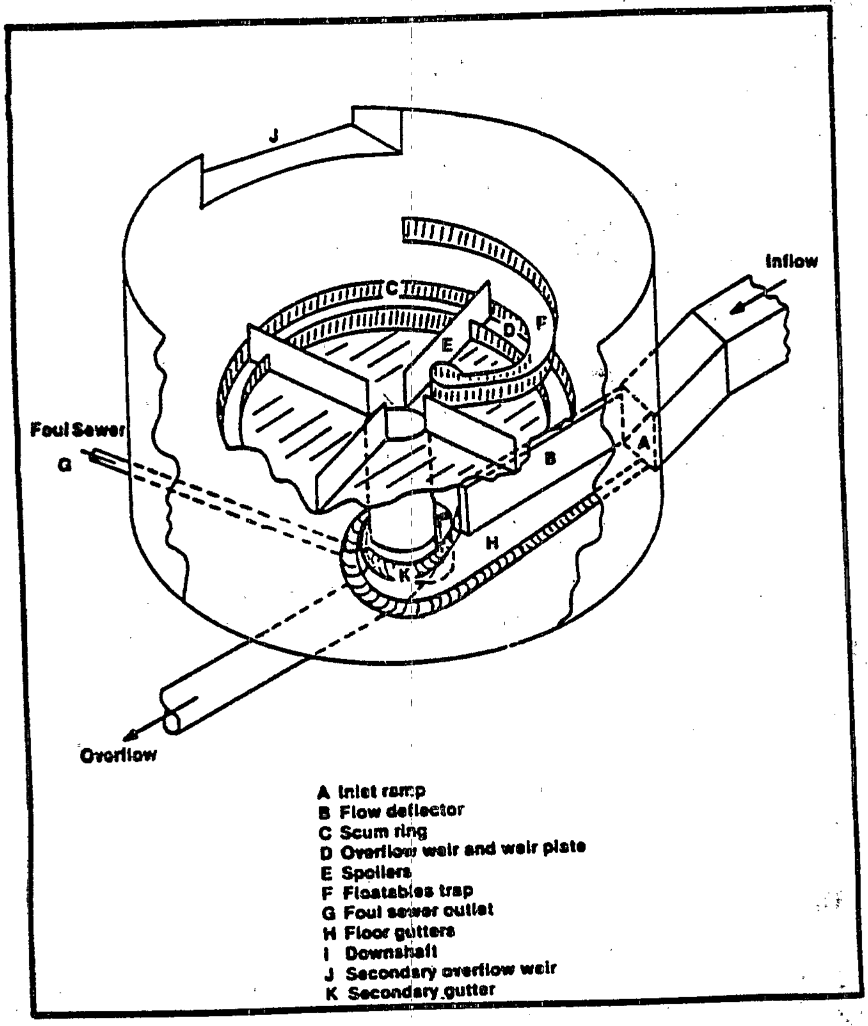


Figure 6. Isometric View of Swirl Combined Sewer Overflow Regulator/Separator

Table 6. Swirl Regulator/Separator Suspended Solid Removal: Syracuse, New York Prototype Results

Mass loading (kg) per storm			Average SS per storm (mg/ℓ)		
Inf.	Eff.	Removal	Inf.	Eff.	Removal
374	179	52%	535	345	36%
103	24	77%	374	165	55%
463	167	64%	342	202	41%

At present, there is a strong need to develop and have a reserve of control hardware for urban runoff control and to effectively reduce the associated high cost implications for conventional storage tanks, etc. It is felt that the swirl/helical type regulators, previously applied only to CSO, can also be installed on separate storm drains before discharge and the resultant concentrate flow can be stored in relatively small tanks, since concentrate flow is only a few percent of the total flow.

Stored concentrate can later be directed to the sanitary sewer for subsequent treatment during low-flow or dry-weather periods, or if capacity is available in the sanitary interceptor/treatment system, the concentrate may be diverted directly to it without storage.

This method of stormwater control (illustrated in Figure 7) is more economical than building huge holding reservoirs for untreated run-off, and offers a feasible approach to the control and treatment of separately sewered urban stormwater[77].

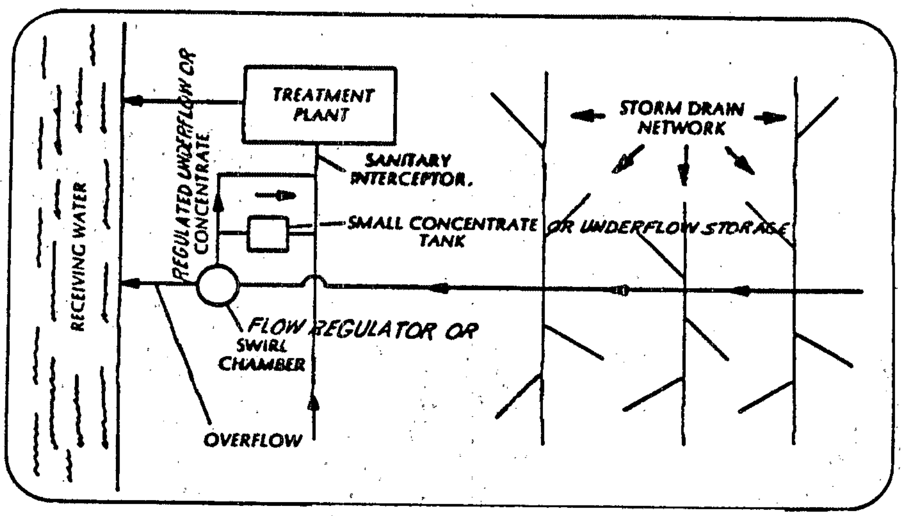


Figure 7. Urban Stormwater Runoff Pollution Control by Connecting to Existing Sanitary Sewerage System-Schematic

Vortex Energy Dissipators

The SCSP has demonstrated vortex energy dissipators (in these cases Hydrobrakes) in Rochester, New York[63] and Cleveland, Ohio[79,80]. They can be used as upstream off-line flow attenuators for controlled entry (as described in the previous subsection, "Controlled Stormwater Entry"), in-line or in-sewer flow back-up devices, and as CSO regulators. The flow rate is regulated by the vortex internal energy dissipator concept. It delivers a pre-designed virtually constant discharge rate, compatible with the downstream sewerage system capacities and water quality objectives regardless of upstream head variations. This is accomplished without the need of moving parts, orifice closure, or external energy.

Rubber "Duck Bill" Tide Gate

Figure 8 shows a prototype rubber "duck bill" tide gate. The prevailing problems with conventional flap-type gates are their failure to close tight and the need for constant maintenance. Poor tide gate performance results in higher treatment costs, treatment plant upsets, and greater pollutional loads due to downstream overflows and plant bypassing[81].

A project with New York City demonstrated the "duck bill" tide gate[81]. It is a totally passive device, requiring no outside energy to operate and was maintenance-free, yet sealed tightly around large solid objects. Because of its successful demonstration in NYC the city is planning its installation in other locations and it is being used in many other municipalities today.

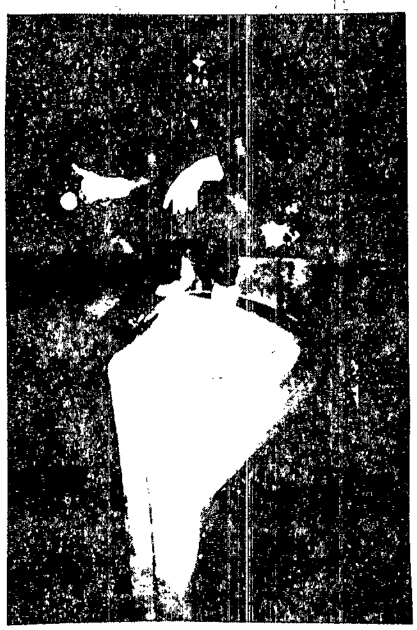


Figure 8. Prototype Rubber "Duck Bill" Tide Gate, New York City, New York

Maintenance

The Program has fostered concepts for improved sewerage system inspection and maintenance emphasizing that it is absolutely necessary for a total system approach to municipal water pollution control.

Premature overflows and backwater intrusion during dry as well as wet weather caused by malfunctioning regulators and tide gates, improper diversion settings, and partially blocked interceptors can thus be alleviated. The resulting pollution abatement obtained is a dual benefit of required system maintenance. Some cities have adopted this approach and have gained high CSO control cost benefits.

Infiltration/Inflow (I/I) Control

Various methods to reduce or eliminate I/I and for infrastructure improvement have been developed and demonstrated by the Program, e.g., inspection, installation (including trenchless plowing in) and rehabilitation (including liners and Insituform[81a] [now used by industry]) practices, and new piping (including sulfur impregnation of concrete pipe [which increases pipe strength and corrosion resistance thereby lowering pipe costs and reducing infiltration from deterioration]) and jointing materials (including heat shrinkable tubing [which expands after installation creating tighter joints]).

STORAGE

Because of the high volume and variability associated with storm flow, storage is considered a necessary control alternative. It is the Program's best documented abatement measure. But it is only the upstream part (process) of the control-treatment system. Project results and theory indicate storage must be considered at all times in system planning, because it allows for maximum use of existing dry-weather plant and downstream drainage facilities, optimum economic sizing of new CSO and stormwater treatment facilities, and results in the lowest cost in terms of pollutant removal.

Storage facilities may be constructed in-line (flow through by gravity) or off-line (flow through by pumping); they may be open or closed; they may be constructed inland and upstream, on the shoreline, or in the receiving water; and they may have auxiliary functions, such as sedimentation treatment, flood protection, flow attenuation to enhance receiving water pollutant assimilation, hazardous materials capture, sewer relief, flow transmission, and dry-weather flow equalization.

It is important to state that storage facilities can be applied to separate stormwater the same way they are applied to CSO for bleed or pump back to the sewage treatment plant.

Storage concepts investigated include the conventional concrete holding tanks and earthen basins, and the minimum land requirement concepts of: tunnels, underground and underwater containers, underground "silos", natural and mined under and above ground formations, and the use of abandoned facilities and existing sewer lines[82,83].

The in-receiving water flow balance method (Figure 9) is a recently developed storage alternative[84]. In-receiving water storage facilities contain CSO or stormwater between plastic curtains suspended from floating wooden pontoons. After cessation of the overflow, pumps start and the surrounding waterbody will enter the compartments and push the storm flow back towards the first compartment where it is pumped to the plant. Thus, the waterbody is used as a flow balance medium. The pumps will stop based on receiving sewer and treatment plant handling capacity and an override from a specific ionic (e.g. chlorides) or other parameter sensors that indicates too high a receiving water dilution.

The storage method is low cost, due to the employment of low cost materials (plastic and wood), the time required to install the unit (several days to months vs. months to a year), and the absence of land requirements. Studies show that costs could be about 5 to 15% of conventional concrete tank costs.

The facility which was tested at three locations for stormwater control in Sweden performed very satisfactorily, and was able to take ice and wind loads without adverse impact. It is desirable to demonstrate a facility in a harsh urban estuarine or marine site, such as a project will be doing shortly in Fresh Creek Basin in New York City.

A storage/sedimentation design manual[85] has been finalized.

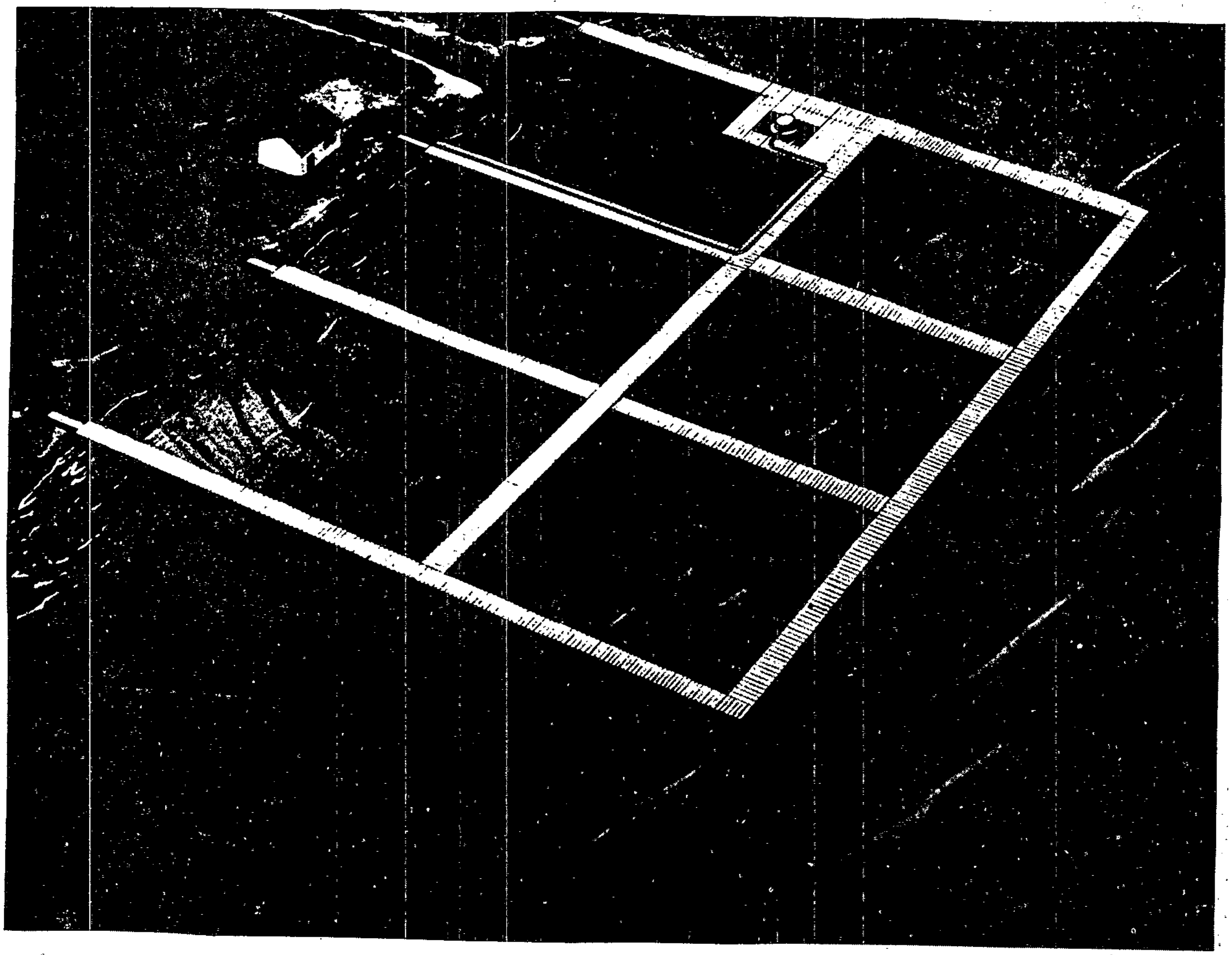


Figure 9. Isometric View of In-Receiving-Water Flow Balance Method

TREATMENT

Due to adverse and intense flow conditions and unpredictable shock loading effects, it has been difficult to adapt existing treatment methods to storm-generated overflows, especially the microorganism dependent biological processes. Physical/chemical treatment techniques have shown more promise than biological processes in overcoming storm shock loading effects. To reduce capital investments, projects have been directed towards high-rate operations approaching maximum loading.

Storm-flow treatment methods demonstrated by the Program include physical, physical-chemical, wetlands, biological, and disinfection[86]. These processes, or combinations of these processes, can be adjuncts to the existing sanitary plant or serve as remote satellite facilities at the outfall.

Physical/Chemical Treatment

Physical processes with or without chemicals, such as: fine screens, swirl degritters, high-rate filters (HRF), sedimentation, and dissolved air flotation (DAF), have been successfully demonstrated. Physical processes have shown importance for storm-flow treatment because they are adaptable to automated operation, rapid startup and shutdown, high-rate operation, and resistance to shock loads.

The Program thought that the high-rate processes: DAF, fine mesh screening, and HRF are ready for municipal installation.

The microstrainer conventionally designed for polishing secondary sewage plant effluent, has successfully been applied to CSO's; and high-rate applications have given SS removals higher than 90%[87].

Full-scale microscreening units were demonstrated in two locations. In Syracuse, New York, SS removals of about 50% were achieved[88].

A past Cleveland, Ohio pilot study using 6 in. columns showed high potential for treating CSO's by a fine screening/HRF system[89]. A large scale (30 in. diameter) fine screening/HRF pilot system was evaluated in New York City for the dual treatment of dry- and wet-weather flows[90]. Removals of SS and BOD were 70% and 40%, respectively. The screening portion of the NYC project used a 70 mesh Discrostrainer which produced a high solids content cake which can eliminate a sludge-concentrating step. Results from a 5.0 MGD screening and DAF demonstration pilot plant in Milwaukee indicate that greater than 70% removals of BOD and SS are possible[91,92]. By adding chemical coagulants, 85 to 97% phosphate reduction can be achieved as an additional benefit.

Based on Program pilot plant studies, two full-scale screening/DAF prototype systems (20 and 40 MGD) have been demonstrated[93]. Removals of SS and BOD were 70% and 55%, respectively. Treatment processes, e.g., microscreens and DAF are now being used by municipalities.

The swirl has also been developed for grit removal. The small size, high efficiency and absence of moving parts offer economical and operational advantages over conventional degritting facilities.

A full-scale demonstration of a (16 ft diameter/11 MGD design flow rate) swirl degritter has been completed in Tamworth, Australia[94,95]. Removal efficiencies confirmed laboratory results. Compared with a conventional grit chamber, construction costs are halved, and operation and maintenance costs are considerably lower.

Biological Treatment

The biological processes: trickling filtration, contact stabilization[96-98], biodisks, and lagoons have been demonstrated. They have had positive evaluation, but with the exception of long-term storage lagoons they must operate conjunctively with dry-weather flow plants to supply biomass, and require some form of flow equalization.

Disinfection

Because disinfectant and contact demands are great for storm flows[99], research has centered on high-rate applications by static and mechanical mixing, higher disinfectant concentrations[100-104], and more rapid oxidants, i.e., chlorine dioxide[101-104], ozone[100], and ultraviolet (UV) light; and on-site generation[100,105,106]. Demonstrations in Rochester and Syracuse, New York[104]; East Chicago, Indiana[107]; and Philadelphia, Pennsylvania[103], indicate that adequate reductions of fecal coliform can be obtained with contact times of two minutes or less by induced mixing and dosing with chlorine and/or chlorine dioxide. A pilot scale UV light demonstration with a contact time of less than ten seconds was conducted at New York City.

The hypochlorite batching facility is still being used in New Orleans, Louisiana to protect swimming beaches in Lake Poncetrain[106]. The SCSP supported the development of a brine hypochlorite generator now being used in industry[105].

Treatment/Control Design Guidebook

A compilation of the SCSP's best research efforts in CSO treatment/control over its 18 year duration has been published[86]. Because of flow similarities, this is also an important reference for urban stormwater treatment.

Treatment Process Performance

Treatment process costs and performance in terms of design influx (gpm/ft ^{2}) and BOD and SS removal efficiency is provided in Table 7. The high-rate performance of the swirl, microstrainer, screening/HRF and screening/DAF systems, is apparent when compared to sedimentation.

Table 7. Wet-Weather Treatment Plant Performance Data

Device	Control alternatives	Design loading rate (gpm/ft²)	Removal efficiency (%)	
			BOD_5	SS
Primary	Swirl concentrator	60	25—60	50
	Microstrainer	20	40—60	70
	High-rate filtration	24	60—80	90
	Dissolved air flotation	2.5	50—60	80
	Sedimentation	0.5	25—40	55
	Representative performance		40	60
Secondary	Contact stabilization		75—88	90
	Physical-chemical		85—95	95
	Representative performance		85	95

Maximizing Treatment

The operator may maximize wastewater treatment at the sanitary plant during wet weather. He should try to contain as much flow or treat as much wastewater as possible during a storm-flow occurrence. Treatment maximization can be enhanced by advanced signals of relatively high storm flows from remotely stationed rain gauges and/or radar. This would serve to reduce wet-weather by-passing, which at the beginning of storm flow can have a high pollutant concentration (including floatables), as previously described. Although this extra plant burden may decrease treatment efficiencies somewhat and create added sludge or solids handling problems, these practices for only short periods during storm flows are well worth the effort. If the operator determines that the hydraulic loading will cause a serious upset of a unit process, then primary treatment plus disinfection should be considered as a minimum measure. Effectiveness evaluation should be made for the entire treatment plant drainage area and be based on the total mass of pollutants captured or prevented from overflowing the combined sewers while also taking into account settling tank efficiency decrease as a function of higher influent hydraulic loading (or overflow rates).

SLUDGE/SOLIDS

Another Program area is the sludge and solids associated with storm flow treatment. Sludge handling and disposal must be considered an integral part of CSO treatment because it significantly affects the efficiency and cost of the total waste treatment system. Studies have shown that the annual quantity of CSO solids is at least equal to solids from dry-weather flow[108]. This is a significant finding for the Municipal Pollution Control Program. The results of a project on CSO sludges are covered in three published reports covering: characterization[108], impact assessment[109], and treatability[110]. A similar study was conducted for separate stormwater sludge and residuals[111].

INTEGRATED SYSTEMS

The most promising and common approach to urban storm flow management involves the integration of control and treatment. Integrated systems is divided into storage/treatment, dual-use wet-weather flow/dry-weather flow facilities, and control/treatment/reuse.

Storage/Treatment

When there is storage, there is treatment by settling, pump-back/bleed-back to the municipal works, and sometimes disinfection. Treatment which receives detention also provides storage. The break-even economics of supplying storage must be evaluated when treatment is considered. The Program has demonstrated all of these storage/treatment concepts full scale.

Dual Use Wet-Weather Flow/Dry-Weather Flow Facilities

The concept of dual use is maximum utilization of wet-weather facilities during non-storm periods and maximum utilization of dry-weather facilities during storm flows. The Program has demonstrated the full scale dual-use of high-rate trickling filters[112], contact stabilization[96-98], HRF[90], and equalization basins[113]. Various municipalities are employing dual-use microscreening.

In Clatskanie, Oregon, a full-scale dual facility constructed to alleviate flow bypassing caused by excessive infiltration was evaluated. The plant is in permanent use. Both wet- and dry-weather flow treatment is provided for in the same units and consists of primary sedimentation and conventional activated sludge for dry-weather periods converting to higher rate DAF and contact stabilization for wet-weather periods.[96,97].

Control/Treatment/Reuse

"Control/Treatment/Reuse" is a catch-all for all integrated systems. A prime consideration should be the various nonstructural and land management techniques. In Mt. Clemens, Michigan, a series of three "lakelets" have been incorporated into a CSO treatment/park development[114]. Treatment is being provided so that these lakes are aesthetically pleasing and allow for recreation and reuse for irrigation.

An in-house paper covering subportable reuse was published by the ASCE[115].

Wetlands

The use of wetlands for urban runoff pollution control has been investigated[116]. It has been found that with controlled runoff entry and wetlands management and maintenance that significant receiving-lake water benefits are obtained without degrading the wetlands[117].

REFERENCES

1. Lager, J.A., and Smith, William G., Metcalf & Eddy Engineers, Inc., Palo Alto, CA, "Urban Stormwater Management and Technology: An Assessment, "USEPA Report No. EPA-670/2-74-040, NTIS No. PB 240 687.

2. Lager, J.A., et al., Metcalf & Eddy Engineers, Inc., Palo Alto, CA, "Urban Stormwater Management and Technology: Update and User's Guide," USEPA Report EPA-600/8-77-014, NTIS No. PB 275 654.

3. Sullivan, R.H., et al., American Public Works Assoc., Chicago, IL, "Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges, Vol. III - Characterization of Discharges," USEPA Report No. EPA-600/2-77-064c, NTIS No. PB 272 107.

4. Huber, W.C., et al., University of Florida, Gainesville, FL, "Urban Rainfall-Runoff-Quality Data Base," USEPA Report No. EPA-600/2-81-238, NTIS No. PB 82-221 094.

5. Huber, W.C., et al., University of Florida, Gainesville, FL, "Urban Rainfall-Runoff-Quality Data Base," USEPA Project Summary No. EPA-600/S2-81-238, NTIS No. PB 82-221 094.

6. Spiegel, S.J., et al., O'Brien & Gere Engineers, Inc., Syracuse, NY, and Ott, R., Department of Drainage and Sanitation, Onondaga County, North Syracuse, NY, "Evaluation of Urban Runoff and Combined Sewer Overflow Mutagenicity," USEPA Report No. EPA-600/2-84-116, NTIS No. PB84-211168.

7. Spiegel, S.J., et al., O'Brien & Gere Engineers, Inc., Syracuse, NY, and Ott, R., Department of Drainage and Sanitation, Onondaga County, North Syracuse, NY, "Evaluation of Urban Runoff and Combined Sewer Overflow Mutagenicity," Project Summary No. EPA-600/S2-84-116.

8. Olivieri, V.P., et al., The Johns Hopkins University, Baltimore, MD, "Microorganisms in Urban Stormwater," USEPA Report No. EPA-600/2-77- 087, NTIS No. PB 272 245.

9. Proceedings of National Conference Orlando, Florida, November 26-28, 1979, "Urban Stormwater and Combined Sewer Overflow Impact on Receiving Water Bodies," USEPA Report No. EPA-600/9-80-056, NTIS No. PB 81-155 6.

10. Field, R., and Turkeltaub, R., USEPA, Edison, NJ, "Urban Runoff Receiving Water Impacts: Program Overview, "Journal of the Environmental Engineering Division, ASCE, Vol. 107, No. EE1, Feb., 1981, pp. 83-100.

11. Sullivan, R.H., et al., American Public Works Assoc., Chicago, IL - "Nationwide Evaluation of Combined Sewer Overflows and Urban Storm- water Discharges, Volume I - Executive Summary," USEPA Report No. EPA-600/2-77-064a, NTIS No. PB 273 133.

12. Heaney, J.F., et al., University of Florida, Gainesville, FL, "Nationwide Evaluation of Combined Sewer Overflows and Urban Storm- water Discharges, Volume II - Cost Assessment and Impacts," USEPA Report No. EPA-600/2-77-064b, NTIS No. PB 266 005.

13. Keefer, N., et al., The Sutron Corporation, Arlington, VA, "Dissolved Oxygen Impact from Urban Storm Runoff," USEPA Report No. EPA-600/2-79-156, NO NTIS.

14. Meinholz, T.L., et al., (Rexnord) Metropolitan Sewage District of County of Milwaukee, WI, "Verification of the Water Quality Impacts of Combined Sewer Overflows," USEPA Report No. EPA-600/2-79-155, NTIS No.

15. Pitt, R., Private Consultant, Blue Mounds, WI; Bozeman, M., Woodward-Clyde Consultants, San Francisco, CA, "Sources of Urban Runoff Pollution and Its Effects on an Urban Creek," USEPA Report No. EPA- 600/2-82-090, NTIS No. PB 83-111 021.

16. Pitt, R., Private Consultant, Blue Mounds, WI; Bozeman, M., Woodward-Clyde Consultants, San Francisco, CA, "Sources of Urban Runoff Pollution and Its Effects on an Urban Creek," USEPA Project Summary No. EPA-600/S2-82-090, NTIS No. PB 83-111 021.

17. Tomlinson, R.D., et al., Municipality of Metropolitan Seattle, Seattle, WA, "Fate and Effects of Particulates Discharged by Combined Sewers and Storm Drains," USEPA Report No. EPA-600/2-80-111, NTIS No. PB 81-118 390.

18. Medina, M., Duke University, Durham, NC, "Level III: Receiving Water Quality Modeling for Urban Stormwater Management," -USEPA Report No. EPA-600/2-79-100, NTIS No. PB 80-134 406.

19. Medina, M.A., et al., Duke University, Durham, NC, "River Quality Model for Urban Stormwater Impacts," USEPA Journal No. EPA-600/J-81- 234, NTIS No. PB 81-221 087.

20. Moffa, P.E., et al., Stearns & Wheler, Civil and Sanitary Engineers, Cazenovia, NY, "Methodology for Evaluating the Impact and Abatement of Combined Sewer Overflows: A Case Study of Onondaga Lake, New York," USEPA Report No. EPA-600/8-80-048, NTIS No. PB 81-141 913.

21. Mancini, J.L., Mancini & DiToro Assoc., Valley, NB, "Development of Methods to Define Water Quality Effects of Urban Runoff," USEPA Project Summary No. EPA-600/S2-83-125, NTIS No. PB 84-122 928.

22. Mancini, J.L., Mancini & DiToro Assoc., Valley, NB, "Development of Methods to Define Water Quality Effects of Urban Runoff," USEPA Report No. EPA-600/2-83-125, NTIS No. PB 84-122 928.

23. Mancini, J.L., Mancini & DiToro Assoc., Valley, NB, "A Method for Calculating Effects on Aquatic Organisms, Of Time Varying Concentrations," Water Research, Vol.17, No. 10, pp. 1355-1362, 1983.

24. Foreman, K.M., Grumman Aerospace Corp., Bethpage, NY, "Field Testing of Prototype Acoustic Flowmeter," USEPA Report No. EPA-600/2-79-084, NTIS No. PB80-121 544.

25. Anderson, R.J., and Bell, S.S., City of Milwaukee, WI, "Wastewater Flow Measurement in Sewers Using Ultrasound," USEPA Report No. EPA-600/2-76-243, NTIS No. PB 262 902.

26. Shelley, P.E., EG&G Washington Analytical Services Center, Inc., Rockville, MD, "Design and Testing of Prototype Automatic Sewer Sampling System," USEPA Report No. EPA-600/2-76-006, NTIS No. PB 252 613.

27. Shelley, P.E., and Kirkpatrick, G.A., EG&G Washington Analytical Services Center, Inc., Rockville, MD, "Sewer Flow Measurement - A State-of-the-Art assessment," USEPA Report No. EPA-600/2-75-027, NTIS No. PB 250 371.

28. Shelley, P.E., and Kirkpatrick, G.A., EG&G Washington Analytical Services Center, Inc., Rockville, MD, "An Assessment of Automatic Sewer Flow Samplers-1975," USEPA Report No. EPA-600/2-75-065, NTIS No. PB 250 987.

29. Huber, W.C., et al., University of Florida, Gainesville, FL, "Storm Water Management Model User's Manual, Version III," USEPA Report No. Pending, (Interim availability: University of Florida).

30. Huber, W.C., et al., University of Florida, Gainesville, FL, "Storm Water Management Model User's Manual, Version III," USEPA Project Summary No. Pending, (Interim availability: University of Florida).

31. Roesner, L.A., et al., Camp Dresser & McKee Inc., Annadale, VA, "Storm Water Management Model User's Manual Version III, Addendum I - Extran," USEPA Report No. Pending, (Interim availability: University of Florida).

32. Geiger, W.F., and Dorsch, H.R., Dorsch Consult Ltd., Toronto, Ontario, Canada, "Quantity-Quality Simulation (QQS): A Detailed Continuous Planning Model for Urban Runoff Control - Volume I Model Description, Testing, and Applications," USEPA Report No. EPA-600/2-80-011, NTIS No. PB 80-190 507.

33. Geiger, W.F., and Dorsch, H.R., Dorsch Consult Ltd., Toronto, Ontario, Canada, "Quantity-Quality Simulation (QQS): A Detailed Continuous Planning Model for Urban Runoff Control - Volume II User's Manual," USEPA Report No. EPA-600/2-80-116, NTIS No. PB 80-221 872.

34. Litwin, Y.J., et al., Ramlit Assoc., Berkeley, CA, "Areawide Stormwater Pollution Analysis with the Macroscopic Planning (ABMAC) Model," USEPA Project Summary No. EPA-600/S2-81-223, NTIS No. PB 82- 107 947.

35. Litwin, Y.J., et al., Ramlit Assoc., Berkeley, CA, "Areawide Stormwater Pollution Analysis with the Macroscopic Planning (ABMAC) Model," USEPA Report No. EPA-600/2-81-223, NTIS No. PB 82-107 947.

36. Smith, W.G., and Strickfaden, M.E., Metcalf & Eddy Engineers, Inc., Palo Alto, CA, "EPA Macroscopic Planning Model (EPAMAC) for Stormwater and Combined Sewer Overflow Control: Application Guide and User's Manual," USEPA Report No. EPA-600/2-83-086, NTIS No. PB 83-259 689.

37. Smith, W.G., and Strickfaden, M.E., Metcalf & Eddy Engineers, Inc., Palo Alto, CA, "EPA Macroscopic Planning Model (EPAMAC) for Storm- water and Combined Sewer Overflow Control: Application Guide and User's Manual," USEPA Report No. EPA-600/S2-83-086, NTIS No. PB 83- 259 689.

38. Watt, T.R., et al., Detroit Metro Water Department, Detroit, MI, "Sewerage System Monitoring and Remote Control," USEPA Report No. EPA-670/2-75-020, NTIS No. PB 2 107.

39. Metropolitan Sewer Board, St. Paul, MN, "Dispatching Systems for Control of Combined Sewer Losses," USEPA Report No. 11020FAQ03/71, NTIS No. PB 203 678.

40. Leiser, C.P., Municipality of Metropolitan Seattle, Seattle, WA, "Computer Management of a Combined Sewer System," USEPA Report No. EPA-670/2-74-022, NTIS No. PB 235 717.

41. Lager, J.A., et al., Metcalf & Eddy, Inc., Palo Alto, CA, "Urban Stormwater Management and Technology: Update and User's Guide," USEPA Report No. EPA-600/8-77-014, NTIS No. PB 275 654.

42. Lager, J.A., and Smith, W.G., Metcalf & Eddy Engineers, Inc., Palo Alto, CA, "Urban Stormwater Management and Technology : An Assessment," USEPA Report No. EPA-670/2-74-040, NTIS No. PB 240 687.

43. Brater, E.F., and Sherrill, J.D., University of Michigan, Ann Arbor, MI, "Rainfall-Runoff Relations on Urban and Rural Areas," USEPA Report No. EPA-670/2-75-046, NTIS No. PB 2 830.

44. Yen, B.C., and Chow, V.T., University of Illinois, Urbana, IL, "Urban Stormwater and Runoff Determination of Volumes and Flowrates," USEPA Report No. EPA-600/2-76-116, NTIS No. PB 253 410.

45. Field, R., et al., USEPA, Storm and Combined Sewer Program, Edison, NJ, "Porous Pavement: Research; Development; and Demonstration," Transportation Engineering Journal of ASCE, Vol. 108, No. TE3, May 1982, pp. 244-258

46. Diniz, E., Espey, Huston & Assoc., Inc., Albuquerque, NM, "Porous Pavement: Phase I - Design and Operational Criteria," USEPA Report No. EPA-600/2-80-135, NTIS No. PB 81-104 796.

47. Goforth, G.F., Espey, Huston & Assoc., Inc., Austin, TX; Diniz, E.V., Resource Technology, Inc., Albuquerque, NM; and Rauhut, J.B., Austin, TX, "Stormwater Hydrological Characteristics of Porous and Conventional Paving Systems," USEPA Report No. EPA-600/2-83-106, NTIS No. PB 84-123 728.

48. Goforth, G.F., Espey, Huston & Assoc., Inc., Austin, TX; Diniz, E.V., Resource Technology, Inc., Albuquerque, NM; and Rauhut, J.B., Austin, TX, "Stormwater Hydrological Characteristics of Porous and Conventional Paving Systems," USEPA Project Summary No. EPA-600/S2-83- 106, NTIS No. PB 84-123 728.

49. Benjes, H.H., Culp, Wesner, Culp Consulting Engineers, El Dorado, CA, "Cost Estimating Manual- Combined Sewer Overflow Storage Treatment," USEPA Report No. EPA-600/2-76-286, NTIS No. PB 266 359.

50. Benjes, H.H. Jr., Culp, Wesner, Culp Consulting Engineers, El Dorado, CA, Field, R., Storm and Combined Sewer Program, Edison, NJ, "Estimate Sewer Overflow Facility Costs," Water & Wastes Engineering, September 1978, pp. 56-62.

51. Heaney, J.F., et al., University of Florida, Gainesville, FL, "Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges," Volume II - Cost Assessment and Impacts, USEPA Report No. EPA-600/2-77-064b, NTIS No. PB 266 005.

52. Sonnen, M., Water Research Engineers, Walnut Creek, CA, "Abatement of Deposition and Scour in Sewers," USEPA Report No. EPA-600/2-77-212, NTIS No. PB 276 585.

53. Yen, B.C., et al., University of Illinois, Urbana, IL, "Stormwater Runoff on Urban Areas of Sleep Slope," USEPA Report No. EPA-600/2-77- 168, NTIS No. PB 272 755.

54. Kaufman, H.L., and Lai, F.H., Clinton Bogert Assoc., Fort Lee, NJ, "Conventional and Advanced Sewer Design Concepts for Dual Purpose Flood and Pollution Control - A Preliminary Case Study, Elizabeth, NJ," USEPA Report No. EPA-600/2-78-090, NTIS No. PB 285 663.

55. Field, R., and Weisman, D.A., USEPA Storm and Combined Sewer Program, Edison, NJ, "A Planning and Design Guidebook for Combined Sewer Overflow Control," USEPA Report No. EPA-600/2-82-084, NTIS No. PB 82- 259 235.

56. Wuelschleger, R.E., et al., Envirex Environmental Sciences Div., Milwaukee, WI, "Methodology for the Study of Urban Storm Generated Pollution and Control," USEPA Report No. EPA-600/2-76-145, NTIS No. PB 258 243.

57. Dalrymple, R.J., et al., Beak Consultants for American Public Works Assoc., Chicago, IL, "Physical and Settling Characteristics of Particulates in Storm and Sanitary Wastewater," USEPA Report No. EPA-670/2-75-011, NTIS No. PB 2 001.

58. Field, R., Storm and Combined Sewer Program, USEPA, Edison, NJ, "Stormwater Pollution Control: A New Technology," 28 Minute Film distributed by the General Services Administration (GSA), National Audio Visual Center, Washington, DC 20409.

59. Lynard, W., et al., Metcalf & Eddy Engineers, Inc., Palo Alto, CA, "Urban Stormwater Management and Technology: Case Histories," USEPA Report No. EPA-600/8-80-035, NTIS No. PB 81-107 153.

60. Heaney, J.F., et al., University of Florida, Gainesville, FL, "Stormwater Management Model: Level I - Preliminary Screening Procedures," USEPA Report No. EPA-600/2-76-275, NTIS No. PB 259 916.

61. Heaney, J.F., et al., University of Florida, Gainesville, FL, "Stormwater Management Model: Level I - Comparative Evaluation of Storage/Treatment and Other Management Practices," USEPA Report No. EPA-600/2-77-083, NTIS No. PB 265 671.

62. Moffa, P., and Karanik, J., Onondaga County, NY, "Methodology for Evaluating the Impact and Abatement of Combined Sewer Overflows - A Case Study of Onondaga Lake, New York," USEPA Report No. EPA-600/8-80- 048, NTIS No. PB 81-141 913.

63. Murphy, C.B., et al., O'Brien & Gere Engineers, Inc., Syracuse, NY, Quinn, T.J., and Stewart, J.E., Monroe County Division of Pure Waters, Rochester, NY, "Best Management Practices: Implementation," USEPA Report No. EPA-905/9-81-002, NTIS No. PB 82-169 210.

64. Pitt, R.E., Woodward Clyde Consultants, San Francisco, CA, "Demonstration of Nonpoint Pollution Abatement Through Improved Street Cleaning Practices," USEPA Report No. EPA-600/2-79-161, NTIS No. PB 80-108 988.

65. Pitt, R.E., Consulting Environmental Engineer, Blue Mounds, WI, "Characterization , Sources, and Control of Urban Runoff by Street and Sewerage Cleaning," USEPA Report No. Pending.

66. Pitt, R.E., Consulting Environmental Engineer, Blue Mounds, WI, "Characterization, Sources, and Control of Urban Runoff by Street and Sewerage Cleaning," USEPA Project Summary No. Pending.

67. Aronson, G.L., et al., Environmental Design & Planning, Inc., Boston, MA, "Evaluation of Catchbasin Performance for Urban Stormwater Pollution Control," USEPA Report No. EPA-600/2-83-043, NTIS No. PB 83- 217 745.

68. Aronson, G.L., et al., Environmental Design & Planning, Inc., Boston, MA, "Evaluation of Catchbasin Performance for Urban Stormwater Pollution Control," USEPA Report No. EPA-600/S2-83-043, NTIS No. PB 83-217 745.

69. Pisano, W.C., and Queriroz, C.S., Energy and Environmental Analysis, Inc., Boston, MA, "Procedures for Estimating Dry Weather Pollutant Deposition in Sewerage Systems," USEPA Report No. EPA-600/2-77-120, NTIS No. PB 270 695.

70. Pisano, W.C., et al., Northeastern University, Boston, MA, "Dry- Weather Deposition and Flushing for Combined Sewer Overflow Pollution Control," USEPA Report No. EPA-600/2-79-133, NTIS No. PB 80-118 524.

71. Kaufman, H.L., and Lai, F.H., Clinton Bogert Assoc., Ft. Lee, NJ, "Review of Alternatives for Evaluation of Sewer Flushing Dorchester Area - Boston," USEPA Report No. EPA-600/2-80-118, NTIS No. PB 81-1 648.

72. Chandler, R.W., and Lewis, W.R., Water Utilities Department, Dallas, TX, "Control of Sewer Overflows by Polymer Injection," USEPA Report No. EPA-600/2-77-189, NTIS No. PB 272 654.

73. American Public Works Assoc., Chicago, IL, "Combined Sewer Regulator Overflow Facilities," USEPA Report No. 11022DMU07/70, NO NTIS.

74. American Public Works Assoc., Chicago, IL, "Combined Sewer Regulation and Management: A Manual of Practice," USEPA Report No. 11022DMU08/70, NTIS No. PB 195 676.

75. Freeman, P.A., Peter Freeman Assoc., Inc., Berlin, MD, "Evaluation of Fluidic Combined Sewer Regulators Under Municipal Service Conditions," USEPA Report No. EPA-600/2-77-071, NTIS No. PB 272 834.

76. Field, R., USEPA, Storm and Combined Sewer Program, Edison, NJ, "The Dual-Functioning Swirl Combined Sewer Overflow Regulator/Concentrator," USEPA Report No. EPA-670/2-73-059, NTIS No. PB 227 182.

77. Field, R., and Masters, H.E., USEPA, Edison, NJ, "Swirl Device for Regulating and Treating Combined Sewer Overflow," USEPA Report No. EPA-625/2-77-012, EPA Technology Transfer Capsule Report, CERI (Cincinnati) 2012.

78. Sullivan, R.H., et al., American Public Works Assoc., Chicago, IL, "Swirl and Helical Bend Pollution Control Devices: Design Manual," USEPA Report No. EPA-600/8-82-013, NTIS No. PB 82-266 172.

79. Matthews, T.M., et al., Snell Environmental Group, Akron, OH, "Hydrobrakes Regulated Storage System for Stormwater Management," USEPA Report No. EPA-600/2-83-097, NTIS No. PB 84-110 378.

80. Matthews, T.M., et al., Snell Environmental Group, Akron, OH, "Hydrobrakes Regulated Storage System for Stormwater Management, USEPA Project Summary No. 600/S2-83-097, NTIS No. PB 84-110 378.

81. Field, R., USEPA, Storm and Combined Sewer Program, Edison, NJ, "An Overview of the U.S. Environmental Protection Agency's Storm and Combined Sewer Program Collection System Research," Water Research, Vol. 16, Pergamon Press Ltd., pp. 859-870, 1982.

81a. Driver, T. and Olsen, M., Driver and Olsen, Inc., Northbrook, IL, "Demonstration of Sewer Relining by the Insituform Process, Northbrook, IL," USEPA Report No. EPA-600/2-83-064, NTIS No. PB 83-245 878.

82. Field, R., and Struzeski, E.J., USEPA, Storm and Combined Sewer Program, Edison, NJ, "Management and Control of Combined Sewer Overflows," Journal Water Pollution Control Federation, Washington DC, Vol. 44, No. 7, pp. 1393-1415, July 1972.

83. Field, R., Storm and Combined Sewer Program, Edison, NJ; Lager, J.A., Metcalf and Eddy, Inc., Palo Alto, CA, "Urban Runoff Pollution Control State-of-the-Art," Journal of The Environmental Engineering Division, American Society of Civil Engineers, Vol. 101, No. EE1, pp. 107-125, February 1975.

84. Soderland, H., Kjessler & Mannerstrale AB, Swedish Council for Building Research, Stockholm, Sweden, "Flow Balancing Method for Stormwater and Combined Sewer Overflow," ISBN 91-540-3765-4: D17:1982, pp. 1-27, 1982.

85. Smith, William G., et al., Metcalf & Eddy Engineers Inc., Palo Alto, CA, "Storage/Sedimentation Facilities for Control of Storm and Combined Sewer Overflows Design Manual," USEPA Report No. Pending, (USEPA Contract No. 68-03-2877).

86. Field, R., and Weisman, D.A., USEPA, Storm and Combined Sewer Program, Edison, NJ, "A Planning and Design Guidebook for Combined Sewer Overflow Control and Treatment," USEPA-600/2-82-084, NTIS No. PB 82- 259 235.

87. Maher, M.B., Crane Company, King of Prussia, PA, "Microstraining and Disinfection of Combined Sewer Overflows - Phase III," USEPA Report No. EPA-670/2-74-049, NTIS No. PB 235 771.

88. Drehwing, F., et al., O'Brien & Gere Engineers, Inc., Syracuse, NY, "Disinfection Treatment of Combined Sewer Overflows, Syracuse, New York USEPA Report No. EPA-600/2-79-134, NTIS No. PB 80-113 459.

89. Nebolsine, R., et al., Hydrotechnic Corp., New York, NY, "High-Rate Filtration of Combined Sewer Overflows," USEPA Report No. 11023EY104/72, NTIS No. 211 144.

90. Innerfield, H., and Forndran, A., New York City Department of Water Resources, New York, NY, "Dual Process High-Rate Filtration of Raw Sanitary Sewage and Combined Sewer Overflows," USEPA Report No. EPA-600/2-79-015, NTIS No. PB 296 626/AS.

91. Gupta, M.K., et al., Envirex, Environmental Science Division, Milwaukee, WI, "Screening/Flotation Treatment of Combined Sewer Overflows, Volume I - Bench Scale and Pilot Plant Investigations," USEPA Report No. EPA-600/2-77-069a, NTIS No. PB 272 834.

92. The Ecology Division, Rex Chainbelt, Inc., Milwaukee, WI, "Screening/Flotation Treatment of Combined Sewer Overflows," USEPA Report No. 11020FDC-01/72, NO NTIS.

93. Meinholz, T.L., Envirex, Inc., Milwaukee, WI, "Screening/Flotation Treatment of Combined Sewer Overflows - Volume II: Full Scale Operation, Racine, WI," USEPA Report No. EPA-600/2-79-106a, NTIS No. PB 80-130 693.

94. Shelley, G.J., et al., George J. Shelley Consulting Engineers, Tamworth, New South Wales, Australia, "Field Evaluation of a Swirl Degritter at Tamworth N.S.W., Australia," USEPA Report No. EPA-600/2- 81-063, NTIS No. PB 81-187 247.

95. Shelley, G.J. et al., George J. Shelley Consulting Engineers, Tamworth, New South Wales, Australia, "Field Evaluation of a Swirl Degritter at Tamworth N.S.W., Australia," USEPA Project Summary No. EPA-600/S2-81-063, NTIS No. PB 81-187 247.

96. Benedict, A.H., and Roelfs, V.L., Whitely-Jacobsen and Assoc., Portland, OR, "Joint Dry-Wet Weather Treatment of Municipal Wastewater at Clatskanie, Oregon," USEPA Report No. EPA-600/2-81-061, NTIS No. PB 81-187 262.

97. Benedict, A.H., and Roelfs, V.L., Whitely-Jacobsen and Assoc., Portland, OR, "Joint Dry-Wet Weather Treatment of Municipal Wastewater at Clatskanie, Oregon," USEPA Project Summary No. EPA- 600/S2-81-061, NTIS No. PB 81-187 262.

98. Agnew, R.W., et al., Envirex, Milwaukee, WI, "Biological Treatment of Combined Sewer Overflow at Kenosha, WI," USEPA Report No. EPA-670/2-75-019, NTIS No. PB 2 107.

99. Field, R., et al., USEPA, Storm and Combined Sewer Program, Edison, NJ, "Proceedings of Workshop on Microorganisms in Urban Stormwater," USEPA No. EPA-600/2-76-244, NTIS No. PB 263 030.

100. Glover, G.E., and Herbert, G.R., Crane Company, King of Prussia, PA, "Micro-straining and Disinfection of Combined Sewer Overflows - Phase II," USEPA Report No. EPA-R2-73-124, NTIS No. PB 219 879.

101. Drehwing, F.J., et al., O'Brien & Gere Engineers, Inc., Syracuse, NY, "Combined Sewer Overflow Abatement Program, Rochester, NY - Volume II Pilot Plant Evaluations," USEPA Report No. EPA-600/2-79-031b, NTIS No. PB 80-159 262.

102. Moffa, P.E., et al., O'Brien & Gere Engineers, Inc., Syracuse, NY, "Bench-Scale High-Rate Disinfection of Combined Sewer Overflows with Chlorine and Chlorine Dioxide," USEPA Report No. EPA-670/2-75-021, NTIS No. PB 2 296.

103. Maher, M.B., Crane Company, King of Prussia, PA, "Microstraining and Disinfection of Combined Sewer Overflows - Phase III," USEPA Report No. EPA-670/2-74-049, NTIS No. PB 235 771.

104. Drehwing, F., et al., O'Brien & Gere Engineers, Inc., Syracuse, NY, "Disinfection/Treatment of Combined Sewer Overflows, Syracuse, New York," USEPA Report No. EPA-600/2-79-134, NTIS No. PB 80-113 459.

105. Leitz, F.B., et al., Ionics, Inc., Watertown, MA, "Hypochlorite Generator for Treatment of Combined Sewer Overflows," USEPA Report No. 11023DAA03/72, NTIS No. PB 211 243.

106. Pontius, U.R., et al., Pavia-Byrne Engineering Corp., New Orleans, LA, "Hypochchlorination of Polluted Stormwater Pumpage at New Orleans," USEPA Report No. EPA-670/2-73-067, NTIS No. PB 228 581.

107. Connick, D.J., et al., Environmental Design & Planning, Inc., Allston (Boston) MA, "Evaluation of a Treatment Lagoon for Combined Sewer Overflow," USEPA Report No. EPA-600/S2-81-196, NTIS No. PB 82-105 214.

108. Gupta, M.K., et al., Envirex, Environmental Science Division, Milwaukee, WI, "Handling and Disposal of Sludges from Combined Sewer Overflow Treatment - Phase I (Characterization)," USEPA Report No. EPA-600/2-77-053a, NTIS No. PB 270 212.

109. Huibregtse, K.R., et al., Envirex, Environmental Science Division, Milwaukee, WI, "Handling and Disposal of Sludges from Combined Sewer Overflow Treatment - Phase II (Impact Assessment)," USEPA Report No. EPA-600/2-77-053b, NTIS No. PB 280 309.

110. Osantowski, R., et al., Envirex, Environmental Science Division, Milwaukee, WI, "Handling and Disposal of Sludges from Combined Sewer Overflow Treatment - Phase III (Treatability Studies)," USEPA Report No. EPA-600/2-77-053c, NTIS No. PB 281 006.

111. Huibregtse, K.R., et al., Envirex, Environmental Science Division, Milwaukee, WI, "Evaluation of Secondary Impacts of Urban Runoff Pollution Control," USEPA Report No. EPA-600/2-82-045 NTIS No. PB 82-230 319, 1982.

112. Homack, P., et al., E.T. Killiam Assoc., Inc., Millburn, NJ, "Utilization of Trickling Filters for Dual Treatment of Dry and Wet Weather Flows," USEPA Report No. EPA-670/2-73-071, NTIS No. PB 231 251.

113. Welborn, H.L., Y-T-O & Assoc., Walnut Creek, CA, "Surge Facility for Wet-and Dry-Weather Flow Control," USEPA Report No. EPA-670/2-74-075, NTIS No. PB 283 905.

114. Mahida, V.U., and DeDecker, F.J., Spalding DeDecker Assoc., Madison Heights, MI, "Multi-Purpose Combined Sewer Overflow Treatment Facility, Mt. Clemens, MI," USEPA Report No. EPA-670/2-75-010, NTIS No. PB 2 914.

115. Field, R., and Fan, C-Y., USEPA, Edison, NJ, "Industrial Reuse of Urban Stormwater," Journal of the Environmental Engineering Division, ASCE, Vol. 107, No. EE1, February 1981, pp. 171-189.

116. Litwin, Y.J., et al., Ramlit Associates, Inc., Berkeley, CA, "The Use of Wetlands for Water Pollution Control," USEPA Report No. EPA-600/2-82-086, NTIS No. PB 83-107 466.

117. Hickock, et al., Eugene A. Hickock and Associates, Wayzata, MN, "Urban Runoff Treatment Methods, Volume I - Non-Structural Wetland Treatment," USEPA Report No. EPA-600/2-77-217, NTIS No. PB 278 172.

☆U.S. GOVERNMENT PRINTING OFFICE: 1990 - 748-159/00375

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Official Business
Penalty for Private Use, $300

Please make all necessary changes on the above label, detach or copy, and return to the address in the upper left-hand corner.

If you do not wish to receive these reports CHECK HERE ☐; detach, or copy this cover, and return to the address in the upper left-hand corner.

EPA/600/8-89/054