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URBAN RUNOFF POLLUTION CONTROL TECHNOLOGY OVERVIEW

Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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by

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report developed for the EPA Office of Air, Land and Water Use, Office of Research and Development "State-of-the-Art Research Seminar Series," on September 28, 1976, constitutes a review of EPA's R&D Program for Urban Runoff Pollution Control. It describes completed work, ongoing work and future work required to abate pollution from wet-weather flows and presents the overall philosophy of approach to this specific problem as far as EPA's R&D Program sees it.

Francis T. Mayo
Director
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ABSTRACT

This Overview describes the major elements of the Urban Runoff Pollution Control Program. Problem Definition, User Assistance Tools, Management Alternatives and Technology Transfer are covered, including some of the highlights of the Program's future direction and products from over 150 of its research projects. References are cited for completed Program reports, ongoing Program projects, and in-house documents.

Capital cost comparisons for storm and combined sewer control/treatment are given, along with a specific example of cost-effect solution for urban runoff pollution control by in-line storage in Seattle. In a study done in Des Moines, using a simplified receiving water model, four control alternatives were compared, considering cost and effectiveness in terms of a frequency of D.O. standard violations.

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INTRODUCTION

Control and treatment of stormwater discharges and combined sewage overflows from urban areas are problems of increasing importance in the field of water quality management. Over the past decade much research effort has been expended and a large amount of data has been generated, primarily through the actions and support of the U.S. Environmental Protection Agency's Storm and Combined Sewer Research and Development Program.

The products of the Program (Figure 1.) as it will be presented will be divided into the following areas, common to the major elements of Combined Sewer Overflow Pollution Control, and Sewered and Unsewered Runoff Pollution Control: Problem Definition, User Assistance Tools (Instrumentation, Computers), Land Management, Collection System Control, Storage, Treatment, Sludge and Solids, Integrated Systems, and Technical Assistance and Technology Transfer.

Table 1. breaks down these categories into more specific elements which will be discussed individually. There have been many projects under the Program -- about 150, so only a basic Program direction and the more significant products, both completed and anticipated, will be highlighted. References are cited for completed Program reports (numerically indicated), ongoing Program projects (indicated by "P" numbers), and in-house and miscellaneous documents (indicated by "R" numbers).

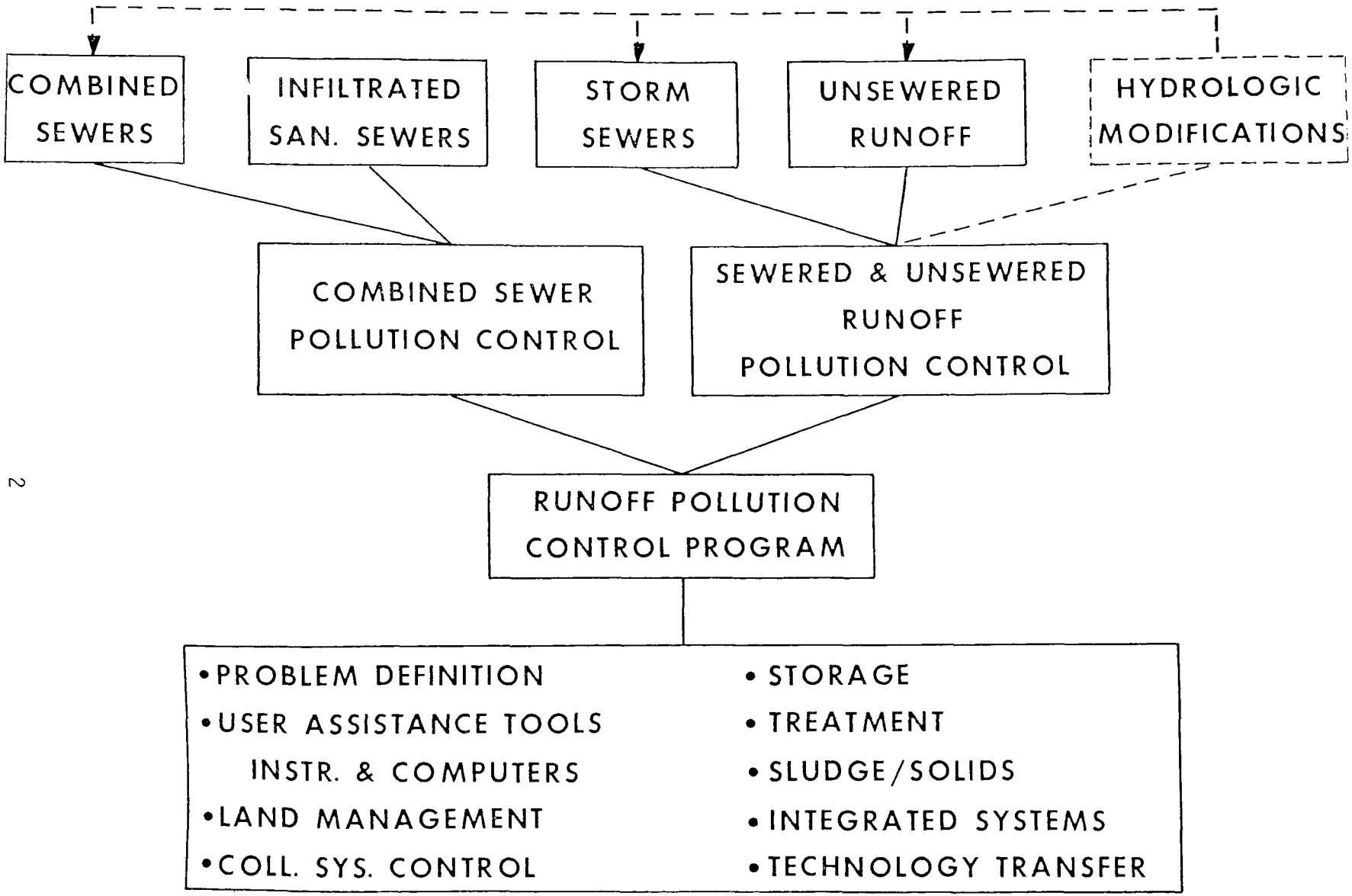


Figure 1. EPA Storm and Combined Sewer R&D Program

CATEGORIES	INITIATED/ACCOMPLISHED	ONGOING
PROBLEM DEFINITION		
Characterization	Prelim. appraisals CSO/SW prob., CSO/SW char., deicing, sed./eros., loading factors, rec. water impacts, nat'l assess. impacts/costs	-Direct rec. water/source loading factor analysis -Dev. S&CS strategy document -Analyze optimum S&CS/DWF T/C combinations
Solution Methodology	SOTA S&CS tech., plan/select guide, conduct of SW studies, SOTA's sed./eros. & deicing control, unit cost factor dev.	
USER ASSISTANCE TOOLS		
Instrumentation	Raingage, flow measuring, sampling, monitoring, control	-Verif. magnetic flowmeter for simultaneous press/gravity flow meas. (supplement) -Demo in-situ TOC anal. & storm flow sampler (Syracuse-supplement) -Dev. syst. analysis program for quantification/handling of CSO sludge/solids -Dev. autom. oper. model for real-time control w/rain fall predict. -Hydr. model for steep slopes (supplement)
Simulation Models	Simplified, detailed/complex, operational, dissemination	
LAND MANAGEMENT	NON-STRUCTURAL:	
Retention/detention	Land use planning, upstream impoundment (structural), porous pavement	-Eval. effect of sed. trapping efficiency of off-stream det./ret. -Demo in-situ hydrophobic substance -Demo sed./eros. control techniques in SE USA (supplement) -Demo improved street cleaning practices
Enforced controls	Air pollution, eros./sed., cropping, berms, chemical use, hydrophobic, deicing	
Neighborhood sanitation	Street cleaning, solid waste management	
COLLECTION SYSTEM CONTROLS		
Sewer separation	May require separate treatment system	-Demo periodic sewer flushing: CSO 1st flush relief -Eval. strength increases from sulfur impregnation of concrete pipe -Dev. autom. operational model for real-time control w/rainfall predict.
Runoff inlet/catch basin	Effectiveness eval., improved design, cleaning	
Sewers	"First flush" relief: flushing/cleaning, new designs (low flow carrying vel. and added storage), I/I prevent and control (with manuals), polymers to increase capacity	
Improved regulators and tide gates	Positive control, increased diversion to treatment, swirl & helical, fluidic reg.	
Remote monitoring with supervisory control	Provides storage/discharge options	
Fully automated control	Automates storage/discharge options	
STORAGE		
In-Line	Use excess sewer capacity	
Off-Line	Surface (rect. tanks, earthen basins, abond. quarries), subterrain. (natural formations, silos & tunnels), underwater, solids impacts	
TREATMENT		
Physical treatment with and without chemicals	Fine screening, microstraining, sed., filt., dissolved air flotation, swirl/spiral separation	-Demo fine screening/microstraining, swirl reg. and high-rate disinf. by ClO_2/Cl_2 and mixing incl: resid. toxic/carcinogenic Cl_2 comp. viral disinf. eval.) (Syracuse-supplement) -Feas. of land disposal (Envirex-supplement)
Biological treatment	Contact stabilization, trickling filters, lagoons, rotating biological contactors. Generally assoc. w/continuously operated plant	
Physical-chemical	Precipitation, filtration, adsorption, ion exchange, break-pt Cl_2	
Disinfection	Chlorination, hypochlorination, ozonation, chlorine dioxide, on-site gen., high-rate, mixing, micro-organism indicator study (pathogen, virus), 2-stage	
Land disposal	Marsh land	
SLUDGE/SOLIDS		
Characterization/Quantification	Classification requirement, treatability, vital parameters, amount, solids content	-Evaluate: methods of ultimate disposal of WWF solids and impacts of WWF sludges/solids on DWF plant (Envirex-supplement)
Treatment handling schemes	On-site vs DWF trmt., land disposal	
Process evaluations	Thickening, digestion, centrifugation, vacuum filtration, incineration	
INTEGRATED SYSTEMS (Varies)	Most common master plan approach	
Storage/treatment	Pump-back, sed. in storage, disinfection, break-even econ. w/treatment	
Dual use WWF/DWF (storage/treatment	Lagoon storage/treat., HRTF, contact stab., P-C, hi-rate filter, equalization, combined sewers	
Control/treatment/reuse	Treatment-park, new town devel. (land mgmt-treat), storage/treat. marina feas., lakelets for storage/treat./reuse	
TECHNICAL ASSISTANCE AND TECHNOLOGY TRANSFER		-Continuous (15% - 20% of prog. time) NOTE: Anticipate increase in EPA construction grant (201) and planning grant (208) assist. due to CSO emphasis
Consultation to Fed., state, local govts. and quasi-govt. agencies	EPA, OAWP (needs surveys): EPA TT (seminars, film production); EPA Reg. receiving H_2O impact studies; EPA Hq and Regions on 201/208 studies and seminars; Reg. V on 108 grants; NSF, DOT, OWRT (reviews, confer, steering committees); CEQ & NCWQ (proposal and rept reviews, joint nat'l assess. projects)	
Public Inf. Requests	Documents, lectures, films, confer., articles, reports, example methodology for prob. solution, conf. moderator, prog. committees	
Consultation to foreign govt. and international confer.	TT (France, Japan, Denmark, Norway, Sweden, Canada, Netherlands, Australia, New Zealand), Canadian (TAG) IJC (steering com.) IAWPR (confer & prog. committees); various conferences and publications	
In-House seminars	Various tech. areas; overviews	
SWMM	Short course,; user's assistance manuals/dissemination	
Higher Education	SCS prog. university course man.	
Planning/design/SOTA/assess manuals and extra-mural publications	Overall prog. concepts, sol. method, sampling/anal., costs, specific processes	

Table 1. Summary Storm and Combined Sewer Program

PROBLEM DEFINITION

The program starts with "Problem Definition" broken into "Characterization" and "Solution Methodology" (Figure 2.).

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 bath, what do you do with the dirty water?"

Three types of discharges are involved: combined sewer overflows (CSO), storm drainage in separate systems, and overflows from infiltrated sanitary sewers. Significantly, the storm path and collection system configuration may have a pronounced influence on combined overflow quality, resulting in simultaneous discharge mixtures of sewage and runoff at different points, varying from raw to highly diluted as the system adjusts to a particular storm pattern. The problem constituents of general concern are visible matter, infectious bacteria, organics, and solids and in addition may include nutrients, heavy metals and pesticides.

CHARACTERIZATION

Representative Concentrations

Figure 3. gives some representative concentrations for comparison purposes. As shown the average BOD concentration in combined sewer overflow is approximately one-half the raw sanitary sewage BOD. However, storm discharges must be considered in terms of their shockloading effect due to their great magnitude. A not uncommon rainfall intensity of 1 in./hr will produce urban flowrates 50 to 100 times greater than the dry-weather flow (DWF) from the same area. 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. Bacterial contamination of separate storm wastewaters is typically 2 to 4 orders of magnitude less than that of untreated sanitary wastewaters. Significantly, however, it is 2 to 4 orders of magnitude greater than concentrations considered safe for water contact activities.

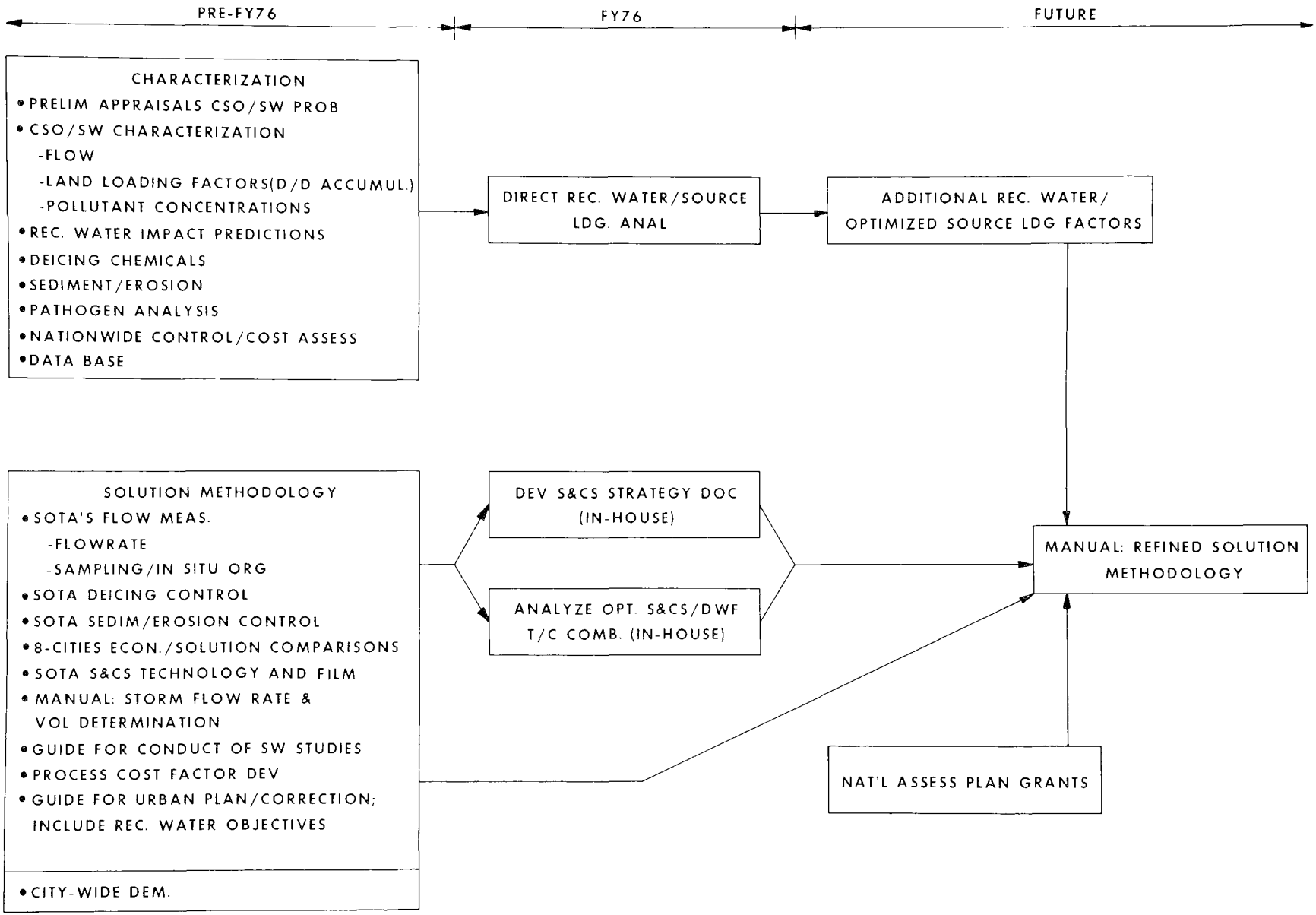


Figure 2. Problem Definition

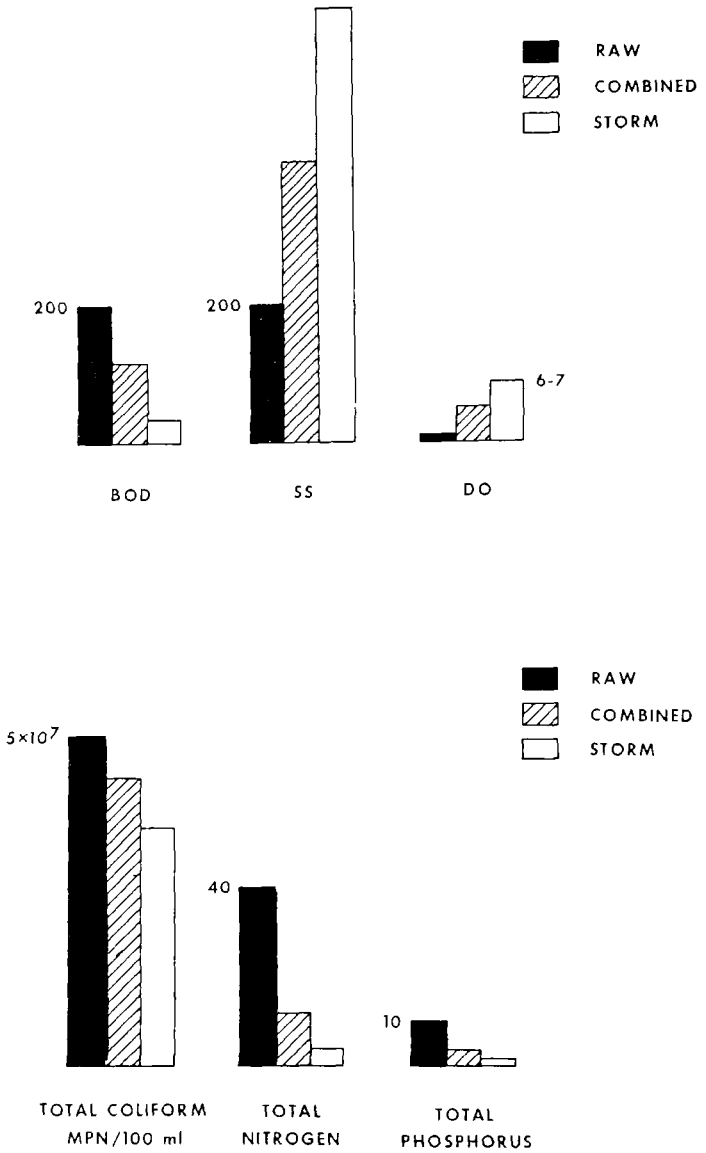


Figure 3. Representative Strengths of Wastewaters (Flow Weighted Means in mg/l)

Microbiological studies of both sanitary sewage and storm runoff have shown a consistently high recovery of both pathogenic and indicator organisms (160). The most concentrated pathogens were Pseudomonas aeruginosa and Staphylococcus aureus at levels ranging from 10^3 to 10^5 and from 10^0 to 10^3/100ml, respectively. Salmonella and enteroviruses, though frequently isolated were found at levels of only 10^0 to 10^4/10 liters of urban runoff. This strongly indicates that all types of urban runoff, in general, are hazardous to health.

Representative Loads

From 40% to 80% of the total annual organic loading entering receiving waters from a city is caused by sources other than the treatment plant (R-1). Assuming treatment plants are operating properly, during a single storm event, from 94% to 99% of the organic load and almost all settleable solids are attributed to wet-weather flow (WWF) sources (R-1).

The runoff of toxic pollutants, particularly heavy metals, is also high--considerably higher than typical industrial discharges. For example, New York Harbor receives metals from treatment plant effluents; discharges from combined sewer overflows and separate storm sewers; and untreated wastewater included in the CSO and from sewered areas not yet served by treatment plants. As can be seen in Table 2., urban runoff is the major contributor of heavy metals to the Harbor (R-2).

Potential Impacts

Approximately one-half of the stream miles in this country are water quality limited and 30% of these stream lengths are polluted to a certain degree with urban runoff. Hence, generally speaking, secondary treatment of DWF is not sufficient to produce required receiving water quality; and control of runoff pollution becomes an alternative for maintaining stream standards. Accordingly, both water quality planning and water pollution abatement programs need to be based on an analysis of the total urban pollution loads.

TABLE 2. —Metals Discharged to the Harbor from New York City Sources

Source	Cu	Cr	Ni	Zn	Cd
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	2,040	2,010	10,940	265
Weighted average concentration (mg/l)	0.25	0.12	0.11	0.62	0.015

*In reality, shockload discharges are much greater.

Until the urban stormwater situation is analyzed and efficient corrective measures taken, there is little or no sense in seeking higher levels of treatment efficiency in existing plants. For example,

- In Roanoke, VA domestic waste load removal was upgraded from 86% to 93%, yet there was no dramatic reduction in the BOD load (3.2 million pounds before upgrading, compared to 3.1 million pounds after)(41).

- If Durham, NC provided 100% removal of organics and suspended solids from the raw municipal waste on an annual basis, the total reduction of pollutants discharged to the receiving water would only be 59% of the ultimate BOD, and 5% of the suspended solids (112).

These examples are for separate systems. Communities with combined systems offer a potentially greater pollutional impact since additional loads come from domestic wastewaters, dry-weather sediment wash-out, and more impervious and populated lands.

Receiving Water Quality Impacts

For the aforementioned Durham study it was found that during storm flows, dissolved oxygen content of the receiving watercourse was independent of the degree of treatment of municipal wastes beyond secondary treatment. Oxygen sag estimates were unchanged even if the secondary plant was assumed upgraded to zero discharge, and stormwater discharges governed the oxygen sag 20 percent of the time.

There is an R&D study (P-68) in the Milwaukee area to determine water quality impacts from wet-weather discharges. This study is being worked in conjunction with a 201, Step 1 construction grant for the evaluation of combined sewer overflow pollution and control; and will provide the necessary "receiving water impact" basis for these evaluations.

Early results from direct receiving water sampling in the Milwaukee River provide strong evidence of CSO impacts on intensifying D.O. sag and increasing fecal coliform concentration. Figure 4. represents D.O. analyses for the Wells Street sampling station that lies at the downstream portion of the combined sewer area. Samples were collected at three hour intervals during 72 hours of dry weather during June 1975, averaged for the stream cross-section, and followed approximately nine days of antecedent dry weather. D.O. values hovered around 6 to 8 mg/l.

Figure 5. is for the same Wells Street location representing data from six days of monitoring following a 0.26 inch rainfall on October 14-15, 1975. Continuous monitoring at the site showed D.O. levels between 5.0 and 7.8 mg/l for the three days prior to rainfall. (The lag between the end of the storm and beginning of data acquisition was due to equipment malfunction.) The graph indicates a highly significant D.O. sag to zero mg/l and six days after the storm required for recovery.

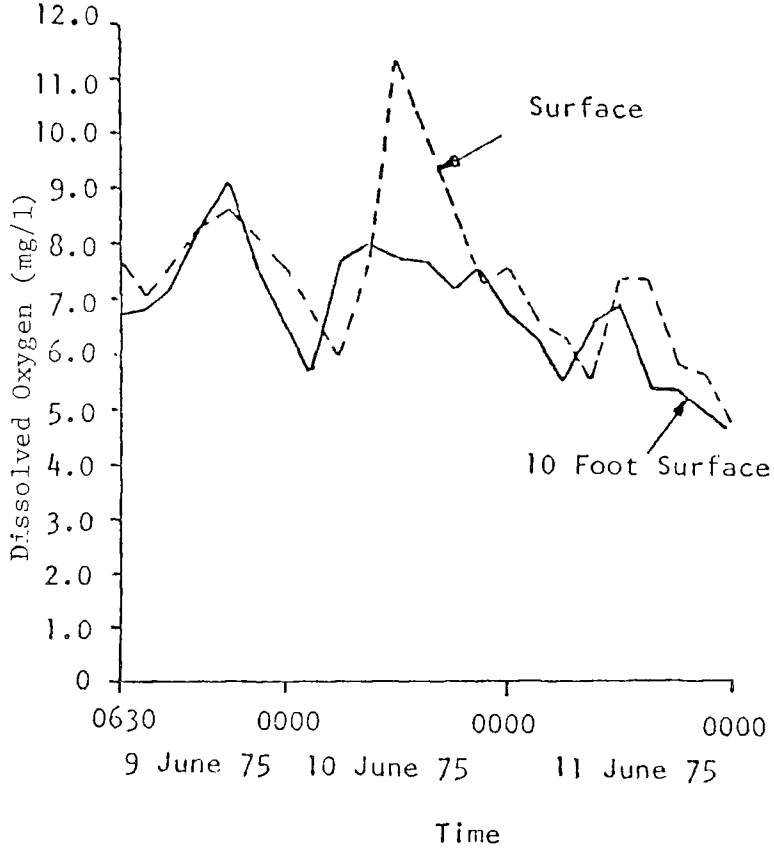


Figure 4. Dry Weather

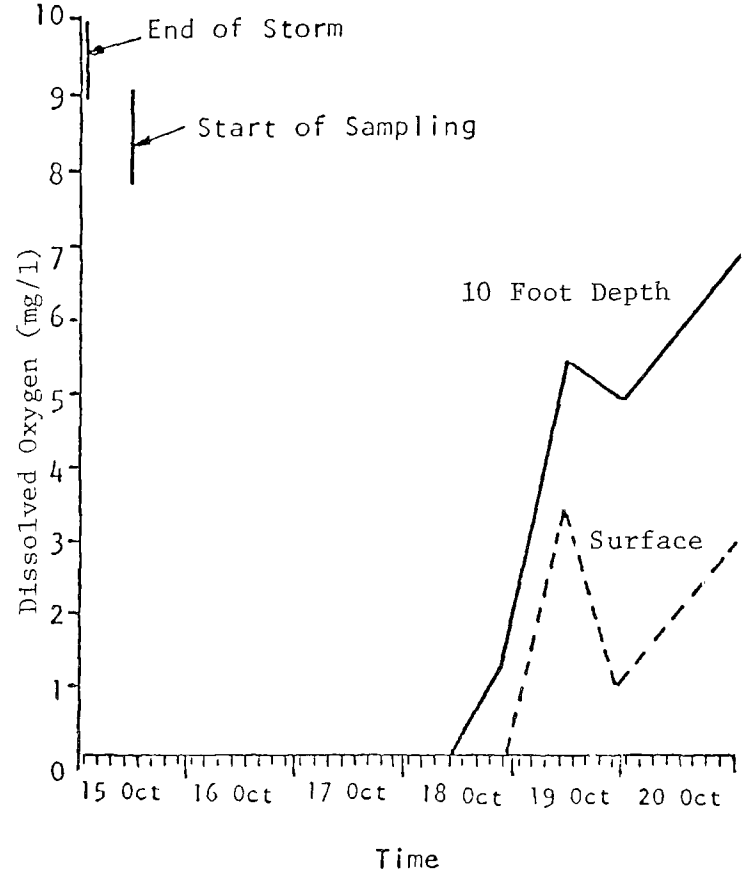


Figure 5. Wet Weather

Dissolved Oxygen Concentration, Wells Street
Milwaukee River, Milwaukee, WI

Adverse combined sewer overflow effects on fecal coliform concentrations in the Milwaukee River in the proximity of Lake Michigan were also deciphered. Figures 6. and 7. depict fecal coliform in the Milwaukee River during the same dry- and wet-weather monitoring periods as in Figures 4. and 5., respectively. Additionally, Figures 6. and 7. contain the Brown Deer Road monitoring site which is well above the intensely urbanized combined sewer overflow area. There is nearly a two log increase in enteric microorganisms downstream in the CSO area after wet-weather discharges indicating a potential health hazard for the nearby Lake beach fronts. Brown Deer Road showed no significant difference in fecal coliform concentration.

Due to Health Department findings, shell fishing must cease in Narragansett Bay in the vicinity of the Providence, RI overflows for periods of seven and ten days following rainfalls of one-half and one inch, respectively.

Other studies (P-15, 157,R-3) based on mass balance effects of urban runoff in receiving waters have reinforced these findings.

Erosion/Sediment Impacts

Erosion-sedimentation causes the stripping of land, filling of surface waters, and water pollution. Urbanization causes accelerated erosion, raising sediment yields two to three orders of magnitude from 10^2 - 10^3 tons/sq mi/yr to 10^4 - 10^5 tons/sq mi/yr (164). At the present national rate of urbanization, i.e., 4,000 ac/day, erosion/sedimentation must be recognized as a major environmental problem.

Characterization: Products

Past characterization studies for storm flow provide a data base for pollutant source accumulation, and hydraulic and pollutant loads (2,20,34,35, 41,47,51,53,54,59,60,63,65,67,73,81,82,83,88,102,123,124,127,128,143,149). A computerized data base and retrieval system has been developed for urban runoff (P-49). The data base contains screened and reasonably accurate data that is intended for model verification and future study area data synthesis -- especially useful to 201 and 208 planning agencies.

Besides the more generalized characterization studies, specific studies have been carried out for deicing salt (67,109,86), sediment/erosion (129), and pathogenic impacts (160) from storm flows.

Nationwide Cost Assessment

Sewer Separation --

The concept of constructing new sanitary sewers to replace existing combined sewers has largely been abandoned for pollution control due to enormous costs, limited abatement effectiveness, inconvenience to the public, and extended time for implementation. The use of alternate measures for combined sewer overflow control could reduce costs to about one-third the cost for separation (2,102). It is emphasized that sewer separation would not cope with the runoff pollution load.

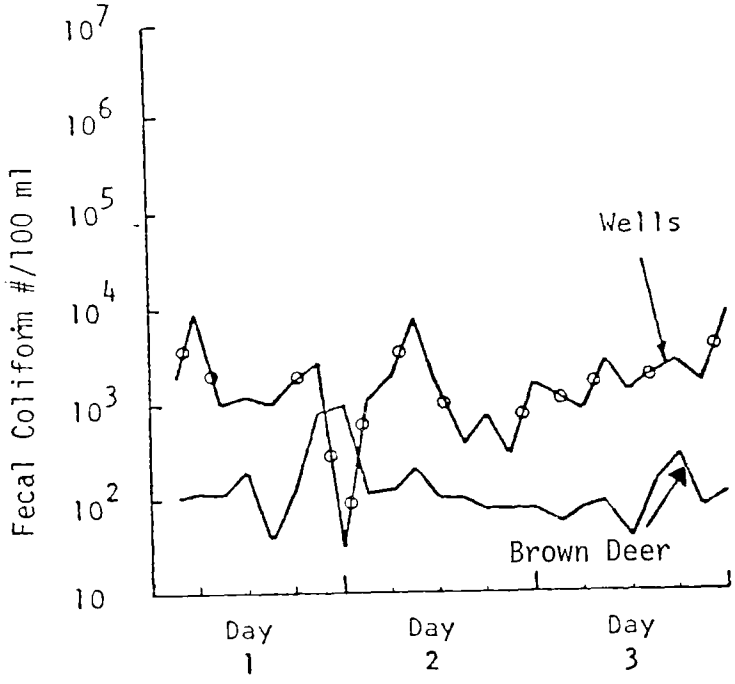


Figure 6. Dry Weather

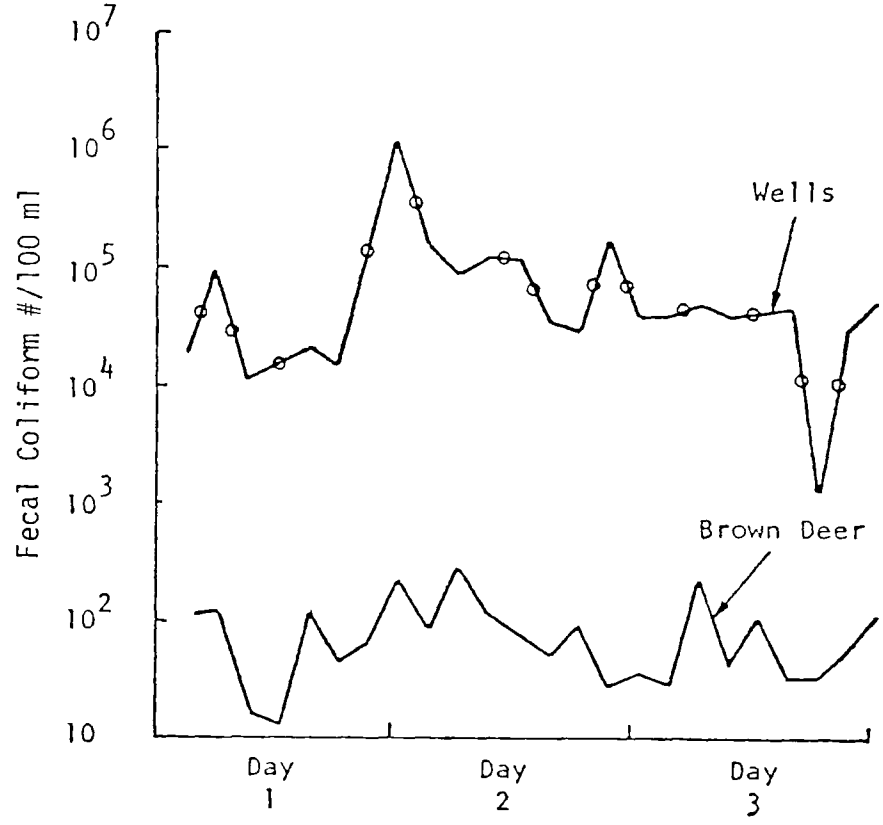


Figure 7. Wet Weather

Fecal Coliform Concentrations, Wells Street (CSO Area)
& Brown Deer Road (Separate Drainage Area)
Milwaukee River, Milwaukee, WI

High Costs Implied --

However, even in alternate approaches high costs have been implied. The 1974 Needs Survey (R-4), the 1967 EPA survey by the American Public Works Association (2), and the 1975 National Commission on Water Quality (NCWQ) Report (R-5), identified national costs for abating combined sewer overflow pollution at $26 billion, or approximately one-fourth of the total for municipal sewage control. The cost of abating separate stormwater pollution was estimated at $235 billion by the Needs Survey and $173 billion (for 75% BOD reduction) by another NCWQ report (R-6).

There must be a more accurate assessment of the problem both nationwide and regional to provide the necessary foundation for policy and law making, and firmer pollution abatement targets -- realistically, can a job be done for the money allotted?

New R&D Estimates Imply Lower Costs--

The recently completed Nationwide Assessment report (157) has attempted to more accurately assess these national cost estimates by reflecting a more logical consideration of such items as: climate, land usage, and degree of urbanization; pollution abatement of storm flow only and not separate, conventional flood control; appropriate design flows; and the benefits of optimized coordinated systems of smaller storage-treatment units not taken into consideration in earlier estimates. The resultant national cost for combined sewer overflow and separate stormwater pollution control was $23 billion at 75% BOD removal (Curve A, Figure 8.) (157). It is estimated that the incremental costs for combined sewer overflow pollution abatement alone would be $9 billion (Curve D, Figure 8).

Additional national cost reductions were shown by the multi-purpose coordinated use of wet and dry weather flow treatment facilities, and storm flow storage facilities used as dual sedimentation-treatment processes (see Curve B, Figure 8.). Within certain control levels best management practices, e.g., street cleaning and sewer flushing, could further reduce control costs (Curve C, Figure 8.).

When compared to prior studies the major reduction in the national figure for stormwater control is attributable to discounting storm sewer line construction (at $84 billion) and flood control (at $73 billion). These new estimates are admittedly limited because of required assumptions and the simplistic approach taken; but the point is, R&D should not shy away from separate stormwater research and control implementation based on even rougher preliminary surveys (e.g., the 1974 Needs or NCWQ surveys), if what is required is better estimating procedures; especially when stormwater pollution is site specific, and its abatement may be cost-effective in certain areas of the country.

SOLUTION METHODOLOGY

The second area under Problem Definition, "Solution Methodology" naturally followed initial "Characterization" for providing a uniform and necessary background for the user community.

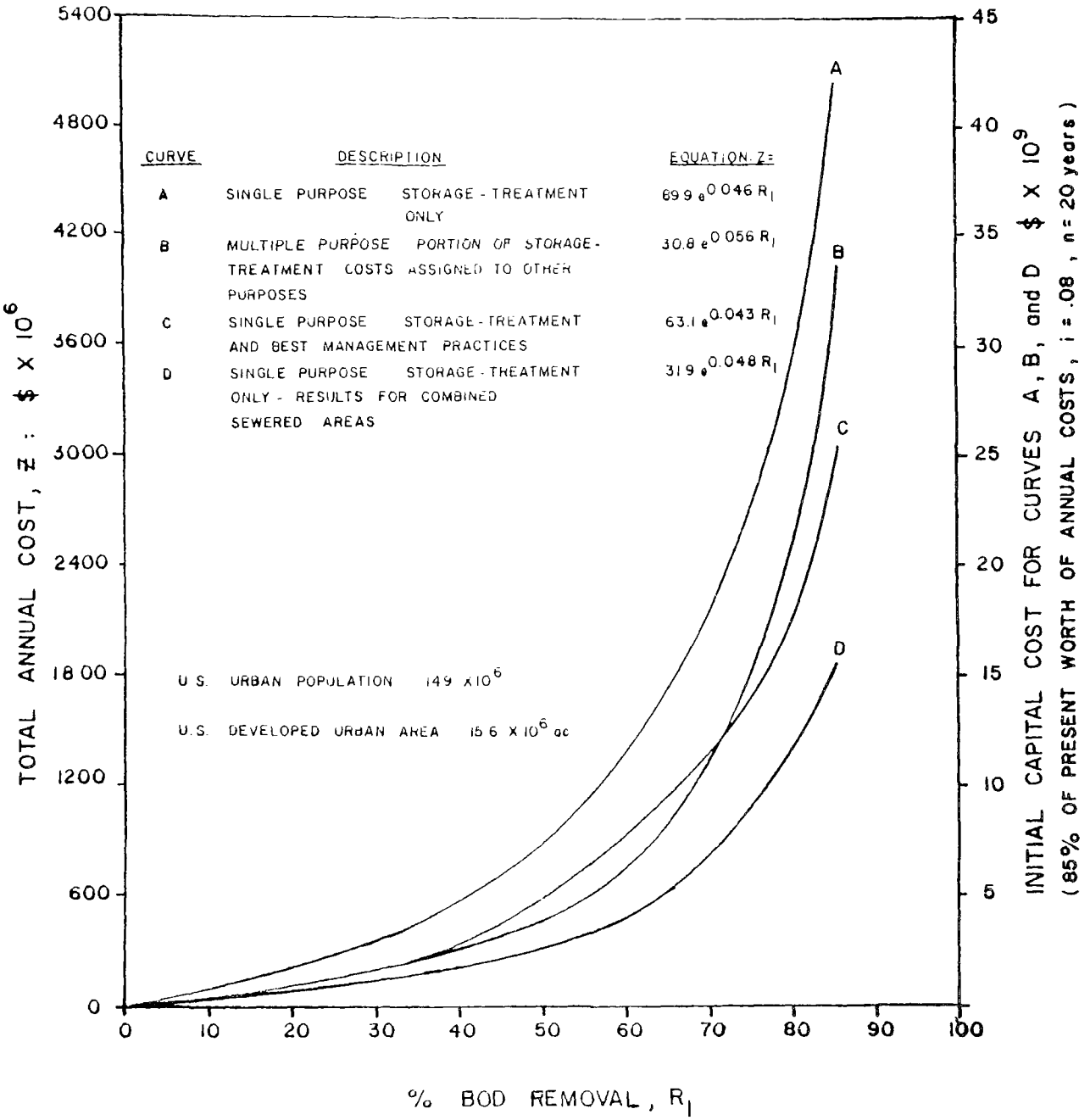


Figure 8. Single Purpose and Multiple Purpose Stormwater Pollution Control Costs for US

More Accurate Problem Assessment

Considering the limitations in the presently available data base, the first and most fundamental approach should be a more accurate assessment of the problem. Ideally, this should involve acquiring data on a city-wide basis for both DWF and wet-weather flow (WWF) including upstream-downstream pollutant mass balances and the effects of the waste loads on the receiving waters.

Cost-Effective Approach

Integrated with a more accurate assessment is the consideration of cost-effective approaches to WWF pollution control.

Present abatement alternatives exhibit an extraordinary range of cost-effectiveness. For example, cost-effectiveness in terms of dollars/lb of pollutant removed for an alternative such as storage plus primary treatment, varies over a range of 75:1, depending on such factors as location and land costs, type and condition of sewerage systems, pollution loads, and type of storage configuration. This very high cost-effectiveness variability demonstrates the irrationality of any attempt to prescribe uniform national standards for the technology of total urban load abatement as opposed to requiring site-specific studies.

There is an excellent opportunity to bring down the high costs implied for storm flow control. The most cost-effective solution methodology must thoroughly consider:

1. Wet-weather pollution impacts in lieu of blindly upgrading existing municipal plants.

2. Structural vs. land management and non-structural techniques. Studies have indicated that it may be cheaper to remove pollutants from the source by such measures as street, catch basin, and sewer cleaning than by eliminating them by downstream treatment. Certain land use, zoning, and construction site erosion control practices are other ways of alleviating the solids burden to the receiving stream or treatment plant;

3. Integrating dry and wet-weather flow systems to make maximum use of the existing sewerage system 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 (see Figure 8. for example) where cost differences accelerate at much higher rates than pollutant control increases. This phenomena is caused by the need to size storage-treatment facilities at disproportionately greater capacities for the less frequent storm events required for higher percent pollutant controls.

Until two important philosophies are allowed to prevail, the high cost implications for wet-weather pollution abatement will continue. First, flood and erosion control technology must be integrated with pollution control technology so that the retention and drainage facilities required for flood and erosion control can be simultaneously designed for integrated dual-benefits of pollution control. Second, if land management and non-structural 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.

Example Solution Methodology

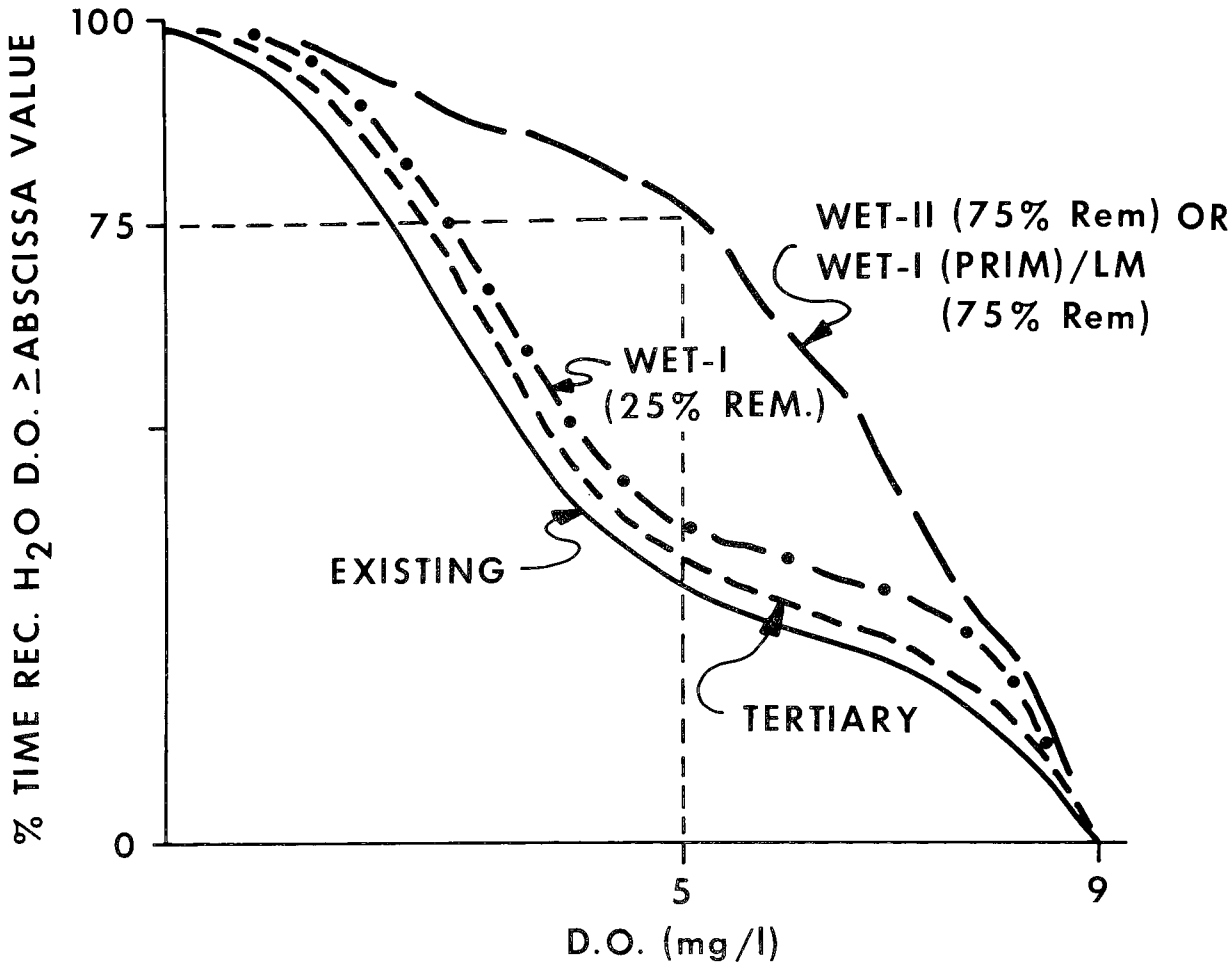
It is worthwhile to discuss a hypothetical example of a cost-effective solution methodology. Figure 9. represents one such approach. This case is for D.O.; actual studies should include other parameters and should represent at least one year of continuous data (at a minimum rainfall data). By this analysis a truer cost-effectiveness comparison can be made based on total time of receiving water impacts and associated abatement costs. For example, if a 5 mg/l D.O. is desired in the receiving water 75% of the time as a standard, 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 $3M. This or similar methodologies (157, Chapter VII) can help set cost-effective standards as well as select alternatives.

At this juncture it is most appropriate to bring out the fact that there is a critical lacking of meaningful water quality standards--especially for storm flow transient effects! This limitation forces the use of (1) existing criteria not well backed up by ecological receiving water effects, or (2) arbitrary percent control of combined sewer overflow or storm discharges. A critical need exists for the technology development sectors to join together with the receiving water ecology sectors to define and establish wet-weather receiving water effects--for only then will the right benchmarks be available for proper solution methodology. It is felt that the present state-of-the-art is advanced far enough to generate land runoff pollutant loadings from different control options and subsequent receiving water pollutant concentration. By filling the important gap of an adequate set of receiving water quality standards to work with, the necessary foundation tools will be available for a true cost-effective solution methodology.

Overcome Administrative Problems

It is essential to include these concepts to handle the job properly. However, there are basic problems in administration that must be overcome.

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 grant coverage must be adequate to stimulate such an approach. For example, EPA would have to join with the Corps, Soil Conservation Service, Department of Transportation, and perhaps other Federal agencies as well as



CONTROL ALTERNATIVES	% BOD REMOVAL		COST ($\$\times10^6$)
	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 9. Example Solution Methodology

departments of pollution control, sanitation, planning and flood control at the local level. EPA's present policy of funding construction will also need expansion to cover cost-effective land management and non-structural techniques promulgated by its planning grant approach.

Solution Methodology: Products

Highlighted solution methodology products are the often referenced eight city studies (41,51,53,54,49,60,65,83) which involved an economic comparison of pollution control alternatives for both dry and wet weather flow.

The state-of-the-art text on urban stormwater management and technology (102) is considered an excellent program milestone and guide for planners and engineers. It organizes and presents more than 100 completed Program projects as of December 1973. The text is presently being updated and will include comprehensive guidelines for total city-wide, wet-weather pollution control planning and countermeasure selection (P-5). Other in-house Program documents (111, R-6a, R-6b, R-6c, R-6d, R-6e, R-6f, R-6g, R-6h, R-6i) must also be included in this category.

A film is available covering the entire Program, and in particular full-scale control technologies (R-7). Program seminar proceedings (6,40,96) with themes of "design, operation, and costs" have been published. Urban runoff seminar proceedings for 208 planning agencies (140a) are also available. Separate engineering manuals are available for urban storm flowrate and volume determination (140,123), storm sewer design (71), and conducting urban stormwater pollution and control studies (145). SOTA's on storm flow measuring (130) and sampling (87,133) have also been published. All these documents are valuable references for the planning and implementing of urban stormwater studies for PL 92-500, 201, Step 1, and 208 grants.

In the area of "unit cost information" a manual (156) is at press which contains summary unit cost graphs on construction and operation of the basic urban stormwater storage and treatment devices. An example on storage facility construction costs is presented in Figure 10. Additional cost information and equations can be obtained from the abovementioned text on urban stormwater management and technology (102), the SWMM user's manual (116), the nationwide stormwater assessment document (157), and the manual for preliminary (level I) stormwater control screening (153).

Other important and widely referenced SOTA manuals are available for deicing pollution (100,104) and erosion control (68,70,90,92,168,169). The SOTA document on size and settling velocity characteristics of particles in storm and sanitary water (115) is important because it offers information for physical treatability of suspended solids and anticipated settlement in receiving waters. More information of this nature, along with the availability of pollutants with the suspended solids, is needed. These, along with the aforementioned solution methodology documents, are or should be serving for 201 and 208 studies.

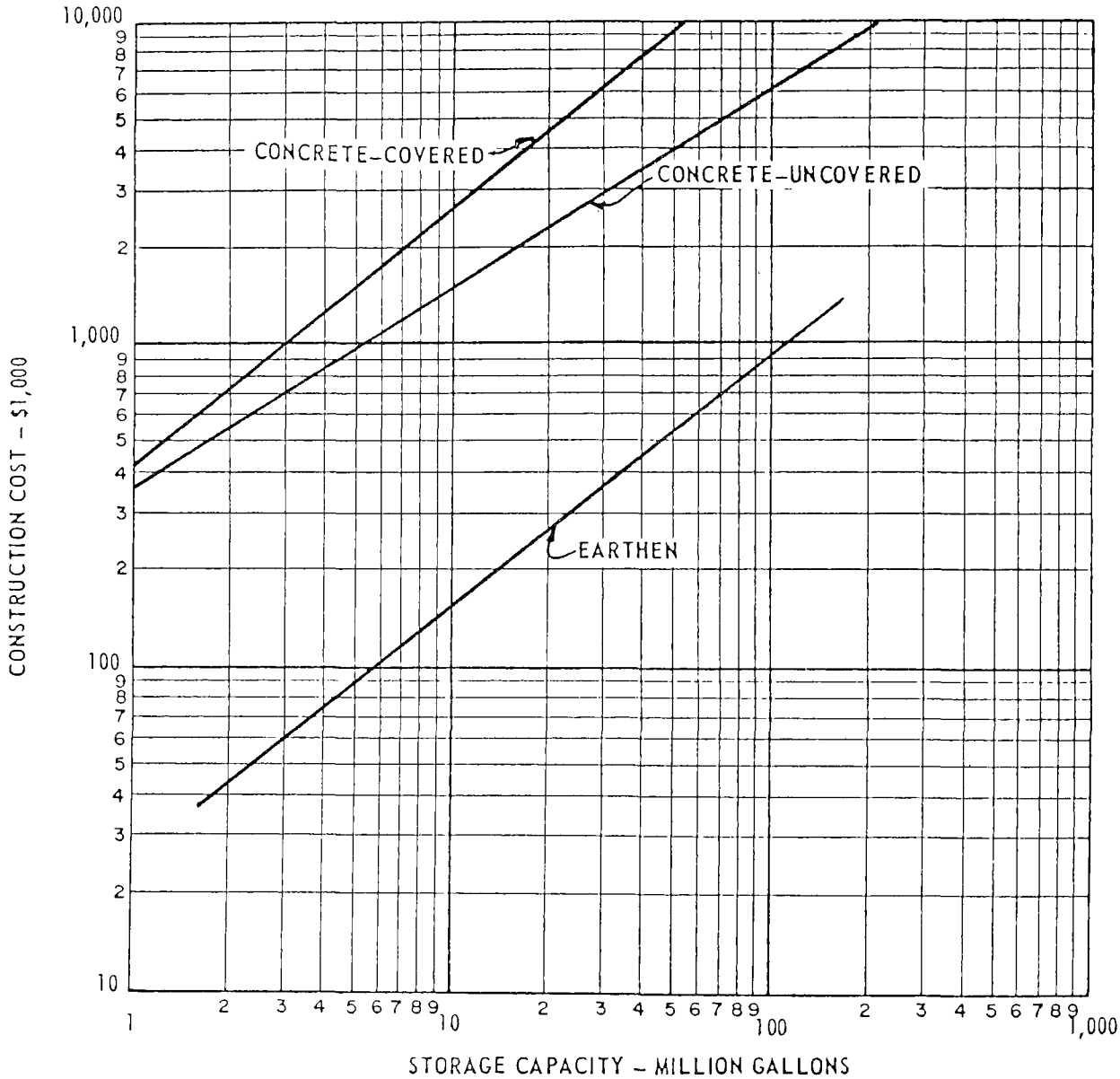


Figure 10. Construction Cost Example: Storage Facilities

Looking to the near future a city-wide demonstration (P-15) of a multi-faceted approach methodology is nearing completion in Rochester, N.Y. The product from this study will serve as an example for other cities.

There is also an endeavor to study direct receiving water impacts along with verification of a water quality model. This task will serve as an important demonstration by lending credence to the implications of storm flow impacts. The previously discussed Milwaukee project (P-68) covers this objective. Other demonstration sites are being sought by the Program. Receiving water impacts have been included in an ongoing project in Lancaster, PA (P-4) and additional non-EPA funds to conduct a receiving water impact analysis for the ongoing Rochester project (P-15) have been secured.

In FY 78 the Program would like to initiate an assessment of the various 201 and 208 planning grants, and later a refined manual on solution methodology culminating Program objectives in the area of problem definition.

USER ASSISTANCE TOOLS

The User Assistance Tools are divided into "Instrumentation" and "Simulation Models."

INSTRUMENTATION

The qualitative and quantitative measurement of storm overflows is essential for planning, process design, control, evaluation, and enforcement. "Urban intelligence systems" require real-time data from rapid remote sensors in order to achieve remote control of a sewerage network. Sampling devices do not provide representative aliquots, and in-line measurement of suspended solids and organics is needed. Conventional rate-of-flow meters have been developed mainly for relatively steady-state irrigational streams and sanitary flows and not for the highly varying surges encountered in storm and combined sewers. A schematic of instrumentation development by the Program is shown on Figure 11.

The electromagnetic (P-45), ultra-sound (150), and passive sound (139) flowmeters have been developed to overcome these adverse storm flow conditions (which require dual pressure-gravity measurement of unsteady flows by non-intrusive instrumentation). Further demonstration of the electromagnetic and passive sound flowmeters will take place shortly. Passive sound instruments offer the additional benefit of extremely low power requirements rendering them amenable to installation at remote overflow locations (where power may not exist) and integration into city-wide, in-sewer, sensing, and control systems. A prototype sampler for capturing representative solids in storm flow, and overcoming storm flow adversities, has been developed and compared with conventional samplers. Favorable results have been obtained and a design manual (135) is available. Demonstration of two previously developed instantaneous, in situ monitoring devices for suspended solids (113) (based on the optical principle of suspended solids depolarizing polarized light) and TOC (126) were successfully conducted.

Separate SOTA reports for flow measurement (130) and sampling (87,133) have been mentioned under problem definition. A SOTA on organic analyzers (110) is also available. Because storm flow conditions are extremely adverse, the manuals and instruments developed for the Program in this area are useful for the monitoring of all types of waste flows.

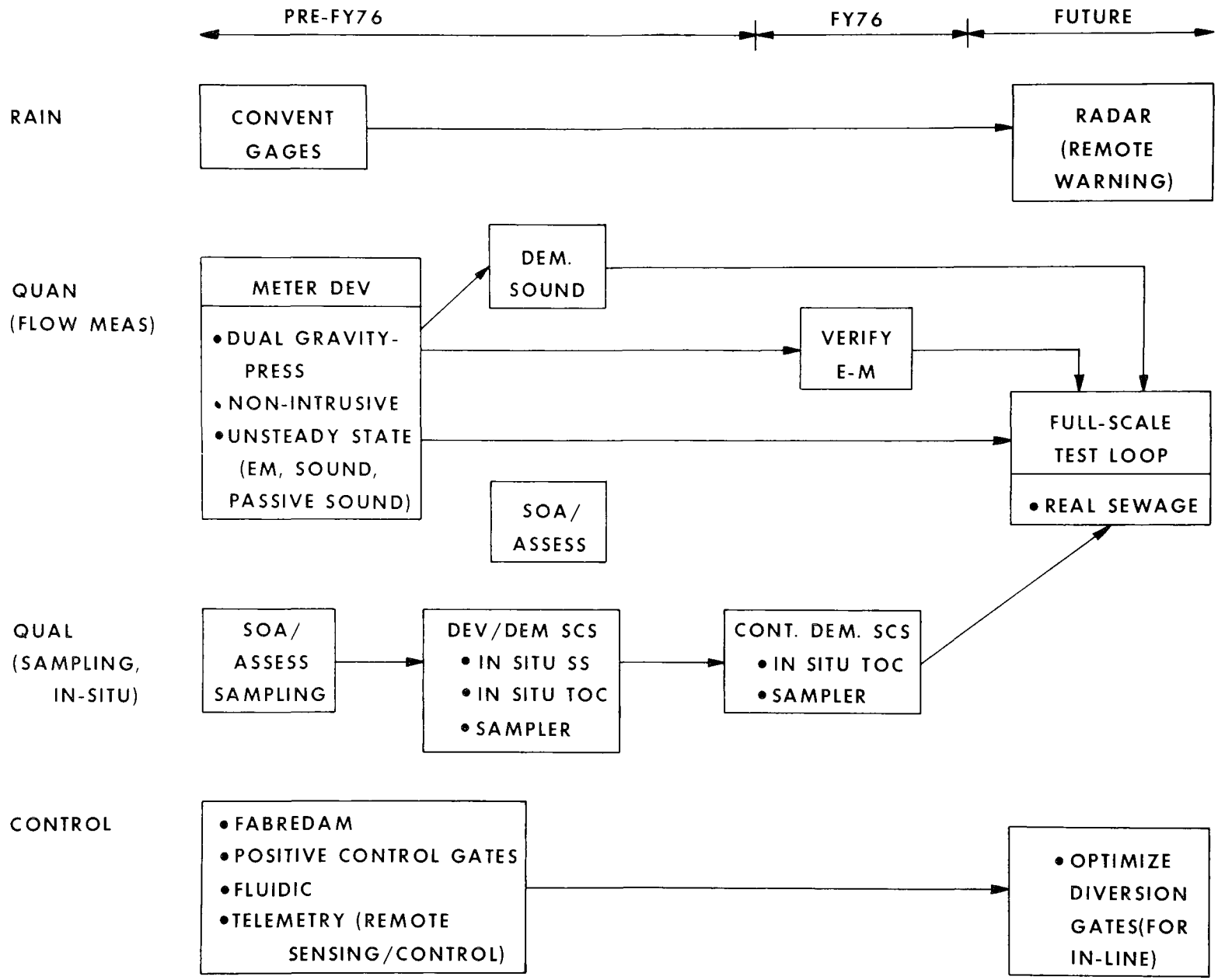


Figure 11. Instrumentation for Total System Management

Remote raingaging by radar is being considered for an automated combined sewer flow routing project in San Francisco (P-25).

Instrumentation: Products

An instrumentation product summary is listed on Table 3.

Table 3. Instrumentation: Products
Flow Measuring Devices Development o Electromagnetic (open-channel and press flow) (P-45) o Ultra-sound (150) o Passive Sound (139) Sampler Development (135) *In situ* suspended solids monitor development (113) *In situ* TOC monitoring system development (126) SOTA/Assessment reports o Sampling (133) o Flow measuring (130) o Organics monitoring (110)

SIMULATION MODELS

Math models are needed to predict complex dynamic responses to variable and stochastic climatological phenomena. Models have been subcategorized into three groups: (1) simplified for preliminary planning, (2) detailed for planning and design, and (3) operational for supervisory control (Figure 12.).

The Storm Water Management Model (SWMM) provides a detailed simulation of the quantity and quality of stormwater during a specified precipitation event. Its benefits for detailed planning and design have been demonstrated and the model is widely used. However, for many users it is too detailed; e.g., the 208 planning effort needs simplified procedures to permit preliminary screening of alternatives. Consequently, current Program thinking on urban water management analysis in general, and SWMM in particular, involves four levels of evaluation techniques ranging from simple to complex procedures that can be worked together. The major portions of all four levels have been developed (Table 4.).

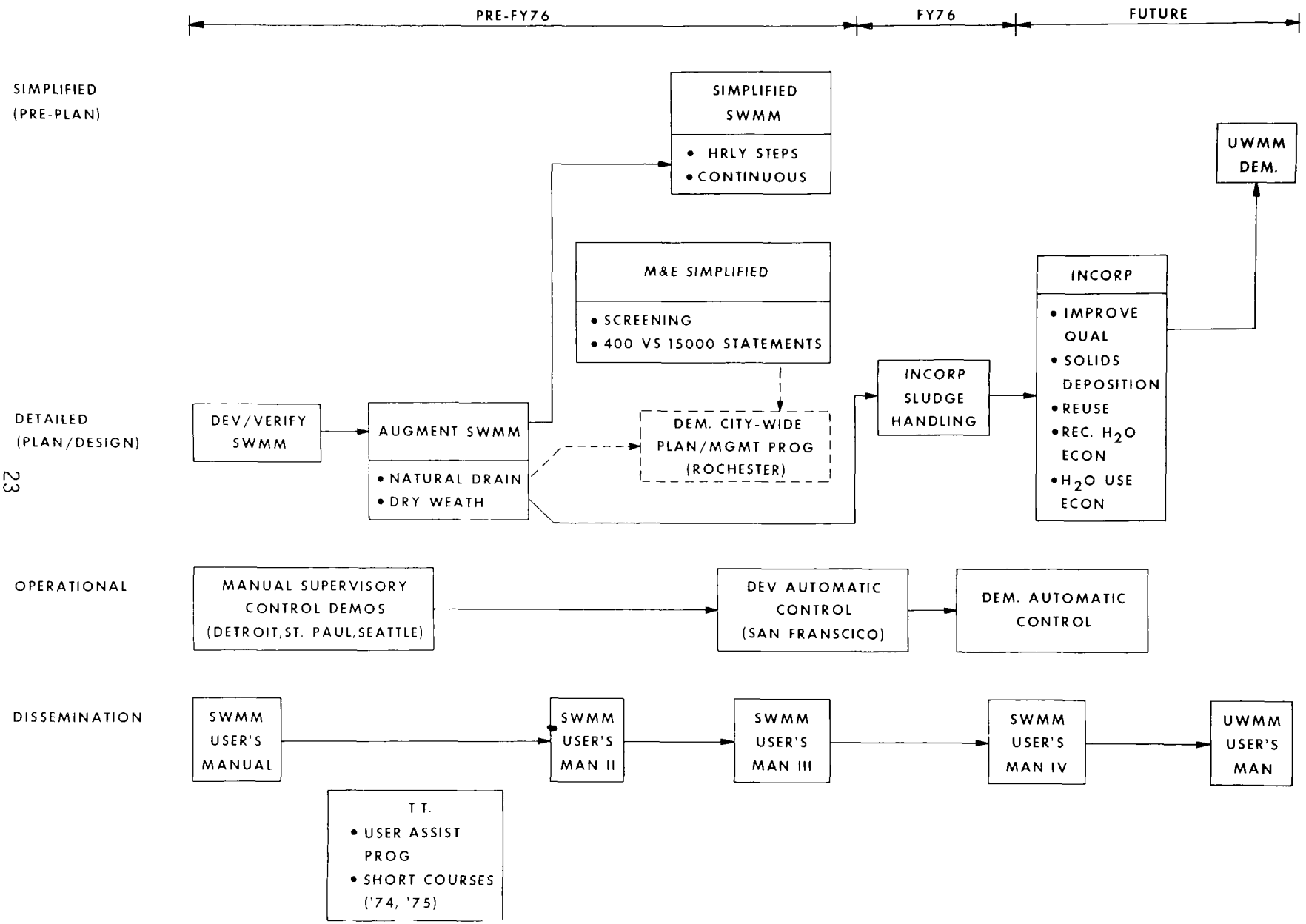


Figure 12. Simulation Models for Total System Management

Table 4. Levels of Urban Water Management Analysis
Preliminary: Print out information from Nationwide Assessment (157)
Level I: Desktop - no computer, statistical analysis
o UF Methodology (153) o Hydroscience methodology (R-8)
Level II: Simplified continuous simulation model
o Simplified SWMM (by M&E) (148)
Level III: Refined continuous simulation model
o Continuous SWMM (P-53) o STORM (R-9, R-10)
Level IV: Sophisticated single event simulation model
o Detailed SWMM (116,125)

Planning/Design Models

Level I--

The Level I procedure as developed by the University of Florida (153) was directly derived from the previously mentioned nationwide cost assessment project (157). This assessment document already contains data on land use; drainage system types; runoff volumes and pollutant quantities; costs and cost-effective control strategies for the 248 Standard Metropolitan Statistical Areas in the country. The information, also itemized for States and EPA regions, can be used in the early stages of problem assessment, determining national cost requirements and preliminary planning.

In Level I, a "desktop" statistical analysis procedure permits the user to estimate the quantity and quality of urban runoff in the combined, storm and unsewered portions of each urban area in his jurisdiction.

For example, under the University of Florida approach, equations such as those shown in Table 5. have been statistically developed to estimate BOD_5, SS, VS, PO_4 and N loads as a function of land use, type of sewer system, precipitation, population density, and street sweeping frequency. The α and β terms represent normalized loading factors in lb/ac-in. tabularized as functions of land use, i and pollutant type, j, for separate and combined areas, respectively. These factors were derived from a statistical review of available stormwater pollutant loading and effluent concentration data (157).

Similarly, Table 6. gives equations for analyzing runoff for both stormwater flow prediction and DWF prediction. Here again the equations were based on a statistical analysis of available data.

Table 5. Pollutant Analysis

The following equations may be used to predict annual average loading rates as a function of land use, precipitation and population density.

Separate Areas: $M_s = \alpha(i,j) \cdot P \cdot f_2(PD_d) \cdot \gamma \frac{lb}{acre\text{-}yr}$

Combined Areas: $M_c \quad \beta(i,j) \cdot P \cdot f_2(PD_d) \cdot \gamma \frac{lb}{acre\text{-}yr}$

where
- M = pounds of pollutant j generated per acre of land use i per year,
- P = annual precipitation, inches per year,
- PD_d = developed population density, persons per acre,
- α, β = factors given in table below,
- γ street sweeping effectiveness factor, and
- $f_2(PD_d)$ population density function.

Land Uses:
- i = 1 Residential
- i 2 Commercial
- i 3 Industrial
- i 4 Other Developed, e.g., parks, cemeteries, schools (assume $PD_d = 0$)

Pollutants:
- j = 1 BOD_5, Total
- j 2 Suspended Solids (SS)
- j 3 Volatile Solids, Total (VS)
- j 4 Total PO_4 (as PO_4)
- j 5 Total N

Population Function:

i = 1	$f_2(PD_d)$	$0.142 + 0.218 \cdot PD_d^{0.54}$
i 2,3	$f_2(PD_d)$	1.0
i 4	$f_2(PD_d)$	0.142

Factors α and β for Equations: Separate factors, α, and combined factors, β, have units lb/acre-in. To convert to kg/ha-cm, multiply by 0.442.

	Land Use, i	Pollutant, j: 1. BOD_5	2. SS	3. VS	4. PO_4	5. N
Separate Areas, α	1. Residential	0.799	16.3	9.45	0.0336	0.131
	2. Commercial	3.20	22.2	14.0	0.0757	0.296
	3. Industrial	1.21	29.1	14.3	0.0705	0.277
	4. Other	0.113	2.70	2.6	0.00994	0.0605
Combined Areas, β	1. Residential	3.29	67.2	38.9	0.139	0.540
	2. Commercial	13.2	91.8	57.9	0.312	1.22
	3. Industrial	5.00	120.0	59.2	0.291	1.14
	4. Other	0.467	11.1	10.8	0.0411	0.250

Street Sweeping: Factor γ is a function of street sweeping interval, N_s, (days):

$$\gamma \begin{cases} N_s/20 & \text{if } 0 \le N_s \le 20 \text{ days} \\ 1.0 & \text{if } N_s > 20 \text{ days} \end{cases}$$

Table 6. Runoff Analysis
Stormwater Flow Prediction
$AR = (0.15 + 0.75\ I/100)\ P - 5.234\ (DS)^{0.5957}$
where AR = Annual Runoff, in/yr
$I = 9.6\ PD_d^{(0.573-0.0391\ \log_{10} PD_d)}$
where I = Imperviousness, Percent and
PD_d = Population Density in Developed Portion of the Urbanized Area, Persons/Acre
P = Annual Precipitation, in/yr and
$DS = 0.25-0.1875\ (I/100) \quad 0 \leq I \leq 100$
where DS = Depression Storage, in. $(0.005 \leq DS \leq 0.30)$
Dry Weather Flow Prediction
$DWF = 1.34\ PD_d$
where DWF = Annual Dry-Weather Flow, in/yr, and
PD_d = Developed Population Density, Persons/Acre

A generalized method for evaluating the optimal mix of storage and treatment and its associated costs has also been developed. Also, procedures for comparing tertiary treatment with stormwater management and possible savings from integrated management of domestic wastewater, stormwater quality and stormwater quantity from combined and separate drainage areas, are available.

The Hydroscience approach offers another procedure for assessing urban pollutant sources, loadings, and control. Both approaches, available in the form of user's manuals, are at press (153, R-8).

Level II--

Level II involves a simplified continuous model for planning and preliminary sizing of facilities. The model can run on daily time steps to screen the entire history of rainfall records or hourly time steps to screen the worst two years. It is inexpensive to set up and use, flexible enough to be applicable to a variety of system configurations, and accurate even though only very moderate expenditures are made for data collection and preparation. It is especially valuable in sizing storage facilities based on storm return periods and available in-line capacity. A user's manual is available (148).

Level III--

Level III involves a more refined continuous model approach (e.g., STORM, continuous SWMM) which in addition to Level II provides for flow time routing and continuous receiving water impact analyses. The number of program statements involved here is in the order of a few thousand as compared to a few hundred for the Level II effort. A user's manual and program for STORM is available (R-9, R-10). The continuous SWMM user's manual is in preparation; however, the computer program is available from the University of Florida.

Level IV--

The aforementioned three levels essentially represent various degrees of planning efforts and the models involved are typified by relatively large time steps (hours) and long simulation times (months and years). Data requirements are kept to a minimum and their mathematical complexity is low.

Design models on the other hand are oriented toward the detailed simulation of a single storm event. They provide a complete description of flow and pollutant routing from the point of rainfall through the entire urban runoff system and into the receiving waters. Such models may be used for predictions of flows and concentrations anywhere in the rainfall-runoff system and can illustrate the detailed and exact manner in which abatement procedures or design options affect them. As such, these models are a highly useful tool for determining least-cost abatement procedures for both quantity and quality problems in urban areas. They are typified by short time steps (minutes) and short simulation times (hours). Data requirements are usually very extensive. The EPA SWMM is such a model. SWMM user's manuals and other pertinent references that were revised at critical junctures are available (42,43,44,45,116,120). The Program would like to end the simulation modeling program by expanding SWMM into an Urban Water Management Model which integrates both dry- and wet-weather flow analyses including sludge handling capabilities. This is emphasized in the Program report on future direction of the modeling development (136).

Operational Models

There is also a defined program for operational models. Operational models are used to produce actual control decisions during a storm event. Rainfall is entered from telemetered stations and the model is used to predict system responses a short time into the future. Various control options may then be employed, e.g., in-system storage, diversions, regulator settings. The Program has demonstrated supervisory control models in Detroit (118), Minneapolis-St. Paul (19), and Seattle (29,98); and have recently started on a program in San Francisco (P-25) riding "piggy-back" with a $100 million construction grant, to develop a fully automated operational model which includes rainfall prediction.

Simulation Models: Products

Other simulation model products include demonstration of a dissemination and user assistance capability (122) and development of a short course and course manual (125, P-51) for stormwater management model application. Of particular note is the SOTA assessment document on 18 available mathematical

models for storm and combined sewer management (141). The document presents a summary of the objectives, advantages and limitations of each model along with a side-by-side comparison to aid in assessing the applicability of a model for a particular purpose. Table 7. summarizes simulation model products.

Table 7. Simulation Models: Products
o Development of a computer model (SWMM) for storm water management (42,43,44,45).
o Updated and refined user's manual modifying and improving SWMM (116).
o Demonstration of a stormwater management model dissemination and user assistance capability (122).
o User's manual for "desk-top calculation" procedure for preliminary stormwater management planning (153).
o User's manual for simplified model application for preliminary stormwater management planning (148).
o Course manual and seminar for stormwater management model application (125).
o Assessment of mathematical models for storm and combined sewer management (141).
o Refine and augment the capabilities of SWMM and develop decision-making capabilities (120).
o Evaluation of available runoff prediction methods for storm flowrate and volume determination (140).

MANAGEMENT ALTERNATIVES

Wet weather flow control can be grouped into three management alternatives. First there is the choice as to where to attack the problem: at the source, (e.g., the street, gutters, and catchment areas) by land management, in the collection system, or off-line by storage. Pollutants can be removed by treatment and by employing complex or integrated systems which combine variations of control and treatment including the dual-use of dry-weather facilities. Second, there is the choice of how much control or degree of treatment to introduce. Thirdly, there is the impact assessment, public exposure, and priority ranking with other needs. The proper management alternatives can only be made after a cost-effective analysis involving goals; values; and hydrologic-physical system evaluations, generally assisted by mathematical model simulations, pilot-scale trials, and new technology transfer.

LAND MANAGEMENT

Land Management includes all measures for reducing urban and construction site stormwater runoff and pollutants before they enter the downstream drainage system (Figure 13). On-site measures include structural, semi-structural and non-structural techniques that affect both the quantity and quality of runoff.

Careful consideration must be given to land use planning since urbanization accelerates hydrograph and pollutograph peaks and total loads by creating impervious surfaces for pollutants and water to run off from. This causes excessive water pollution, erosion, sedimentation and flooding. Discreet selection of land management techniques can reduce drainage and other downstream control costs associated with these problems.

Until two important philosophies prevail, the high cost implications for wet-weather pollution abatement will continue. Established flood and erosion control technology must be integrated with pollution control technology so that the retention and drainage facilities and other non-structural management techniques required for flood and erosion control can be simultaneously designed for pollution control.

Structural/Semi-Structural Control

Structural and semi-structural control measures require physical modifications in a construction or urbanizing area and includes such techniques as: on-site storage, porous pavement, overland flow modifications and solids separation.

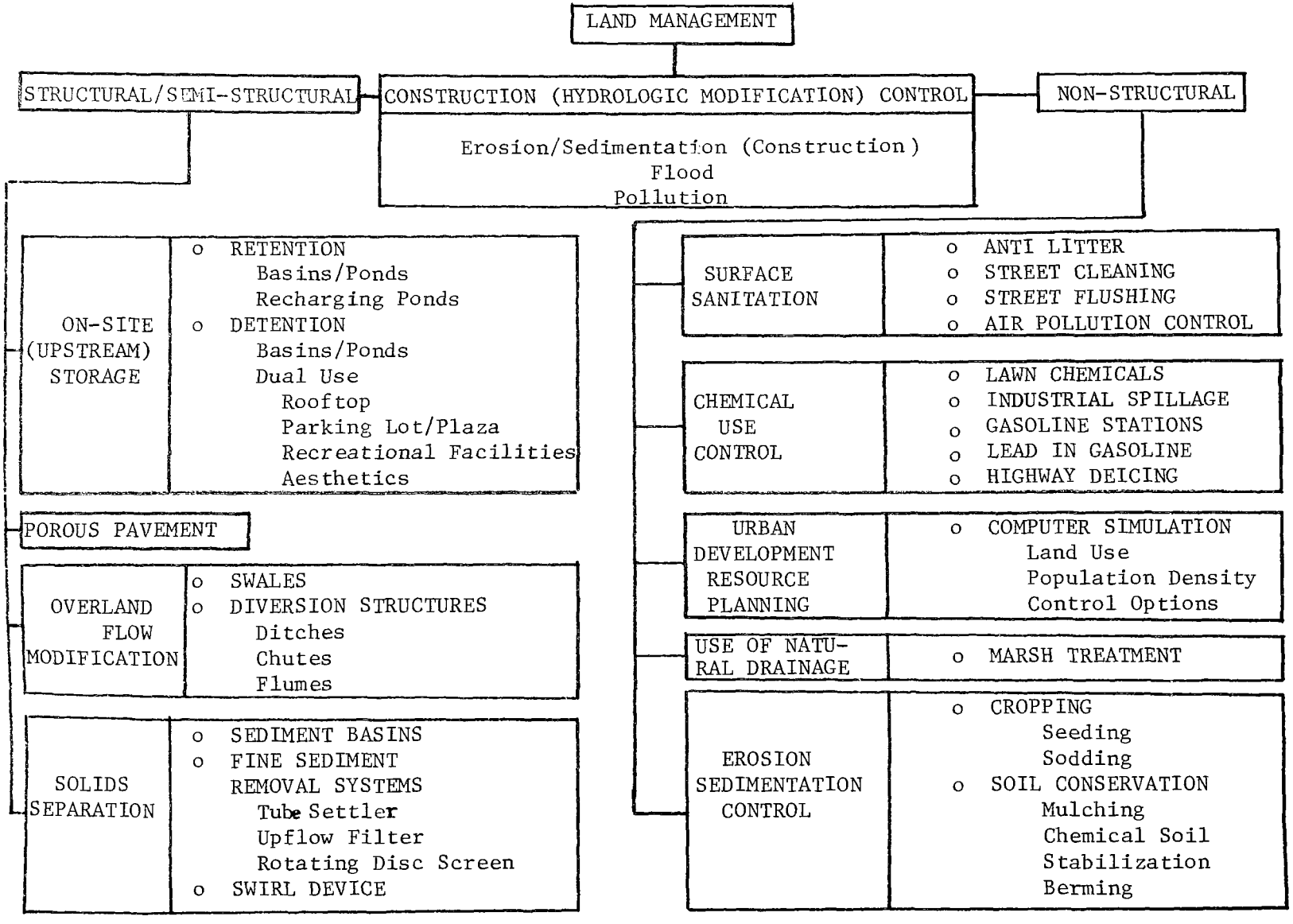


Figure 13. Land Management

On-Site (Upstream) Storage--

On-site or upstream storage refers to detention (short term) or retention (long term) of runoff prior to its entry into a drainage system. Simple ponding techniques are utilized on open areas where stormwater can be accumulated without damage or interference to essential activities. Oftentimes, on-site storage does or can be designed to provide for the dual or multi-benefits of aesthetics, recreation, recharge, irrigation, or other uses. For example, in Long Island, NY, groundwater supplies are being replenished by retention-recharge. The dual benefit of recharging is stressed because urbanization depletes groundwater supplies; however, potential groundwater pollution must also be considered.

Successful variations of detention that take advantage of facilities primarily used for other purposes are ponding on parking lots, plazas, recreation and park areas; and ponding on roof tops. The fundamental approach is the same as for other forms of detention but low cost is implied. Dual purpose basins used for recreation and athletics when dry are also employed.

Surface ponding is the most common form of detention being used by developers. Apparent economic benefits of surface ponding for flood protection are derived from the savings over a conventional sewer project. Several surface ponding sites are listed in Table 8. where a cost comparison is made between a drainage system using surface ponds to decrease peak flows and a conventional storm sewer system. It is important to note that pollution and erosion control benefits of the basins are not included in this comparison.

Table 8. Cost Comparison Between Surface Ponding Techniques and Conventional Sewer Installation (R-8).

Site	Description	Cost estimate, $	
		With surface ponding	With Conventional sewers
Earth City, Missouri	A planned community including permanent recreational lakes with additional capacity for storm flow	2,000,000	5,000,000
Consolidated Freightways, St. Louis, Missouri	A trucking terminal using its parking lots to detain storm flows	115,000	150,000
Ft. Campbell, Kentucky	A military installation using ponds to decrease the required drainage pipe sizes	2,000,000	3,370,000
Indian Lakes Estates, Bloomington, Illinois	A residential development using ponds and an existing small diameter drain	200,000	600,000

Porous Pavement--

Another approach to stormwater management is the use of an open graded asphalt-concrete pavement which under pilot testing has allowed over 70 in./hr of stormwater to flow through (Figure 14.) (64). Stability, durability,

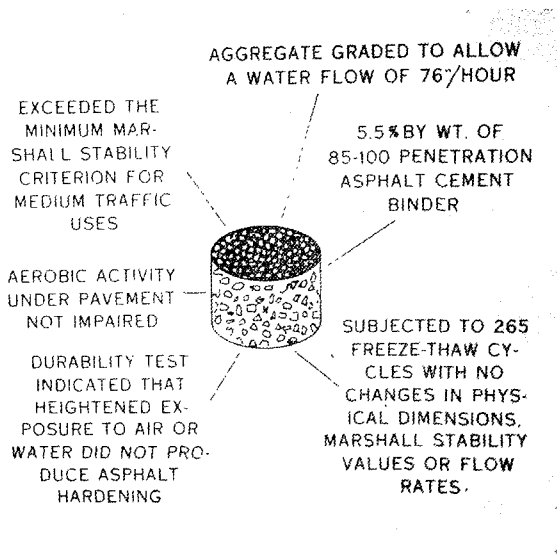


Figure 14. Porous Asphaltic-Concrete Features

and freeze-thaw tests have been positive and it is comparable in cost to conventional pavement. Long-term tests are still required to evaluate clogging resistance and the quality of water that filters through. If the soil porosity under the pavement allows free drainage there will be no water residue; however, the coarse sub-base and porous nature of the pavement can serve for ponding capacity if storm quantities exceed soil infiltration. A 4-inch pavement and 6-inch base could store 2.4 in. of runoff volume in its voids. The proven use of porous pavement can be an important tool in preserving natural drainage and decreasing downstream drainage and pollution control facility requirements. As a result of Program studies a feasibility report (64) is available. The Program is currently evaluating a porous pavement parking lot (P-16) and results of this study will be available next year.

Overland Flow Modification--

Another form of structural and semi-structural control is overland flow modification including swales and diversion structures (e.g., ditches, chutes, flumes). These modifications are usually of lower cost than subterranean sewer construction and importantly allow vegetative cover and soil infiltration to reduce runoff and pollutant loadings.

Solids Separation--

Sediment basins trap and store sediment from erodible areas in order to conserve land and prevent excessive siltation downstream. If designed properly, these basins can remain after construction for on-site storage. A project (P-46) is evaluating the efficiency of sediment basins.

Because a significant portion of the eroded solids may be colloidal or unsettleable and therefore cannot be treated in conventional sedimentation basins, special devices for fine-particle removal are required. An ongoing project (P-73) has developed a SOTA (163) on methods for fine-particle removal and is now undertaking the evaluation of three solids separation devices (i.e., tube settler, up-flow filter, and rotating disc screen).

The swirl concentrator has been developed for erosion control (P-3, 99) to remove settleable solids at much higher rates than sedimentation. A prototype device is presently being evaluated at a construction site (P-74).

Non-Structural

Non-Structural control measures involve surface sanitation, chemical use control, urban development resource planning, use of natural drainage, and certain erosion/sedimentation control practices (Figure 13.).

Surface Sanitation--

Maintaining and cleaning the urban area can have a significant impact on the quantity of pollutants washed off by stormwater. Cleanliness starts with reduction of litter and debris at the neighborhood level. Both street repair and street sweeping can further minimize the pollutants washed off. It has been estimated that street sweeping costs per ton of solids removed are about half the costs for solids removed via the sewerage system.

The effectiveness of street sweeping operations with respect to stormwater pollution has been analyzed by EPA (73,88,128,157,P-49). It was found that a great portion of the overall pollution potential is associated with the fine solids fraction of the street surface contaminants and that only 50 percent of the dry weight solids are picked up by conventional broom sweepers (73) as compared to 93 percent removal by more advanced techniques (128) (Table 9.).

Table 9. Advanced* Street Cleaner Pollutant Recovery Percentage

Parameter	% Recovery
Dry Weight Solids	93
Volatile Solids	80
BOD	67
COD	84
Total PO_4-P	85
Heavy Metals	83-98

*Broom and Vacuum Combination

Cities clean their streets for aesthetic reasons, removing the larger particles and brushing aside the fines. Conventional sweepers are utilized and satisfy the aesthetics problem. More advanced street cleaning procedures such as a combination of sweeping and vacuuming would not only satisfy the aesthetics problem but would also attack the source of stormwater related pollution problems by removing the finer or more pollutant prone range of particles.

Further verification of the benefits of street cleaning will be carried out in an ongoing grant (P-25). Also, a desk-top analysis comparing the cost-effectiveness of street cleaning and sewer flushing with downstream treatment methods is nearing completion under another study (P-73). Flushing of streets can be used to remove street contaminants effectively; however, it may necessitate more frequent catch basins and sewer cleaning. Street cleaning is estimated to cost $3 to $13/curb mi or about $0.75/ac.

Air pollution abatement plans must also consider water pollution reduction benefits from decreased fall out.

Chemical Use Control--

One of the most overlooked measures for reducing the pollution potential from neighborhood areas is the reduction in the indiscriminate use of chemicals such as fertilizers and pesticides, and the mishandling of other materials such as oil, gasoline, and highway deicing chemicals. Aside from air pollution control, de-leaded gasoline also results in water pollution control.

The progression of studies in deicing chemical control, and resulting reports, is depicted in Figure 15. The Program's motivation from the start has been to determine the extent of environmental damages and costs associated with the use of chemical deicers so that the economic validity of alternative approaches could be assessed.

Until the Program's assessment of the problem in 1971 (67) there had been only limited research on highway deicing effects. Inquiries concerning this work indicated such an increased public awareness of the salt problems, that it seemed appropriate to firm up recommendations for alternatives to snow and ice control. A search was conducted (76) to define alternatives. The need for an accurate economic impact analysis of using deicing salt, and a requirement to identify a substance which can be applied to pavement to reduce ice adhesion was indicated. These two needs became projects which have recently been completed (138,152). Hydrophobic substances have been identified and are being investigated, and even though material and application costs appear greater than for salt (0.20-0.25/yd^2 vs. $0.03/yd^2), when considering total damage to the environment ($3 billion annually, including paved area, highway structures and vehicles) the costs are acceptable.

After the 1973 assessment of the problem (86,R-11), the Program recognized that it was not practical to ban salt since the "bare pavement" philosophy was very popular and considered by most highway authorities as the safest way for ice and snow removal. The major problems were identified

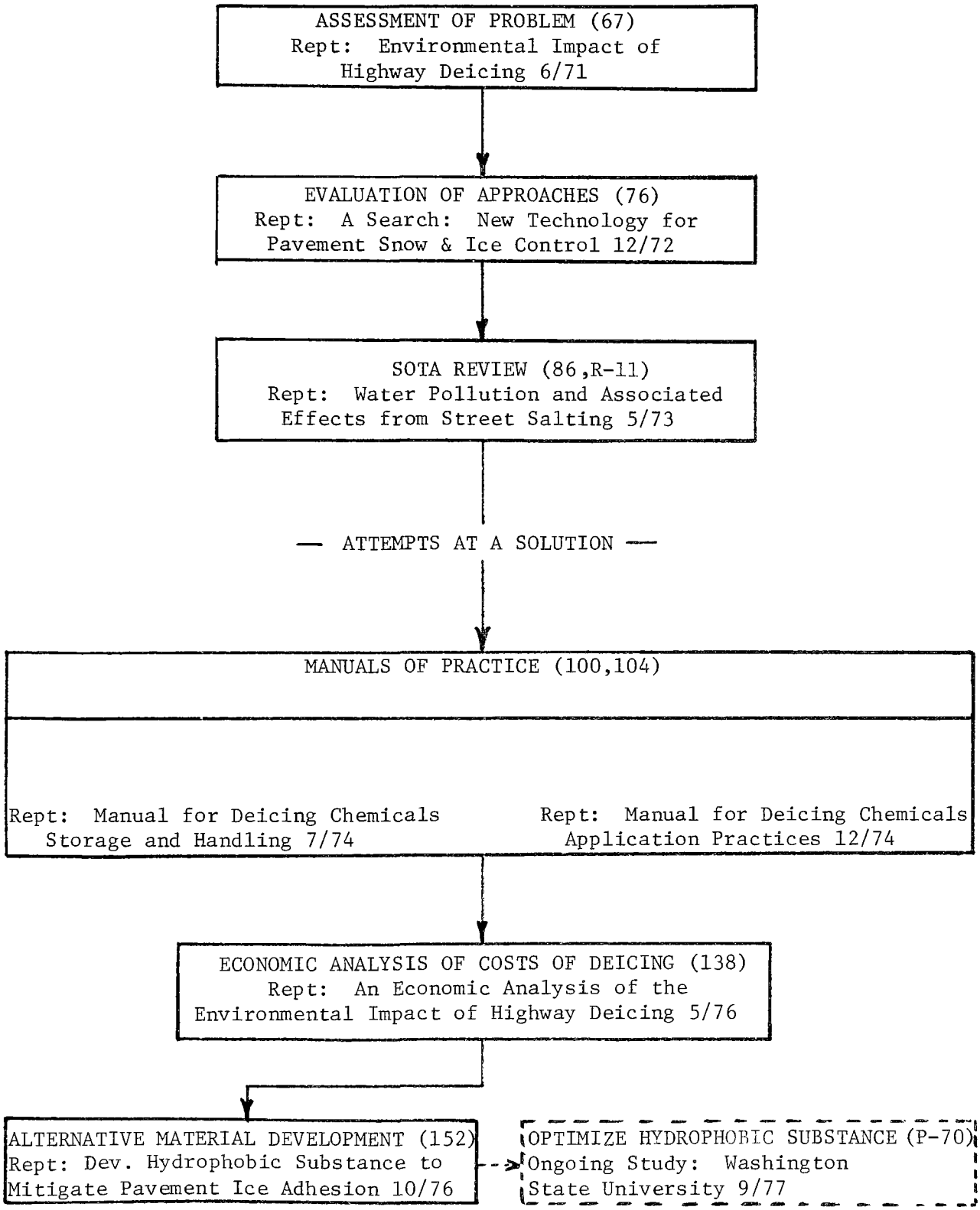


Figure 15. Deicing Chemical Control (Land Management/Non-Structural)

with sloppy salt storage practices and over-application on highways, consequently, a 1974 project resulted in manuals of practice for improvement in these areas. These manuals (100,104) were recognized as highly significant by the user community and the Federal Highway Administration (FHWA) requested permission to reprint them for their own distribution. To date, over 7000 copies have been distributed to the user community.

It is believed that the outcome of EPA work has prompted several states to enact legislation controlling the application and storage of salt. In the future it is hoped to verify the cost-effectiveness of the hydrophobic substances both through research of R&D (P-70) and in a joint effort with the FHWA.

Urban Development Resource Planning--

The goal of urban development resource planning is to develop a macroscopic management concept to prevent the problems resulting from shortsighted urbanization plans. As previously discussed, the planner must be aware of totally integrating planned urban hydrology with erosion-sedimentation and pollution control. This new breed of planner has to consider the new land development planning variables of land usage, population density and total wet and dry runoff control as they integrate to effect water pollution. Computer simulation will most likely play an important role. A simple land planning model has been developed by G.K. Young (140a, Chapter I, pp 98-121) to encompass the pertinent variables and the most effective control options based upon receiving water pollutant absorption capacity. A new project is planned to perfect this area.

Use of Natural Drainage--

The traditional urbanization process upsets the existing water balance of a site by replacing natural infiltration areas and drainage with impervious areas. The net impact is increased runoff, decreased infiltration to the groundwater and increased flowrates, all contributing to increased channel erosion and the transport of surface pollutants to the stream. Promulgating the use of natural drainage concepts will reduce drainage costs; enhance aesthetics, groundwater supplies, and flood protection; and lower pollution.

A project in Houston (P-16) focuses on how a "natural drainage system" can be integrated into a reuse scheme for recreation and aesthetics. Good land use management will allow runoff to flow through low vegetated swales and into a network of wet-weather ponds, strategically located in areas of porous soils. This system will cause some of the runoff to seep into the ground and retard the flow of water downstream, thus preventing floods caused by development and enhancing pollution abatement. The concept of considering urban runoff as a benefit as opposed to a wastewater, in a new community development, will be employed and evaluated.

Another project in Wayzata, MN (P-28) is using marshland for stormwater treatment. After sufficient testing it has been determined that controlled stormwater retention in the marsh resulted in better vegetative conditions which in turn enhanced stormwater nutrient removal. It was found that if the marshlands were filled in by urbanization it would have a detrimental effect on the nearby Lake.

Erosion/Sedimentation Control (Non-Structural)--

Other nonstructural soil conservation practices such as cropping (seeding and sodding) and the use of mulch blankets, nettings, chemical soil stabilizers and berming may be relatively inexpensive. Two ongoing projects (P-72, P-74) are evaluating many of these low structural intensive management practices for proposed erosion control manuals.

Integrated Benefits

While the flood control benefits of all the above land management control measures are easy to see, the stormwater pollution and erosion control effects are difficult to quantify. But briefly stated, detaining or retaining flow upstream offers the opportunity for flow quiescence resulting in solids separation. It also decreases downstream drainage velocities and discharges to streams resulting in less overflow pollution, siltation and scour. Aside from causing downstream erosion, this scouring can also increase pollution loads in the scouring stream.

Erosion/Sediment Control: Products

By showing the genealogy of the products through past milestone events (Figure 16.) the strategy which has guided the Program in this category can be demonstrated. The original "Guidelines for Erosion and Sediment Control Planning and Implementation" (70) are still applicable to communities initiating an urban sediment control program.

For erosion-sedimentation controls, many agencies (e.g., The Department of Transportation and Soil Conservation Service, and state and local departments) and factors must be considered and interrelated in product development and technology implementation. For example, the Soil Conservation Service has published a document with the State of Maryland entitled "Standards and Specifications for Soil Erosion and Sediment Control in Developing Areas" (R-12). Other states are using this document as a model ordinance. Local laws will have an important impact on any Best Management Practices proposed by EPA. Therefore, there must be close liaison between all groups.

A recently developed training program consists of an instructor's manual (168), a workbook (169), and 2762 slides with integrated audio cassettes. The program is directed to the local land developer and inspector, the excavation contractor, and the job foreman. It is designed to directly support the Maryland "Standards and Specifications for Erosion and Sediment Control in Developing Areas." As the state and local agencies move toward setting standards for control on non-point sources, the need for this type of training program becomes urgent.

Future Program plans include an evaluation of various cities' erosion control programs. This product will be the foundation for National Standards and Specifications for sediment and erosion control in developing areas and with the findings of the Urban Runoff Program will lead to the National Best Management Practice for this category.

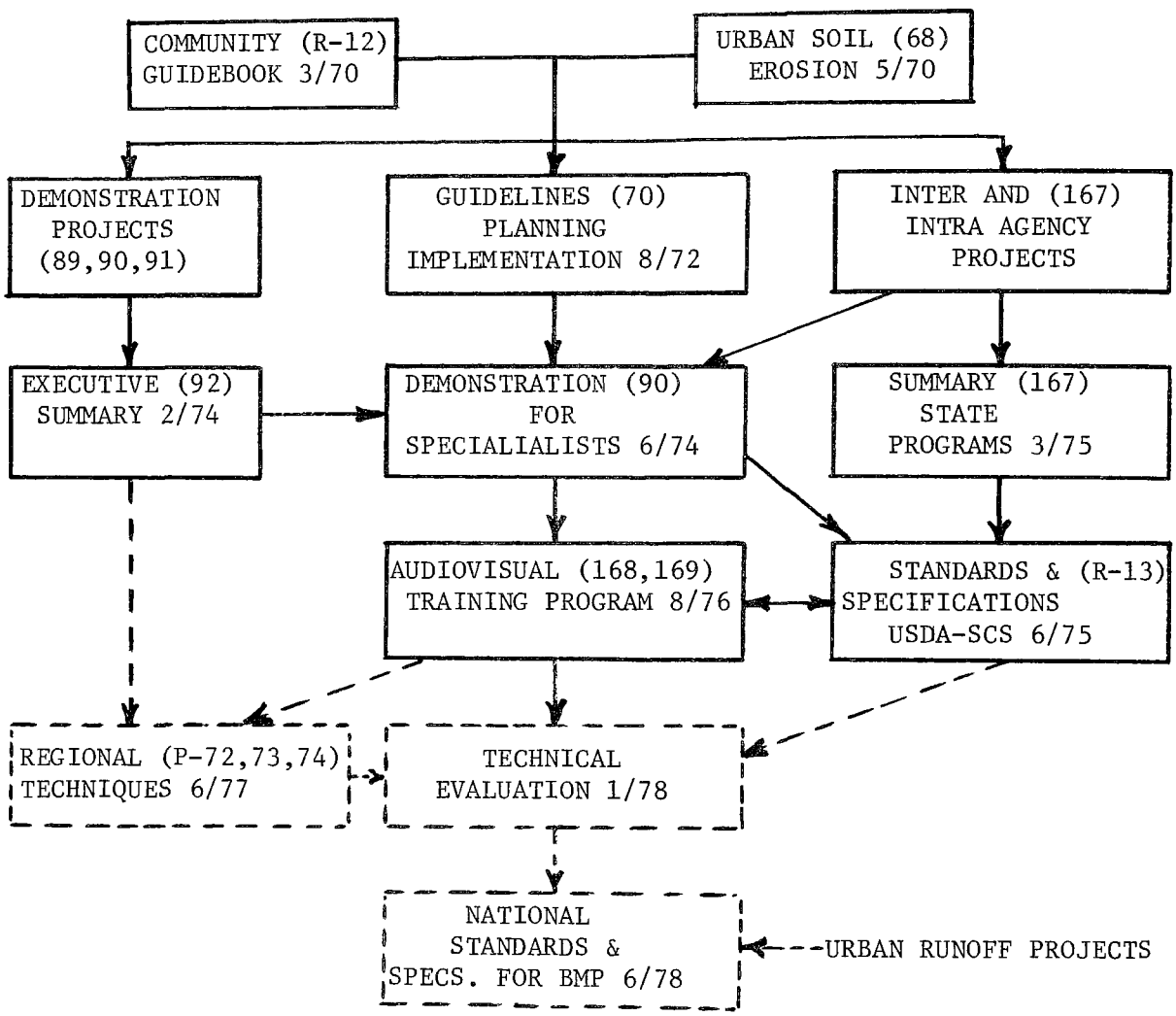


Figure 16. Erosion/Sedimentation Control: Products

Hydrologic Modification Category Status

It is important to discuss the status of the Hydrologic Modification Program category.

The product "Impact of Hydrologic Modification on Water Quality" (129) describes the scope and magnitude of water pollution and flood and erosion-sediment problems caused by hydrologic modifications such as dams, impoundments, channelization, in-water construction, out-of-water construction, land reclamation, and dredging. It is an excellent overview document.

There are important administrative decisions affecting this category.

1. The out-of-water construction element is no longer part of this category. It is the construction site erosion-sedimentation category previously defined.

2. There has been an interagency agreement assigning the U.S. Army Corps of Engineers the function of dredging impacts and control.

3. The R&D activities for land reclamation are mainly conducted by other EPA offices (e.g., beach reclamation in the Office of Oil and Special Materials Control Branch and strip mine reclamation in the Office of Energy, Minerals, and Industry).

The Program strategy is to allocate most of the resources to urban runoff and then to construction.

COLLECTION SYSTEM CONTROLS

The next category, collection system control (Figure 17.), pertains to those management alternatives concerned with wastewater interception and transport. These alternatives include sewer separation; improved maintenance and design of catch basins, sewers, regulators and tide gates; and remote flow monitoring and control. The emphasis, with the exception of sewer separation, is on optimum utilization of existing facilities and fully automated control. Because added use of the existing system is employed, the concepts generally involve cost-effective, low-structurally intensive control alternatives. To accomplish this an extensive and dependable intelligence system is necessary.

Catch Basins

A project is assessing the value of catch basins (P-17,174) as they are presently designed and maintained. Optimized basin configuration, design and maintenance for removing solids before sewerage system entry has also being investigated. Evaluations showed that a catch basin contains approximately 0.18 lb-BOD_5 or the equivalent of one person's daily contribution. Consequently, the utilization of catch basins (which depends on a city's network configuration and multi-agency desires) can either contribute to the pollutional load or aid in reducing downstream treatment depending on their design and maintenance. A full-scale demonstration of catch basin technology is recommended (p-17).

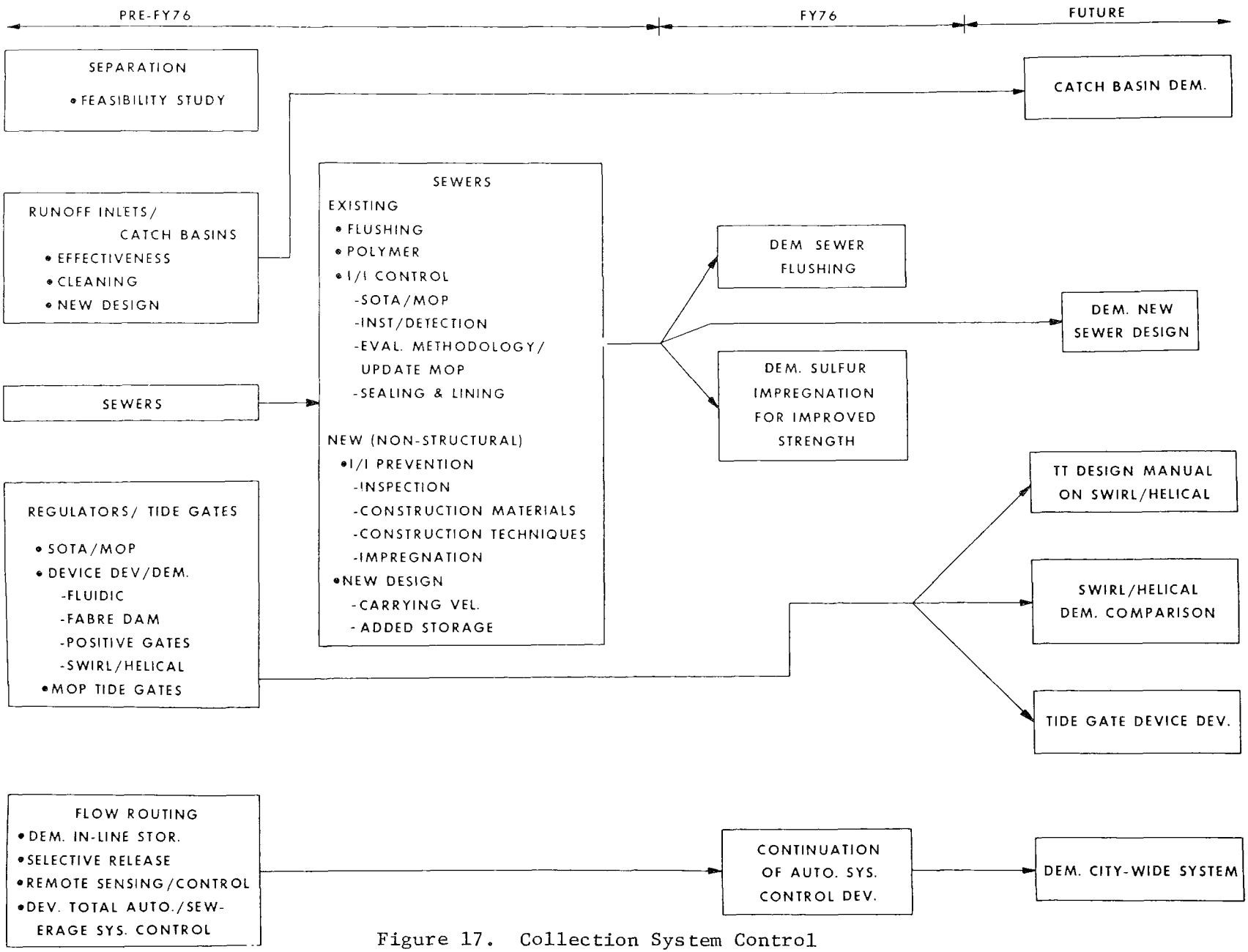


Figure 17. Collection System Control

Sewers

Solids deposition in lines has always been a plague to effective maintenance. Recently, the significance of such loads as a major contributor to first flush pollution has been recognized (P-66; 140a, Chapter II, pp 62-82).

Work is being conducted on new sewer designs for low flow solids carrying velocity to alleviate sewer sedimentation and resultant first flush and premature bypassing (P-50); and also on sewer designs for added storage (P-13,165). As a natural follow-up to Program work with a controlled test loop (13,14), a project has just been initiated to demonstrate periodic sewer flushing during dry weather for first flush relief (P-66).

Polymers To Increase Capacity--

Research (6,11, P-6) has shown that polymeric injection can increase flow capacity as much as 2.4 times (at a constant head). This method can be used as a short or long-term correction of troublesome pollution-causing conditions such as localized flooding and excessive overflows. Direct cost savings may be realized by eliminating relief sewer construction (6); however, additional cost verification at the site is necessary.

Infiltration/Inflow--

The Program SOTA (27) and manual of practice (MOP) (28) on infiltration/inflow (I/I) identified a significant problem which led to fruitful countermeasure research and a national emphasis on I/I control. Program developments have included detection methodology and instrumentation (27,28,10); preventive installation and construction techniques, new and improved materials (22,27,28, 52,61, P-31,P-41); and correction techniques (12). A project to update and develop practices for determining and correcting infiltration and its economic analysis (P-18,166) is nearing completion. An in-house paper on the analysis and evaluation of I/I has been published (R-14). Another project is evaluating the strength increases and erosion resistance, and resulting infiltration prevention from sulfur impregnation of concrete pipe (P-30,52). Since pipe costs are significant, an increase in strength could lead to a decrease in pipe materials and construction costs.

Flow Routing

Another collection system control method is in-sewer or in-line storage and routing of storm flows to make maximum use of existing interceptors and sewer line 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 proved to be effective in Minneapolis-St. Paul (19), Detroit (40,118), and Seattle (29,98). Seattle results are discussed later (Section 7, pp. 56-58) to indicate potential control and cost benefits.

An ongoing project mentioned earlier with the City of San Francisco is developing an automatic operational model for real-time control (P-25). Future demonstration of the system is anticipated.

Regulators and Tide Gates

Program pace-setters in the area of flow regulator technology were the SOTA (23) and MOP (24).

Conventional regulators malfunction and cause excessive overflows. The new improved devices such as fluidic and positive control regulators have been developed and demonstrated (P-7,9,23,24,98,173). The swirl and helical regulator devices are significant enough to single out separately.

Swirl and Helical Device Development--
The dual functioning swirl device has shown outstanding potential for providing both quality and quantity control (R-15,93).

A swirl flow regulator/solids-liquid separator has been demonstrated in Syracuse, NY (P-2; R-16; 140a, Chapter II, pp. 99-117). Figure 18. is an isometric review. The device, of simple annular shape construction, requires no moving parts. It provides a dual function, regulating flow by a central circular weir while simultaneously treating combined wastewater by a "swirl" action which imparts liquid-solids separation. The low-flow concentrate is diverted via a bottom orifice to the sanitary sewerage system for subsequent treatment at the municipal works, and the relatively clear supernatant overflows the weir into a central downshaft and receives further treatment or is discharged to the stream. The device is capable of functioning efficiently over a wide range (80:1) of combined sewer overflow rates, and can effectively separate suspended matter at a small fraction of the detention time required for conventional sedimentation or flotation (seconds to minutes as opposed to hours by conventional tanks). Tests indicate at least 50 percent removal of suspended solids and BOD. Tables 10. and 11. contain further treatability details on the Syracuse prototype. The capital cost of the 6.8 mgd Syracuse prototype was $55,000 or $8,100/mgd and $1,000/ac which makes the device highly cost-effective.

The swirl concept (for dual dry/wet-weather flow treatment) has been piloted as a degritter (P-71) in Denver, CO and as a primary clarifier in Toronto, Canada (P-71). Test results are very encouraging and the concept has been further developed for erosion control.

A helical or spiral-type regulator/separator has also been developed based on principles similar to those of the swirl device. The device is beneficial since its solids separation action is created by only a bend in the sewer line, and it is of relatively low depth.

Swirl and Helical: Products--Important products for this category are design manuals for the swirl (69,93,101) and helical (132) regulator/separators, swirl degritter (99) and swirl erosion control devices (151); and a Technology Transfer Capsule Report (162) which ties the various swirl applications together.

Maintenance

Improved sewerage system inspection and maintenance is absolutely neces-

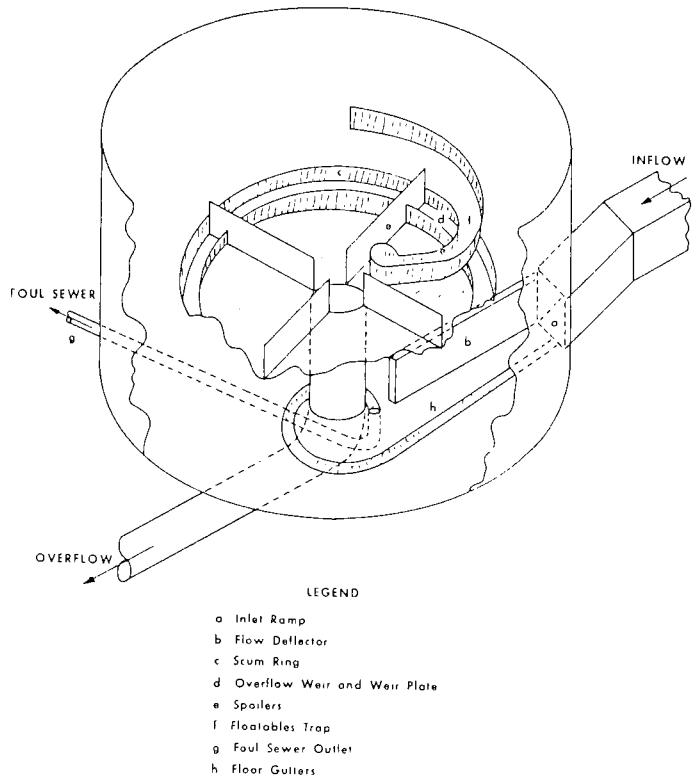


Figure 18. Isometric View of Swirl Regulator/Concentrator

sary for a total system approach to municipal water pollution control. We cannot afford the upgrading and proper operation of sewage treatment plants while a significant amount of sewage leaks into streams at the upstream points in the sewer network! Premature overflows and backwater intrusions during dry as well as wet weather caused by malfunctioning regulators and tide gates, improper diversion settings, and partially filled interceptors can thus be alleviated. Although the resulting abatement obtained is from a non-structural approach, it must be viewed as an ancillary benefit of required system maintenance. Regulatory agencies should be anxious to strive for policy to enforce collection system maintenance.

Table 10. Swirl Regulator/Concentrator: Suspended Solids Removal									
	Swirl Concentrator						Conventional Regulator		
	Mass Loading kg			Average SS per storm, mg/l			Mass Loading kg		
Storm No.	Inf.	Eff.	% Rem.[b]	Inf.	Eff.	% Rem.[b]	Inf.	Underflow	% Rem.[a]
02-1974	374	179	52	535	345	36	374	101	27
03-1974	69	34	51	182	141	23	69	33	48
07-1974	93	61	34	110	90	18	93	20	22
10-1974	256	134	48	230	164	29	256	49	19
14-1974	99	57	42	159	123	23	99	26	26
01-1975	103	24	77	374	167	55	103	66	64
02-1975	463	167	64	342	202	41	463	170	34
06-1975	112	62	45	342	259	24	112	31	27
12-1975	250	168	33	291	232	20	250	48	19
14-1975	83	48	42	121	81	33	83	14	17
15-1975	117	21	82	115	55	52	117	72	61

[a]For the conventional regulator removal calculation, it is assumed that the SS concentration of the foul underflow equals the SS concentration of the inflow.

[b]Data reflecting negative SS removals at tail end of storms not included.

Table 11. Swirl Regulator/Concentrator: BOD_5 Removal						
	Mass Loading, kg			Average BOD_5 per storm, mg/l		
Storm No.	Influent	Effluent	% Rem.	Inf.	Eff.	% Rem.
7-1974	277	48	82	314	65	79
1-1975	97	30	69	165	112	32
2-1975	175	86	51	99	70	29

STORAGE

Storage is perhaps the most cost-effective method available for reducing pollution resulting from combined sewer overflows and managing urban stormwater runoff. Furthermore, it is the best documented abatement measure in present practice. Program technological advancement for this category is depicted on Figure 19. (Storage with the resulting sedimentation that occurs, can also be thought of as a treatment process.)

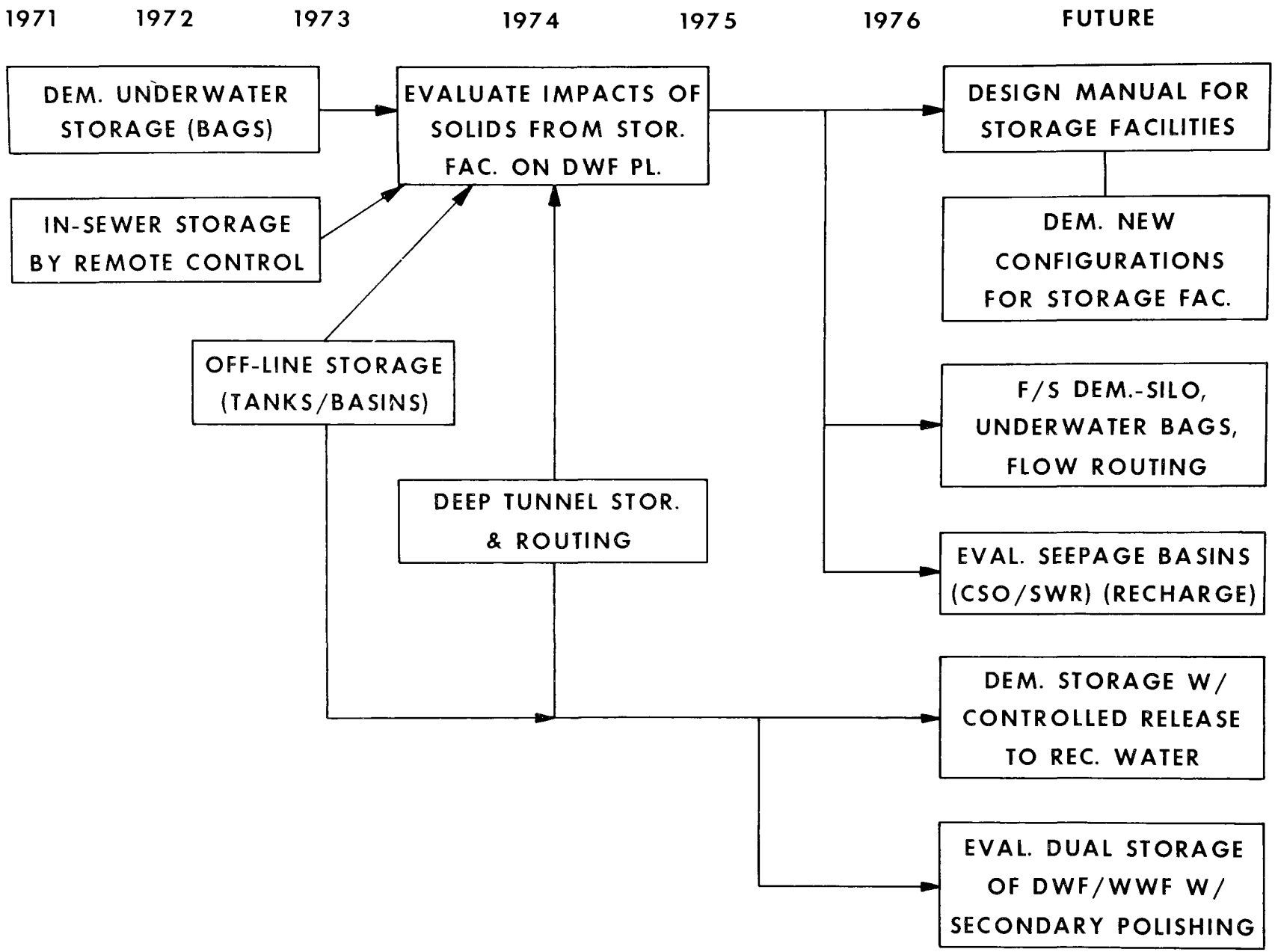


Figure 19. Storage

The concept is to capture wet-weather flow and bleed it back to the treatment plant during low flow dry-weather periods. The result of controlling overflow by detention is shown on Figure 20. Notice how an entire hypothetical overflow event at point A is prevented by storage with controlled dewatering.

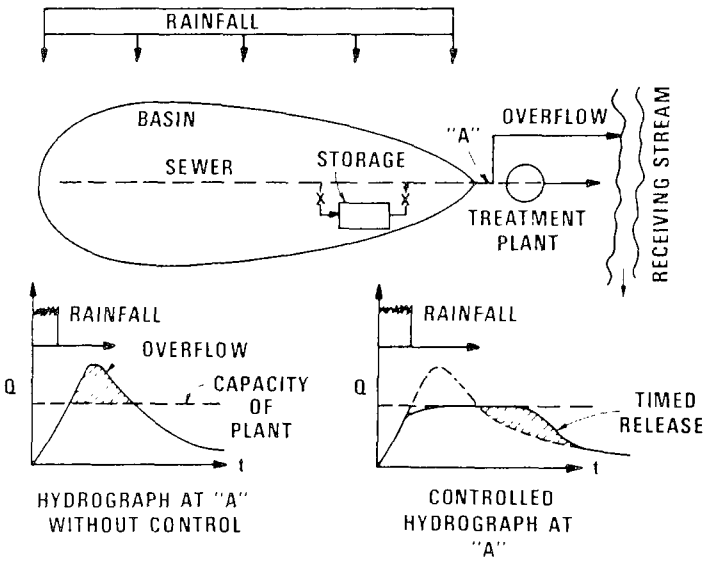


Figure 20. Results of Controlling Storm Flow by Storage

Storage facilities possess many of the favorable attributes desired in combined sewer overflow control: (1) they are basically simple in structural design and operation; (2) they respond without difficulty to intermittent and random storm behavior; (3) they are relatively unaffected by flow and quality changes; and (4) they are capable of providing flow equalization and, in the case of sewers and tunnels, transmission. (Frequently they can be operated in concert with regional dry-weather flow treatment plants for benefits during both dry- and wet-weather conditions (107).) Finally, storage facilities are relatively fail-safe and adapt well to stage construction.

Storage facilities may be constructed in-line or off-line; they may be open or closed; they may be constructed inland and upstream, or on the shoreline; they may have auxiliary functions, such as flood protection, sewer relief, and flow transmission. (And they may be used for hazardous spill containment during dry weather.)

Disadvantages of storage facilities are their large size and dependency on other treatment facilities for dewatering and solids disposal.

Storage concepts investigated by the program include the conventional concrete holding tanks (18,134) and earthen basins (30,72); and the minimun-land-requirement concepts of: tunnels (40), underground (85) and underwater containers (15,25,26), underground "silos (96)," gravel packed beds with overhead land use (154), natural (85) and mined under and above ground formations, and the use of abandoned facilities and existing sewer lines (19,29,98,118).

A 3.5 MG asphalt-lined storage basin in Chippewa Falls, WI (72) was constructed on reclaimed land and eliminated 59 out of 62 overflows during the evaluation period.

Inherent in many of these storage schemes is the pumping/bleeding back of the stored flow to the DWF plant during off-peak hours. The impacts of this increased load on the DWF plant (both from a hydraulic and increased solids point of view) is an important consideration and has been investigated in an ongoing project (159,161). Once this impact information is available, the SOTA on storage in the form of a design manual could be summarized.

The feasibility of off-line storage and deep tunnel storage along waterways for selective discharge based on least receiving water impacts is presently being investigated in Rochester, N.Y. (P-15). It is envisioned that this concept along with dual DWF/WWF storage, will be demonstrated in post FY 76 plans as part of a tie-in to construction grants.

Future Program plans include the investigation of new storage configurations, e.g., floating storage facilities, cofferdams, storage under piers, etc. Full-scale demonstration of some of the more promising configurations, such as silos and underwater bags, is also desirable.

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. The newer physical/chemical treatment techniques have shown more promise in overcoming these adversities. To reduce capital investments, projects have been directed towards high-rate operations approaching maximum loading boundaries. Applications include pretreatment or roughing, main or sole treatment, and particularly with microstrainers and filters, polishing devices.

The various treatment methods which have been developed and demonstrated by the Program for storm flow include physical and physical-chemical, biological, and disinfection (Figure 21.). 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 (34,37,38,78,105), swirl primary separators (162, P-29) and swirl degritters (99,162,158, P-29), high-rate filters (35, P-39), sedimentation (36,81), and

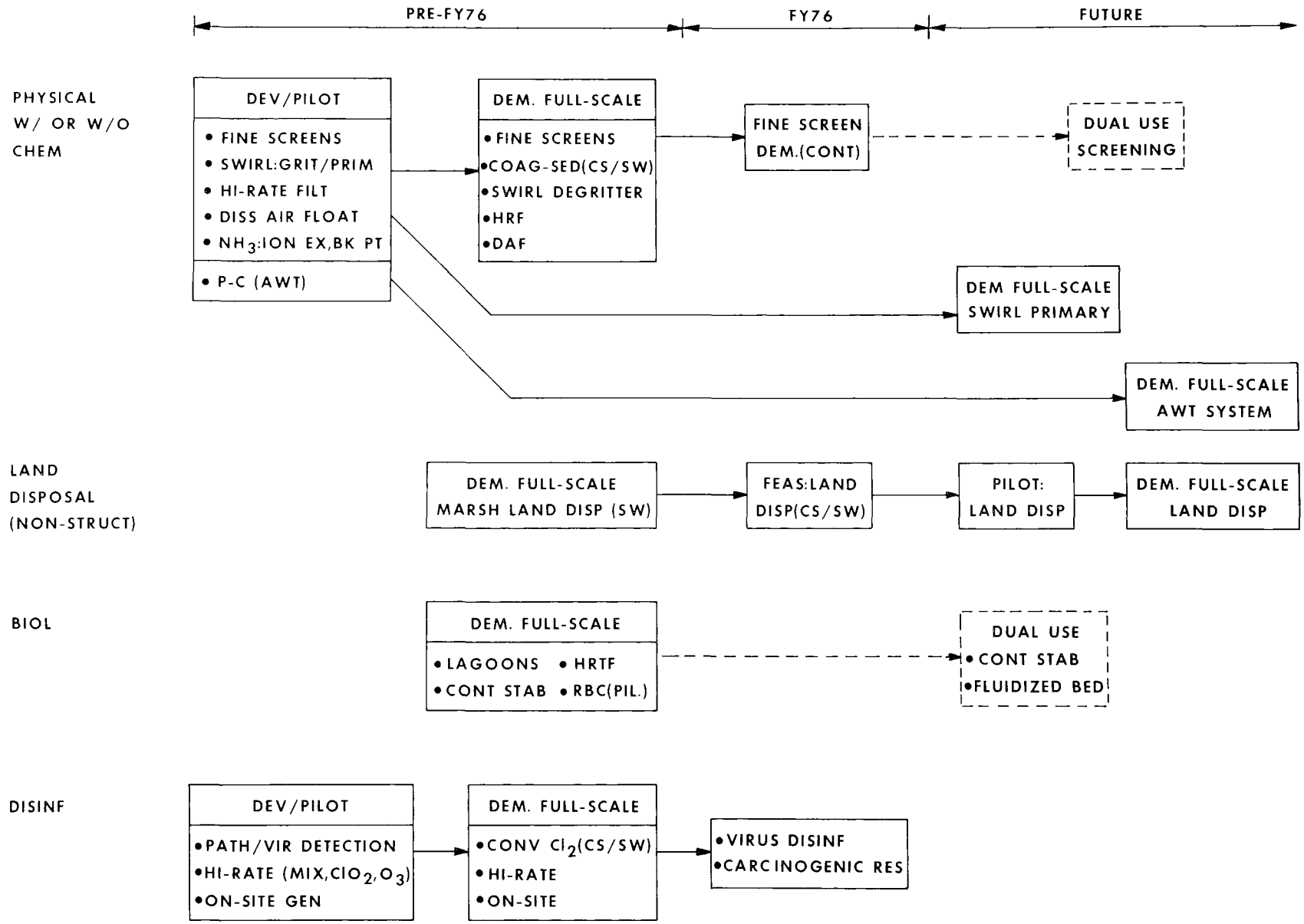


Figure 21. Treatment

dissolved air flotation (20,21,131), have been developed and demonstrated by the Program. Ammonia removal (P-12 and advanced physical-chemical-adsorption systems (81) have also been developed and tested at the pilot level. Physical processes have shown importance for stormwater treatment because of their adaptability to automated operation, rapid startup and shut-down characteristics, high-rate operation, and very good resistance to shock loads.

This year an investment was made in a grant continuation (P-2) to further compare three different fine screens for combined sewer overflow treatment. In the near future the Program desires to implement a full-scale swirl primary treatment demonstration.

A microstrainer is conventionally designed for polishing secondary sewage plant effluent at an optimum rate of approximately 10 gpm/sq ft. Tests on a pilot microscreening unit of 23 micron aperture in Philadelphia have shown that at high influx rates of 25-30 gpm/sq ft, suspended solids removals in combined overflows as high as 90% can be achieved (34,78,105).

A study in Cleveland (35) showed high potential for treating combined sewer overflows by in-pipe coagulation-filtration using anthrafilt and sand in a 7 foot deep bed. With the high loadings of 16 to 32 gpm/sq ft surface area, removal of solids was effectively accomplished throughout the entire depth of filter column. Test work showed suspended solids removal up to and exceeding 90 percent and BOD removals in the range of 60 to 80 percent. Substantial reductions, in the order of 30 to 80 percent of phosphates, can also be obtained. A large-scale high-rate filtration unit in New York City is being evaluated for the dual-treatment of dry and wet-weather flows (P-39).

Results from a 5.0 mgd screening and dissolved-air flotation demonstration pilot plant in Milwaukee (20), indicate that greater than 70 percent removals of BOD and suspended solids are possible. By adding chemical coagulants, 85 to 97 percent phosphate reduction can be achieved as an additional benefit. Based on these findings two full-scale prototypes (20 and 40 mgd) have been demonstrated in Racine, WI (P-23).

Land Disposal

As previously discussed, the use of marshlands for disposal of stormwater has been demonstrated in Minnesota. The feasibility of land disposal of raw CSO has also been investigated (161). Because of the cost of collection and transportation and large land requirements this concept does not appear feasible. Land disposal of CSO sludges, liquid or dewatered, appears feasible and promising for ultimate sludge disposal; however, further investigation in this area is required.

Biological Treatment

The following biological processes have been demonstrated: contact stabilization (117), high-rate trickling filtration (95), rotating biological contactors (106), and lagoons (108,30). The processes have had positive

evaluation, but with the exception of long term storage lagoons, must operate conjunctively with DWF plants to supply biomass, and require some form of flow equalization.

Disinfection

Because disinfectant and contact demands are great for storm flows, research has centered on high-rate applications by mixing and more rapid oxidants, i.e., chlorine dioxide (ClO_2) and ozone (O_3); and on-site generation (149,31,34,78,94,105,119). Because of new concerns, a recent grant supplement tied onto a full-scale demonstration in Syracuse, NY (P-2) will allow viral disinfection and carcinogenic chlorine residual compound studies.

Treatment Process Performance

Treatment process performance in terms of design influx rate (gpm/sq ft) and BOD_5 and suspended solids (SS) removal efficiency is provided in Table 12. The high-rate performance of the swirl, microstrainer, filter, and dissolved air flotation is apparent when compared to sedimentation.

Table 12. Wet-Weather Treatment Plant Performance Data

Device	Control Alternatives	Design Loading Rate (gpm/ft^2)	Removal Efficiency (%)	
			BOD_5	SS
Primary	Swirl Concentrator[a,b]	60	25-60	50
	Microstrainer[c]	20	40-60	70
	High-Rate Filtration[d]	24	60-80	90
	Dissolved Air Flotation[d]	2.5	50-60	80
	Sedimentation[e]	0.5	25-40	55
	Representative Performance		40	60
Secondary	Contact Stabilization[f]		75-88	90
	Physical-Chemical[g]		85-95	95
	Representative Performance		85	95

[a]Field, 1976 (R-16)

[b]Sullivan, 1974 (101)

[c]Maher, 1974 (105)

[d]Lager and Smith, 1974 (102); w/chem. add.; hi-rate filter incl. pre-screens

[e]Performance data based on domestic wastewater treatment

[f]Agnew, et al., 1975 (117)

[g]Estimate based on performance of these units for domestic wastewater (102)

Treatment: Products

The products associated with the treatment category up to this point are in the form of project final reports and design/user's manuals as referenced.

SLUDGE/SOLIDS

Due to the documented deleterious effect of CSO on the quality of receiving waters, WWF sludge handling and disposal has been given less emphasis previously in concession to the problems of treating the combined overflow itself. Sludge handling and disposal should be considered an integral part of CSO treatment because it significantly affects the efficiency and cost of the total waste treatment system. Flow characterization studies show that the annual quantity of CSO solids is at least equal to and in most cases greater than solids from DWF. For example, 29% of the sewered population in the U.S. is served by combined sewers. This represents a service area of $3x10^6$ acres. Assuming an average yearly rainfall of 36 in. and 50% of the runoff resulting in an overflow, the yearly volume of CSO in the U.S. would be $1.5X10^{12}$ gal. The corresponding average yearly volume of sludge resulting from treatment of all CSO nationwide is estimated at $41X10^9$ gal or 2.8% of the volume tested. The average solids content of this sludge would be about 1%.

In comparison, an average yearly volume of dry weather sludge of $35X10^9$ gal may be expected from the same service area.

Consequently, if nationwide CSO treatment was instituted there would be an equal or greater problem with CSO sludge as there now is with municipal sludge.

The chronology of the Program's WWF sludge/solids technological advancement is contained in Figure 22. The need for defining the problem was recognized and, in FY 73, a contract was awarded (P-21) to characterize and preliminarily quantify CSO sludge/solids and perform treatability studies. Sludge handling/disposal techniques are also being evaluated and a nationwide assessment of the sludge problem has been conducted (P-24). As part of this assessment, the "impacts" of the following alternatives are being considered: bleed-back of the sludge to the municipal dry weather treatment plant, handling the sludges with parallel facilities at the dry weather plant, handling the sludges at the site of CSO treatment, and land disposal of either untreated or treated sludges.

Sludge: Products (Table 13)

Two reports are presently available (159,161). The first covers the characterization, treatability, and quantification of CSO sludges and solids and the second is a "rough cut" at assessing the impact of handling and disposal.

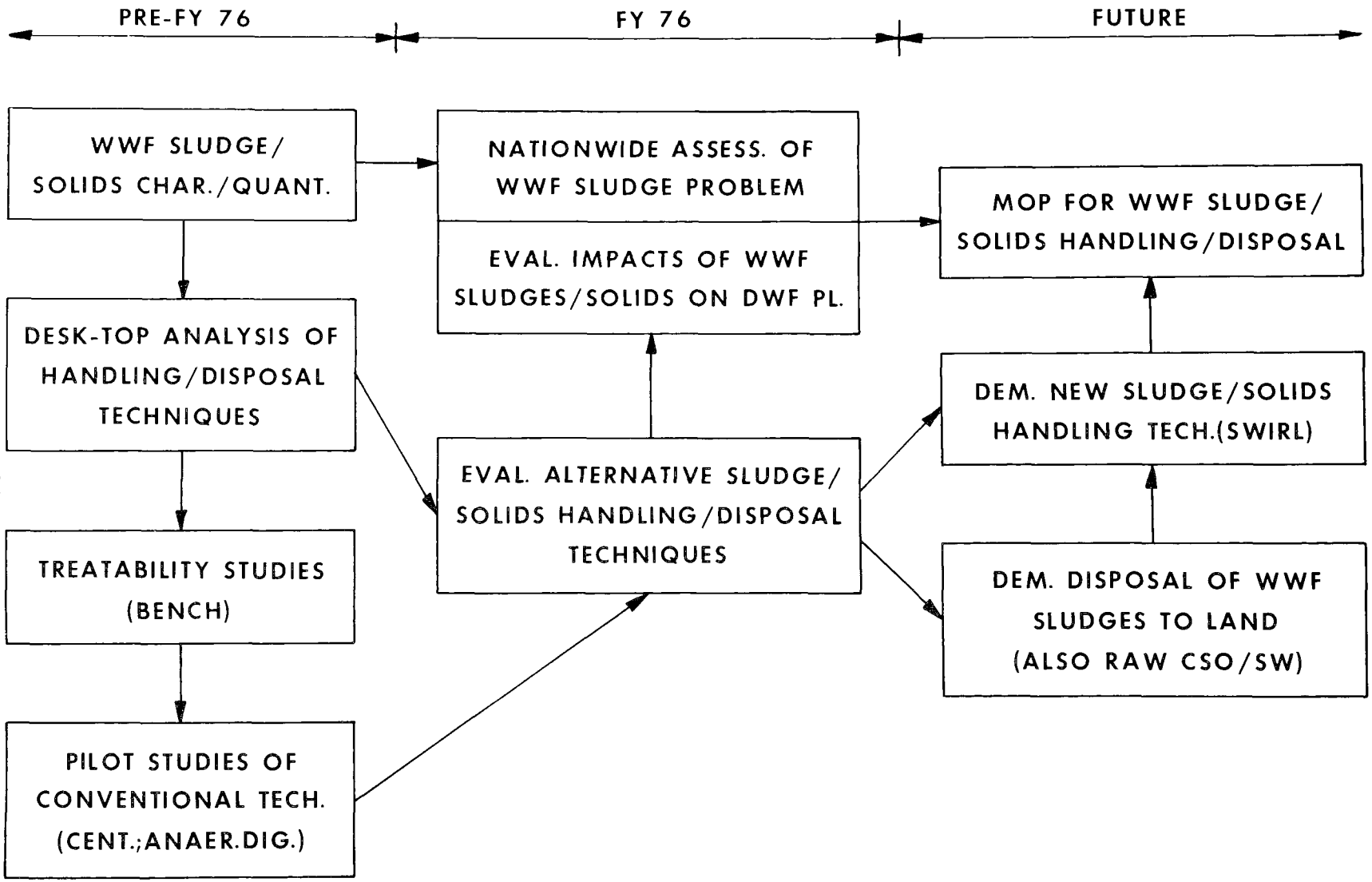


Figure 22. Sludge/Solids

Table 13. Sludge/Solids: Products
o Characterization and Quantification of CSO Sludges and Solids. (Draft report available) (159)
o WWF Sludge/Solids Impact Assessment. (Preliminary Report available) (161)
o WWF Sludge/Solids Treatability Studies. (159)

The characterization, quantification, and treatability evaluation of sludges from separate stormwater will be done in the future.

INTEGRATED SYSTEMS

By far the most promising and common approaches to urban stormwater management involve the integrated use of control and treatment with an area-wide multidisciplinary perspective. When a single method is not likely to produce the best possible answer to a given pollution situation, various treatment and control measures may be combined for maximum flexibility and efficiency.

Integrated systems is divided into (1) Storage/Treatment, (2) Dual Use WWF/DWF Facilities, and (3) Control/Treatment/Reuse (Figure 23).

Storage/Treatment

Where there is storage, there is treatment by settling, pumpback to the municipal works, and sometimes disinfection; and treatment, which receives detention, provides storage. In any case, the break-even economics of supplying storage must be evaluated when treatment is considered (35). The program has demonstrated all of these storage-treatment concepts on a full-scale basis (15,18,25,26,29,30,40,72,102,108,114,118,134,146,147,154, P-10, P-37).

Dual Use, WWF/DWF Facilities

The concept of dual use is -- maximum utilization of wet-weather facilities during nonstorm periods and maximum utilization of dry-weather facilities during storm flows for total system effectiveness. The program has demonstrated the dual use of high-rate trickling filters (95), contact stabilization (117), and equalization basins (107,114). On a pilot scale the Program has evaluated advanced physical-chemical treatment (81); and is in the process of demonstrating large-scale, high-rate filtration (P-39).

It should also be mentioned that combined sewers themselves are dual use systems.

Control/Treatment/Reuse

The sub-category, "Control/Treatment/Reuse" is a "catch-all" for all

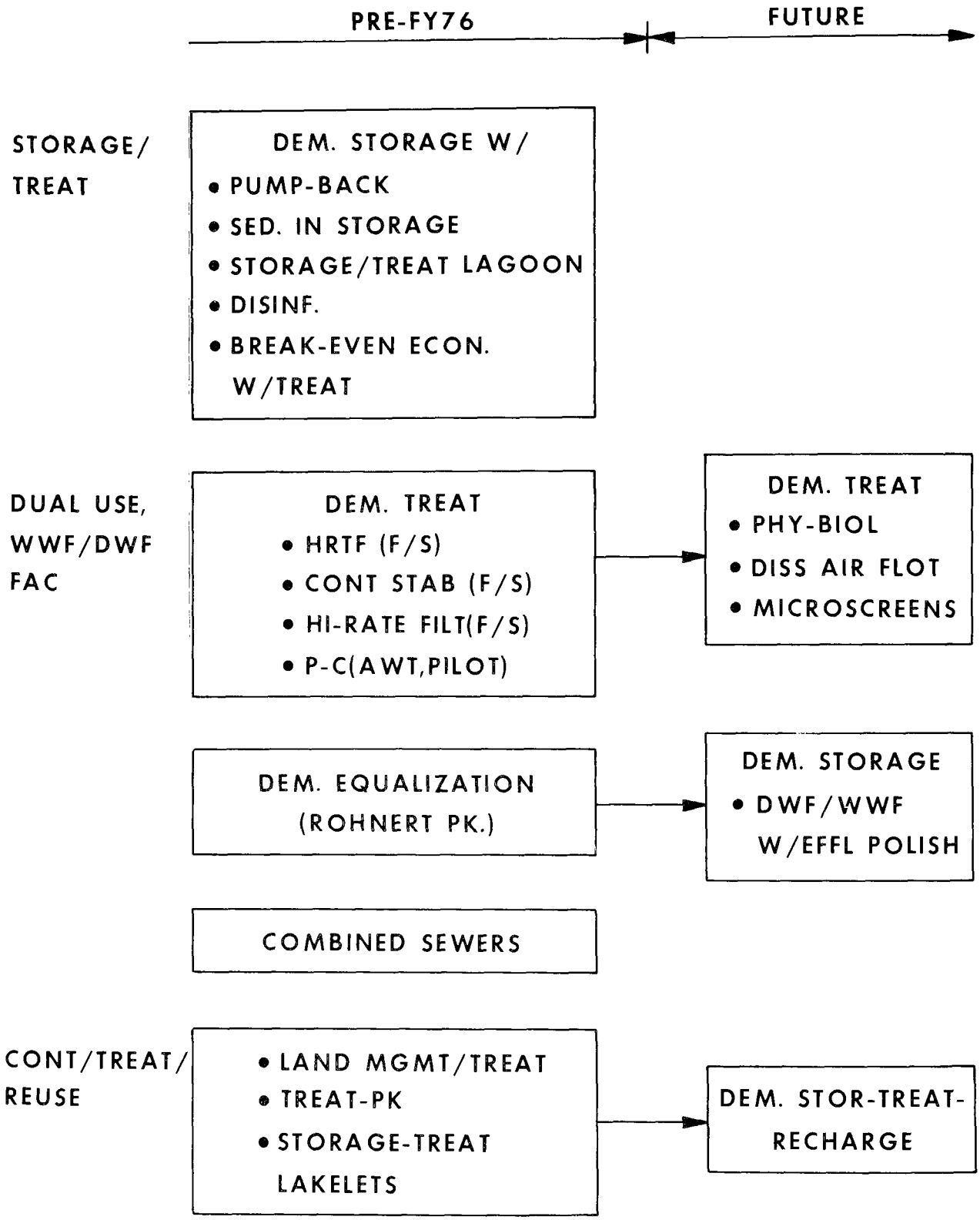


Figure 23. Integrated Systems

integrated systems. As the prime consideration, it is reasonable to apply the various non-structural and land management techniques to reduce downstream loads and treatment costs.

Previous projects have evaluated the reuse of stormwater runoff for aesthetic, recreational, and subpotable and potable water supply purposes (62,79). In Mt. Clemens, MI, a series of three "lakelets" has been incorporated into a CSO treatment-park development (114). Treatment and disinfection is being provided so that these lakes are aesthetically pleasing and allow for recreation and reuse for irrigation. Other projects have shown the feasibility of reclaiming stormwater (3,39).

The previously mentioned Houston project (P-16) is focusing on how a "natural drainage system" can be integrated into a reuse scheme for recreation and aesthetics.

Integrated Systems: Products

The specific outputs from the integrated systems work have been predominantly in the form of demonstrations, documented by final reports. The previously referenced SOTA Assessment Report (102) neatly summarizes the work in this area and ties it into wastewater management systems planning, design, and program implementation. Specific demonstration products are classified into main and complementary units for interrelating storm flow devices and unit processes and interfacing with dry-weather facilities. In the future it is important to evaluate storage used for DWF and WWF along with secondary effluent polishing.

TECHNICAL ASSISTANCE/TECHNOLOGY TRANSFER

The Technology Transfer area covers the formal dissemination of Program findings in the form of actual project reports, films, journal papers, SOTA reports, and manuals of practice and instruction. To date the Program has published approximately 160 reports, and it is the intent here to concentrate on the "user" type of document.

SIGNIFICANT DOCUMENTS COMPLETED

Reports generated by the program have received widespread recognition both within this country and abroad. Many have been referenced by EPA Headquarters and used for 201/208 studies. Some of the more significant documents are indicated in Table 14. The first set of reports, item No. 1,

Table 14. Significant Documents Completed	
1.	Assessment - Problems of CSO/SW (2,20,34,35,41,47,51,53,54,59,60,63,65,67, 73,81,82,83,88,102,112,123,124,127,128,143,149)
2.	CSO/SW Seminar Reports (6,40,96,140a)
3.	MOP - I/I Prevention and Correction (27,28,97)
4.	MOP - Regulation and Management (23,24)
5.	Design Manuals - Swirl: Regulator/Degritter/Erosion Control (69,93,99,101)
6.	Design Manual - Helical Regulator/Separator (132)
7.	Assessments - Sources/Impacts of Urban Runoff Pollution (157,164,127,88, 128,73)
8.	Assessments - Sampling/Flowrate Measurement (133,130)
9.	Assessment - Impact of Deicing (67,86)
10.	MOP's - Deicing Chemical Usage/Storage & Handling (100,104)
11.	Assessment - SOTA Urban Stormwater Management Technology (102,111,137)
12.	Users Manuals - SWMM, Version I and II (44,116)
13.	Course Manual - SWMM Application (125)
14.	SOTA - Urban Water Management Modeling (136)
15.	MOP - Determination of Flowrates/Volumes (140)
16.	Assessment/MOP - Stormwater Models (141)
17.	MOP - Procedures for Stormwater Characterization/Treatment Studies (145)
18.	MOP's - Sediment & Erosion Control (68,70,168,169)
19.	User's Manuals - Simplified Urban Runoff Planning Models/Tools (148,153)
20.	Assessment - Nationwide Stormwater/Characterization/Impacts/Costs (157)

set the pace for EPA's Program by identifying stormwater and combined sewer overflow as major sources of water pollution and provided a characterization data base (Refs. see item 1, Table 14.). As previously mentioned, the manuals of practice on infiltration/inflow (27,28,97) and regulators (23,24), Nos. 3 and 4, flagged two prime and basic problems leading to fruitful countermeasure research and a national emphasis on I/I control. Specific research products coming out of the regulator MOP's were the

swirl (69,93,99,101) and helical (132) devices -- resultant design manuals are listed as Nos. 5 and 6. No. 8 cites two instrumentation reports (130,133) for flow analysis which have proven to be highly useful to the engineering community, including Construction Grants. An assessment of the significant impacts of highway deicing chemical use (67,86) and practicable MOP's on control through proper salt storage and use (100, 104) are covered by items 9 and 10. Nos. 11 through 18 relate to Approach and Solution Methodology, the goal of the program. Item 19 refers to two very important user's manuals containing relatively simple urban runoff assessment planning methods (148,153) which can be applied to 201 and 208 studies; and item 20 cites the previously mentioned national assessment of urban runoff control and costs (157).

SIGNIFICANT DOCUMENTS ANTICIPATED (Table 15)

In the immediate future a construction and O&M cost estimating manual (156) for CSO storage and treatment will be released, along with three other assessments: two on WWF sludge handling, disposal, and impact problems (159,161), and the other on pathogens in stormwater (160).

Ongoing work will also lead to an updated SOTA and a planning document providing guidance and examples for total municipal studies (P-5) and a refined SWMM user's manual (P-53).

Table 15. Significant Documents Anticipated
Estimating Manual CSO Storage and Treatment Costs (156)
User's Manual - SWMM Version III
Assessments - WWF Sludge Handling/Disposal Problems/Impacts (159/161)
Assessment - Pathogens in Stormwater and Combined Sewer Overflow (160)
SOTA/Planning Guide - Update Storm and Combined Sewer Overflow Management and Treatment/Total Approach Methodology
Design Manual - Swirl: Primary Treatment
MOP - I/I Analysis, Prevention and Control
Instruction Manual - Storm and Combined Sewer Overflow Technology
Post FY 76
MOP - Pollution Control from Construction Activities
MOP - Refined Solution Methodology
MOP - Land Management
Design Manual - Storage Facilities
Consolidated Design Text Swirl and Helical

CAPITAL COSTS COMPARISONS FOR STORM AND COMBINED SEWER CONTROL/TREATMENT

Table 16. shows a capital cost comparison for various SCS control and treatment methods.

Sewer separation is very costly with a national average of $20,000/ac (2,102). In-system control storage costs were found to be as low as $0.02 and $0.25/gal for Detroit and Seattle, respectively (R-6d, 111). These figures represented 1/10th the cost for large off-line facilities, and 1/25th the costs for separation in Detroit and Seattle, respectively. Off-line storage varies from $0.03 to $4.75/gal depending on whether earthen or concrete basins are employed (102).

Per acre costs can only be given in wide ranges since they significantly vary with climate, receiving water, terrain, degree of urbanization, sewer network configuration, etc. Per capita and per acre unit costs may be applicable for gross estimating; but it is best to fix unit costs per gallon for storage and per mgd for treatment as design factors for the user engineer confronted with site-specific conditions.

These data are based on a limited number of specific projects thus they represent only a range of placement. In extrapolating these costs into master plan systems for cities, the totals frequently approach $500 to $1,000 per capita.

Physical treatment costs range between $2,000 to $35,000/mgd; whereas physical with chemical treatment varies between $35,000 and $80,000/mgd. Biological treatment ranges between $17,000 and $80,000/mgd depending on whether land is available for lagooning or if contact stabilization or trickling filtration (102) is resorted to. As can be seen from the table, costs for the swirl at $2,000/mgd and $500/acre (P-4) are considerably lower than other forms of treatment installation.

Preliminary figures for incorporating land management techniques show a definite cost-effectiveness benefit.

It must be mentioned that the various alternatives offer different degrees of removal which will have a significant bearing on the selection process.

Table 16. Typical Capital Costs for SCS Control/Treatment (ENR 2000)

COMPONENT DEVICES	$/GAL	$/MGD	$/ACRE
SEPARATION			10,000 (SEATTLE) 6,500 (DES MOINES) 32,000 (CLEVELAND) 20,000-NATIONAL AVE.
STORAGE			
• IN-LINE	0.02 0.25 (DETROIT) (SEATTLE)		400 (SEATTLE) 250 (MINNEAPOLIS)
• OFF-LINE			
-EARTHEN	0.03-0.26		
-CONCRETE TANKS	1.00-4.75		7,000 (JAMAICA,NYC)
TREATMENT			
• PHYSICAL W&W/O CHEMICALS			
-FINE SCREENING/MICROSTRAINING		5,000/12,000	2,000/13,000
-SEDIMENTATION		10,000-50,000	3,500-6,500
-HI-RATE FILT		70,000	10,000
-DISS AIR FLOAT		40,000	6,500 (MILWAUKEE)
-SWIRL		8,000 (SYRACUSE) 2,000 (LANCASTER)	500(SYRACUSE) 500(LANCASTER)
• BIOLOGICAL			
-CON. STAB/TRICK. FILTER		80,000	1,700
-LAGOONS		17,000	5,000
• PHYSICAL-CHEMICAL SYSTEMS		$150,000-2\times10^6$	
• DISINFECTION			
-CONVENTIONAL		1,500	
-HI-RATE(STATIC MIXING)		900	
INTEGRATED SYSTEMS			
• STORAGE/TRMT/REUSE		1×10^6(KINGMAN LAKE)	10,000(KINGMAN LAKE)
-TREATMT-PARK CONCEPT		17,000(MT. CLEMENS)	5,000(MT. CLEMENS)
LAND MANAGEMENT			
• STRUCTURAL			
-DIVERSION BERMS			160
• NON-STRUCTURAL			
-STREET CLEANING			0.7

SEATTLE: IN-LINE STORAGE IS COST-EFFECTIVE

A case study illustrating cost-effectiveness by Seattle's flow routing approach is worthwhile discussing (98,140a).

COSTS

The Seattle in-line storage system covering 13,250 acres costs $5.3M or $400 per acre as opposed to tens of thousands of dollars per acre for other alternatives. A specific Seattle study revealed $10,000 per acre for separation. The low cost is attributed to a quasi-structural system which takes advantage of the existing combined sewer network; and control gates installed at strategic points only. The system is highly signal and computer oriented with minimal hardware requirements. In fact, one-half the costs were for computers and related software. Of course, in-line storage is site specific since implementation of the concept requires a relatively large and flat existing combined system.

POLLUTANT REDUCTION

Overflow and pollutant reduction from 12 major overflow points averaged 55% and 68%, respectively. Also, 90% of the overflow volume was reduced by experimental automatic control.

EFFECTIVENESS

Effectiveness of the system is proven by a one to two mg/l D.O. increase and a 50% coliform reduction in the receiving water.

DES MOINES: CONTROL COSTS VS. D.O. VIOLATIONS

Based on a study for the City of Des Moines (157) using a simplified receiving water model, four control alternatives were compared considering cost and true effectiveness in terms of frequency of D.O. standard violations.

As Table 17 depicts, 25% BOD removal of WWF coupled with secondary treatment of DWF results in slightly higher D.O. levels in the receiving water than tertiary treatment and no control of urban runoff. The annual cost of 25% BOD removal for WWF is 10% of the cost for tertiary treatment. However, existing DWF treatment facilities exhibit a comparable effect to these two options at no additional cost. However, significant increase in the minimum D.O. levels of the Des Moines River is obtained by 75% BOD removal of WWF with the annual cost of this level of control being lower than the cost of tertiary treatment. The application to Des Moines demonstrated clearly the overwhelming effect of urban runoff pollution on critical D.O. concentrations. The cost-effectiveness of various treatment alternatives can be determined realistically only by a continuous analysis of the frequency of water quality violations.

In the selection of the "best" control strategy, other factors that may become important are: (1) recovery of receiving waters from shock loads caused by runoff, (2) local and regional water quality goals, and (3) public willingness to pay the costs associated with each level of control.

Table 17. Des Moines: Control Costs vs Violations of DO Standard (4 PPM)

Options	Total Annual Cost ($/yr)	% of Precipitation Events Violating Standard
1. DWF Tertiary Treatment	6.3M	40
2. WWF 25% BOD Removal	0.6M	30
3. WWF 75% BOD Removal	4.0M	3
4. DWF Secondary Trt Only	0	42

CONCLUSION

The pertinent research needs in the areas of solution methodology, non-structural and structural control and treatment techniques, and integrated systems have been covered in enough detail now to conclude with an item of overlying importance. Mandates of the law are upon us, emphasizing WWF pollution control; monies are being spent at large scale by EPA and others for water pollution cleanup. In order for governments to execute their function in this area properly, it is a must that WWF pollution be considered and R&D be fostered to back this need.

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Note: Number in left margin corresponds to reference numbers cited in report text.

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72.	EPA-R2-72-070	*Storage and Treatment of Combined Sewer Overflows: by the City of Chippewa Falls, WI	GPO EP 1.23/3:72-070 NTIS PB 214 106
73.	EPA-R2-72-081	*Water Pollution Aspects of Street Surface Contaminants: by J.D.Sartor and G.B.Boyd, URS Research Co., San Mateo, CA	GPO EP 1.23/2:72-081 NTIS PB 214 408
74.	EPA-R2-72-082	*Feasibility Study of Electromagnetic Subsurface Profiling: by R.M. Morey and W.S. Harrington, Jr., Geophysical Survey Systems, Inc., North Billerica MD	GPO EP 1.23/2:72-082 NTIS PB 213 892
75.	EPA-R2-72-091	*A Pressure Sewer System Demonstration: by I.G.Carcich, et al, New York State Department of Environmental Conservation, Albany, NY	GPO EP 1.23/2:72-091 NTIS PB 214 409
76.	EPA-R2-72-125	*A Search: New Technology for Pavement Snow and Ice Control: by D.M. Murray and M.R. Eigerman, ABT Associates, Inc., Cambridge, MD	GPO EP 1.23/2:72-125 NTIS PB 221 250
77.	EPA-R2-72-127	*Selected Urban Stormwater Runoff Abstracts, July 1971-June 1972: by D.A. Sandoski, The Franklin Institute Research Lab., Philadelphia, PA	GPO EP 1.23/2:72-127 NTIS PB 214 411
78.	EPA-R2-73-124	Microstraining and Disinfection of Combined Sewer Overflows-Phase II: by G.E. Glover, G.R. Herbert, Crane Company, King of Prussia, PA	GPO EP 1.23/2:73-124 NTIS PB 219 879
79.	EPA-R2-73-139	*The Beneficial Use of Stormwater: by C.W. Mallory, Hittman Associates, Columbia, MD	GPO EP 1.23/2:73-139 NTIS PB 217 506

*Copies may be obtained from EPA Storm and Combined Sewer Section, Edison, NJ 08817

Ref. No.	Report Number	Title/Author	Source
80.	EPA-R2-73-145	*A Thermal Wave Flowmeter for Measuring Combined Sewer Flows: by P. Eshleman and R. Blase, Hydrospace Challenger, Inc., Rockville, MD	GPO EP 1.23/2:73-145 NTIS PB 227 370
81.	EPA-R2-73-149	Physical-Chemical Treatment of Combined and Municipal Sewage: by A.J. Shuckrow, et al., Pacific NW Lab., Battelle Memorial Institute, Richland, WA	GPO EP 1.23/2:73-149 NTIS PB 219 668
82.	EPA-R2-73-152	*Combined Sewer Overflow Study for the Hudson River Conference: by A.I. Mytelka, et al., Interstate Sanitation Commission, New York, NY (jointly sponsored by Office of Enforcement & General Council and Office of Research & Monitoring, EPA)	GPO EP 1.23/2:73-152 NTIS PB 227 341
83.	EPA-R2-73-170	*Combined Sewer Overflow Abatement Plan, Des Moines, IA: by P.L.Davis, et al., Hennington, Durham, and Richardson, Inc., Omaha, NE	GPO EP 1.23/2:R2-73-170
84.	EPA-R2-73-238	*Flow Augmenting Effects of Additives on Open Channel Flows: by C. Derick and K. Logie, Columbia Research Inc., Gaithersburg, MD	GPO EP 1.23/2:73-238 NTIS PB 222 911
85.	EPA-R2-73-242	*Temporary Detention of Storm and Combined Sewage in Natural Underground Formations: by City of St. Paul, St. Paul, MN	GPO EP 1.23/2:73-242
86.	EPA-R2-73-257	Water Pollution and Associated Effects from Street Salting: by R.Field, H.E.Masters, A.N.Tafuri, Edison Water Quality Research Lab., EPA, Edison, NJ and E.J.Struzeski, EPA, Denver, CO	In-House Report NTIS PB 222 795
87.	EPA-R2-73-261	*An Assessment of Automatic Sewer Flow Samplers: by P.E.Shelley and G.W.Kirkpatrick, Hydrospace Challenger Inc., Rockville, MD	GPO EP 1.23/2:R2-73-261 NTIS PB 223 355

*Copies may be obtained from EPA Storm & Combined Sewer Section, Edison, NJ 08817

Ref. No.	Report Number	Title/Author	Source
88.	EPA-R2-73-283	*Toxic Materials Analysis of Street Surface Contaminants: by R.E.Pitt and G.Amy, URS Research Co., San Mateo, CA	GPO EP 1.23/2:R2-73-283 NTIS PB 224 677
88a	EPA-600/2-73-002	A Portable Device for Measuring Waste-water Flow in Sewers: by Michael A. Nawrocki, Hittman Associates, Inc., Columbia, MD	GPO EP 1.23/2:600/2-73-002 NTIS PB 235 634
89	EPA-660/2-73-035	Joint Construction Sediment Control Project: by B.C.Becker, et al., Water Resources Administration, State of Maryland	GPO EP 1.23/2:660/2-73-035 NTIS PB 235 634
90.	EPA-660/2-74-071	Programmed Demonstration for Erosion and Sediment Control Specialist: by T.R.Mills, et al., Water Resources Administration, State of Maryland	GPO EP 1.23/2:660/2-74-071
91.	EPA-660/2-74-072	Demonstration of the Separation and Disposal of Concentrated Sediments: by M.A.Nawrocki, Hittman Associates, Columbia, MD	GPO EP 1.23/2:660/2-74-072
92.	EPA-660/2-74-073	An Executive Summary of Three EPA Demonstration Programs in Erosion and Sediment Control: by B.C.Becker et al., Hittman Associates, Columbia, MD	GPO EP 1.23/2:660/2-74-073
93.	EPA-670/2-73-059	*The Dual-Functioning Swirl Combined Sewer Overflow Regulator/Concentrator: by R.Field, USEPA, Edison, NJ	GPO EP 1.23/2:670/2-73-059 NTIS PB 227 182/3

*Copies may be obtained from EPA Storm and Combined Sewer Section, Edison, NJ 08817

Ref. No.	Report Number	Title/Author	Source
94.	EPA-670/2-73-067	*Hypochlorination of Polluted Stormwater Pumpage at New Orleans: by U.R. Pontius, E.H.Pavis, Byrne Engineering Corp., New Orleans, LA	GPO EP 1.23/2:670/2-73-067 NTIS PB 228 581
95.	EPA-670/2-73-071	*Utilization of Trickling Filters for Dual-Treatment of Dry and Wet-Weather Flows: by P.Homack, et al., E.T. Killam Assoc., Inc., Millburn, NJ	GPO EP 1.23/2:670/2-73-071 NTIS PB 231 251
96.	EPA-670/2-73-077	*Combined Sewer Overflow Seminar Papers: by Storm and Combined Sewer Technology Branch, USEPA, Edison, NJ	GPO EP 1.23/2:670/2-73-077 NTIS PB 231 836
97.	EPA-670/9-74-004	*Excerpts from "Control of Infiltration and Inflow into Sewer Systems," and "Prevention and Correction of Excessive Infiltration and Inflow into Sewer Systems Manual of Practice, January 1971." Complete reports can be purchased from NTIS, See PB numbers listed on third page of this Bibliography.	NTIS Pending
98.	EPA-670/2-74-022	*Computer Management of a Combined Sewer System: by C.P.Leiser, Municipality of Metropolitan Seattle, Seattle, WA	GPO EP 1.23/2:670/2-74-022 NTIS PB 235 717
99.	EPA-670/2-74-026	*The Swirl Concentrator as a Grit Separator Device: by R.H.Sullivan, et al., American Public Works Assoc., Chicago, IL	NTIS PB 233 964
100.	EPA-670/2-74-033	*Manual for Deicing Chemical Storage and Handling: by D.L.Richardson, et al., Arthur D. Little, Inc., Cambridge, MD	NTIS PB 236 152 50k
101.	EPA-670/2-74-039	*Relationship between Diameter and Height for Design of a Swirl Concentrator as a Combined Sewer Overflow Regulator: by R.H.Sullivan, et al., American Public Works Assoc., Chicago, IL	NTIS PB 234 646

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Ref. No.	Report Number	Title/Author	Source
102.	EPA-670/2-74-040	*Urban Stormwater Management and Technology An Assessment: by J.A.Lager and W.G.Smith, Metcalf & Eddy, Inc., Palo Alto, CA	NTIS PB 240 687
103.	EPA-660/2-74-043	Prediction of Subsoil Erodibility Using Chemical, Mineralogical and Physical Parameters: by C.B.Roth, D.W.Nelson, M.J.M.Romkens, Cincinnati, OH	GPO EP 1.23/2:660/2-74-043 NTIS PB 231 846
104.	EPA-670/2-74-045	*Manual for Deicing Chemicals: Application Practices: D.L.Richardson, Arthur D. Little, Inc., Cambridge, MD	NTIS PB 239 694
105.	EPA-670/2-74-049	*Microstraining and Disinfection of Combined Sewer Overflows-Phase III: by M.B.Maher, Crane Co., King of Prussia, PA	GPO EP 1.23/2:670/2-74-049 NTIS PB 235 771
106.	EPA-670/2-74-050	Combined Sewer Overflow Treatment by the Rotating Biological Contactor Process: by F.L.Welsh, D.J.Stucky, Autotrol Corp., Milwaukee, WI	NTIS ONLY PB 231 892
107.	EPA-670/2-74-075	*Surge Facility for Wet- and Dry-Weather Flow Control: by H.L.Welborn City of Rohnert Park, CA	GPO EP 1.23/2:670/2-74-075 NTIS PB 238 905
108.	EPA-670/2-74-079	An Evaluation of Three Combined Sewer Overflow Treatment Alternatives: by J.W.Parks, et al., City of Shelbyville, IL	NTIS ONLY PB 239 115
109.	EPA-670/2-74-086	Chemical Impact of Snow Dumping Practices: by J.P.O'Brien, et al., Arthur D. Little, Inc., Cambridge, MD	NTIS ONLY PB 238 764
110.	EPA-670/2-74-087	Assessment and Development Plans for Monitoring of Organics in Storm Flows: by A.Molvar, A.Tulmello, Raytheon Co., Portsmouth, RI	NTIS ONLY PB 238 810

*Copies may be obtained from EPA Storm and Combined Sewer Section, Edison, NJ 08817

Ref. No.	Report Number	Title/Author	Source
111.	EPA-670/2-74-090	*Countermeasures for Pollution from Overflows: by R.Field, USEPA, and J.A.Lager, Metcalf & Eddy, Inc., Palo Alto, CA	NTIS PB 240 498
112.	EPA-670/2-74-096	*Characterization and Treatment of Urban Land Runoff: by Newton V. Colston, Jr., North Carolina State University, Raleigh, NC	NTIS PB 240 978
113.	EPA-670/2-75-002	*Suspended Solids Monitor: by John W. Liskowitz, et al., American Standard Inc., New Brunswick, NJ	NTIS PB 241 581
114.	EPA-670/2-75-010	*Multi-Purpose Combined Sewer Overflow Treatment Facility, Mt. Clemens, MI: by V.U.Mahida, F.J.DeDecker, Spalding DeDecker & Assoc., Madison Heights, MI	NTIS PB 242 914
115.	EPA-670/2-75-011	*Physical and Settling Characteristics of Particulates in Storm and Sanitary Wastewater: by R.J.Dalrymple, et al, Beak Consultants for American Public Works Assoc., Chicago, IL	NTIS PB 242 001
116.	EPA-670/2-75-017	*Stormwater Management Model User's Manual-Version II: W.C.Huber, et al., University of Florida, Gainesville, FL	NO NTIS
117.	EPA-670/2-75-019	*Biological Treatment of Combined Sewer Overflow at Kenosha, WI: by R.W.Agnew,et al., Envirex, Milwaukee, WI	NTIS PB 242 126
118.	EPA-670/2-75-020	*Sewage System Monitoring and Remote Control: by T.R.Watt, et al., Detroit Metro Water Department, Detroit MI	NTIS PB 242 107
119.	EPA-670/2-75-021	*Bench-Scale High-Rate Disinfection of Combined Sewer Overflows: by P.E. Moffa, et al., O'Brien & Gere Engrs., Syracuse, NY	NTIS PB 242 296

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Ref. No.	Report Number	Title/Author	Source
120.	EPA-670/2-75-022	*Urban Stormwater Management Modeling and Decision-Making: by J.P.Heaney and W.C.Huber, University of Florida, Gainesville, FL	NTIS PB 242 290
121.	EPA-670/2-75-035	Stream Pollution Abatement by Supplemental Pumping: by C.W.Reh and W.E. Saddler, City of Richmond, VA	NTIS ONLY PB 239 566
122.	EPA-670/2-75-041	*Storm Water Management Model: Dissemination and User Assistance: J.A.Hagerman and F.R.S.Dressler, University City Science Center (UCSC), Philadelphia, PA	NTIS PB 2242 544
123.	EPA-670/2-75-046	*Rainfall-Runoff Relations on Urban and Rural Areas: by E.F.Brater and J.D.Sherrill, University of Michigan, Ann Arbor, MI	NTIS PB 242 830
124.	EPA-670/2-75-054	Characterization and Treatment of Combined Sewer Overflows: by Engineering Science Inc. for City and County of San Francisco, CA	NTIS ONLY PB 241 299
125.	EPA-670/2-75-065	*Short Course Proceedings, Application of Stormwater Management Models: F.DiGiano, et al., University of Massachusetts, Amherst, MA	NTIS PB 247 163
126.	EPA-670/2-75-067	*Automatic Organic Monitoring System for Storm and Combined Sewers: by A.Tulumello, Raytheon Co., Portsmouth, RI	NTIS PB 244 142
127.	EPA-440/9-75-004	*Water Quality Management Planning for Urban Runoff: by G.Amy, et al., Woodward-Clyde, San Francisco, CA	NTIS PB 241 689
128.	EPA-600/2-75-004	*Contributions of Urban Roadway Usage to Water Pollution: by D.G.Shaheen, Biospherics Inc., Rockville, MD	NTIS PB 245 854

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Ref. No.	Report Number	Title/Author	Source
129.	EPA-600/2-75-007	Impact of Hydrologic Modifications on Water Quality: by J.Bhutani, et al., Mitre Inc., McLean, VA	NTIS PB 248 523
130.	EPA-600/2-75-027	*Sewer Flow Measurement-A State-of-the-Art Assessment: by P.E.Shelley and G.A.Kirkpatrick, EG&G Washington Analytical Services Center, Inc., Rockville, MD	NTIS PB 250 371
131.	EPA-600/2-75-033	*A Treatment of Combined Sewer Overflows by Dissolved Air Flotations: by T.A.Bursztynsky, et al., Engineering Science Inc., Berkeley, CA	NTIS PB 248 186
132.	EPA-600/2-75-062	*The Helical Bend Combined Sewer Overflow Regulator: by R.H.Sullivan, et al., American Public Works Assoc., Chicago, IL	NTIS PB 250 619
133.	EPA-600/2-75-065	*An Assessment of Automatic Sewer Flow Samplers-1975: by P.E.Shelley, EG&G Washington Analytical Services Center, Inc., Rockville, MD	NTIS PB 250 987
134.	EPA-600/2-75-071	*Detention Tank for Combined Sewer Overflow: by Consoer, Townsend and Associates, Milwaukee, WI	NTIS PB 250 427
135.	EPA-600/2-76-006	*Design and Testing of a Prototype Automatic Sewer Sampling System: by P.Shelley, EG&G Washington Analytical Service Center Inc., Rockville, MD	NTIS PB 252 613
136.	EPA-600/2-76-058	Future Direction of Urban Water Models: by M.Sonnen, Water Resources Engineers (WRE), Walnut Creek, CA	NTIS ONLY PB 249 049
137.	EPA-600/2-76-095	*Urban Runoff Pollution Control Program Overview: FY 76: R.Field, A.N.Tafuri, H.E.Masters, USEPA, Edison, NJ	NTIS PB 252 223 In-house Report

*Copies may be obtained from EPA Storm and Combined Sewer Section, Edison, NJ 08817

Ref. No.	Report Number	Title/Author	Source
138.	EPA-600/2-76-105	*An Economic Analysis of the Environmental Impact of Highway Deicing: by D.M.Murray and U.F.W.Ernst, Abt Associates, Inc., Cambridge, MA	NTIS PB 253 268
139.	EPA-600/2-76-115	*A Passive Flow Measurement System for Storm and Combined Sewer: by K.Foreman, Grumman Ecosystems Corp., Bethpage, NY	NTIS PB 253 383
140.	EPA-600/2-76-116	*Urban Stormwater Runoff Determination of Volumes and Flowrates: by B.C.Yen and V.T.Chow, University of Illinois, Urbana, IL	NTIS PB 253 410
140a.	WPD 03-76-04	*Proceedings Urban Stormwater Management Seminars: Atlanta, GA, Nov. 4-6, and Denver, CO, Dec. 2-4, 1975, Edited by Dennis Athayde, USEPA, Water Planning Div., Washington, DC	NTIS PB 260 889
141.	EPA-600/2-76-175a	*Assessment of Mathematical Models for Storm and Combined Sewer Management: by A.Brandstetter, Battelle, Pacific Northwest Lab., Richland, WA	NTIS PB 259 597
142.	EPA-600/2-76-175b	Assessment of Mathematical Models for Storm and Combined Sewer Management-Appendix: by A.Brandstetter, Battelle, Pacific Northwest Lab., Richland, WA	NTIS ONLY PB 258 644
143.	EPA-600/2-76-217a	Urban Runoff Characteristics-Vol. I, Analytical Studies: by H.C.Preul and C.N.Papadakis, University of Cincinnati, Cincinnati, OH	NTIS ONLY PB 258 033
144.	EPA-600/2-76-217b	Urban Runoff Characteristics-Vol. II, by H.C.Preul and C.N.Papadakis, University of Cincinnati, Cincinnati, OH	NTIS ONLY PB 258 034
145.	EPA-600/2-76-145	*Methodology for the Study of Urban Storm Generated Pollution and Control: by Envirex, Environmental Sciences Division, Milwaukee, WI	NTIS PB 258 743

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Ref. No.	Report Number	Title/Author	Source
146.	EPA-600/2-76-222a	*Wastewater Management Program, Jamaica Bay-Vol.I, Summary Report: by D.L.Feurstein and W.O.Maddaus, City of New York, NY	NTIS PB 260 887
147.	EPA-600/2-76-222b	Wastewater Management Program, Jamaica Bay-Vol. II, Supplemental Data, NYC Spring Creek: by D.L. Feurerstein and W.O.Maddaus, City of New York, NY	NTIS ONLY PB 258 308
148.	EPA-600/2-76-218	*Development and Application of a Simplified Stormwater Management Model: by Metcalf & Eddy, Inc. Palo Alto, CA	NTIS PB 258 074
149.	EPA-600/2-76-244	*Proceedings of Workshop on Micro-organism in Urban Stormwater: March 24, 1975, Storm and Combined Sewer Section, USEPA, Edison, NJ	NTIS Pending
150.	EPA-600/2-76-243	*Wastewater Flow Measurement in Sewers Using Ultrasound, Milwaukee: by R.J.Anderson and S.S.Bell, City of Milwaukee, WI	NTIS Pending
151.	EPA-600/2-76-271	*The Swirl Concentrator for Erosion Runoff Treatment: by R.H.Sullivan, et al., American Public Works Assoc., Chicago, IL	NTIS Pending
152.	EPA-600/2-76-242	*Development of a Hydrophobic Substance to Mitigate Pavement Ice Adhesion: by B.H.Alborn and H.C.Poehlmann, Ball Bros., Inc., Boulder, CO	NTIS Pending
153.	EPA-600/2-76-275	*Storm Water Management Model Level I Preliminary Screening Procedures: by J.P.Heaney, et al., University of Florida, Gainesville, FL	NTIS PB 259 916
154.	EPA-600/2-76-272	*Demonstration of Void Space Storage with Treatment and Flow Regulation: by Karl R. Rohrer Assocs., Inc., Akron, OH	NTIS Pending

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Ref. No.	Report Number	Title/Author	Source
155.	EPA-600/2-76-228	Demonstration of Interim Techniques for Reclamation of Polluted Beach-water: by J.F.Weber, City of Cleveland, OH	NTIS ONLY PB 258 192
156.	EPA-600/2-76-286	*Cost Estimating Manual--Combined Sewer Overflow Storage Treatment: by H.H.Benjes, Jr., Culp, Wesner, Culp, Inc., El Dorado Hills, CA	NTIS Pending
157.		Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges, Vol. II: Cost Assessment and Impacts: by J.F.Heaney, et al., University of Florida, Gainesville, FL	At Printers
158.		Field Prototype Demonstration of the Swirl Degritter: by R.H.Sullivan, et al., American Public Works Assoc., Chicago, IL	DRAFT
159.		*Handling and Disposal of Sludges from Combined Sewer Overflow Treatment-Phase I (Characterization): by M.K. Gupta, et al., Envirex, Environmental Science Division, Milwaukee, WI	At Printers
160.		Microorganisms in Urban Stormwater: by V.P.Olivieri, et al., The Johns Hopkins University, Baltimore, MD	DRAFT
161.		Assessment of the Impact of the Handling and Disposal of Sludges Arising from Combined Sewer Overflow Treatment: by M.J.Clark and A.Geinopolos, Envirex, Environmental Sciences Division, Milwaukee, WI	DRAFT
162.		Swirl Device for Regulating and Treating Combined Sewer Overflows, EPA Technology Transfer Capsule Report: by R.Field and H.E.Masters, USEPA, Storm and Combined Sewer Sec., Edison, NJ	At Printers

*Copies may be obtained from EPA Storm and Combined Sewer Section, Edison, NJ 08817

Ref. No.	Report Number	Title/Author	Source
163.	EPA-600/2-77-033	Methods for Separation of Sediment from Storm Water at Construction Sites: by J.F.Ripken, et al., Univ. of Minnesota, Minneapolis, MN	NTIS ONLY Pending
164.		Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges, Vol. III: Characterization: by R.H.Sullivan, et al., American Public Works Assoc., Chicago, IL	DRAFT
165.		Cost-Effective Pollution Control of Combined Wastes and Urban Runoff: by Clinton Bogert Assocs., Fort Lee, NJ	DRAFT
166.		Analysis of Practices for Preparing an Economic Analysis and Determining Infiltration and Inflow: Vol. II: Manual of Practice, Sewer System Evaluation Rehabilitation and New Construction: by R.H.Sullivan, et al., American Public Works Assoc., Chicago, IL	DRAFT
167.	EPA-440/9-75-001	Report on State Sediment Control Institutes Program: USEPA, Office of Water Planning and Standards	NTIS PB 241 088
168.	EPA-600/8-76-001a	Erosion and Sediment Control Audio-Visual Training Program: Instruction Manual: by The State of Maryland Water Resources Administration; Dept. of Transportation, The Federal Highway Administration; The U.S. Department of Agriculture, Soil Conservation Service; and USEPA, Office of Research and Development	NTIS PB 256 901
169.	EPA-600/8-76-001b	Erosion and Sediment Control Audio-visual Training Program: Workbook: by The State of Maryland Water Resources Administration; Department of Transportation, The Federal Highway Administration; The U.S. Department of Agriculture, Soil Conservation Service; and USEPA, Office of Research and Development	NTIS PB 258 471

Ref. No.	Report Number	Title/Author	Source
170.	EPA-600/2-77-015	*Treatment of Combined Sewer Overflows by High Gradient Magnetic Separation: by John Oberteuffer, et al., Sala Magnetics, Cambridge, MA	NTIS Pending
171.		Cottage Farm Combined Sewer Detention and Chlorination Station, Cambridge, MA: by Commonwealth of MA Metropolitan District Commission, Boston, MA	NTIS ONLY Pending
172.		Bachman Treatment Facility for Excessive Storm Flow in Sanitary Sewers: by H.W.Wolf, Texas A&M University, for Dallas Water Utilities, Dallas, TX	NTIS ONLY Pending
173.		Evaluation of Fluidic Combined Sewer Regulators Under Municipal Service Conditions: by P.A.Freeman, Peter A. Freeman Assoc., Inc., Berlin, MD	At Printers
174.		Catchbasin Technology Overview and Assessment: by J.J.Lager, et al., Metcalf & Eddy, Inc., Palo Alto, CA, in association with Hydro-Research-Science, Santa Clara, CA	At Printers

ONGOING URBAN RUNOFF POLLUTION CONTROL PROJECTS

Project Reference Number	On-Going Projects
P-1	"Nationwide Characterization, Impacts, and Critical Evaluation of Combined Sewer Overflow, Stormwater, and Non-Sewered Urban Runoff." American Public Works Association, 68-03-0283
P-2	"Disinfection/Treatment of Combined Sewer Overflows - Syracuse, N.Y." Onondaga County, N.Y., 802400
P-3	"Development of a Swirl Concentrator and a Helical Combined Sewer Overflow Dual Functioning Regulator-Separator." American Public Works Association, 68-03-0272
P-4	"Demonstration of a Swirl Regulator/Solids Separator System for Control of Combined Sewer Overflows." City of Lancaster, Pennsylvania, 802219
P-5	"State-of-the-Art Update on Storm and Combined Sewer Overflow Management and Treatment, and An Urban Planning Guide for the Assessment of Storm Flow Pollution and the Selection of System Pollution Control Methods." Metcalf & Eddy, Inc., 68-03-2228
P-6	"Use of Polymers to Reduce or Eliminate Sewer Overflows in the Bachman Creek Sewer." City of Dallas, Texas, 11022 DZU
P-7	"Combined Sewer Fluidic Regulator Demonstration." City of Philadelphia, 11022 FWR
P-8	"Development of a Flocculation-Flotation Module." Hercules, Inc., 14-12-855
P-9	"Stormwater Treatment Facilities." City of Dallas, Texas, 11023 FAW
P-10	"The Lawrence Avenue Underflow Sewer System." City of Chicago 11022 EMD

Note: Number appearing in left margin corresponds to reference numbers cited in report text.

Project Reference Number	On-Going Projects
P-11	"Microorganisms in Stormwater." John Hopkins University, 802709
P-12	"Nutrient Removal Using Existing Combined Sewer Overflow Treatment Facilities." Onondaga County, N.Y., 802400
P-13	"Comparison of Alternate Sewer Design." City of Elizabeth New Jersey, 802971
P-14	a) "Refine/Verify a Simplified Model to Handle Large Areas with Minimal Data Input as a Planning Aid." Rochester Pure Water Agency, Y-005141
P-15	b) "Combined Sewer Overflow Abatement Program - Rochester, N.Y." Rochester Pure Water Agency, Y-005141
P-16	"Maximum Utilization of Water Resources in a Planned Community." Rice University, 802433
P-17	"Evaluation of Present Catch Basin Technology and Demonstration and Evaluation of New Upstream Attenuator/Solids Separator Design." Metcalf & Eddy, Inc., 68-03-0274
P-18	"Analysis of Practices for Preparing an Economic Analysis and Determining Infiltration." American Public Works Association, 803151
P-19	"Engineering Aspects of Storm and Combined Sewer Overflow Technology A Manual of Instruction." North Carolina State University, 801358
P-20	"Develop a Movie on Nature/Impacts of Stormwater Pollution As Compared to Other Forms of Water Pollution." (SRO ID No. 61ABR), EPA, Technology Transfer
P-21	"Characterization and Disposal of Combined Sewer Overflow Sludges and Solids." Envirex, 69-03-0242
P-22	"Development and Demonstration of Combined Sewage Treatment Utilizing Screening and Spilt-Air Flotation." City of Milwaukee (Hawley Road) 11020 FDC
P-23	"Demonstration of Screening/Dissolved-Air Flotation as an Alternative to Combined Sewer Separation." City of Racine, Wisconsin, 11023 FWS

Project Reference Number	On-Going Projects
P-24	"Sludge Treatment and Disposal Methods for Combined Sewer Overflow." Envirex, 68-03-0242
P-25	"Demonstration Real-Time Automatic Control in Combined Sewer System." City and County of San Francisco, California, 803743
P-28	"Evaluation of Stormwater Treatment Methods." Minnehaha Creek Watershed District, 802535
P-29	"Evaluation and Technology Transfer of the Swirl Concentrator Principle." American Public Works Association, 803157
P-30	"Demonstration/Evaluation of Impregnated Concrete Pipe and Other Methods of Infiltration Control." Texas Water Quality Board, 802651
P-31	"Trenchless Sewer Construction and Sewer Design Innovation." Sussex County Council, Delaware, 800690
P-32	"The Somerville Marginal Conduit Including Pretreatment Facilities." Boston Metropolitan District Commission, 11023 DME
P-34	"Large Scale Demonstration of Treatment of Storm-Caused Overflows by the Screening Method." City of Fort Wayne, Indiana, 11020 GYU
P-37	"Boston University Bridge Storm Water Detention and Chlorination Station." Boston Metropolitan District Commission, 11023 FAT
P-39	"Ultra-High Rate Filtration of Combined Sewer Overflow and Raw Dry Weather Sewage at Newtown Creek Sewage Treatment Plant." City of New York, 803271
P-40	"East Chicago Treatment Lagoon." East Chicago Sanitary District, 11020 FAV
P-41	"Evaluation of Various Aspects of an Aluminum Storm Sewer System." City of LaSalle, Illinois, 11032 DTI
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P-66	"Characterization of Solids Behavior in, and Variability Testing of Selected Control Techniques for Combined Sewer Systems." Northeastern University, 804578
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P-73	"Methods of Separation of Sediment From Storm Water at Construction Sites." University of Minnesota, 803579
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Note: Number appearing in left margin corresponds to reference numbers cited in report text.

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16. ABSTRACT

This Overview describes the major elements of the Urban Runoff Pollution Control Program. Problem Definition, User Assistance Tools, Management Alternatives and Technology Transfer are covered, including some of the highlights of the Program's future direction and products from over 150 of its research projects. References are cited for completed Program reports, ongoing Program projects, and in-house documents.

Capital cost comparisons for storm and combined sewer control/treatment are given, along with a specific example of cost-effect solution for urban runoff pollution control by in-line storage in Seattle. In a study done in Des Moines, using a simplified receiving water model, four control alternatives were compared, considering cost and effectiveness in terms of a frequency of D.O. standard violations.

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