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<u>Narragansett Bay Combined Sewer Overflows</u> 67 pp

Metcalf & Eddy

Narragansett Bay Estuary Program

Current Report

The Narragansett Bay Project

NARRAGANSETT BAY COMBINED SEWER OVERFLOWS

PREPARED FOR:
U.S. EPA REGION I
AND THE
NARRAGANSETT BAY PROJECT

PREPARED BY:
METCALF & EDDY

#NBP-91-58

The Narragansett Bay Project is sponsored by the U.S. Environmental Protection Agency and the R.I. Department of Environmental Management.

FOREWORD

The United States Congress created the National Estuary Program in 1984, citing its concern for the "health and ecological integrity" of the nation's estuaries and estuarine resources. Narragansett Bay was selected for inclusion in the National Estuary Program in 1984 and designated an "estuary of national significance" in 1988. The Narragansett Bay Project (NBP) was established in 1985. Under the joint sponsorship of the U.S. Environmental Protection Agency and the Rhode Island Department of Environmental Management, the NBP's mandate is to direct a five-year program of research and planning focussed on managing Narragansett Bay and its resources for future generations. The NBP will develop a comprehensive management plan by December, 1991, which will recommend actions to improve and protect the Bay and its natural resources.

The NBP has established the following seven priority issues for Narragansett Bay:

* management of fisheries
* nutrients and potential for eutrophication
* impacts of toxic contaminants
* health and abundance of living resources
* health risk to consumers of contaminated seafood
* land-based impacts on water quality
* recreational uses

The NBP is taking an ecosystem/watershed approach to address these problems and has funded research that will help to improve our understanding of various aspects of these priority problems. The Project is also working to expand and coordinate existing programs among state agencies, governmental institutions, and academic researchers in order to apply research findings to the practical needs of managing the Bay and improving the environmental quality of its watershed.

This report represents the technical results of an investigation performed for the Narragansett Bay Project. The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under Contract # 68-D-90163 with Metcalf & Eddy. It has been subject to the Agency's and the Narragansett Bay Project's peer and administrative review and has been accepted for publication as a technical report by the Management Committee of the Narragansett Bay Project. The results and conclusions contained herein are those of the author(s), and do not necessarily represent the views or recommendations of the NBP. Final recommendations for management actions will be based upon the results of this and other investigations.

EXECUTIVE SUMMARY

This report addresses combined sewer overflow (CSO) issues in Narragansett Bay using currently available information. The information presented in this report will be used by EPA to assist in developing CSO-related recommendations which will be contained in the Narragansett Bay Project Comprehensive Conservation and Management Plan (CCMP) which is currently being developed.

This report contains a brief history of the CSOs owned by the Narragansett Bay Commission (NBC) and the Blackstone Valley District Commission (BVDC); estimates of CSO flows and pollutant loads from available reports and information; comparison of CSO flows and pollutant loads with flows and loads from other pollutant sources; a summary of major current CSO problems; a summary of potential health and environmental significance of CSOs; a review of NBC abatement activities and schedules and a review of EPA and Rhode Island CSO policies.

Based upon the information presented in this report, it is recommended that the NBC reevaluate its planned schedule for CSO abatement projects. On a more regional basis, whether the CSOs under NBC or BVDC jurisdiction should receive highest priority cannot be determined until the BVDC has completed facilities plans for its CSOs and has evaluated their impacts on receiving waters. Currently available information on CSO loads indicates that the focus of CSO abatement should be on bacteria and, to a lesser extent, solids and metals. CSO abatement strategies should be developed to address these contaminants and comply with the CSO abatement policies of RIDEM and EPA.

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NARRAGANSETT BAY COMBINED SEWER OVERFLOWS

This report addresses combined sewer overflow (CSO) issues in Narragansett Bay using currently available information. The information presented in this report will be used by EPA to assist in developing CSO-related recommendations which will be contained in the Narragansett Bay Project Comprehensive Conservation and Management Plan (CCMP) which is currently being developed.

This report contains the following information:

- Brief history of the CSOs owned by the Narragansett Bay Commission (NBC) and the Blackstone Valley District Commission (BVDC)
- Estimates of CSO flows and pollutant loads from available reports and information
- Comparison of CSO flows and pollutant loads with flows and loads from other pollutant sources
- Summary of major current CSO problems
- Summary of potential health and environmental significance of CSOs
- Review of NBC abatement activities and schedules
- Review of EPA and Rhode Island CSO policies
- Recommendations

BACKGROUND AND HISTORY OF NARRAGANSETT BAY CSOs

This project compares flows and loads from combined sewer systems which discharge into the Upper Narragansett Bay and its tributaries with other major sources of pollution. The area of Narragansett Bay impacted by CSOs includes the Providence River and the Seekonk River. Five tributaries drain into these portions of the bay which are the Blackstone, Pawtuxet, Woonasquatucket, Mosshasuck, and Ten Mile rivers. The major combined drainage areas cover portions of nine communities in Rhode Island. This combined area is comprised of two distinct regions, each having a regional commission with authority over wastewater issues.

Narragansett Bay Commission

Sewer systems in the Narragansett Bay region date back to the 1800s. As was common practice at the time, combined sewers were installed to convey both sewage and stormwater to nearby waterways. As this was recognized as a public health risk, construction of a wastewater treatment facility at Field's Point was initiated in 1890. The sewer system tributary to the treatment plant services the cities of Providence and North Providence and portions of Johnston, Lincoln, and Cranston. During large storm events when hydraulic capacity is exceeded at the treatment plant and in the conveyance pipes, millions of gallons of combined wastewater and stormwater are discharged at 65 locations along the Seekonk, Mosshasuck, West, Woonasquatucket, and Providence Rivers.

The Narragansett Bay Commission (NBC) was formed in May, 1982 with the goals of correcting the CSO problem and improving the water quality of local rivers and the Narragansett Bay. The NBC service area is shown in Figure 1. The commission assumed responsibility for the Field's Point Treatment Facility and several pumping stations, all tributary sewer interceptors and flow regulators, and the 65 CSO outlets, shown in Figure 2.

All 65 CSOs in Providence are regulated under the National Pollutant Discharge Elimination System Permit No. RI0100315 in accordance with Section 402 of the Clean Water Act (Public Law 92-500 and amendments). The permit sets discharge requirements for the CSOs and requires that best practicable waste treatment technology (BPWTT) be applied. BPWTT is defined as the most cost-effective treatment technology available, and may vary from site to site. The Rhode Island Department of Environmental Management (RIDEM) is responsible for administering and enforcing the Clean Water Act in the state. RIDEM has defined required CSO treatment to be the equivalent of primary waste treatment with disinfection.

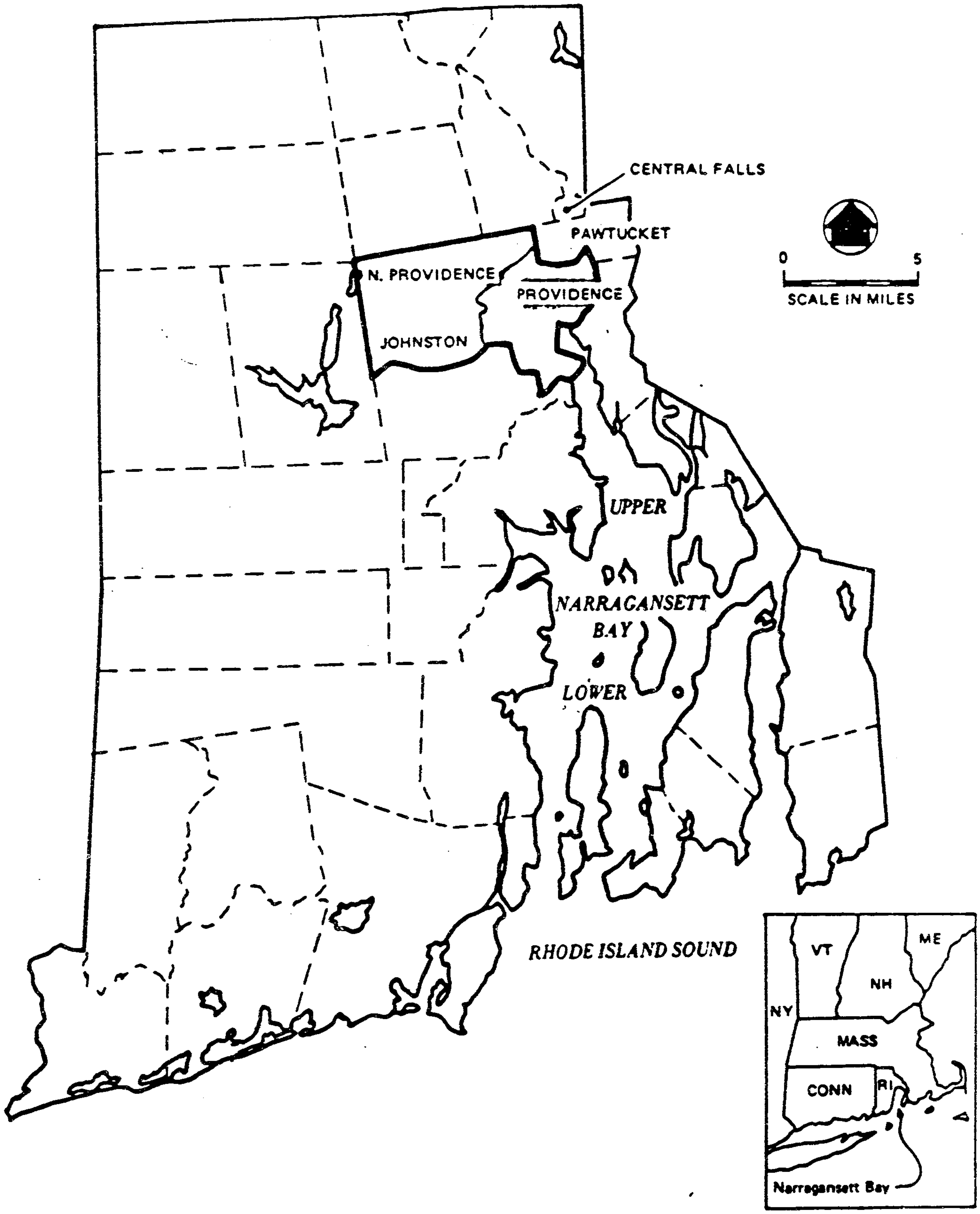


FIGURE 1. NBC SERVICE AREA

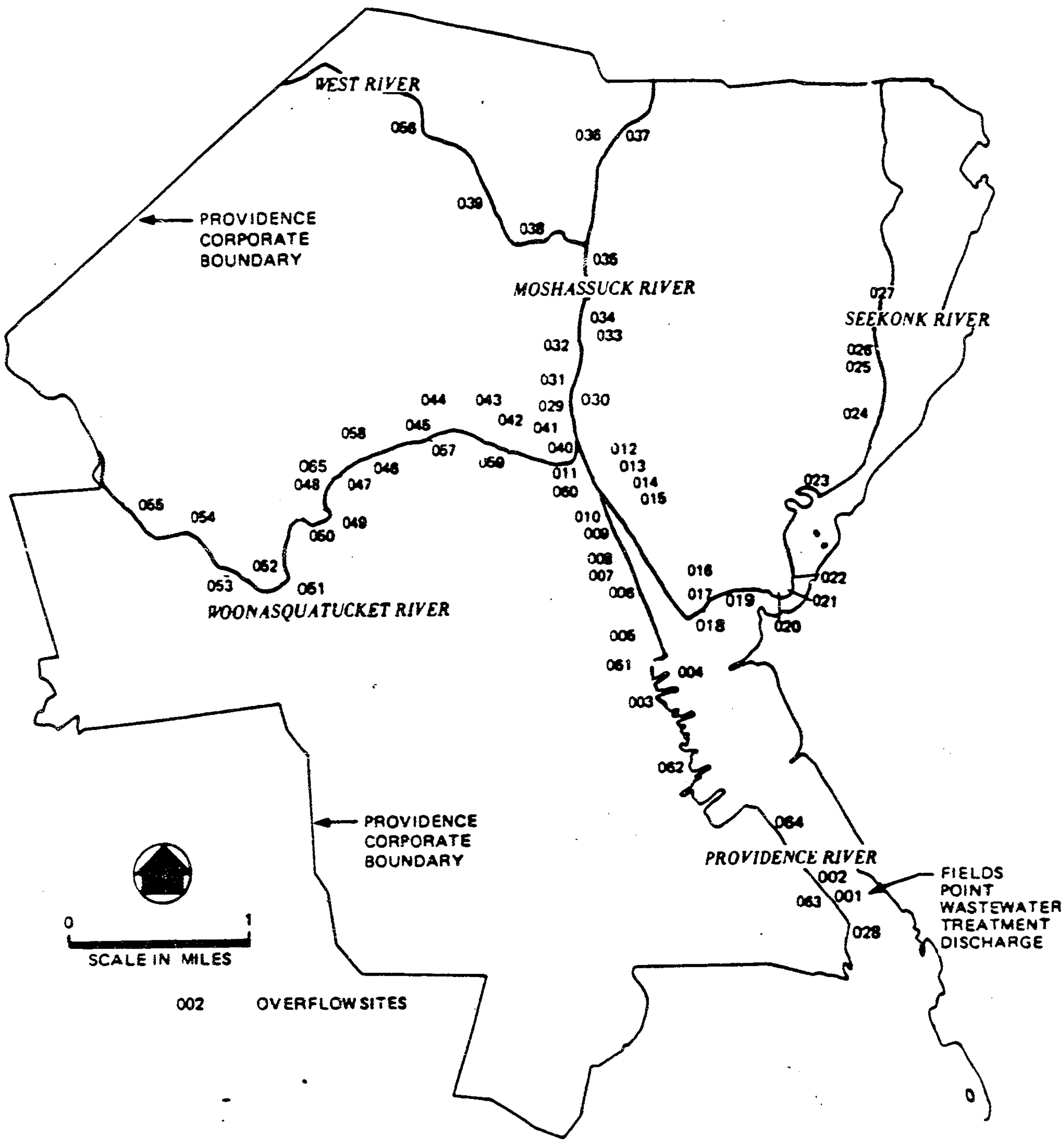


FIGURE 2. NBC COMBINED SEWER OVERFLOW SITES

Blackstone Valley District Commission

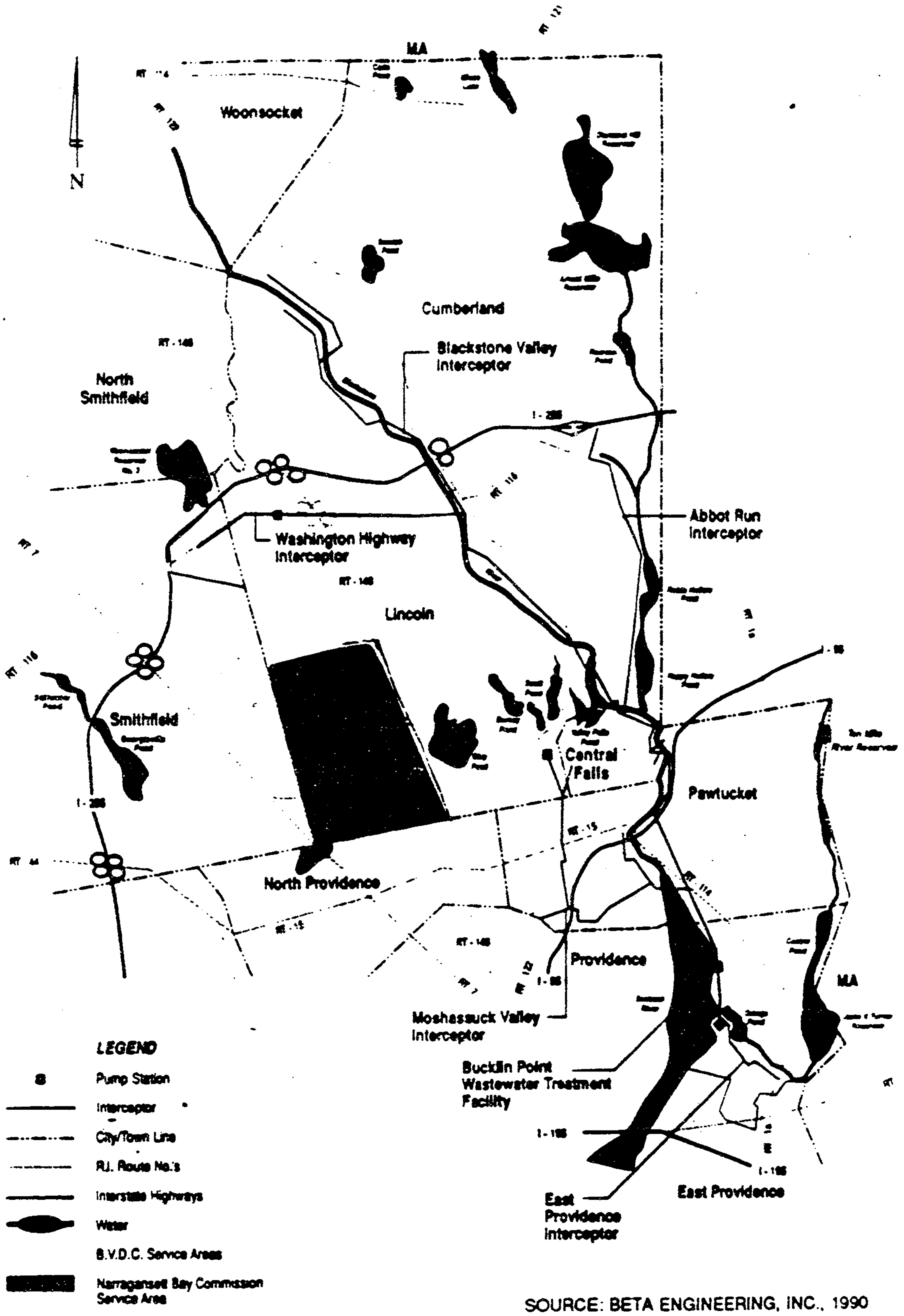
The Blackstone Valley District Commission (BVDC) was established by the Blackstone Valley Sewer District Act in 1947 with the objective of cleaning up pollution in the Blackstone and Mosshasuck River watersheds. The sewer district is comprised of the communities of East Providence, Central Falls, Pawtucket, Cumberland, Lincoln, and Smithfield. The BVDC service area is shown in Figure 3.

A wastewater treatment facility was completed at Bucklin Point in East Providence in 1952. A large portion of the sewer system tributary to the Bucklin Point treatment plant consists of combined sewers which discharge untreated wastewater to the Blackstone, Seekonk, and Mosshasuck Rivers during wet weather events. Thirty overflows are located in Pawtucket and Central Falls and were owned and operated by these individual communities until 1989, when they were transferred to the jurisdiction of the BVDC. The locations of these overflow sites are shown in Figure 4. Eight additional CSOs which are actually emergency bypass structures for the Bucklin Point treatment plant and its tributary siphons and pump stations are also operated by the BVDC.

The Commission was issued its initial NPDES permit by the EPA in 1974. Revisions were issued in June 1977 and November 1983. The permit gives BVDC the authority to operate the Bucklin Point treatment facility and to discharge wastes to the Seekonk, Blackstone, and Mosshasuck Rivers. The permit also requires the BVDC to develop a program for abatement or control of combined sewer overflows and emergency bypasses operated by the Commission which discharge untreated or partially treated wastes. A new permit is currently being drafted. There is an unresolved issue of how much flow will be allowed to discharge through the Bucklin Point facility's North Diversion Structure.

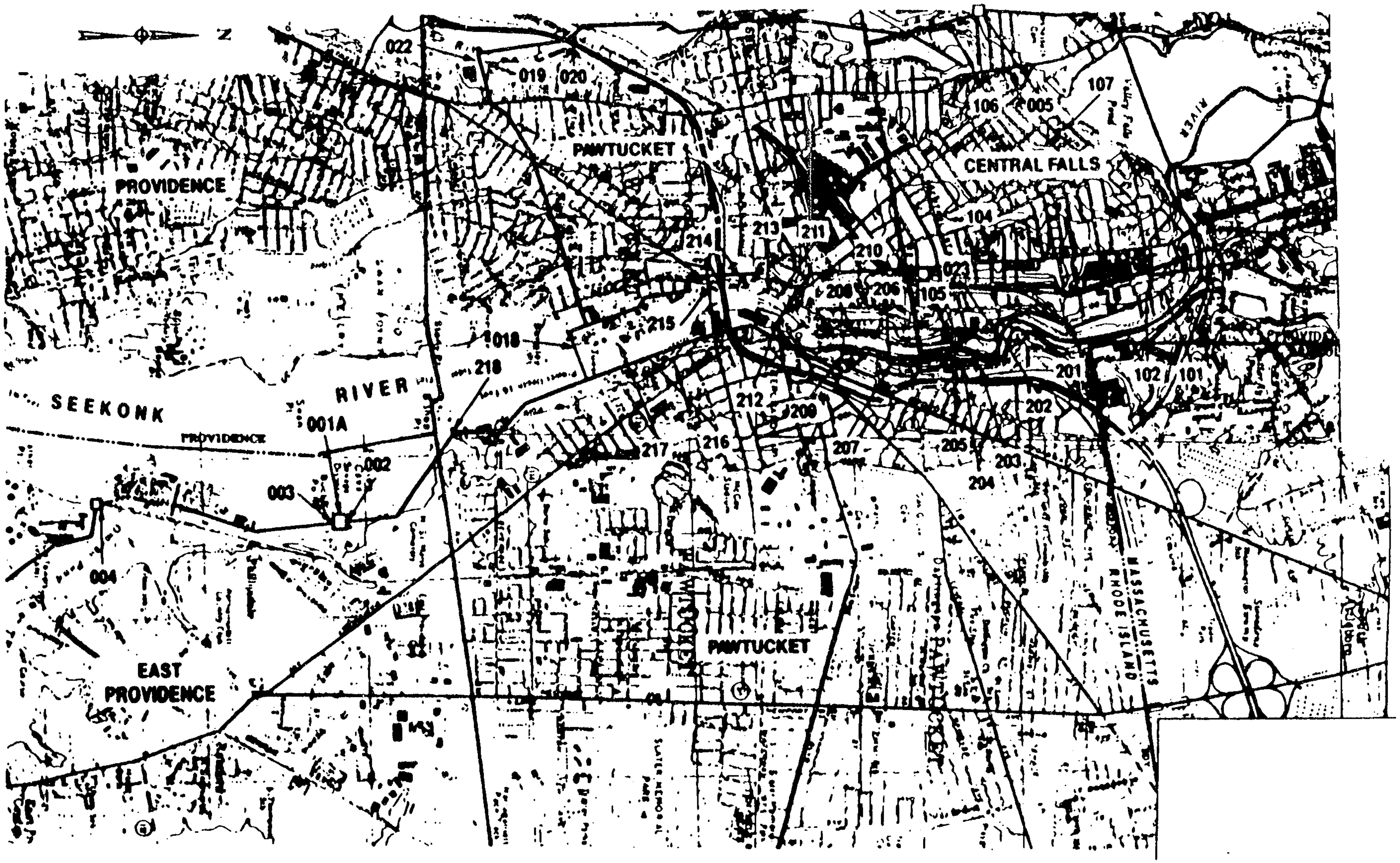
Previous CSO Mitigation Studies

The combined sewer issue was first addressed in two combined sewer management reports prepared by Anderson Nichols-Waterman Engineering and completed in 1977. One report addressed the 65 combined sewer outfalls in the city of



SOURCE: BETA ENGINEERING, INC., 1990

FIGURE 3. BVDC SERVICE AREA



SOURCE: BETA ENGINEERING, INC., 1990

FIGURE 4. BVDC COMBINED SEWER OVERFLOW SITES

Providence, and the second report addressed the 30 CSOs in Pawtucket and Central Falls.

The combined sewer report for the city of Providence recommended that the 65 CSOs be consolidated and treated at nine satellite treatment facilities. For planning purposes, the areas tributary to each facility were designated as CSO Areas 1 through 9. Detailed studies of Areas 2 and 9 were initiated prior to 1982. After formation of the Narragansett Bay Commission in 1982, the seven remaining CSO areas were consolidated into four study areas, designated A through D, which were based on drainage basins. Detailed studies of these areas have also been completed. The locations of the six NBC CSO study areas are shown in Figure 5. Reports on each individual CSO area are discussed below.

CSO Area 9. The CSO study in Area 9 was initiated in 1980 by Hayden-Castellucci and was completed in 1983. Area 9 consists of 23 flow regulators connecting to one overflow pipe, which runs parallel to the South Providence Interceptor for 3 1/2 miles and discharges to the Providence River. The study included data collection and analysis and evaluation of abatement alternatives. It was discovered that significant dry weather discharges were occurring at the site. The final report recommended that a diversion structure be constructed within the system to convey up to 14 MGD of dry and wet weather flow to the Field's Point Wastewater Treatment Facility (WWTF). The report also recommended construction of a treatment facility utilizing aerated grit chambers and a detention/contact basin to treat 75 MGD of additional wet weather flow. The NBC has elected to reevaluate the recommendation for a detention/contact basin. However, the diversion structure has been installed and is believed to have eliminated a significant source of pollution to the Providence River. In addition, a 3-foot weir has been installed in the interceptor downstream of the diversion structure to provide some in-line storage.

In the Area 9 project, approximate calculations based on field sampling results rather than mathematical models were used to estimate flows and loads. Current standard engineering practice involves use of a combination of field sampling and modeling to best estimate CSO flows and loads.

TABLE 4. ANNUAL LOADS AS A FUNCTION OF DRAINAGE AREA

	Pollutant Load(1) (lbs/acre combined area/yr)			
	Area A	Area C	Area D	Average
Combined Sewer Area (acres)	618	1,051	987	-
CSO Flow Volume (MG/acre/yr)	0.20	0.13	0.25	0.19
BOD_5	71	69	395	178
TSS	369	62	360	264
Fecal Coliform (MPN x 10^{13}/acre/yr)	0.75	0.44	10.06	3.75
Copper	0.29	0.08	0.30	0.22
Lead	0.24	0.05	0.25	0.18
Zinc	0.40	0.12	0.34	0.29
Phosphorus	3.68	1.40	3.03	2.70
NH_3	13.39	2.41	4.88	6.89
Nitrate	0.42	0.27	6.08	2.26

(1) Annual load from Table 3 divided by combined sewer drainage area.

A wet weather study completed by Wright (1990) included sampling of the Area 9 overflow during three storm events in 1988-89. The results indicated that the diversion and weir appear to be capturing a significant quantity of overflow. Wright concluded that the in-line storage capacity in the combined sewer appeared to be large and that pollutant loads from this outfall were insignificant in relation to WWTF, bypass, and tributary loads. CSO discharges in the other NBC study areas were not included in Wright's study.

CSO Area 2. The engineering study of CSO Area 2 was conducted by CE Maguire, Inc., and was completed in 1982. Area 2 encompasses the Lower Woonasquatucket River drainage basin. The system contains eighteen flow regulators that connect to fourteen outfall sites. Field surveys, flow monitoring, and sampling were conducted during the study. The final recommendations were for modifications to the flow regulators at the critical overflow sites to prevent clogging and eliminate dry weather discharges, modifications to provide for in-line storage at the largest overflow site, and structural repairs to the Pleasant Valley Parkway Interceptor. Construction of the recommended measures has been completed; and, according to NBC personnel, the system appears to be working as designed. In the 1982 report, it was predicted that an estimated 33 MG per year of overflow would still occur in the study area after implementation of the recommended abatement measures. This may be conservative since NBC personnel have stated that overflows rarely occur at the Area 2 sites since completion of the project.

CSO Area A. The Area A study, conducted by Metcalf & Eddy, Inc., was initiated in 1984 and completed in 1986. Area A is known as the Seekonk River Interceptor drainage basin. There are ten CSO outfalls in the study area, all of which discharge to the Seekonk River between Fox Point and Butler Hospital. Land use in the area is primarily residential and institutional.

The field program in Area A was conducted in 1984 and consisted of inspections of the sewer system and both dry and wet weather flow monitoring and sampling. Dry weather flow monitoring was conducted for a two-week period at six locations. Four locations were upstream of flow regulators at combined sewer outfall sites, and two locations were at the upstream and downstream ends of the interceptor. Sampling was conducted at each location hourly over 24 hours for seven days. Wet weather flow was monitored at the same six locations at 15 to 30 minute intervals during six storm events in October and November of 1984. The samples were analyzed for 5-day BOD, suspended solids, total and fecal coliform, ammonia-nitrogen, total Kjeldahl nitrogen, total phosphorus, and thirteen metals. Pollutant concentrations in the combined sewage were slightly lower than "typical" concentrations in CSOs for some parameters such as BOD and suspended solids.

Two computer models were used to estimate the combined sewage quantities discharged to the Seekonk River under various rainfall conditions. The Storm Water Management Model, or SWMM, was used to predict CSO flows and loads during single storm events, including the six monitored storm events and three synthetic rainfall events, or design storms, developed as part of this study. SWMM is the most widely used and accepted technique to estimate CSO flows and loads. It is a deterministic model which routes time varying rainfall-runoff as well as base sewage flows through the combined sewage collection system, and determines the quantity and quality of overflows to the receiving waters. As six storms were monitored at four CSO locations, there were a total of twenty-four flow hydrographs with which to calibrate the model. The best calibration was selected from the six storm events for each overflow subarea sampled. Calibration parameters were 1) combined sewer land area, 2) percent impervious area, 3) surface detention on impervious areas, and 4) percent of impervious area with zero detention. The SWMM-generated hydrographs generally fell within fifteen percent of the measured hydrographs before adjusting the calibration parameters. Discrepancies in flow verifications for intense rainfall events were believed to indicate that all runoff was not actually entering the combined collection system, while in the SWMM model it is assumed that it does. This was attributed primarily to clogged catch basins in the study area. This was verified by a dye test conducted during one storm event. Pollutant calibrations were conducted using the verified flow hydrographs. Model-generated pollutographs verified well with measured data. The total pollutant loads for the six monitored storm events were not presented in the final report. Total loads of BOD, suspended solids, and total coliform were presented for the three design storm events.

The simplified SWMM model (S/SWMM) was used to predict annual CSO discharges for typical average, wet, and dry rainfall years. At the time of this study, computers were not as advanced as at present, and a long-term simulation with the SWMM model was very cumbersome and expensive. The S/SWMM model uses gross subbasin characteristics and pollutant concentrations to calculate quantity and quality of flow and is therefore much faster than the SWMM model when modeling long rainfall sequences, although results may not be as accurate. With modern computers, the SWMM model can be used more efficiently to simulate runoff over long periods of time. No calibration was involved in the S/SWMM modeling. Input parameters developed and calibrated with the SWMM model were used along with yearly rainfall data in the S/SWMM model to simulate annual CSO loads of BOD_5, suspended solids, and total coliform. Annual loads were not simulated for metals or nutrients.

Following determination of pollutant loads from the combined sewer areas, modeling of the receiving waters was conducted to predict the impacts of CSOs and their various abatement alternatives on the Providence River and Upper Narragansett Bay during the design storm events. A model developed by Applied Science Associates was supplemented with a two-dimensional channel model to predict the fate of pollutants in the Seekonk and Providence Rivers. The ASA model is a hydrodynamic and pollutant transport model that was developed for the Upper Narragansett Bay in the early 1980s. The model was used during a 1983 study to demonstrate area-wide water quality benefits of CSO control (Metcalf & Eddy, 1983).

Water quality and tidal data was obtained from previous studies and from monitoring conducted on the Seekonk River. The model simulated the hydrodynamic conditions caused by the tides and fresh water inputs to the Seekonk including CSOs. The model also simulated dissolved oxygen (DO) and biochemical oxygen demand (BOD) concentrations and total coliform populations in the water.

In the Area A study, pollutant discharges to the Seekonk River included only the Area A CSO discharges and the BVDC WWTF discharges. Direct runoff, storm drains, upstream discharges in Pawtucket and Central Falls, and downstream discharges in the Providence River were not included because adequate data did not exist for use in the model. This approach tends to exaggerate the significance of CSO and BVDC treatment plant discharges in terms of water quality impacts. While the modeling is useful in comparing the effects of various treatment alternatives, it is less useful in determining the impacts of CSO abatement schemes on pollutant levels in the Providence River and Upper Bay.

CSO Area B. The CSO study for Area B, the Mosshasuck River Interceptor drainage basin, was completed in 1988 by O'Brien and Gere, Inc. There are sixteen active combined sewer overflows in the study area of which nine discharge to the Mosshasuck River, three to the West River (a tributary to the Mosshasuck), and four to the Providence River. The study area consists primarily of residential and commercial land uses.

Field data collection in Area B took place during 1986. Dry and wet weather flow monitoring was conducted at sixteen locations throughout the study area. Ten flow gages were installed in combined sewers near outfalls, five were installed in interceptors (three in the Mosshasuck River Interceptor and two in the Branch Avenue Interceptor), and one was installed in a separated storm sewer. Wet weather flow was monitored during five storm events which occurred between May and October, 1986, and which had total rainfalls varying from 0.44 to 1.95 inches. Samples were collected at seven of the monitoring stations - six combined sewer locations and the one separate sewer location - during the five storm events and were analyzed for BOD_5, suspended solids, total and fecal coliform, total Kjeldahl nitrogen, and total phosphorus. In addition, five grab samples were collected during the fifth storm event and were analyzed for metals and priority pollutants. It was determined that there were no significant contributions of these toxics from CSO discharges, and they were excluded from the data analysis.

As in the Area A study, the SWMM model was used to predict total pollutant loads from Area B CSOs during the wet weather events and the three design storm events which were developed in the Area A study. The report presented total CSO BOD_5 and fecal coliform loads for two monitored storm events and for the design storms. Loadings of these pollutants contributed by separate storm sewers in the study area, which comprise about 40 percent of the total land area, were also simulated. Loadings of suspended solids and nutrients were not simulated for the design storm events. Of the total loadings from both combined and separated sewer areas, it was estimated that combined sewers contribute approximately 60 percent of the BOD_5 load and greater than 99 percent of the fecal coliform load.

It was reported that the S/SWMM model was used to predict annual loads from CSO discharges in Area B. However, the loads were not presented in the final report. The S/SWMM results were obtained from NBC personnel and have been presented later in this report. It appears that flow volumes were simulated using S/SWMM, and then average concentrations of BOD_5, TSS, and total coliform that had been presented in the Area A CSO report were used to estimate annual CSO loads of these pollutants.

Applied Science Associates conducted the receiving water modeling, as was the case in the study of Area A. The ASA model was used to simulate the effects of CSO discharges to the West, Mosshasuck, and upper Providence Rivers during the design storm events and for various proposed abatement scenarios. Data from two dry and two wet weather surveys conducted on the receiving waters as part of the Area B field program was used to calibrate and verify the ASA model. Upstream pollutant discharges to the Mosshasuck River were not accounted for in the receiving water modeling. The predicted effects of CSO discharges on the receiving rivers are discussed later in this report.

CSO Area C. The Area C CSO study, which encompasses the Upper Woonasquatucket River Interceptor drainage basin, was completed by Camp Dresser and McKee, Inc., in 1989. Area C contains eleven flow regulators connecting to seven combined sewer overflow sites which discharge to the Woonasquatucket River. The major type of land use is residential.

Field data collection was performed from October 1986 through November 1987. Dry weather flow monitoring was conducted for two seven-day periods at fourteen locations in the study area. Seven of the gaging sites were in combined sewers, six were in the Woonasquatucket River Interceptor, and one was at a connection from the Johnston sewer system. Samples were collected at three of the combined sewer monitoring sites over one twenty-four hour period. The samples were analyzed for BOD_5, suspended solids, total and fecal coliform, ammonia, nitrate and nitrite, phosphorus, and six metals. Wet weather flow monitoring was conducted at three CSO outlets and at one storm drain during three storm events in 1987. Total rainfall during these events ranged from 0.54 to 1.12 inches. Samples collected at these locations were analyzed for the same parameters as the dry weather samples. Flow monitoring and sampling was also conducted at four sites in the Woonasquatucket River during the three storm events, with six samples collected during each event.

The computer models SWMM and STORM were used to predict CSO loads to the river under various rainfall conditions. The SWMM model was calibrated with data collected during the three storm events and was used to predict flow volumes for the individual storm events and design storms. The Storage Treatment Overflow Runoff Model (STORM) was used to simulate annual flow volumes and also to estimate both annual and design storm pollutant loads. STORM uses the modified rational method to simulate runoff volumes and requires hourly rainfall data, monthly evaporation rates, depression storages and runoff coefficients for each sub-basin. It is thus somewhat similar to S/SWMM, in that it involves a substantially simpler calculation effort than the SWMM model using gross sub-basin characteristics. Pollutant build-up and wash-off rates are the calibration parameters used in simulating pollutant loads. STORM was calibrated using both field data and calibrated SWMM results for the individual storm events before simulating annual flow volumes. CSO loadings of BOD, suspended solids, fecal coliform, nitrate, copper, and zinc were predicted for the three design storms. Annual loadings for these same constituents were also estimated for CSOs, dry weather overflows, separate storm drains, and direct runoff. Since only one storm drain was sampled during one storm event, the validity of the model predicted storm drain loads is questionable. It was discovered that the dry weather overflow loadings were caused primarily by a chronic blockage at one of the flow regulators, which has since been corrected.

Two receiving water models were used to predict the impacts of CSO discharges on the Woonasquatucket and Providence Rivers. The non-tidal portion of the Woonasquatucket River was modeled by Camp Dresser & McKee using the Receiving Water Quality Model (RWQM). The model uses hourly pollutant flows and loads from CSOs generated by the STORM model and routes these loads through the receiving water, providing time histories of how pollutant concentrations in the river change over time and distance as a result of the CSO loadings. The tidal portion of the Woonasquatucket River (downstream of the Rising Sun Dam), along with the Providence River and upper bay, were modeled by ASA using the hydrodynamic and pollutant transport model that was used in the Area A and B studies.

CSO Area D. The draft final report for the remaining NBC study area was submitted by Greeley and Hansen in August 1990. Area D encompasses the Allen's Avenue Interceptor drainage basin. This is the interceptor immediately upstream of the Field's Point WWTF. There are fourteen outfall locations in the study area of which ten were determined to be active combined sewer overflows. Nine of these discharge to the Providence River and one to the Woonasquatucket River. Unlike the other CSO study areas, the major land use in Area D is industrial.

Field investigations took place in 1989. Flow monitors were installed at seven combined sewer locations, five interceptor locations, and at one storm sewer outfall. Flow monitoring was conducted between March and November of 1989 during dry and wet weather. Dry weather samples were collected at three CSO sites over one 24-hour period. Wet weather sampling was performed at four of the CSO monitoring stations and at the storm sewer station during three storm events with total rainfalls varying from 0.44 to 1.35 inches. Both dry and wet weather samples were analyzed for BOD, solids, fecal coliform, nitrate and nitrite, chloride, phosphorus, cadmium, copper, and lead. Grab samples collected during one storm event were analyzed for some additional metals.

The SWMM model was calibrated and verified with field data measured during three storm events and was used to predict pollutant loadings from the CSOs for the three design storms and also to simulate annual loadings. Rainfall data for the design storms and the average wet and dry years was the same data used in the studies of Areas A, B, and C. Output hydrographs verified well with the measured field data. The design storm and average annual loadings were presented for BOD_5, suspended solids, and fecal coliform in the draft report. As in the previous studies, these loadings were used as base conditions with which to compare the various abatement alternatives.

Receiving water modeling was again conducted using the ASA hydrodynamic and pollutant transport model. The model incorporated inputs from tributaries and other point sources into the Providence River. The river-based sampling program for this effort included sampling and flow monitoring near the mouths of the Blackstone, Moshassuck, Pawtuxet, Ten Mile, and Woonasquatucket Rivers; of the Field's Point, East Providence, and BVDC WWTFs; of two WWTF bypasses; at the CSO Area 9 outfall; and at eight stations in the Providence River. Loadings from each of these point sources were input into the model when simulating impacts of the design storm events on the river and upper bay. Impacts of CSO reductions in all of the study areas on the area receiving waters are discussed in the CSO priorities section of this report.

BVDC CSO's. The thirty CSOs located in Pawtucket and Central Falls were addressed in a 1977 Combined Sewer Management Report by Anderson Nichols - Waterman Engineering, and a Step One Facilities Plan for the two cities was completed in 1980. The recommended plan was to treat the CSOs at six flow-through treatment sites via screening, sedimentation, and disinfection. As the BVDC has recently acquired responsibility for these CSOs, it is expected that these recommendations will be reevaluated through a new facilities planning process.

CHARACTERIZATION OF CSO FLOWS AND LOADS

All of the aforementioned studies involved quantification of CSO flows and pollutant loads which are summarized in this section. CSO flows and loads are presented for three separate conditions: wet weather event loads, design storm loads, and average annual loads.

CSO Wet Weather Event Loads

Wet weather monitoring programs were conducted during the CSO area studies in order to characterize pollutant loadings and collection system behavior during storm events. In addition, the data was used to calibrate computer models used to predict design storm and annual loads. Pollutant loads for the storm events monitored are presented in Table 1 for CSO Areas B and C. In these studies, the EPA Storm Water Management Model (SWMM) was calibrated and verified with measured flow and rainfall data and then used to determine CSO flow volumes for the individual rainfall events. Then statistical pollutant concentrations were developed using measured data and were applied to the SWMM output to determine pollutant loadings for the storm events. In the Area C study, pollutant concentrations were input into the STORM Model to predict the storm event pollutant loadings from CSO's, based on the SWMM-generated flow volumes. In addition, storm event loads from CSO Area 9 measured in the recent Wet Weather Study (Wright, 1990) are presented. Computer models were not used to generate the Area 9 storm event loads. Sufficient field data was collected to allow reliable predictions to be made by integration of measured pollutant loadings over time. Wet weather event loads were not presented in reports on the other CSO study areas.

CSO Design Storm Loads

The CSO studies of Areas A, B, C, and D included derivation of synthetic storm events that statistically represent rainfall events of selected frequencies in Providence. These synthetic storm events were then simulated using the SWMM model to determine the flow volumes from combined sewer overflows for storms of varying frequency and intensity.

Three synthetic storms, or design storms, were developed with recurrence intervals of 3 months, 6 months, and 12 months. The design storm characteristics are:

TABLE 1. CSO FLOWS AND LOADS DURING WET WEATHER SURVEYS

Study Area	Storm Date	Storm Characteristics: Peak Intensity (in/hr)	Storm Characteristics: Duration (hrs)	Storm Characteristics: Total Rainfall (in)	Flow Volume (MG)	BOD_5 lbs	TSS lbs	FC MPNx10^{13}	NH_3 lbs	NO_3 lbs	PO_4 lbs	Cd lbs	Cr lbs	Cu lbs	Pb lbs	Ni lbs	Zn lbs
9(1)	10-22-88	0.19	11	0.90	3.27	-	12,254	26.4	10	27	12	0.05	0.7	4.7	4.0	2.0	-
9	5-10-89	0.15	32	2.24	3.82	-	1,619	8.92	124	43	114	0.04	0.6	1.8	2.2	1.1	-
9	6-13-89	0.11	8	0.42	0.48	-	381	1.78	54	9	20	0.01	0.1	0.5	0.2	1.3	-
B(2)	7-2-86	0.35	10	1.95	22.0	6,742	-	980	-	-	-	-	-	-	-	-	-
	9-16-86	0.28	2	0.44	6.5	2,521	-	330	-	-	-	-	-	-	-	-	-
C(3)	4-28-87	0.21	8	0.81	3.0	1,956	1,704	11.0	-	6.5	-	-	-	0.8	-	-	2.1
	8-27-87	0.12	13	0.54	0.5	475	409	1.7	-	1.1	-	-	-	0.2	-	-	0.5
	10-28-87	0.38	6	1.12	3.6	2,983	2,767	13.0	-	7.8	-	-	-	1.8	-	-	4.5

1. Wright, 1990
2. O'Brien and Gere, 1988
3. Camp Dresser & McKee, 1989

Recurrence Interval	Total Rainfall (in.)	Peak Intensity (in/hr)	Duration (hr)
3 mo.	1.61	0.60	6
6 mo.	2.24	0.77	6
12 mo.	2.46	0.91	6

The predicted mass loadings of BOD_5, total suspended solids (TSS), fecal coliform, and some metals and nutrients are presented in Table 2. In the Area A study, design storm loads were developed for BOD_5, TSS, and total coliform. Since fecal coliform is currently the more widely-used pathogen indicator, design storm loads have been estimated using an average geometric mean concentration of fecal coliform from the sampling program conducted during the Area A study. This concentration was applied to the SWMM-predicted overflow volumes for each design storm. This same approach was used to estimate metals and nutrient loads from Area A. In each case, an arithmetic mean concentration was computed from the summary of wet weather sampling results presented in the CSO report (Metcalf & Eddy, 1986) and was applied to the flow volume. Since the Area A sampling program did not include analysis for nitrate, an arithmetic mean concentration from the Area C sampling program was used as a rough estimate.

The Area B design storm loads of BOD_5 and fecal coliform shown in Table 2 are the SWMM-modeled results from the CSO study (O'Brien and Gere, 1988). Metals were not analyzed in the Area B sampling program, and mean concentrations of TSS and nutrients were not presented in the Area B report. Therefore, arithmetic mean concentrations of solids, metals, and nutrients measured in the Area C sampling program were used to make approximations of these loads in Area B. Area C concentrations were chosen rather than those from Areas A or D because land use in Area C more closely resembles that in Area B.

All of the design storm loads shown from Area C were estimated during the CSO study by Camp Dresser and McKee, with the exception of lead, ammonia, and nitrate loads. These have been estimated using arithmetic mean concentrations from the Area C sampling program along with the model-predicted flow volumes.

TABLE 2. CSO DESIGN STORM POLLUTANT LOADS

Study Area	Design Storm	Total Volume (MG)	BOD_5 (lb)	TSS (lb)	Fecal Coliform (MPN X 10^{13})	Copper (lb)	Lead (lb)	Zinc (lb)	Total Phosphorus (lb)	NH_3 (lb)	Nitrate (lb)
A(1)											
	3 mo.	6.4	1,235	9,559	23.96	9.24	7.58	12.71	116.92	424.97	13.35
	6 mo.	8.6	1,420	11,525	32.19	12.41	10.19	17.07	157.11	571.06	17.94
	12 mo.	10.8	1,567	13,045	40.43	15.59	12.79	21.44	197.30	717.14	22.52
B(2)											
	3 mo.	15.9	4,785	11,619	720	10.61	6.63	25.20	177.73	305.07	33.16
	6 mo.	23.2	6,630	16,954	980	15.48	9.68	36.77	259.34	445.13	48.38
	12 mo.	27.8	8,206	20,315	1,240	18.55	11.60	44.06	310.76	533.39	57.98
C(3)											
	3 mo.	8.74	3,879	3,536	31	1.58	3.65	4.20	97.70	167.69	18.86
	6 mo.	12.65	4,711	4,301	45	2.08	5.28	5.41	141.40	242.71	27.30
	12 mo.	16.61	4,992	4,523	59	2.22	6.93	5.64	185.67	318.69	35.82
D(4)											
	3 mo.	16.53	25,959	23,227	648	22.54	16.55	22.06	197.19	317.15	395.75
	6 mo.	23.96	37,662	33,697	947	27.98	23.98	31.98	285.82	459.71	573.64
	12 mo.	33.23	51,990	46,576	1,463	38.81	33.26	44.35	396.40	637.57	795.58

1. BOD and TSS loads from Metcalf & Eddy, 1986. Fecal coliform (FC), metals, phosphorus, and NH_3 loads have been estimate using CSO volumes as shown and average CSO concentrations from Metcalf & Eddy, 1986 sampling program. Nitrate loads ar based on average concentration from Area C sampling program (Camp Dresser and McKee, 1989).
2. BOD and FC loads from O'Brien and Gere, 1988. TSS, metals, and nutrient loads have been estimated using CSO volumes as shown and average CSO concentrations from Area C sampling program (Camp Dresser and McKee, 1989).
3. All loads from Camp Dresser & McKee, 1989; except for lead, phosphorus, and NH_3 loads which have been estimated using C volumes as shown and average concentrations from Camp Dresser & McKee, 1989 sampling program.
4. BOD, TSS, and FC loads from Greeley and Hansen, 1990. Metals, phosphorus, and nitrate loads have been estimated using CSO volumes as shown and average CSO concentrations from Greeley and Hansen, 1990 sampling program. Nitrate loads are for nitrate plus nitrite. NH_3 loads are based on average concentration from Area C sampling program (Camp Dresser and McKee, 1989).

The Area D CSO study modeled design storm loads of BOD_5, TSS, and fecal coliform. Metals and nutrients loads for Area D are again based on mean concentrations reported from the sampling program in that area. A complete summary of sampling results from Area D was not yet available, so that log means of the maximum and minimum concentrations as reported in the draft CSO report (Greeley and Hansen, 1990) were used rather than arithmetic means of the complete data set.

Average Annual CSO Loads

As part of the Area A study, a statistical analysis of rainfall data over a 34 year period was conducted to obtain characteristic wet, dry, and average rainfall years for the study area. The rainfall data for each year was then input into the S/SWMM computer model to predict annual CSO volumes. The same rainfall data was used to estimate annual loads for the Areas B, C, and D studies, although the STORM and SWMM models were used in Areas C and D rather than S/SWMM. Table 3 summarizes these results for the average (1951), wet (1953), and dry (1981) years. The Area D report presented annual loads for the average rainfall year only.

The same approach was used in deriving the loads shown in Table 3 for Areas A through D as was used for the design storm loads in Table 2. Modeled results for flows, BOD_5 and TSS loads in each area, and fecal coliform loads in Areas C and D are presented. Other annual loads have been approximated using mean concentrations and model-predicted flows. Mean pollutant concentrations in Area C were again used to approximate coliform, metals, and nutrient loadings in Area B. As previously stated, annual BOD_5 and TSS loadings were not presented in the Area B CSO report but were obtained from NBC.

Annual BOD and TSS loads have also been estimated for Areas 2 and 9 and the BVDC CSOs and are included in Table 3. In the Area 2 study by CE Maguire, annual loads were predicted for the various alternative treatment schemes evaluated in the study. The chosen alternative, which involved modifications to the flow regulators at each overflow site and in-line storage at site no. 045, has since been implemented. This has eliminated the dry weather

TABLE 3. ANNUAL CSO FLOWS AND LOADS

CSO Study Area	Year	Total Rainfall (in)	Flow (MG)	BOD_5 (lbs)	TSS (lbs)	Fecal Coliform (MPN x 10^{13})	Copper (lbs)	Lead (lbs)	Zinc (lbs)	Total Phosphorus (lbs)	NH_3 (lbs)	Nitrate (lbs)
A(1)	Wet	54.88	156.9	55,000	287,000	587	226	186	312	2,866	10,418	327
	Dry	36.37	77.2	27,000	141,000	289	111	91	153	1,410	5,126	161
	Average	45.60	124.6	44,000	228,000	466	180	148	247	2,276	8,274	260
B(2)	Wet	54.88	192.7	67,500	352,000	1167	129	80	305	2,154	3,697	402
	Dry	36.37	83.7	29,300	153,000	507	56	35	133	936	1,606	175
	Average	45.60	139.9	49,000	256,000	847	93	58	222	1,564	2,684	292
C(3)	Wet	54.88	--	78,000	67,000	636	85	--	130	--	--	385
	Dry	36.37	--	45,000	40,000	236	55	--	90	--	--	145
	Average	45.60	131.9	73,000	65,000	467	80	55	130	1,474	2,531	285
D(4)	Average	45.60	250.8	389,800	355,800	9,930	293	251	335	2,992	4,812	6,004
2(5)	--	--	33.0	20,700	24,100	200	22	14	52	369	633	69
9(6)	--	--	97.0	60,800	182,600	475	90	82	154	1,870	2,408	1,012
BVDC(7)	--	--	816.0	764,700	1,134,100	16,100	945	773	1,246	11,600	29,600	9,700

1. BOD and TSS loads from Metcalf & Eddy, 1986. Fecal coliform (FC), metals, phosphorus, and NH_3 loads have been estimated using volumes shown and average concentrations from Metcalf & Eddy, 1986 sampling program. Nitrate loads are based on average concentration from Area C sampling program (Camp Dresser & McKee, 1989).
2. BOD and TSS loads from O'Brien and Gere, 1988 (not included in Final Report). FC, metals and nutrient loads have been estimated using volumes shown and average concentrations from Area C sampling program (Camp Dresser & McKee, 1989).
3. All loads from Camp Dresser & McKee, 1989; except for lead, phosphorus, and NH_3 loads which have been estimated using average concentrations from Camp Dresser & McKee, 1989 sampling program.
4. BOD, TSS, and FC loads from Greeley and Hansen, 1990. Metals, phosphorus, and nitrate loads have been estimated using average concentrations from Greeley and Hansen, 1990 sampling program. NH_3 load is based on average concentration from Area C sampling program (Camp Dresser & McKee, 1989). Nitrate load is for nitrate plus nitrite.
5. Flow volume from CE Maguire, 1983. All loads have been estimated using volume shown and average concentrations from Area C sampling program (Camp Dresser & McKee, 1989).
6. Annual flow and loads projected from total load during 3 wet weather events (from Wright, 1990; See Table 1), except for BOD and zinc loads, which are estimated from volume shown and average concentrations from Area C sampling program (Camp Dresser & McKee, 1989).
7. Annual flow and loads estimated by multiplying acres of combined sewer area by the average of loadings per acre from Areas A, C and D (See Table 4).

overflow problem and has reduced the wet weather overflow volume; however, the study estimated that 33 MG per year would still overflow from the combined sewers in this area during in average rainfall year. This estimated volume was used along with average pollutant concentrations measured during the Area C study to approximate current loadings from Area 2. However, this may be conservative since personnel at NBC have reported that overflows in this area are rare since completion of the system modifications.

Estimates of annual loadings from CSO Area 9 have been projected from data reported in the recent Wet Weather Study (Wright, 1990). The Area 9 overflow was monitored during three storm events in 1988-89. Total pollutant loads from these three events were multiplied by a ratio of total average annual rainfall (45.60 inches) over the total rainfall during the three storm events (3.56 inches) to provide an approximation of annual loads. Since BOD_5 and zinc were not analyzed in the Wet Weather Study, mean concentrations from the Area C study were applied to the overflow volume of 97 MG which was projected from the three wet weather events to estimate annual loads for these pollutants.

An estimate of annual loadings from the BVDC CSOs in Pawtucket and Central Falls is also presented in Table 3. Estimated pollutant loads and overflow volumes from three of the other study areas (A,C, and D) were computed on a per acre of combined sewer area basis. These loads are shown in Table 4. An average of the three was taken and multiplied by the number of combined sewer acres in Pawtucket and Central Falls to provide an approximation of annual loads from the BVDC CSO's. As seen in Table 4, there was a wide range in loadings per acre between the three study areas. In general, mean BOD_5 and fecal coliform concentrations were higher in Area D than in the other two areas, mean concentrations of suspended solids and metals in Area C were lower than those in the other areas, and mean concentrations of ammonia and nitrate were particularly high in Areas A and D, respectively. These variations in concentrations are evident in Table 4. In addition, CSO volumes are a function of not only combined sewer acreage but of the sewer system design and degree of maintenance. Therefore, these must be considered very rough approximations of the BVDC CSO loadings.

TABLE 4. ANNUAL LOADS AS A FUNCTION OF DRAINAGE AREA

	Pollutant Load[(1)] (lbs/acre combined area/yr)			
	Area A	Area C	Area D	Average
Combined Sewer Area (acres)	618	1,051	987	-
CSO Flow Volume (MG/acre/yr)	0.20	0.13	0.25	0.19
BOD_5	71	69	395	178
TSS	369	62	360	264
Fecal Coliform (MPN x 10^{13}/acre/yr)	0.75	0.44	10.06	3.75
Copper	0.29	0.08	0.30	0.22
Lead	0.24	0.05	0.25	0.18
Zinc	0.40	0.12	0.34	0.29
Phosphorus	3.68	1.40	3.03	2.70
NH_3	13.39	2.41	4.88	6.89
Nitrate	0.42	0.27	6.08	2.26

(1) Annual load from Table 3 divided by combined sewer drainage area.

A CSO modeling study is being initiated by the BVDC for the overflows in Pawtucket and Central Falls, and flow monitoring and modeling of Areas 2 and 9 will be included in a systemwide study of the entire NBC sewer system which is currently underway. Therefore, more accurate predictions of CSO inputs from these three study areas should be available in the near future.

Discussion of CSO Modeling Results

The procedures followed in combined sewer modeling in Areas A through D were well established and accepted and were based on sufficient field measurements to support the validity of the methods. Due to the continued increase in speed and power of computers, the current state-of-the-art allows long term modeling of CSO flows and loads using SWMM (thus avoiding the need for the simplified models such as S/SWMM and STORM).

Modeled loadings of BOD_5 and fecal coliform in Area D appear disproportionately large when compared to those from the other modeled areas. This is partially due to pollutant concentrations in the area. The mean BOD concentration in Area D was two to four times larger than that in Area C or A, and the log mean fecal coliform concentration was three to five times higher than that in the same two areas. Also, the mean concentration of nitrate plus nitrite in Area D was about 2.9 mg/l, which when used produced an annual estimate of 6,000 pounds. The mean nitrate concentration of 0.25 mg/l from Area C was used to estimate annual nitrate loads in the other modeled areas. The larger size and thus annual flow in Area D also accounts somewhat for the range in estimated loadings. The fact that S/SWMM was used to model annual loads in Areas A and B, STORM in Area C, and SWMM in Area D may also account in part for variations in BOD and coliform loads. Despite this, the modeling results appear to be reasonable estimates which should serve the purposes of aiding in selection of priority areas and of comparing CSO pollutant inputs to those from other point or nonpoint sources.

Land Use Characteristics

A breakdown of land use characteristics of the CSO study areas is presented in Table 5. A comparison of this data with pollutant loads from the various study areas does not reveal any definite trends regarding the relationship between land use patterns and CSO loads. With the exception of Area D, the largest land use category in each of the study areas is residential, which comprises about 70 percent of Areas A and C and about 51 percent of Pawtucket and Central Falls. Industrial zones are the smallest land use category in these areas, comprising 12 percent of the land in Pawtucket and Central Falls, 9 percent in Area C, and only 1 percent in Area A. In contrast, industrial zones make up 40 percent of the total study area in Area D, making this the major land use type in this area. Land uses in Area B are presented only for the combined sewer portion of the study area.

In attempting to draw conclusions on the effect of land uses on CSO loads, one must examine pollutant concentrations in the CSOs as opposed to the actual loads. Area D is the only study area which varies significantly in land use distribution from the other areas. It is possible that the higher mean concentration of BOD_5 in Area D could be partly related to the larger percentage of industrial land use. This is less likely in the case of fecal coliform.

During the wet weather study (Wright, 1990), an attempt was made to forecast annual pollutant loadings from five different watersheds based on three measured storm events. Separate relationships could not be derived for the watersheds using the three storm event data base. This confirms that substantial additional data would be required to start to develop a clear relationship between land use and water quality. The need for such data is questionable, given that a model of the entire system is being prepared.

TABLE 5. LAND USE CHARACTERISTICS

CSO Study Area	Total Area (acres)	Land Use(1) Residential (acres)	Residential (%)	Commercial (2) (acres)	Commercial (2) (%)	Industrial (acres)	Industrial (%)	Other(3) (acres)	Other(3) (%)	Type of Drainage System Combined (acres)	Combined (%)	Separate (acres)	Separate (%)	Unsewered (acres)	Unsewered (%)
A	1,385	971	70	239	17	14	1	161	12	618	45	767	55	0	0
B	2,600	860	65	188	14	160	12	115	9	1,323	51	1,080	41	197	8
C	1,681	1,190	71	167	10	148	9	176	10	1,051	63	388	23	242	14
D	1,406	386	27	282	20	576	41	162	12	987	70	169	12	250	18
2	1,711	-	-	-	-	-	-	-	-	500	29	1,211	71	0	0
9	2,050	-	-	-	-	-	-	-	-	1,305	64	-	-	-	-
Pawtucket	5,704	2,927	51	1,203	21	661	12	913	16	3,500	61	-	-	-	-
Central Falls	834	426	51	178	21	102	12	128	16	796	95	-	-	-	-

1. With the exception of Study Area B, land use characteristics shown are for the entire study area. In Area B, land uses and percentages shown are for the combined sewer area only.
2. Commercial area includes public and institutional.
3. Other area includes open space.

In general, it has been diff cult to derive distinct relationships between land use and water quality. For example, in EPA's Nationwide Urban Runoff Program Study (EPA, 1983), which was based on stormwater sampling from twenty-eight urban areas around the country, it was concluded that:

> "As a result of extensive examination ... geographic locations, land use category, or other factors ... appear to be of little utility in consistently explaining ... variability in urban runoff..."

The above applies to stormwater runoff. The sewage portion of combined sewage may have some relation to the type of land use (i.e. residential vs. commercial), however extensive sampling in various points of the system would be needed to define this.

COMPARISON OF CSO POLLUTANT LOADS WITH OTHER SOURCES

Estimates of annual pollutant loads to the Providence River and upper Narragansett Bay from sources other than CSOs have been derived from the various literature available and are summarized in this section for comparison with CSO loadings. Other sources of pollutants include wastewater treatment facilities (WWTFs), WWTF bypasses, tributaries, industrial discharges, and stormwater runoff via separate storm sewers and direct runoff.

Estimated annual WWTF effluent loads are presented for the NBC Field's Point facility and the BVDC Bucklin Point facility. These loads were derived from treatment plant records for the year 1988 and are based on total monthly flows through the facility and average monthly pollutant concentrations in the secondary treatment effluent. Loadings of some pollutants are also presented for the Cranston and East Providence facilities. The Field's Point, BVDC, and Cranston facilities are the three largest, on a wastewater flow basis, discharging into the Upper Bay or its tributaries. The Field's Point and BVDC WWTF's combined discharge over 60 percent of the total flow from municipal WWTF's discharging to the Narragansett Bay. Other facilities in the area generally treat flows of less than 10 MGD.

Annual secondary bypass loads from the Field's Point and BVDC treatment facilities have also been derived from treatment plant records. These bypass flows receive primary treatment and disinfection but do not undergo any secondary treatment. Estimated loads are based on recorded bypass flows and average monthly pollutant concentrations in the primary effluent. In addition, annual bypass loads from the BVDC facility's North Diversion Structure have been computed. These are flows which bypass the entire treatment facility when hydraulic capacity is exceeded, which reportedly occurs during all storm events of any significance. The loads are based on recorded bypass flows and average monthly concentrations recorded in the raw influent.

Tributaries are also a source of pollutants to the Providence River and the Upper Bay. The Seekonk, Moshassuck, Woonasquatucket, and Pawtuxet Rivers discharge pollutant loads to the Providence River, which receives additional loads from other sources before flowing into the Upper Narragansett Bay. Unless stated otherwise, the annual tributary loads presented in this report have been estimated using average discharges from USGS flow monitoring stations along with pollutant concentrations from selected studies. Average discharge for the Seekonk River was estimated as the sum of discharges measured at USGS stations on the Blackstone and Ten Mile rivers. These predicted loads serve only as rough estimates, as river concentrations can vary significantly under wet and dry weather conditions and various base flows. In most cases, only short-term river sampling data was available. Supplementing these rough estimates are predicted annual wet weather loadings from the Wet Weather Study (Wright, 1990). These annual loads are based on statistical relationships from intensive monitoring of three storm events, projected for a full year. These loads do not include dry weather base flows and loads, and do include the effects of CSOs, bypasses, and other sources entering each tributary. Thus, they serve only as another rough check on magnitude of tributary loads.

Caution must be used when comparing tributary loads with those from CSO Areas A, B, C, 2, or the BVDC CSO's, as these CSOs discharge into the tributaries themselves and therefore contribute to the total tributary load. Likewise, the BVDC WWTF loads contribute to the total Seekonk River loads. The Seekonk, Moshassuck, Woonasquatucket, and Pawtuxet Rivers, the Field's Point WWTF, and CSO Areas 9 and D all contribute to the total loads in the Providence River. It is important to keep this concept in mind when comparing pollutant loadings from the various sources.

Estimates of pollutant loadings from separate storm sewers in Providence have been made based on typical pollutant concentrations in urban runoff, as reported in the EPA's Final Report on the Nationwide Urban Runoff Program, and on an estimated volume of 1390 MG of stormwater annually from Providence storm drains (Martin and Robadue, 1983). These resulting loadings are presented in Table 6.

Limited data was available on industrial discharges during preparation of this report. However, it is assumed that pollutant loads from the majority of industries in the watershed are included in either the tributary loads or WWTF loads presented herein.

The estimated annual loads from all of the various sources are presented in the following tables according to each particular pollutant evaluated: fecal coliform bacteria, metals, BOD, TSS, nutrients, and organics.

Fecal Coliform Bacteria

Fecal coliform bacteria are not of themselves a health hazard. They are used as indicators of pathogenic organisms which are associated with untreated human and animal wastes and which do present a health hazard. These bacteria are a major pollution problem in the Providence, Seekonk, Moshassuck, Woonasquatucket, and Pawtuxet rivers. High fecal coliform concentrations have caused the Providence and Seekonk rivers to be permanently closed to shellfish harvesting and swimming.

TABLE 6. ESTIMATED LOADS FROM SEPARATED SEWERS IN PROVIDENCE

Parameter	Concentration[1] (mg/l)	Annual Load[2] (lbs)
BOD_5	9	104,360
TSS	84	974,010
Fecal Coliform[3]	1.1×10^4	57.9×10^{13}
Copper	0.030	350
Lead	0.087	1,010
Zinc	0.180	2,090
Phosphorus	1.165	13,510
Nitrate	0.695	8,060

1. Average of maximum and minimum concentrations reported by USEPA (1983) in stormwater.
2. Based on total flow volume from City of Providence separate storm drains of 1390 MG per year (Martin and Robadue, 1983).
3. Concentration in MPN/100 ml; load in MPN.

Sources of fecal coliform in the Providence River and its tributaries are presented in Table 7 along with the estimated annual load from each. CSOs and WWTF bypasses represent the major sources of fecal coliform. The largest single contributor is the BVDC facility's secondary bypass, followed by the facility's North Diversion Structure bypass. The combined BVDC CSOs represent the largest area-wide source.

Fecal coliform bacteria are not routinely monitored in treatment plant bypass flows. Therefore, in estimating loads from the North Diversion Structure, a fecal coliform concentration of 10^6/100 ml was assumed in the raw influent, based on wet weather sampling conducted in a 1985 study (Tutela Engineering, 1985). A review of monthly monitoring records from the BVDC plant revealed that concentrations of pollutants such as BOD and TSS in the primary effluent are only slightly lower, if at all, than concentrations in the raw influent, and in many cases were higher. This has been caused by the unsatisfactory performance of the primary settling tanks due to hydraulic deficiencies since the addition of the secondary treatment facilities in the 1970's. Therefore, the fecal coliform concentration of 10^6/100 ml which was used in estimating loads from the North Diversion Structure was also assumed in estimation of secondary bypass loads. This concentration is also consistent with data presented in Wright (1990). BVDC is in the process of completing a construction program initiated in the early 1980's to upgrade the treatment facility.

In estimating the secondary bypass load from the Field's Point WWTF, a fecal coliform concentration of 10^5/100 ml was assumed in the primary effluent. This has been cited in literature as a typical concentration found in wastewater that has undergone primary treatment (Metcalf & Eddy, 1983).

The Field's Point WWTF is currently under construction which involves upgrading four primary treatment clarifiers. This project is expected to be completed in the spring of 1991, at which time up to 123 MGD of wet weather flow will receive full primary treatment and disinfection. Annual effluent

TABLE 7. ANNUAL FECAL COLIFORM BACTERIA LOADS TO THE PROVIDENCE RIVER AND VICINITY

Source	Annual Load (MPN x 10^{13})	Date Source
CSOs		
CSO Area A	466	See Table 3
CSO Area B	847	See Table 3
CSO Area C	467	See Table 3
CSO Area D	9,930	See Table 3
CSO Area 2	200	See Table 3
CSO Area 9	475	See Table 3
BVDC	16,100	See Table 3
WWTFs		
Field's Point	1.4	Monthly records for 1988
BVDC	2.7	Monthly records for 1988
East Providence	0.01	Roman, 1989
Cranston	0.18	RIDEM, 1990
WWTF Bypasses		
Fields Point Secondary Bypass	80	Monthly records for 1988
BVDC Secondary Bypass	1,010	Monthly records for 1988(1)
BVDC North Diversion Bypass	760	Monthly records for 1988
Rivers		
Blackstone	263	Cabelli, 1989 and Hoffman, 1988
	3,600	Oviatt, 1981
Moshassuck	66	(2)
Woonasquatucket	190	(3)
Pawtuxet	17	Cabelli, 1989 and Hoffman, 1988
	180	Oviatt, 1981
	71	(4)
Seekonk	273	(5)
Storm Drains		
Total Providence	57.9	See Table 6
Direct Runoff		
CSO Area C	.009	Camp Dresser and McKee, 1989

(1) Based on 10 months of recorded bypass flows.
(2) Estimated from USGS flow gage records and an average concentration from O'Brien and Gere (1988) river sampling.
(3) Estimated from USGS flow gage records and an average concentration from Camp Dresser and McKee (1989) river sampling.
(4) Estimated from USGS flow and water quality records at Cranston gage station.
(5) Estimated from USGS flow records and Metcalf & Eddy (1986) river sampling.

loads of fecal coliform from the WWTFs are basically insignificant when compared to bypass and CSO loads. Treatment plant effluent is not typically a significant source of fecal coliform bacteria when the effluent has been properly treated and disinfected.

Mean concentrations of fecal coliform in the CSOs ranged from 9.9×10^5 in Area A to 4.4×10^6 MPN/100 ml in Area D. The combined loading from all of the NBC CSO areas is only slightly less than that of the BVDC CSOs. Considering that the estimated load from the BVDC CSOs was a rough approximation, it may be assumed that CSO loadings of fecal coliform from the two jurisdictions are approximately equal, and that the two are the major contributions of fecal coliform to the Providence River and its tributaries.

The coliform loads shown for the Moshassuck, Woonasquatucket, and Seekonk rivers must be considered crude estimates at best, as there is a wide variation in concentrations measured in these rivers. This is typically the case, since coliform bacteria have a die-off rate measured in hours. Thus, they can be present in very large quantities for a short period of time and then decrease rapidly. However, rough "average" concentrations of 1800, 2890, 230 and 340 per 100ml were used to estimate annual loads from the Moshassuck, Woonasquatucket, Pawtuxet, and Seekonk rivers, respectively. Based on these rough estimates, the Blackstone/Seekonk River would be the largest tributary load. The average flow rate of this river is much greater than that of the other tributaries. The Pawtucket-Central Falls CSOs, which discharge into the Blackstone River upstream, the BVDC bypass loads, and the Area A CSO loads all contribute to the fecal coliform problem in the Seekonk River.

Although data on coliform loads from separate storm sewers and direct runoff is limited, the estimates shown here indicate that the two sources are far less significant when compared to coliform loadings from CSOs.

Metals

Concentrations of certain metals in the Providence River, including copper, zinc, and nickel, have been found to exceed EPA guidelines in the past, and elevated levels of cadmium, chromium, and lead have also been reported. High metals concentrations have been recorded near the Field's Point WWTF outfall.

Table 8 summarizes estimated annual loads of metals to the Providence River from the various sources. Metals loads from the BVDC WWTF have been estimated based on mean concentrations measured in the effluent during the 1986-87 SPRAY cruises (Doering, et al., 1988) and have been compared with predictions from an earlier study by Oviatt. Flow-weighted average concentrations measured at two of the bypasses during the recent Wet Weather Study (Wright, 1990) were used with recorded bypass flows during 1988 to estimate bypass loads. During 1988, approximately 218 MG of primary effluent were discharged from the Field's Point secondary bypass, and 202 MG of untreated combined sewage were discharged at the BVDC North Diversion Structure bypass.

The WWTFs and the Blackstone/Seekonk and Pawtuxet Rivers appear to be major sources of metals discharges. In particular, the Field's Point treatment plant has been noted in previous studies as being a major source of chromium, copper, nickel, and zinc (Olsen and Lee, 1979). The BVDC WWTF also contributes significant loads of metals to the Seekonk River.

Data indicate the Blackstone/Seekonk River as a major contributor of loadings of cadmium, copper, lead, and zinc to the Providence River. It is difficult to determine what the primary sources of metals in the Blackstone/Seekonk River are from the data available. Obviously, the BVDC treatment plant accounts for a portion. The combined CSO loads to the Seekonk River from Area A and from the BVDC CSOs upstream in the Blackstone River together are a significant loading although not as large as that from the WWTF. Data also indicate the Pawtuxet River as a significant contributor of copper, lead and zinc. The Cranston WWTF, plus the smaller WWTFs in Warwick and West Warwick, discharge metals loadings to the Pawtuxet River. There are no combined sewer overflows to the Pawtuxet River.

According to the estimates shown here, contributions of lead and zinc from separated storm drains in Providence are almost as large as those from all of the NBC and BVDC CSOs. An earlier study also suggested that storm runoff is

TABLE 8. ANNUAL METAL LOADS TO THE PROVIDENCE RIVER AND VICINITY

Source	Annual Load (lb)						Data Source
	Cadmium	Chromium	Copper	Lead	Nickel	Zinc	
<u>CSOs</u>							
CSO Area A	-	-	180	148	-	247	See Table 3
CSO Area B	-	-	93	58	-	222	See Table 3
CSO Area C	-	-	80	55	-	130	See Table 3
CSO Area D	-	-	293	251	-	335	See Table 3
CSO Area 2	-	-	22	14	-	52	See Table 3
CSO Area 9	-	-	90	82	-	154	See Table 3
BVDC	-	-	945	773	-	1,246	See Table 3
<u>WWTFs</u>							
Field's Point	850	5,190	6,830	4,500	35,380	28,360	Monthly records for 1988
BVDC	110	-	3,510	1,420	6,490	-	(1)
	40	-	4,860	1,550	-	-	Oviatt, 1981
<u>WWTF Bypasses</u>							
Field's Point Secondary Bypass	4	345	498	149	322	-	(2)
BVDC North Diversion Bypass	3	88	239	103	145	-	(2)
<u>Rivers</u>							
Blackstone	517	3,170	5,190	4,400	4,710	-	Wright, 1990
	3,720	-	19,180	15,870	-	-	Oviatt, 1981
	-	-	-	5,200	-	-	Bricker-Urso, 1989
Ten Mile	82	883	1,030	293	3,250	-	Wright, 1990

TABLE 8 (Continued). ANNUAL METAL LOADS TO THE PROVIDENCE RIVER AND VICINITY

Source	Annual Load (lb)						Data Source
	Cadmium	Chromium	Copper	Lead	Nickel	Zinc	
Rivers (Continued)							
Seekonk	-	-	17,860	6,250	-	57,160	(3)
Pawtucket	136	835	1,630	1,290	2,130	-	Wright, 1990
	-	-	9,500	-	-	23,770	(4)
	54	-	9,200	2,650	-	-	Oviatt, 1981
Moshassuck	12.3	284	508	471	449	-	Wright, 1990
	-	-	-	1,600	-	-	Bricker-Urso, 1989
Woonasquatucket	25	176	562	685	673	-	Wright, 1990
	-	-	-	600	-	-	Bricker-Urso, 1989
Storm Drains							
Total Providence	-	-	350	1,010	-	2,090	See Table 6
Direct Runoff							
CSO Area C	-	-	15	-	-	120	Camp Dresser & McKee, 1989

1. Estimated using effluent flows for 1988 and mean concentrations from 1986-87 SPRAY cruises (Doering, et al., 1988).
2. Estimated using bypass flows for 1988 from monthly plant records and mean concentrations from 3 storm events in 1988-89 (Wright, 1990).
3. Estimated from USGS flow records and mean river concentrations from Kester (1981).
4. Estimated from USGS flow and water quality records at Cranston gage station.

a significant source of lead inputs to the Providence River (Oviatt, 1981). According to the results of the CSO Area C study, storm drains and direct runoff are significant sources of copper and zinc in comparison with CSO loads, but not in comparison with WWTF loads. However, the validity of the model predictions of storm drain loads in Area C is questionable. During the sampling program, only one storm drain was sampled during one storm event. Copper concentrations were found to be similar to those measured in the CSOs, and zinc concentrations were slightly higher. However, only 23 percent of the study area is served by separate storm drains, compared to 63 percent served by combined sewers. Therefore, one would expect the copper and zinc loads from the CSOs to be considerably higher than those from the storm drains in Area C.

The Area C study found metal concentrations in the Woonasquatucket River to be below water quality guidelines and concluded that discharges of metals from Area C have no impact on the Providence River (Camp Dresser and McKee, 1989). Likewise, the Area A study reported metals concentrations in the Seekonk and Providence Rivers below the guidelines, with occasional exceptions of copper concentrations measured in the Seekonk River (Metcalf & Eddy, 1986). Metals were not evaluated in the study of Area B.

Biochemical Oxygen Demand

BOD is measured as an indicator of undecomposed organic matter. Large quantities of organic matter in water bodies can result in reduced levels of dissolved oxygen (DO), which can be a threat to aquatic life. Low levels of dissolved oxygen occur occasionally in the Seekonk and upper Providence Rivers during summer months. Inputs of BOD to the Providence River and its tributaries may contribute to the low DO levels. However, an earlier study indicated that phytoplankton decay and benthic sediments were the major sources of dissolved oxygen demand in the Providence River (Nixon, 1982).

Table 9 presents annual BOD loads from the various sources in the study area. The Field's Point and BVDC WWTF effluents and the Seekonk River are the primary sources of BOD inputs. The average annual BOD concentrations in the

TABLE 9. ANNUAL BOD_5 LOADS TO THE PROVIDENCE RIVER AND VICINITY

Source	Annual Load (lbs)	Date Source
<u>CSOs</u>		
CSO Area A	44,000	See Table 3
CSO Area B	49,000	See Table 3
CSO Area C	72,740	See Table 3
CSO Area D	389,800	See Table 3
CSO Area 2	20,700	See Table 3
CSO Area 9	60,800	See Table 3
BVDC	764,700	See Table 3
<u>WWTFs</u>		
Field's Point	2,397,000	Monthly records for 1988
BVDC	3,514,000	Monthly records for 1988
East Providence	438,000	Olsen and Lee, 1979
Cranston	601,000	RIDEM, 1990
<u>WWTF Bypasses</u>		
Fields Point Secondary Bypass	228,000	Monthly records for 1988
BVDC Secondary Bypass	532,000	Monthly records for 1988[1]
BVDC North Diversion Bypass	427,000	Monthly records for 1988
<u>Rivers</u>		
Seekonk	3,572,700	(2)
Moshassuck	161,500	(3)
Woonasquatucket	289,700	(4)
Pawtuxet	1,901,900	(5)
<u>Storm Drains</u>		
Total Providence	104,360	See Table 6
<u>Direct Runoff</u>		
CSO Area C	8,030	Camp Dresser and McKee, 1989

(1) Based on 10 months of recorded bypass flows.
(2) Estimated from USGS flow records and Metcalf & Eddy (1986) river sampling.
(3) Estimated from USGS flow records and O'Brien and Gere (1988) river sampling.
(4) Estimated from USGS flow records and Camp Dresser and McKee (1989) river sampling.
(5) Estimated from USGS flow and water quality records at Cranston gage station.

Field's Point and BVDC effluents during 1988 were 16.1 and 57.2 mg/l, respectively, which explains why the BVDC plant produced the larger load during that year in spite of a total annual flow of less than half of the flow from Field's Point. The variation in tributary loads shown in Table 9 is attributed to the variation in river flows, since there was very little variation in average BOD concentrations in the four tributaries, which were typically around 2.0 mg/l.

The largest BOD loads from CSOs appear to occur in Area D and in Pawtucket and Central Falls. BOD_5 concentrations measured in combined sewer overflows in Area D ranged from 140 to 250 mg/l (Greeley and Hansen, 1990), as compared with a range from 15 to 110 mg/l in Area C (Camp Dresser and McKee, 1989) and a mean concentration of 42 mg/l in Area A (Metcalf & Eddy, 1986). BOD loads from CSOs in Areas A, B, C, 2, and 9 are small when compared to WWTF loads and bypass loads. Estimates of BOD loads from separate storm drains in Providence indicate that they are significant sources of BOD when compared to CSOs.

The results of the various CSO Area studies seem to indicate that BOD levels in the Providence River and its tributaries are not significantly affected by CSO loads.

Total Suspended Solids

TSS are often measured in wastewater discharges and water bodies as an indication of colloidal matter, which can absorb light rays and interfere with their transmission through the water, thus limiting photosynthetic activity and the growth of organisms such as phytoplankton and other aquatic life. TSS also create aesthetic problems and may settle to create nuisance deposits. The various CSO studies conducted have included TSS as a potential water quality problem in the Providence River and its tributaries.

A summary of estimated TSS loads to the Providence River from the various sources is presented in Table 10. The Pawtuxet and Blackstone/Seekonk rivers have been cited in recent studies as being the major sources of TSS loads to

TABLE 10. ANNUAL TSS LOADS TO THE PROVIDENCE RIVER AND VICINITY

Source	Annual Load (lbs)	Date Source
<u>CSOs</u>		
CSO Area A	228,000	See Table 3
CSO Area B	256,000	See Table 3
CSO Area C	65,000	See Table 3
CSO Area D	355,800	See Table 3
CSO Area 2	24,100	See Table 3
CSO Area 9	182,600	See Table 3
BVDC	1,134,100	See Table 3
<u>WWTFs</u>		
Field's Point	3,271,000	Monthly records for 1988
BVDC	4,591,000	Monthly records for 1988
Cranston	494,000	RIDEM, 1990
<u>WWTF Bypasses</u>		
Fields Point Secondary Bypass	360,000	Monthly records for 1988
BVDC Secondary Bypass	574,000	Monthly records for 1988(1)
BVDC North Diversion Bypass	283,000	Monthly records for 1988
<u>Rivers</u>		
Blackstone	17,199,000	Latimer, et al., 1990
	5,370,000	Wright, 1990
Ten Mile	1,697,800	Latimer, et al., 1990
	220,000	Wright, 1990
Pawtuxet	11,333,700	Latimer, et al., 1990
	5,050,000	Wright, 1990
Moshassuck	1,082,600	Latimer, et al., 1990
	540,000	Wright, 1990
	427,900	(2)
Woonasquatucket	2,315,200	Latimer, et at., 1990
	910,000	Wright, 1990
	608,300	(3)
<u>Storm Drains</u>		
Total Providence	974,010	See Table 6
<u>Direct Runoff</u>		
CSO Area C -	20,360	Camp Dresser and McKee, 1989

(1) Based on 10 months of recorded bypass flows.
(2) Estimated from USGS flow records and O'Brien and Gere (1988) river sampling.
(3) Estimated from USGS flow records and Camp Dresser and McKee (1989) river sampling.

the Providence River (Latimer, 1990, and Quinn, 1988). Estimates of tributary loads from Latimer et al. (1990) are the sum of dry and wet weather estimates, although the dry weather estimates include flows affected by wet weather, resulting in over-estimation of the dry weather fraction. Tributary estimates from Wright (1990) are for wet weather flow only. Average concentrations of TSS in the tributaries are typically below 10 mg/l during dry weather, but can increase by a factor of ten or more during wet weather, according to the various sources.

The Field's Point and BVDC WWTF effluents are also seen to be major sources of TSS loads to the Providence and Seekonk Rivers. Average concentrations in the effluents during 1988 were 21.8 and 68.8 mg/l at the Field's Point and BVDC plants, respectively. The largest CSO loadings of TSS are contributed by Area D and Pawtucket and Central Falls, according to the preliminary estimates. Again, the sum of TSS loadings from all NBC CSO areas approximately equals the total BVDC CSO load.

The summary presented in Table 10 indicates that storm drains are also important sources of TSS. The estimated load from Providence storm drains is only slightly less than the TSS load from all Providence CSOs.

Nutrients

An overabundance of nutrients such as nitrogen and phosphorus in surface waters can stimulate excessive plant growth that can result in eutrophication. Wastewater treatment plant discharges and agricultural runoff are typical sources of high nutrient levels. Past studies of nutrients in the Narragansett Bay have cited elevated levels in the Seekonk and Providence Rivers but have seen little impact from these on nutrient levels in the upper bay. It was concluded that tributaries and WWTFs were the major sources of nutrient inputs to the Providence River, but that these inputs to the bay as a hole were small in relation to the quantities recycled in the bay from benthic and animal excretion (Olsen, 1979).

Estimates of annual nutrient loads to the Providence River are shown in Table 11. As previously stated, CSO loads shown are based on the model-predicted flows from the CSO area studies and mean concentrations from CSO sampling in each area. The mean concentrations in Area D were approximated as the log mean of the reported maximum and minimum values for lack of more complete data. This resulted in a mean nitrate concentration of 2.9 mg/l which was used to estimate the CSO load in Area D. A much lower mean nitrate concentration of 0.25 mg/l was measured in CSO's in Area C.

It is evident that the Blackstone/Seekonk and the Pawtuxet Rivers are the major sources of nutrient inputs to the Providence River. The BVDC treatment plant effluent is the largest point source nutrient input to the Seekonk River. The Cranston, Warwick, and West Warwick WWTFs are most likely the most significant contributors of nutrients to the Pawtuxet River, although current data on nutrient concentrations in these effluents was not available.

Although nutrient contributions from CSOs appear to be relatively small, the total load from all of the Providence and BVDC CSO's represents a significant source of nutrients. However, even the total CSO loading seems to be far outweighed by the effluent loads from the Field's Point WWTF alone or by the BVDC plant loads. In addition, urban runoff can be a significant source of nitrogen and phosphorus loadings. It was estimated that forty-eight percent of the nitrate load from Area C is contributed by direct runoff (Camp Dresser and McKee, 1989). Finally, direct rainfall input of nutrients can be extremely significant. Recent data (Wright, 1990) has indicated large contributions of nitrate and ammonia to the contributing watersheds from direct rainfall.

Organics

At the present time, data on inputs of organics to the Providence River is still being evaluated and, as yet, is not sufficient to develop a budget of annual loads contributed by the various sources, particularly those loads contributed by CSO's. A technical document on toxics, under preparation in support of the CCMP, will include a more detailed analysis of organic inputs.

TABLE 11. ANNUAL NUTRIENT LOADS TO THE PROVIDENCE RIVER AND VICINITY

Source	Annual Load (lb) Phosphorus	Nitrate	NH3	Data Source
CSOs				
CSO Area A	2,276	260	8,274	See Table 3
CSO Area B	1,564	292	2,684	See Table 3
CSO Area C	1,474	285	2,531	See Table 3
CSO Area D	2,992	6,004	4,812	See Table 3
CSO Area 2	369	69	633	See Table 3
CSO Area 9	1,870	1,012	2,408	See Table 3
BVDC	11,600	9,700	29,600	See Table 3
WWTFs				
Fields Point	377,100	-	618,500	Oviatt, 1981
BVDC	544,600	-	326,100	Oviatt, 1981
WWTF Bypasses				
Field's Point Secondary Bypass	10,550	2,110	17,650	(1)
BVDC North Diversion Bypass	4,130	2,140	3,450	(1)
Rivers				
Blackstone	-	290,000	920,000	Wright, 1990
	817,000	-	1,075,800	Oviatt, 1981
Ten Mile	-	50,000	110,000	Wright, 1990
Seekonk	535,900	-	1,875,600	(2)
Pawtuxet	-	70,000	1,560,000	Wright, 1990
	224,100	509,400	407,500	(3)
	837,900	-	910,900	Oviatt, 1981
Moshassuck	-	10,000	60,000	Wright, 1990
	5,600	-	-	(4)
Woonasquatucket	-	20,000	90,000	Wright, 1990
	26,100	65,200	63,700	(5)
Storm Drains				
Total Providence	13,510	8,060	-	See Table 6

TABLE 11 (Continued). **ANNUAL NUTRIENT LOADS TO THE PROVIDENCE RIVER AND VICINITY**

Source	Annual Load (lb)			Data Source
	Phosphorus	Nitrate	NH3	
Direct Runoff				
CSO Area C	-	400	-	Camp Dresser and McKee, 1989

(1) Estimated using bypass flows for 1988 from monthly plant records and mean concentrations from 3 storm events in 1988-89 (Wright, 1990).

(2) Estimated from USGS flow records and mean river concentrations from Metcalf & Eddy, (1986).

(3) Estimated from USGS flow and water quality records at Cranston gage station.

(4) Estimated from USGS flow records and mean river concentrations from O'Brien and Gere (1988).

(5) Estimated from USGS flow records and mean river concentrations from Camp Dresser and McKee (1989).

Some preliminary conclusions have been derived from a recent wet weather study (Latimer, et al., 1990) of inputs of PCBs, petroleum hydrocarbon compounds (PHCs), and TSS, the latter of which has been discussed previously in this report. The study examined loadings during two storm events from the five tributaries to the Providence River; the Field's Point, BVDC, and East Providence WWTFs and their bypasses; and from CSO Area 9. Estimated mass loads from the two storm events sampled indicated the BVDC WWTF as the major source of PHCs, followed by the Pawtuxet and Blackstone Rivers and the Field's Point WWTF. The largest PCB loads were contributed by the Blackstone River, followed by the Pawtuxet River. The PCB load from the Field's Point WWTF was also a significant contribution during one of the storms. The study did not indicate CSO 9 as being a major source of either PHC or PCB loads, when compared to the above-named sources. However, the contribution from all of the CSOs under NBC and BVDC jurisdiction has not been estimated. In addition, there is little information on contributions of these contaminants from direct runoff and separate storm drains, which may be significant sources of PHCs, or from industrial effluents in the area.

CSO PRIORITIES

Based on information presented in the previous sections, an effort has been made to define priorities among the CSO study areas in terms of implementing abatement procedures. In order to do this, the CSO areas must be analyzed in terms of their total flow volumes and pollutant loadings, their effects on the receiving waters, and their significance relative to other pollutant sources.

A preliminary ranking of the NBC CSO areas is presented in Table 12 based on both overflow volumes and mass pollutant loadings. Percentages are based on annual flows and loads from each CSO area for an average rainfall year, as presented in Table 3. As seen in Table 12, for each pollutant just over half of the total input from CSOs is contributed by the BVDC overflows, and slightly less than half is contributed by the combined NBC overflows. Since the projected BVDC loads must be considered rough estimations, it is felt that equal priority should be given to the NBC and BVDC CSOs at this time.

TABLE 12. RANKING OF CSO STUDY AREAS

Area	Percent of Total CSO Flow or Pollutant Load										Overall Qualitative Rank of NBC Subareas
	Flow	BOD_5	TSS	FC	Copper	Lead	Zinc	Phosphorus	NH_3	Nitrate	
A	7.8	3.1	10.2	1.6	10.6	10.7	10.4	10.3	16.2	1.5	3
B	8.8	3.5	11.4	3.0	5.5	4.2	9.3	7.1	5.3	1.7	2
C	8.3	5.2	2.9	1.6	4.7	4.0	5.4	6.6	5.0	1.6	5
D	15.7	27.8	15.8	34.9	17.2	18.2	14.0	13.5	9.4	34.1	1
2	2.1	1.6	1.1	0.7	1.3	1.0	2.2	1.7	1.2	0.4	6
9	6.1	4.3	8.1	1.7	5.3	5.9	6.5	8.4	4.8	5.7	4
BVDC	51.2	54.5	50.5	56.5	55.4	56.0	52.2	52.4	58.1	55.0	

In terms of the NBC study areas, highest priority has been assigned to Area D. This area has the largest annual overflow volume and contributes the largest mass loading of each of the pollutants with the exception of ammonia. Area B is felt to be the second highest priority, based on its mass loadings of fecal coliform and suspended solids, followed by Area A, which contributes the second highest loadings of metals, phosphorus, and ammonia. Area 9 is ranked fourth behind Area A, since Area 9 fecal coliform loads are only slightly higher than those in Area A but loadings of most other pollutants are significantly less in Area 9 than in Area A. Although BOD_5 loads from Area C are higher than those from Areas A, B, or 9, loadings of most other pollutants from Area C are less than those from other areas. Since BOD_5 is not a "priority pollutant" in terms of CSOs, Area C is ranked fifth of the NBC areas, followed by Area 2.

The impacts of CSO reductions on the receiving waters is another important factor to consider in assigning priorities. The Area A CSO Study (Metcalf & Eddy, 1986) concluded that the recommended abatement scheme would result in a significant lowering of coliform bacteria levels in the Seekonk River, but only after improvements at the BVDC WWTF have been completed, since the large coliform loads from the WWTF bypasses will overshadow the effects of any CSO reduction. The study was unable to conclude whether CSO abatement in Area A would result in reduced fecal coliform levels in the Providence River or in a reduction of closed shellfishing areas, since there are additional pollutant discharges both upstream and downstream. It was determined that abatement of Area A CSOs would have no significant effects on BOD or DO levels in the Seekonk River.

Conclusions reached in the Area C CSO Study (Camp Dresser and McKee, 1989) were that fecal coliform levels in the Woonasquatucket River would improve upon implementation of the abatement recommendations, but that little impact would be seen on levels in the Providence River. The study also concluded that no effects on BOD or DO levels in the Woonasquatucket River would be seen as a result of CSO abatement, nor would metals concentrations decrease significantly.

The results of the Area B CSO Study (O'Brien and Gere, 1988) indicated that fecal coliform bacteria levels in the Moshassuck River would be reduced by 75 percent at the downstream end and about 40 percent further upstream as a result of the recommended treatment scheme. However, even 100 percent elimination of the Area B CSOs will not achieve Class B water quality standards in the Moshassuck River due to upstream pollutant concentrations and storm drain discharges. The study also predicted that abatement of Area B CSOs would result in reduced fecal coliform levels in the Providence River between the Moshassuck and Woonasquatucket junction and the Hurricane Barrier. Of course, this prediction has not taken into account the impact of the Area D CSO discharges. Again, it was determined that no significant changes in BOD or DO levels would result, and impacts on levels of metals in the receiving water were not evaluated in Area B.

Results of receiving water modeling in Area D seem to indicate that some reductions in fecal coliform and possibly solids, metals, and nutrient levels may be seen in the Providence River upstream of the Field's Point WWTF as a result of CSO abatement in this area, but that little change would occur in pollutant levels downstream of Field's Point.

The above conclusions support the ranking of Areas D and B as the two highest priority areas, as the most significant impacts to the Providence River would be likely to result from CSO abatement in these two areas. The total impact of individual CSO area abatement schemes on pollutant levels in the Providence River and Upper Narragansett Bay will be evaluated in the systemwide modeling study currently in progress. Until then, based on the above conclusions, the preliminary ranking shown in Table 12 is considered valid.

Finally, a prioritization of four types of point sources has been attempted on a mass loading basis. The distribution of pollutant inputs attributed to each of the major point sources is presented in Table 13. The percentages are based on estimated annual loadings from each point source as presented in Tables 7 through 11. Tributaries are not included in the list of point sources because it is not considered applicable to rank a tributary along with the point sources that discharge into it.

TABLE 13. COMPARISON OF POINT SOURCES

Source	Percent of Total Point Source Flow or Load[1]						
	Flow	BOD_5	TSS	FC	Copper	Lead	Phosphorus
CSOs							
Area A	0.4	0.5	1.9	1.5	1.4	1.7	0.2
Area B	0.5	0.6	2.1	2.8	0.7	0.7	0.2
Area C	0.4	0.8	0.5	1.5	0.6	0.6	0.2
Area D	0.8	4.5	2.9	32.7	2.2	2.9	0.3
Area 2	0.1	0.2	0.2	0.7	0.2	0.2	<0.1
Area 9	0.3	0.7	1.5	1.6	0.7	0.9	0.2
All NBC CSOs	2.5	7.3	9.1	40.8	5.8	7.0	1.1
BVDC	2.7	8.9	9.2	53.0	7.2	9.0	1.2
Subtotal	5.2	16.2	18.3	93.8	13.0	16.0	2.3
WWTFs							
Field's Point	60.6	28.0	26.6	<0.1	52.0	52.6	38.8
BVDC	27.2	40.8	37.3	<0.1	26.7	16.7	56.0
Subtotal	87.8	68.8	63.9	<0.1	78.7	69.3	94.8
WWTF Bypasses							
Field's Point	0.7	2.6	2.9	0.3	3.8	1.7	1.1
BVDC Secondary	0.9	6.2	4.7	3.3	NA[2]	NA	NA
BVDC North Diversion	0.7	5.0	2.3	2.4	1.8	1.2	0.4
Subtotal	2.3	13.8	9.9	6.0	5.6	2.9	1.5
Providence Storm Drains	4.7	1.2	7.9	0.2	2.7	11.8	1.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

1. Based on flows and loads presented in Tables 7 through 11.
2. Not available.

The breakdown presented in Table 13 indicates that the NBC and BVDC CSOs are overwhelmingly the primary source of fecal coliform to the Providence River or its tributaries; although, if CSO study areas are taken individually, most of them are outweighed by the BVDC bypasses. The Field's Point and BVDC WWTFs are the major point sources of all other pollutants analyzed. The combined CSOs make up the second-most significant source of suspended solids, metals, BOD_5, and phosphorus. CSO impacts on nutrients levels in the receiving waters are believed to be minimal in comparison to impacts from WWTF discharges.

ENVIRONMENTAL AND HEALTH SIGNIFICANCE OF CSO DISCHARGES

The environmental and health significance of CSOs in general has been well documented. CSOs are known to contain high concentrations of solids, BOD, bacteria, nutrients, and metals. A convenient summary of CSO characteristics as compared to other sources, taken from the most recent edition of Metcalf & Eddy, Inc. (in press), is given in Table 14. In general, the characteristics of combined sewage reflect the characteristics of untreated municipal wastewater when diluted with stormwater runoff (which itself contains substantial concentrations of certain contaminants).

The characteristics of combined sewage are highly variable, depending on numerous factors such as the characteristics of the rainfall events (storm size, duration, intensity), the watershed (size, slope, impervious area, soils), the combined system (pipe slope, size, flow regulation, sediment build-up), and the wastewater (flow, variability, level of commercial or industrial contribution). Therefore, the values in Table 14 can only be considered typical, but site specific values are needed for confirmation. A comparison of these characteristics with receiving water standards in Rhode Island (and elsewhere) show a strong possibility of violations of solids, turbidity, dissolved oxygen, bacteria, and metals criteria in locations where CSO discharges exist. In addition, CSOs may contribute to eutrophication because of their high nutrient content. Finally, CSOs are known to contain high levels of floatables (trash, debris, sewage-related solids, etc.) which can result in violations of aesthetic criteria. The existence of priority pollutants in CSOs (other than metals) is largely related to the type of

TABLE 14. COMPARISON OF CHARACTERISTICS OF COMBINED SEWAGE WITH OTHER SOURCES

Parameter	Unit	Typical Range of Parameter Concentrations			
		Rainfall(1)	Stormwater Runoff(2)	Combined Sewage(3)	Untreated Municipal Wastewater
Suspended Solids	mg/L		67 - 101	270 - 550	100 - 350
Biochemical Oxygen Demand (5-day)	mg/L	1 - 13	8 - 10	60 - 220	110 - 400
Chemical Oxygen Demand	mg/L	9 - 16	40 - 73	260 - 480	250 - 1,000
Fecal Coliform Bacteria	MPN/100 ml		1,000 - 21,000	200,000 - 1,100,000	10^6 - 10^7
Nitrogen (total as N)	mg/L			4 - 17	20 - 85
Total Kjeldahl Nitrogen			0.43 - 1.00		20 - 85
Nitrate		0.05 - 1.0	0.48 - 0.91		0
Phosphorus (total as P)	mg/L	0.02 - 0.15	0.67 - 1.66	1.2 - 2.8	4 - 15
Metals	µg/L				
Copper			27 - 33		
Lead		30 - 70	30 - 144	140 - 600	
Zinc			135 - 226		

1. Adapted from Huber, 1984
2. Adapted from U.S. Environmental Protection Agency, 1983
3. Adapted from Metcalf & Eddy, Inc., 1977

dischargers to the combined sewer system and the activities within the drainage basin. Of course, the issue of standards violations at CSO discharge points is dependent on contaminant loads and the characteristics of the receiving waters (dilution, mixing, etc.), and must be assessed on a site-specific basis.

With the exception of suspended solids, pollutant concentrations in combined sewage in the NBC study areas generally fall within the ranges shown in Table 14, although lead concentrations measured in Area C CSOs were below the range shown. Mean TSS concentrations in all of the NBC CSO areas were below the range of 270 to 550 mg/l shown in Table 14. The reason for this is unknown, although it may be that stormwater in the area contains less than typical levels of suspended solids. TSS concentrations measured in a storm drain in Area D ranged from 25 to 40 mg/l, as compared to 67 to 101 mg/l cited in the U.S. EPA study; however, only limited stormwater sampling was conducted during the CSO studies.

NBC PROPOSED CSO ABATEMENT PROJECTS

Recommendations made in the various CSO Mitigation Studies have been approved by the NBC with the exception of the CSO Area 9 recommendations. The proposed CSO-related projects are listed below:

- CSO 2: Outfall Rehabilitation
- CSO A Phase I: Seekonk Interceptor
- CSO A Phase II: Treatment and Storage Facilities
- CSO B Phase I: Branch Avenue Rehabilitation
- CSO B Phase II: Moshassuck Interceptor/West River Basin
- CSO C: Upper Woonasquatucket River Interceptor
- CSO D: Allen's Avenue Interceptor
- CSO 9: South Providence Interceptor
- Systemwide CSO Study

The activities involved in each of these proposed projects are listed in Table 15 along with the specific CSO sites that will be controlled by the activity and the projected costs. The schedule proposed by the NBC for implementation of these recommendations is shown in Figure 6.

In CSO Area 2, the study completed in 1982 recommended modifications to the slot/connector structures at most of the CSO sites and rehabilitation of an interceptor to provide in-line storage. These recommendations have been implemented and the system is reported to be operating as designed. Remaining work in the area involves ten outfall headwalls which are in disrepair. This project is currently in the final design stage.

In both Area A and Area B, Phase I recommendations were made for repairs or improvements to the sewer infrastructure that were considered to be in need of immediate attention or that could be implemented in the near term. Design and engineering work for Phase I improvements in Area A was divided into two contracts and is currently underway. Construction is planned to begin in fiscal year (FY) 1991. Phase I structural repairs in Area B are under construction at the present time and design work is being completed for separation of a portion of the combined sewer.

A systemwide study of the entire combined sewer system is currently being conducted which will incorporate the results of the previous studies and will include modeling of Areas 2 and 9, which have not been modeled previously. The results will be used to prioritize construction activities. For the interim period, the proposed schedule is as shown in Figure 6. Implementation of CSO control programs will begin in Areas D and 9, which at this time are considered by the NBC to be the most critical areas.

A study was completed in 1982 of Area 9, where over twenty flow regulators tie in to one overflow point and where dry weather overflows were a significant problem. A diversion structure was installed to convey up to 14 MGD of overflow to the Field's Point treatment facility, thereby eliminating the dry weather overflow, which was a major source of fecal coliform bacteria discharge to the Providence River. However, significant wet weather flows

TABLE 15. SUMMARY OF NBC PROPOSED PROJECTS

Study Area	Recommendations	CSO Sites	Total Project Cost ($ in thousands)
2	Repair outfall headwalls		440
A	Phase I - Cleaning and video inspection of Seekonk River Interceptor - Replace cracked and settled sewers - Internal repairs - Tidegate improvements - New headwalls - Slot rehabilitation		5,500
	Phase II - Primary treatment facility at Butler Hospital - Storage facility near Richmond Square - Storage facility near Hurricane Barrier	 027 023-026 018-022	20,980
B	Phase I - Tide gate replacement and rehabilitation - Weir wall installation and improvements - Slot regulator sealing and improvements - Interceptor cleaning - Branch Ave. interceptor structural rehabilitation - Sewer separation	 029	2,586
	Phase II - Connect to new West River interceptor - In-line storage - Off-line storage facility - Treatment facility near Randall Square - Sewer separation - Diversion/connection to Allens Ave. interceptor	 038, 039, 056 036 037 030, 032, 033, 034 031, 035 012, 013, 015, 016	29,022
C	Two storage/treatment facilities	049-055	38,371

TABLE 15 (Continued). SUMMARY OF NBC PROPOSED PROJECTS

Study Area	Recommendations	CSO Sites	Total Project Cost ($ in thousands)
D	Off-line Storage Facility	004-007, 009-011, 061	78,900
9	Treatment facility (to be re-evaluated)	002	17,086[1]
System-wide Study	In progress		621

(1) Preliminary estimate to be revised.

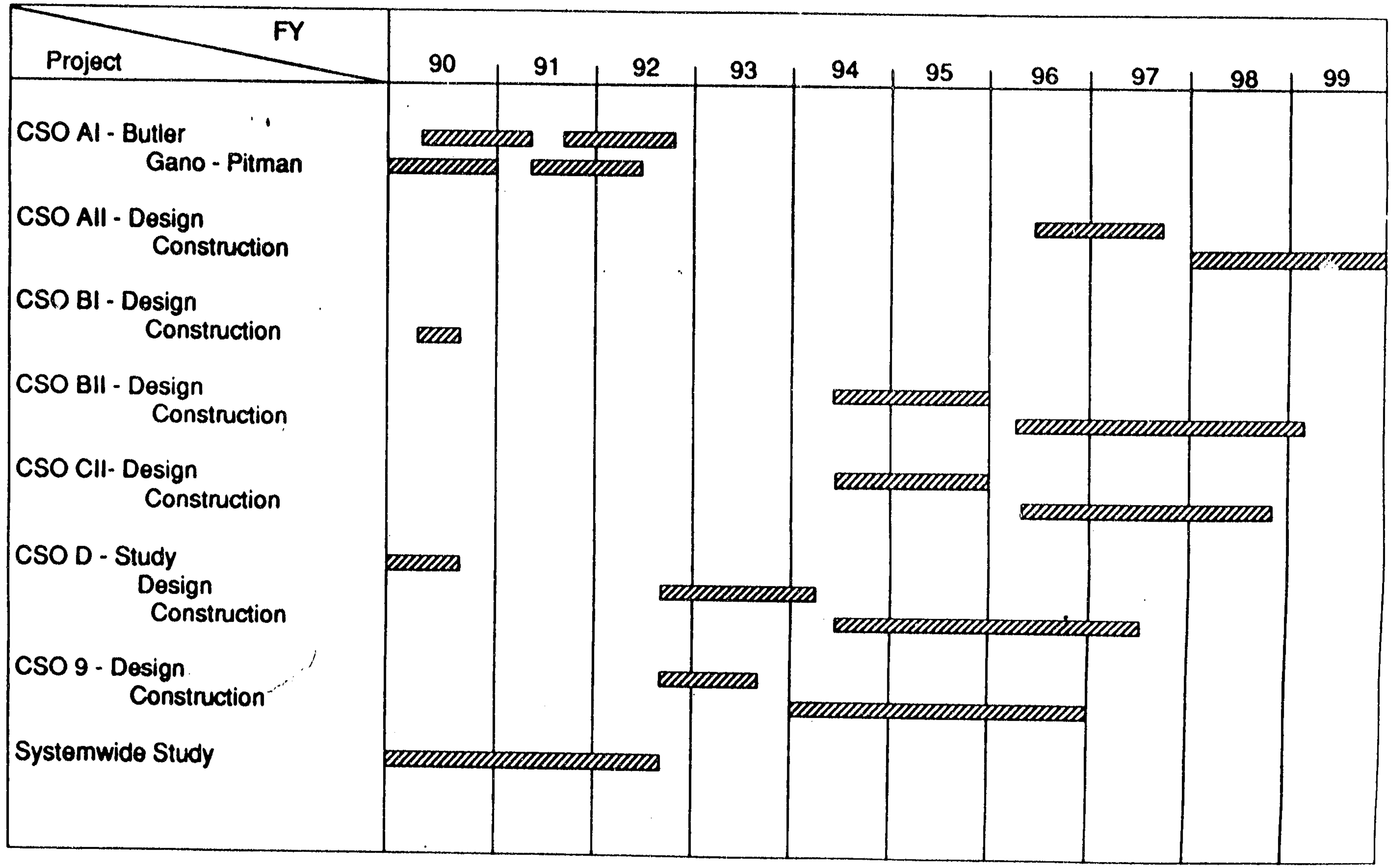


FIGURE 6. NBC PROPOSED SCHEDULE

still discharge from this area. The treatment scheme recommended in the 1982 study (Castellucci, et al.) has not been approved by the NBC. Treatment alternatives for Area 9 overflows will be reevaluated as part of the Systemwide CSO Study. Final design for Area 9, as well as Area D, abatement measures is scheduled for FY 1992.

Final design and engineering for Area B Phase II and Area C CSO controls will be initiated in FY 1994. Controls planned for Area B include a new interceptor, in-line storage, an off-line storage facility, a treatment facility, and sewer separation. In Area C, two storage-treatment facilities have been proposed.

CSO Area A is considered by the NBC to be the lowest priority area. Final design for a treatment facility and two storage facilities is scheduled for FY 1996.

The schedule as presented herein may be revised after the results of the Systemwide CSO Study become available.

CSO REGULATORY POLICIES

EPA headquarters, EPA Region I, and the State of Rhode Island have all issued CSO abatement policies. The EPA national policy was finalized recently, and a guidance document to complement the strategy is still under development. The Region I policy was prepared in 1987. The Rhode Island policy was recently approved by EPA. These policies all interact to influence any CSO abatement strategies proposed for the bay, and are described in this section.

EPA Headquarters Policy

The "National Combined Sewer Overflow Control Strategy" developed by EPA has three stated objectives:

- To ensure that CSO discharges only occur as a result of wet weather.
- To bring all CSO discharge points into compliance with technology-based requirements of the Clean Water Act (CWA) and state water quality standards.
- To minimize water quality, aquatic biota, and human health impacts from wet weather overflows.

The essence of the strategy involves permitting all CSOs as point sources through the NPDES process. EPA's strategy requires development of state strategies by states or regions, many of which are still being developed and reviewed.

To implement the strategy, EPA describes the following considerations:

- Identify and categorize permit status of each CSO discharge point.
- Set permitting priorities.
- Issue permits, using a single system-wide permit when possible.
- Establish compliance schedules consistent with Clean Water Act statutory deadlines, with enforcement schedules when appropriate.
- Use certain minimum technology-based requirements, including proper operation and maintenance, maximum use of collection system storage, pretreatment programs to minimize CSO impact, maximize flow to POTW for treatment, prohibition of DWO's, and control of solids and floatables.
- Establish additional control measures as needed to protect water quality standards.
- Establish compliance monitoring requirements (which may include impact assessment through means such as modeling).
- For certain limited cases, modify state water quality standards (as per 40 CFR 131.10).

EPA Region I Policy

This policy, although developed prior to the EPA headquarters policy discussed earlier, reflects a consistent approach. It focuses on the need to deal with

CSOs as point sources, subject to the technology-based and water quality based requirements of the CWA. At the time this policy was developed, there were no minimum technology-based requirements, therefore use of best professional judgment was recommended. Now, the minimum requirements discussed in the fifth item of the last section are in effect.

The policy focuses on achievement of water quality standards without "across-the-board" changes or downgradings. The approach recommends development of a CSO facilities plan which assesses frequency and magnitude of overflows, water quality impacts, use impairments, correction alternatives, and costs. It recognizes that for limited cases, a standards revision may be needed in which case appropriate regulations (40 CFR 131.10) must be followed. A use attainability analysis would be required to support implementing a standards change for a specific receiving water segment.

State of Rhode Island Policy

As required by the EPA national strategy, Rhode Island has developed and received approval of their CSO strategy. This strategy requires that each CSO receive "equivalent primary treatment," which is defined in terms of removal rates of TSS (50%) and BOD (35%), or settleable solids (100%). This requirement is to apply to all flows up to and including the one year - six hour storm event. The policy then specifies an implementation approach (including identification, prioritization, permitting, control measures and best management practices, monitoring, and compliance scheduling) intended to be consistent with the EPA policy.

The use of a specific treatment technology standard is in compliance with the EPA policy in a strict sense, since the policy allows setting of minimum technology-based requirements. Although EPA has approved the strategy in a letter dated April 24, 1990, they still specified a "major concern" with the use of this treatment technology standard. EPA's concern is that water quality-based requirements may still not be satisfied beyond designated CSO mixing zones. Thus, EPA's position is that it would still have to be demonstrated for each case (through such means as modeling) that CSO discharge impacts would not cause standards violations.

Impact of CSO Policies

The main differences between the EPA and Rhode Island policies are the use of a specific treatment technology and a design storm guideline by the state. These provide uniformity in terms of facility sizing, however there is less flexibility in terms of standards compliance and cost benefit issues. Depending on specific water quality and discharge conditions, facilities could be over-designed or under-designed. An advantage of the state policy is that is recognizes that a wet weather design condition is appropriate for CSOs, in the same manner that a critical low flow is appropriate for a river or stream. In other words, it allows for a periodic standards violation during critical conditions.

For the NBC facilities plans, proposed improvements seem to comply with the requirement for equivalent primary treatment with disinfection in the Rhode Island policy. They also appear to comply with the minimum technology-based requirements of the EPA policy, even though these requirements were not available during facilities planning for most areas. However, some of the facilities proposed in NBC facilities plans are not consistent with the current Rhode Island policy, because they are sized based on a smaller storm event than the required one year - six hour storm. In most cases, the recommended storage/treatment facilities were sized based on a three month storm event. Due to the previous lack of a single "design storm" guideline as currently specified in the Rhode Island policy, most of the projects recommended for the NBC were determined based on cost-benefit and receiving water impact considerations. The Rhode Island policy allows a sewer authority to petition for a waiver from the one year - six hour design storm requirement if it can be demonstrated that significant water quality benefits will occur by incorporating a level of treatment less than that defined by the policy. It is felt that the facilities plans prepared for the NBC in CSO Areas A, B, C and D have demonstrated, via cost/benefit analyses, such significant benefits.

The BVDC system needs and will undertake new facilities planning. Little can be said on past efforts except that they were performed long before current policy was developed. With new facilities planning, BVDC would have the opportunity to comply with policies as they currently exist.

Reevaluation of past NBC efforts in light of current policies would likely result in different recommendations. However, since past plans considered water quality benefits and the "crest of the knee" on the cost/benefit curve, it is possible that the recommended plans may comply with current state policy. Another complicating factor is the evolution of water quality standards, particularly with respect to toxics, in the years during the facility planning efforts. The only definitive way of answering these issues is to conduct complete modeling of both the CSO system and receiving waters, under future assumed conditions with all recommendations in place. If such an analysis shows standards would be violated, reconsideration of some of the recommendations might be required.

RECOMMENDATIONS

Based upon the information presented in this report, it is recommended that the NBC reevaluate its planned schedule for CSO abatement projects. The results of the systemwide CSO modeling study will be most beneficial in assessing the impacts of the various recommended CSO controls on the Providence River and upper bay. However, in the interim, it is felt that consideration should be given towards the construction of CSO controls in the following order of priority: Areas D, B, A, 9, C, and 2. It is understood that further control of CSOs in Area 2 will most likely not be necessary.

On a more regional basis, whether the CSOs under NBC or BVDC jurisdiction should receive highest priority cannot be determined until the BVDC has completed facilities plans for its CSOs and has evaluated their impacts on receiving waters. At the present time, CSOs owned by the two commissions should receive equal priority.

Currently available information on CSO loads indicates that the focus of CSO abatement should be on bacteria and, to a lesser extent, solids and metals. CSO abatement strategies should be developed to address these contaminants and comply with the CSO abatement policies of RIDEM and EPA. It is felt that CSO abatement should not be a high priority as a deterrent to high BOD_5 or nutrient levels in receiving waters in the upper bay area, as CSO abatement will most likely have little effect on concentrations of these constituents in the bay or the Providence River and its tributaries. The full compliance of past CSO facility plan measures with current policy is unlikely. The outcome of the BVDC facilities plan, the system-wide study, and receiving water quality impact assessments should be to achieve water quality standards as well as technology-based requirements specified in the policies. This includes the concept of "equivalent primary treatment" for each CSO discharge at the specified one year - six hour design event.

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