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Maximizing Storage in Combined Sewer Systems

U.S. ENVIRONMENTAL PROTECTION AGENCY

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MAXIMIZING STORAGE IN COMBINED SEWER SYSTEMS

by

Municipality of Metropolitan Seattle
410 West Harrison Street
Seattle, Washington 98119

for

Office of Research and Monitoring

ENVIRONMENTAL PROTECTION AGENCY

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ABSTRACT

Since the first Metropolitan Seattle sewers were constructed, combined wastewater has been discharged into salt water or estuaries along the Seattle waterfront. Beginning in 1958, plans were developed to make use of storage available in the collection system before combined sewage overflows occur. The initial plans included: (1) interception and treatment of raw sewage flowing to salt water points, (2) regulation of lines, and (3) construction of temporary storage tanks at fresh water overflow points. In 1968, a $70 million sewer separation project was approved to increase system storage by reducing storm inflow. Metro funds originally earmarked for storage tanks have been applied to the separation project.

All required construction has been completed in a project to demonstrate the feasibility of applying computer-control concepts to make maximum use of all available storage within a collection system. Automatic and manual sampling programs are monitoring overflows and adjacent waters. Background data, which has been accumulated and analyzed to establish control conditions before computer activation, show dramatic improvements in receiving water quality resulting from interception and treatment phases of construction. Analysis of monitoring data projects a 50% to 70% reduction in pollutant loading to fresh water after sewer separation projects have been finished. Overflow volume, frequency, and quality factors are monitored to serve as a basis for measuring the performance of the control system as it leaves the instrumented local control phase and begins the totally computer-managed phase.

This report is submitted in partial fulfillment of Project Number 11022 ELK, Contract 13-Wash-1, under the sponsorship of Water Quality Research, Environmental Protection Agency.

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TABLES (Continued)

SECTION I
CONCLUSIONS

1. Application of various storage improvement techniques has visibly improved receiving water quality even though overflow sampling analyses are inconclusive.

2. Reductions in coliform levels following the August 1970 interception of major Elliott Bay outfalls by gated regulators range from 63 to 98 percent.

3. Duwamish River minimum dissolved oxygen levels have increased nearly 200% from an average of 2.5 mg/l to 4.5 mg/l. The improvement cannot definitely be attributed to interception until an additional summer's data can be compared.

4. Decreases in ammonia-nitrogen concentrations at certain stations on the Duwamish River are a result of improved nitrification techniques being utilized at the Renton secondary treatment plant discharging into the river upstream of those stations.

5. Following interception of all major outfalls, improved trawl fish catches indicate larger populations of certain fish species, including English sole and Chinook salmon, in the lower Duwamish River.

6. Monitoring of Elliott Bay indicates an improvement of between two and three mg/l of dissolved oxygen in the bay as a result of interception and regulation of 12 former raw sewage outfalls.

7. Automated chemical methods are a precise and useful tool if used for many repetitions of a single analyses or if sufficient accessories are on hand to run different tests in parallel.

8. Samplers and recorders, to be effective, require regular surveillance and maintenance. The smallest failures can reduce valuable data to a level that is unusable for certain statistical analyses.

9. Sampler and recorder data have not only provided valuable data about combined sewer overflows, but also have aided Metro in the operation of the collector system by: (a) allowing early detection of station controller malfunctions and (b) pinpointing hydraulic design weaknesses where, for example, certain stations overflow much more often than others.

10. The best sampling equipment is generally the least complex, is portable, does not require power, is not susceptible to plugging of small suction lines, constrictions, or bends, and is not likely to become damaged when submerged (a large order).

11. Development of an "overflow priority table" will not be a simple task. At Metro regulators, coliform density values would establish a "least desirable" overflow priority station sequence as follows: 40-13-37-36; while BOD and COD levels would reorganize the table thus: 36-17-10-14. A combination of factors would place station 36 (which drains a commercial-residential area but receives many oils and solvents) as the least desirable.

12. Weather studies in the Seattle area indicate a high correlation between peak intensity and total volume of rainfall, so improved control efficiency can be expected by obtaining as much current rain gage data as possible to develop early estimates of flow input to a computer control model.

13. The collected overflow sequential sampling data is too sparse to draw any conclusions other than to iterate the oft-described "first-flush" effects.

14. Water quality data was used to predict overall reduced loading to receiving water of 50% to 65% for solids, nutrients, and BOD and 37% for COD following partial separation. However, stormwater will drain to new areas where storm drains never existed before, and this may influence receiving water quality in some local areas.

15. An exception to the above separation prediction was evidenced at one station where suspended solids actually increased in a storm drain as compared to a combined overflow. However, the low volatile suspended solids (15%) indicate that the increased solids were probably a result of soil erosion and construction materials being washed to the drains by storms.

16. Sequential sampling in storm drains showed a strong inverse relationship between flow and ammonia-nitrogen concentrations.

17. In comparing combined sewers with storm drains, the combined sewers showed a greater degree of correlation between nutrient concentrations and rainfall or various flow parameters.

18. In storm drains, the most significant nutrient correlations were with meteorological data other than rain (e.g. air temperature and wind direction) or historical factors such as antecedent dry weather period and volume and intensity of previous storm flow. The correlation was found somewhat different at combined sewer stations, where the greatest nutrient correlations were with current conditions such as volume of overflow, rain volume, and meteorological factors.

19. At present, programmer inexperience and turnover can be expected to influence all computer process control applications in the wastewater field, generally delaying any schedule for completion.

20. This project is one of a few nationwide attempts to apply computer process control principles in the wastewater field. At this time, there are no standard programming formulas to follow. Each application in each city seems unique, demanding a completely separate program of design and construction.

SECTION II
RECOMMENDATIONS

1. It is recommended that municipalities entering the process control field aim toward standardizing control requirements based somewhat on the experience of this and other research efforts so that computer and control firms can develop a package to satisfy most needs. Standardization could improve the product and the customer's satisfaction while reducing the municipalities' time and cost investment through competition between commercial firms.

2. The attainment of a reduction in the amount of human effort required to maintain a reliable sampling and monitoring system is a difficult task. The industry again should attempt to standardize on specifications. By now, sufficient data and experience should be available to proceed toward this goal.

3. It was premature to develop and publish in this report cost or operational data related to computer process control. A similar absence of such data has been noticed in other published reports on this subject. More economic information should be generated by installations using computer systems for wastewater collection and treatment control purposes.

4. There is a need for more studies and development in the use of water quality monitors within sewage collection systems to base the selection of overflow points on current data rather than a predictive model. A secondary benefit would be the ability to trace the source of waste material discharges to the sewer system that are harmful to the collection system or treatment processes.

5. Investigate all potential applications of computers in the wastewater field. In general, a computer that is large enough to perform some control function will not be continuously occupied with any one task and can become a definite asset in the performance of other control functions and routine common engineering and data processing problems. The following recommendations refer specifically to the demonstration grant project in the Seattle Metro area but might also be applied to other municipalities:

6. It is recommended that a thorough evaluation be made of the relative contributions of interception, regulation, separation, and computer control based on some loading factor such as BOD. This should be followed with a study of the economic relationships of the above, to include the cost effectiveness for each level of reduction.

7. Generate more statistical data on overflows, including volume calculations. This may be done by shifting emphasis of monitoring programs from the sewer separation studies to overflow studies.

8. The separation study should be continued, on a reduced scale, to observe whether effects on the receiving water occur as predicted after all pipeline construction is completed.

9. It is recommended that an effort be made to study changes in West Point Treatment Plant influent characteristics and flow levels as a result of computer control under CATAD.

10. Study the possibility of wastewater quality modeling to automatically update an "overflow priority table."

11. The possibility of expanding computer applications should include the Renton Treatment Plant process control, addition of control to new stations being built or remodeled, inclusion of a river water quality model (related to recommendation 10) and the inclusion of additional rain gages supplied by Metro or the City of Seattle.

12. Complete the sewer separation construction program as presently scheduled, but also study if further separation is needed based on the accomplishments of the CATAD system and alternative treatment and control methods.

13. Economic evaluations should be made to analyze whether the CATAD system provides actual cost benefits to Metro in the form of reduced pumping and treatment or system enlargement costs. An attempt should be made to relate these findings to improved water quality benefits.

SECTION III
INTRODUCTION

This document, "Maximizing Storage in Combined Sewer Systems," is an interim report of the development and present status of a federally assisted demonstration project being administered by the Municipality of Metropolitan Seattle (Metro). Aimed at eliminating or minimizing overflows in a combined sewer system, the Metro project is based on computer control of sewage collection, treatment, and disposal. The system is designed to: (1) continuously monitor water depths and other factors needed to compute flows and capacity in the sewers and treatment works, (2) receive and process meteorological data and predict runoff intensity and volume on the basis of historical records, and (3) reduce flow and store sewage in portions of the pipeline system to permit increased flow from areas experiencing high runoff rates. Other computer functions include the processing of data from an extensive water quality monitoring program and performance of administrative recordkeeping and related data processing jobs.

The combined sewer overflow, a result of excessive amounts of stormwater entering sewer systems of limited design capacity, is an example of the ecological problems receiving extensive attention in an effort to reduce man's adverse impact on the environment. The storm overflow pollution problem in the Seattle combined sewer system is typical of the problem elsewhere; however, Seattle's solution is unusual. A computer-controlled system such as the one in Seattle offers promising solutions to other cities. Construction and basic programming of the entire system is now complete, and operation is about to begin. Metro experience related in this document should be helpful in suggesting ways to speed the difficult process of merging a complex computer system with a combined sewage collection system.

SCOPE

This report describes the procurement and installation of a computer system capable of controlling a large sewer system. Important factors covered are control devices, monitoring equipment and measurement parameters, telemetry methods and data processing requirements, computer programming and data storage details, and human element considerations.

A final report, to be published in 1973, will complete the demonstration grant requirements and describe a representative period of operation of the nation's first computer-controlled sewage collection, treatment, and disposal system.

BACKGROUND

Between 1956 and 1958 an areawide sewerage and drainage survey resulted in a comprehensive plan for the collection, treatment, and disposal of wastes from Seattle and other communities within the drainage basin. (1)

Following completion of the sewerage and drainage plan in 1958, Seattle-area voters approved the formation of the Municipality of Metropolitan Seattle (Metro), a regional agency responsible for the collection, treatment, and disposal of waste water. (2) Consulting engineers were hired to begin preliminary design work to implement the comprehensive plan. (3) The proposed treatment and interceptor system (now completed) was designed with sufficient capacity to accommodate all predicted population and industrial growth within the entire drainage area. For this reason, considerable storage capacity is still available within the interceptors and trunk lines. Regulation, and other ideas to improve storage and reduce the storm inflow and resultant combined system overflows, were recommended and accomplished during this 10-year program.

Despite improvements brought about by the basinwide construction plan, Seattle itself was still plagued by overflows from the 60-year-old combined sewer system. A combination of ideas within the Metro agency staff and its consulting engineers plus the interest of the federal government culminated in a research and development demonstration grant (4), awarded in 1967. The demonstration project is expected to achieve the ultimate in system storage and control in a combined sewer system through computerized "total system management." This revolutionary concept in the field of sanitary engineering has become known as the "Computer Augmented Treatment and Disposal System," or CATAD.

WATER QUALITY STANDARDS

Appendix A details Washington State water quality standards developed in 1967. To meet these standards, combined sewer separation and new sewage collection and treatment facilities were required. Even greater corrective measures are under consideration today as federal agencies enforce existing regulations (5) and begin a new series of discussions of even stricter standards.

As a result, Metro has planned for additional facilities as a part of a second-stage construction program. (6) Appendix B shows second-stage construction costs.

ALTERNATIVE SOLUTIONS TO THE PROBLEM

A wide variety of solutions to the overflow problem of combined sewers has been listed in the past by numerous authorities. (7,8,9) The solutions can be characterized as three methods:

1. Increase the total capacity of the system;
2. Provide automatic control and management of the system;
3. Treat any overflow or bypass resulting after steps 1 and 2 have been completely accomplished.

Storage Capacity

Storage capacity can be gained by reducing inflow or by expanding the system. Total separation has often been considered the ideal solution to the combined sewer problem; but, apart from its tremendous cost, there is increasing concern that other problems may develop as a result of separation. (7,10) Many cities have begun separation projects of limited size. Seattle and Washington, D.C., have begun major projects to separate large portions of their combined sewer systems. The various degrees of partial separation make it difficult to compare costs from city to city, but nearly all cities agree that financing is the major problem in a separation program. (8)

Other methods to increase capacity by reducing storm inflow center on ways to limit infiltration. Included in this area are techniques such as reconstruction (11,12) or use of sealants (13) to repair broken or cracked sewers, replacement or redesign of manhole covers with excessively large ventilation holes, and a number of methods for locating and reducing the number of illegal connections that allow stormwater to enter the system. (14,15)

System Expansion

The second method to increase system capacity is simply by expanding the system itself. Construction of new sewer lines or tunnels (16) either in series or parallel to existing systems and construction of storage tanks (17) or other holding basins (18) are the two most common ways of increasing storage within the system.

Instrumented Controls

Within any combined sewer system, storage capacity can be increased by a number of control techniques. Regulating structures can increase system capacity by restricting flow while using available storage from a trunk sewer entering an interceptor line (19). Motorized gates, weirs, or other flow regulating devices can restrict flow and thereby store sewage within interceptors and trunk lines. Successful use of computers and instrumentation in various industries has led to the application of these techniques to the pollution control field to gain storage in combined sewer systems.

In the Netherlands, remote control of pump stations has been used to store peaks of sewage flow in the interceptor system, thereby maintaining a more uniform flow at the sewage treatment plant. (20) This has resulted in improved sewage treatment efficiency.

Demonstration grants are in progress now in various cities around the country in an effort to show how remote control of gates and other devices within a collection system can be used to maximize storage or to route flows through systems that contain large sewers or a grid network. In either case, the maximum storage available in a combined sewer system is employed through the use of instrumentation at various points. In such instrumented systems, it is likely that computer control and system models are included or planned for future installation when conditions or funds permit such action. The complexities involved suggest that it would be helpful to go into additional detail on the various demonstration grants involving instrumental control systems to distinguish the unique features of each.

Nationwide System Control Projects

Monitoring to detect unusual or unnecessary overflows is the primary feature of the Cincinnati studies. (21) The Minneapolis-St. Paul Sanitary District has adopted a more sophisticated approach by telemetering data from river monitors, mechanical gate diversion points, and sewer flow and level sensors to a central point where a computer assists a dispatcher in routing and storing stormflows to make efficient use of the interceptor capacity. (22) The Detroit project involves even further system control refinements. This project includes rain gages, level sensors, overflow detectors, and a central console for controlling pumping stations and selected regulator gates. Computers are employed to test such pollution control techniques as "storm flow anticipation," "first flush interception," "selective retention," and "selective overflowing." (23)

The Metro setup incorporates all the main features of the other control projects plus additional water quality monitoring functions into one of the most advanced waste transmission and treatment monitoring and control systems in existence today. The Metro CATAD control system is described in greater detail in succeeding chapters of this report. The descriptions of the projects mentioned above have been brief; further details about these demonstration grants can be found in other publications. (24,25,26)

Overflow Treatment

Many cities are engaged in attempts to treat stormwater overflows from combined sewer systems using a combination of methods. A few cities have actually incorporated overflow treatment into regular operating procedures for an entire collection system. Portland, Oregon, has experimented with a rotating fine screen system to separate settleable solids from the overflow stream. Cleveland has investigated both biological and chemical oxidation followed by sedimentation as a treatment procedure for overflows. Philadelphia is testing a combination of microstraining, chlorination, and ozonation. Excess mixtures of stormwater flow and sewage are settled, skimmed, and chlorinated in holding tanks of the Mission township district of Johnson County, Kansas. (27) Other techniques such as dissolved air flotation and crazed resin filtration are being studied to test the feasibility of adopting such techniques for full-scale municipal application.

The Seattle area has also considered proposals for treating overflows. In 1970, a consulting firm presented a detailed study for a proposed screening and chlorination installation. (25) The construction cost was estimated as $800,000 for a facility with the capacity for treating 25 mgd. Considering the construction costs and unknown operating costs and other factors, City of Seattle officials declined the proposal and elected to invest funds into separation projects where considerably more benefit could be obtained for a given amount of money. It is expected that separation projects, together with computerized storage control, will eliminate or reduce overflows to a level so that receiving water quality standards can be met.

SECTION IV
FACTORS AFFECTING STORAGE IN THE SEATTLE SEWER SYSTEM

It would be difficult, if not impossible, to make an accurate evaluation of the success or failure of the effort to maximize the storage within the Seattle combined sewer system if we did not first study all the factors that presently affect storage within the system. These related factors in order of presentation are:

1. System expansion,
2. Improved regulation techniques,
3. Storm inflow reduction.

Historically, system expansion has preceded the other storage improvement techniques; therefore, this aspect is discussed first.

SYSTEM EXPANSION

Implementation of the metropolitan area comprehensive sewage collection and treatment plan of 1958 began in 1960 with numerous independent trunks and small sewage treatment plants. The first-stage construction program, completed in 1970, added the interceptor lines and new facilities shown in Figure 1.

Over the total Seattle area, some 87 miles of sewers between 8 and 108 inches and averaging 56 inches in diameter, all constructed to the design size specified for ultimate flow within the drainage basin, constitute a large portion of the increased system storage potential.

Major features of the expansion are represented pictorially in Figure 2. Pipeline size and construction problems are illustrated by photographs A and B. Photos C and D show the smallest and largest of the four primary treatment plants along Puget Sound, which borders Seattle to the west. Photograph E is representative of the 14 regulator stations already constructed (four more are being planned for future construction). Some 18 pump stations similar to photograph F complete the expansion of the sewer system.

The added facilities together with the existing 1,029 miles of combined sewers in Seattle, including the large North Interceptor sewer and many tributary trunk lines, complete the comprehensive sewage collection system as it exists today. Another method of gaining in-system storage--stormwater holding tanks--has also been considered.

Storage Tanks

A number of cities have studied and built temporary or permanent stormwater storage tanks in some form as a means of preventing stormwater overflows from combined sewer systems to local receiving waters. Columbus, Ohio, and Washington, D.C., are well known examples of this technique. Seattle also planned the construction of storage tanks to remedy a situation along Lake Washington where overflows periodically occured at nearly 60 separate points, as shown in Appendix C.

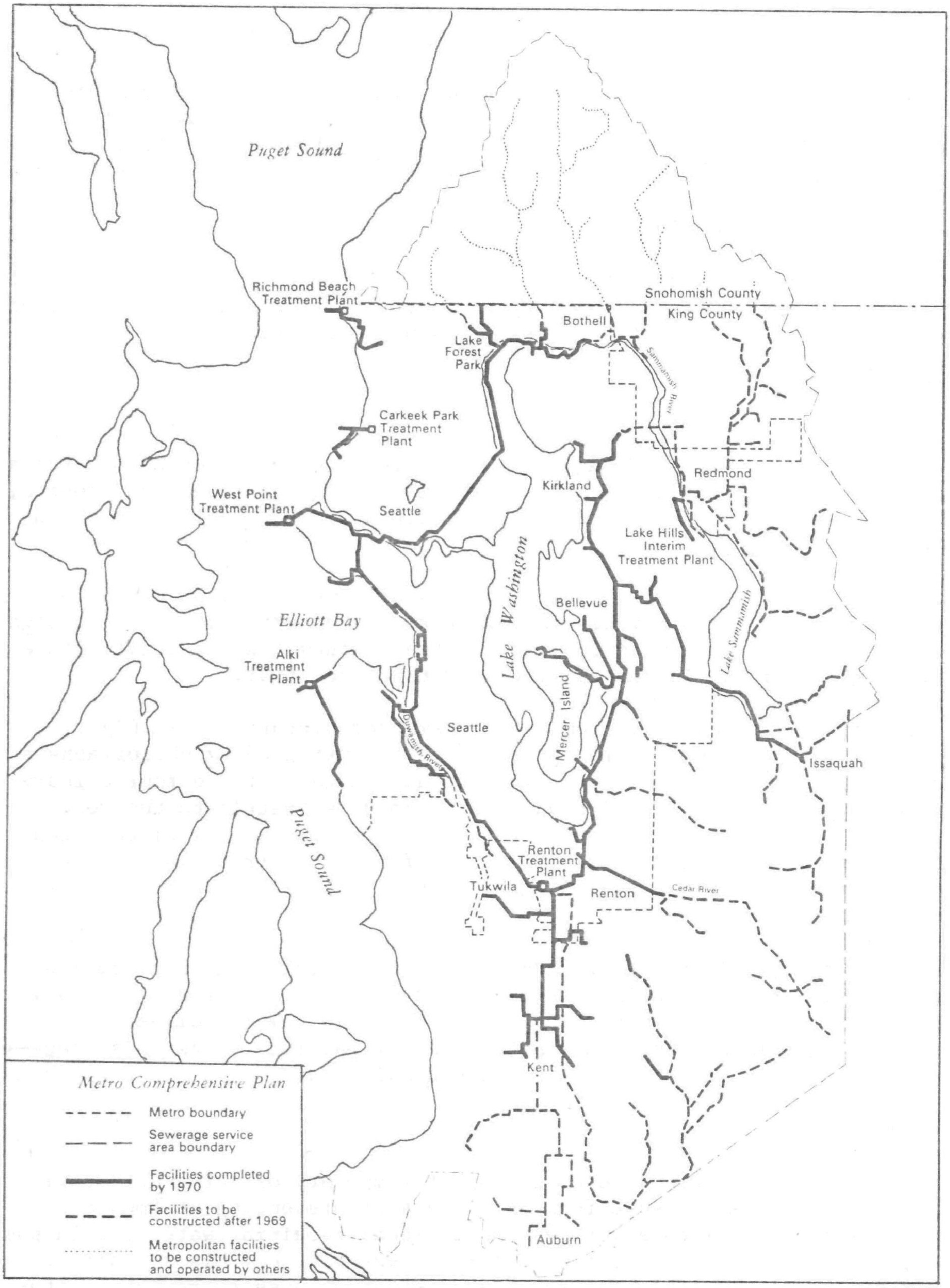
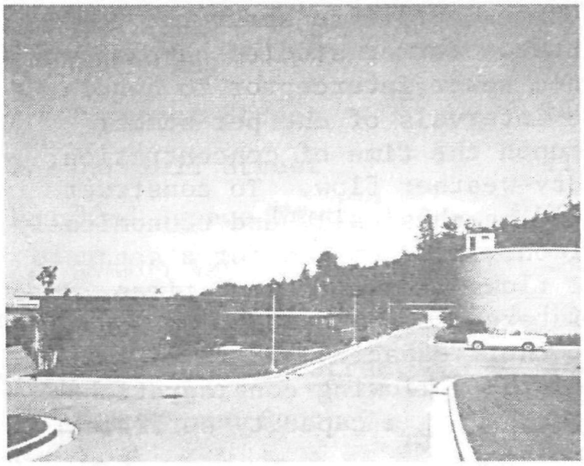


Figure 1. Facilities Expansion

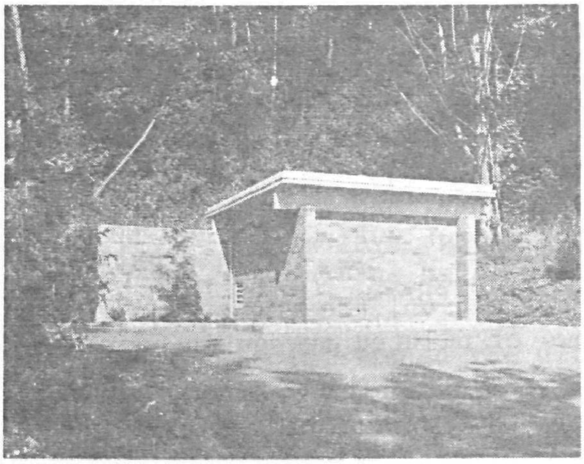
A. Pipeline Laying

B. Tunnel Construction

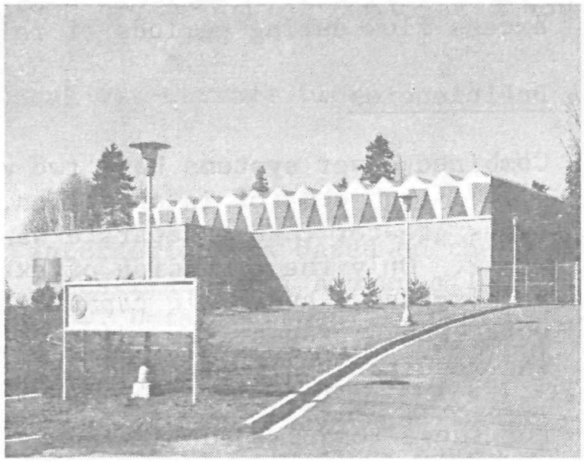


C. Richmond Beach Treatment Plant

D. West Point Treatment Plant



E. Regulator Station



F. Pump Station

Figure 2. Examples of New Facilities

The Brown and Caldwell report (1) recommended, as an interim solution prior to sewer separation, that some 34 storage tanks averaging 1.2 million gallons each be constructed underground along the western shoreline of Lake Washington at points where tributary drainage areas connect to the main interceptor line. The planned stormwater holding tanks were essentially a "stop-gap" measure until sewer separation was financially feasible. (28).

Storage holding tanks will have to be considered as one of the alternative approaches to regaining system storage in the future when population and industrial growth have encroached upon the current excess capacity built into the collection system.

System Expansion Design

Of the expansion projects actually undertaken, a major problem confronting Metro in 1960 was the sizing of interceptors to serve the combined sewer system within the City of Seattle. Former studies have shown that, for the Seattle area, a combined sewer interceptor to handle the flow from storms with recurrence intervals of one per summer needs to have a capacity, depending upon the time of concentration, of some 30 to 60 times the average dry-weather flow. To construct an interceptor of such dimension would be physically and economically unrealistic. As a matter of comparison, interceptors for a separate system are usually designed for peak flows of two to four times the average dry-weather flow. The interceptors had to be designed to afford the maximum utilization of their capacity and to minimize stormwater overflows, keeping in mind the following considerations:

1. Construction of an interceptor having a capacity sufficient for the flow.
2. Partial or complete separation of a portion or all of the tributary area.
3. Construction of holding tanks at overflow points to store excess flow during periods of rain.

Deficiencies

Combined sewer systems have two major deficiencies or drawbacks:

1. The cost of interception, conveyance, and treatment is many times greater than a separate sanitary sewage system.
2. Only the provision of extremely large interceptor sewers and excessive hydraulic capacity in collection, treatment, and disposal works would prevent periodic overflows of diluted sewage in stormwater and resultant pollution of adjacent waters.

For these reasons, the design criteria were based on the assumption that all new areas will be developed with separate sanitary systems and older combined systems eventually will be separated partially or totally. The combined sewer trunks listed in Table 1 had to be intercepted.

TABLE 1

Unintercepted Combined Sewer Trunks (1958)

	Sewer	Service Area (acres)	Trunk Size (inches)	Flow (MGD)[a] DWF	PWWF
1.	Hanford Street	2,900	150 x 100	4.6	308
2.	Lander Street	610	96	1.5	200
3.	Connecticut Street	640	72	1.6	110
4.	King Street	156	48	2.0	48
5.	Madison Street	17	36	0.4	40
6.	University Street	63	49	2.0	130
7.	Vine Street	60	48	0.1	45
8.	Denny Way	1,170	72	2.5	66
9.	Prospect Street	140	30	0.3	49
10.	Garfield Street	210	20	0.3	210
11.	32nd Avenue West	1,400	42	2.0	147
12.	Avalon Way	480	30	0.9	65
13.	Chelan Avenue	1,825	48 x 30	3.0	114
14.	West Michigan Street	210	18	0.9	33
15.	8th Avenue South	180	42	0.5	29
16.	10th Avenue South	130	42	0.3	21
17.	Misc. small trunks (7)	309	15	1.1	13
	Total - (24 outfalls)	10,500	--	24.0	1,430

[a]DWF refers to dry-weather flow; PWWF, peak wet-weather flow.

Interceptor Capacity Analysis

The design capacity for combined sewer interceptors is based on the sum of peak domestic sewage flow, peak industrial flow, and an allowance for infiltration and stormwater inflow. Detailed population and loading studies established the ultimate design flows for domestic and industrial wastes. The Seattle area has allowed a maximum stormwater and infiltration inflow of 3,200 gallons per acre per day (gpad) under winter conditions in existing sewer lines. Inflow allowances have been reduced to 1,100 gpad maximum for new sewer construction. Detailed rainfall analyses assist the engineers in determining overflow frequencies and volumes and, therefore, probably have the greatest significance in interceptor design.

In view of the importance of overflows to the subject matter of this report, some additional detail concerning the interceptor capacity analysis will be repeated from the Brown and Caldwell report. (1) The rainfall analysis shown in Figure 3 and the assumed average values for time of concentration and per capita sewage flow provide the basis for calculating the frequency of overflow from interceptor sewers of various capacities. The effect of interceptor capacity on frequency of overflow is then plotted in Figure 4.

To establish the quantity as well as the frequency of overflow, a statistical study is summarized in Figure 5 (valid for interceptors or holding tanks). The summary shows the percentage of sewage overflow, occurrence of rainfall, and percentage of total sewage not intercepted for the full year. As shown, the total quantity not intercepted is relatively small, even with an interceptor designed to carry only two times the average dry-weather flow of sanitary sewage and ground water. To the engineer, it is also evident that the increase in percentage of sewage intercepted with larger interceptors is slight. By increasing the interceptor capacity from two to five times the dry-weather flow, the quantity of sewage intercepted will be increased during summer conditions only from 98.4 to 99.4 percent while the interceptor capacity has increased to 50 percent. To the design engineer, there is no economic justification for increasing interceptor size to prevent the last small portions of overflow. To the water quality purists, ecologists, and the growing number of concerned individuals, the "minor" overflows remaining are a significant source of pollution.

The Recommendation

After careful analysis of all design considerations, the engineers recommended that the large interceptors to be built between 1960 and 1970 should have a capacity of approximately three times the dry-weather flow. This recommendation was qualified by stating the policy that future additions to the system must be separated and that the existing combined sewer areas should also be gradually separated. The effect is that the interceptor will have many sanitary sewage systems directly tributary to it and will therefore contain a higher percentage of sanitary sewage than the combined sewer trunk lines that are also tributary. Therefore, the engineers stated that when overflows did occur from the combined sewer portions, such overflows would be from the stormwater trunk rather than the interceptor itself. This then leads to a discussion of the method of connecting trunk sewers to interceptors.

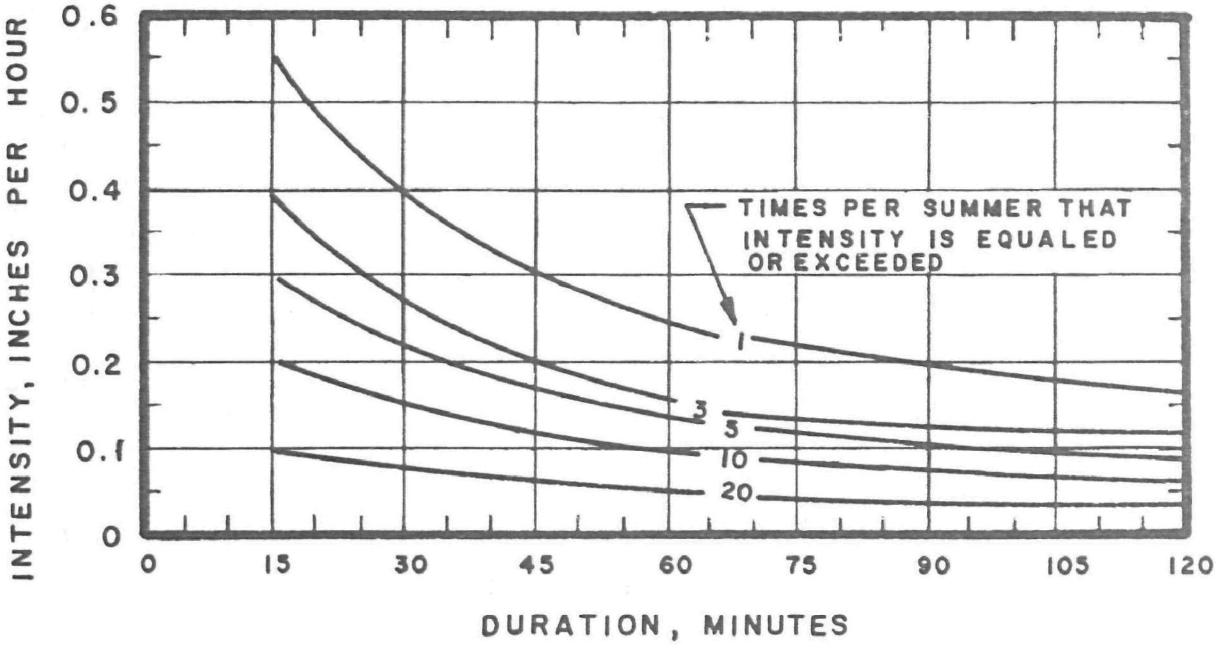


Figure 3. Summer Rainfall Intensity

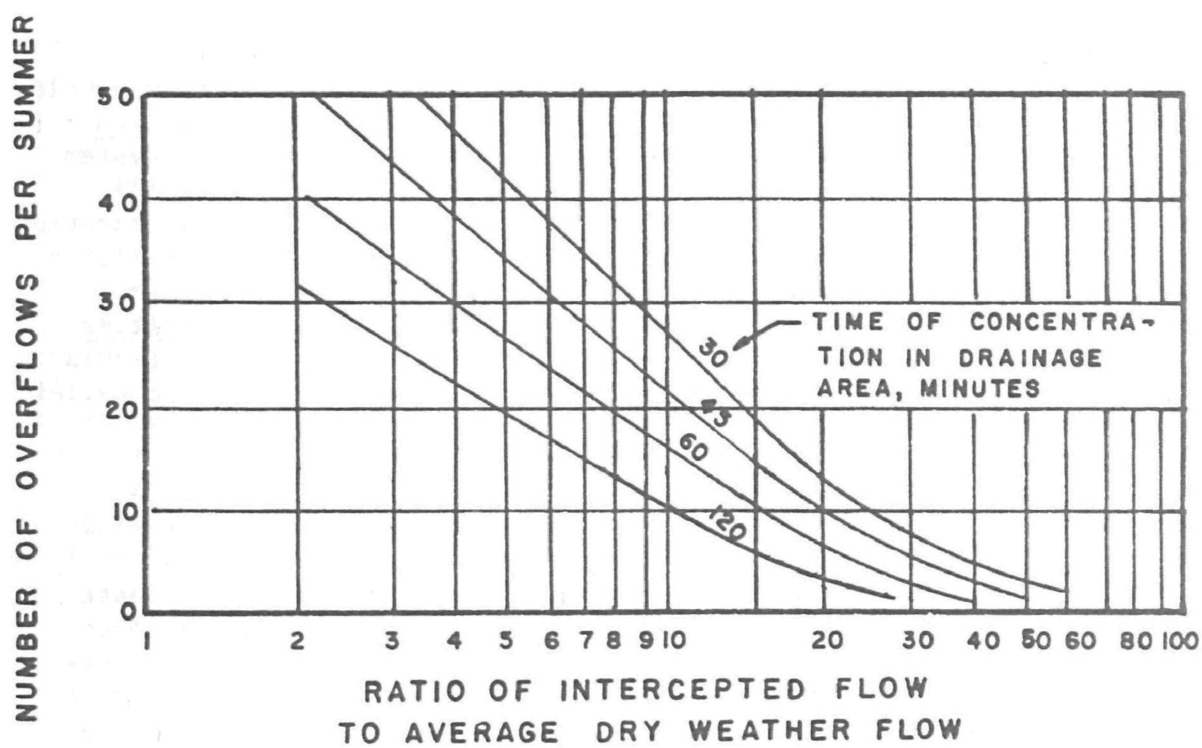


Figure 4. Interceptor Capacity and Overflow Frequency

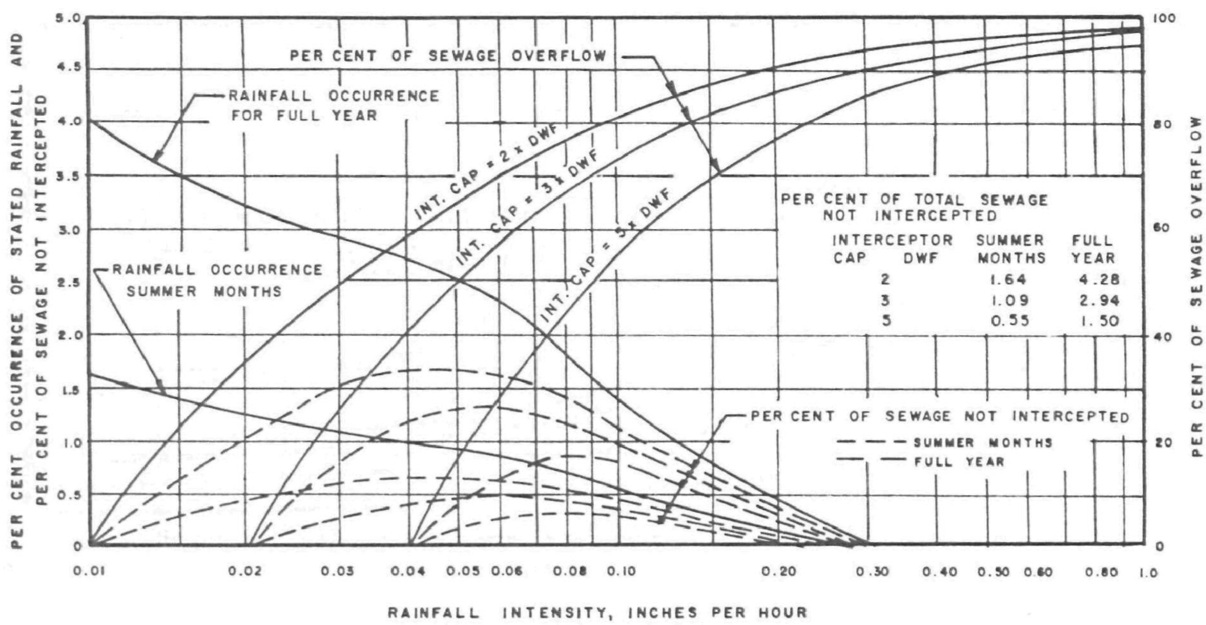


Figure 5. Interceptor Capacity and Overflow Quantity

REGULATION INCREASES STORAGE

The regulator at the physical location of overflow release from a combined sewer system might not be contributing to the overflow problem. The APWA report entitled Problems of Combined Sewer Facilities and Overflows--1967 (9) points out that deficiencies in the sewer system may be such that improvement of the regulator facility alone will not significantly reduce pollution. However, few systems will function effectively with minimum pollution impact if the regulator facilities have not been properly chosen and adequately maintained. A more recent report entitled Combined Sewer Regulator Overflow Facilities (19) indicated that the above statements are true whether the regulator is simple or highly complex or whether it is used strictly as a relief point or functions in conjunction with system storage.

As is common practice in the design of combined systems, Seattle sewers have overflow and bypass structures whereby wet-weather flows in excess of intercepting sewer and pumping station capacities are diverted to convenient points of disposal. Regulators in the Seattle system reflect most of the various designs that have been developed during the history of combined sewer systems. Stationary regulators are represented by the simple short weir in the bottom of an overflow manhole and the more complex side weirs, leaping weirs, and orifice plate design. More sophisticated mechanical regulators and electronic controls are also installed at various locations in the system. Although the majority of these structures are incorporated in trunk lines leading to intercepting sewers, some are also located on the interceptors.

Pre-1960 Regulators

Theoretically, overflow weirs in use in Seattle are designed to function when the flow in the sewer reaches from five to nine times the average dry-weather flow. (1) Because the overflow weir crests generally are set at a height of about 1/4 depth of the upstream sewer, overflowing easily begins when the ratio of stormflow to sanitary flow reaches 2:1, or even less. Mechanical regulators of the Brown and Brown type (29) were first introduced in the Elliott Bay Interceptor line about 1938. In addition to the unsatisfactory maintenance practice established after years of operating these float-controlled regulators, engineering studies in 1960 (3) showed that two regulators allowed less than 3% of the total trunk flow to enter the interceptor even under perfect operating conditions, an amount considerably beneath interceptor capacity. It would appear that storage was not a major consideration in the design of these older regulator facilities. Figure 6 illustrates the storage volume that can be gained by replacing a weir regulator with a motorized gate regulator station such as the one shown in Figure 7.

Sluice Gate Regulators

The simplest, least expensive means of intercepting combined sewer trunks is by means of overflow weirs. Because the peak sanitary sewage flow is only about 5% of the total flow in the trunk under stormflow conditions, the usual weir design would permit overflows to occur before the capacity of the interceptor is reached and before the storage capacity available in the trunk was fully utilized. The problems of fixed weir overflows in Seattle are compounded by tidal fluctuations (11 feet mean and 19 feet maximum), which dictate that any such weir be high enough to prevent the entry of salt water to the interceptor. This situation almost precludes the use of fixed weirs because of the extreme difficulty in relieving the combined sewer system during storms while preventing salt water backflow into the system during dry weather and high tides.

To provide fully for the maximum use of interceptor capacity and minimum occurrence of stormwater overflows requires a design using positive mechanical means of control. The design adapted by Metro for interception of combined sewers provides this control. Thus, it is now possible to make maximum use of the trunk storage capacities as shown in Table 2. Interceptor storage potential for selected lines are shown for comparison.

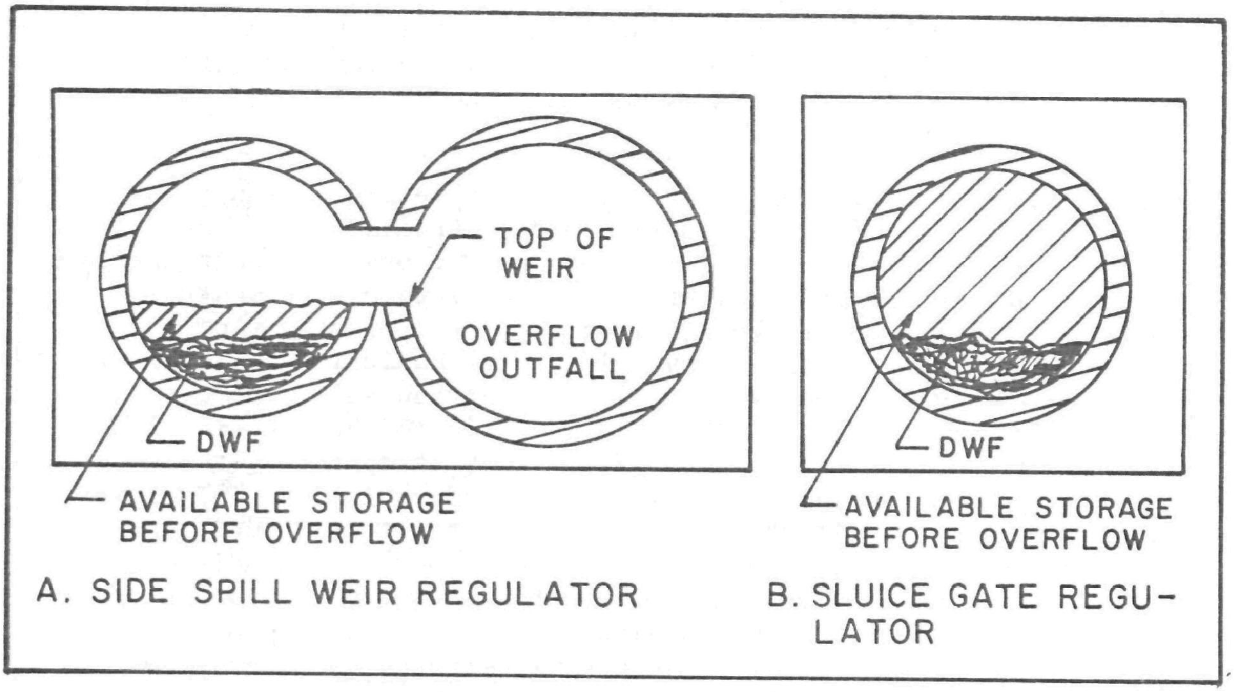


Figure 6. Storage Gained by Gated Regulators

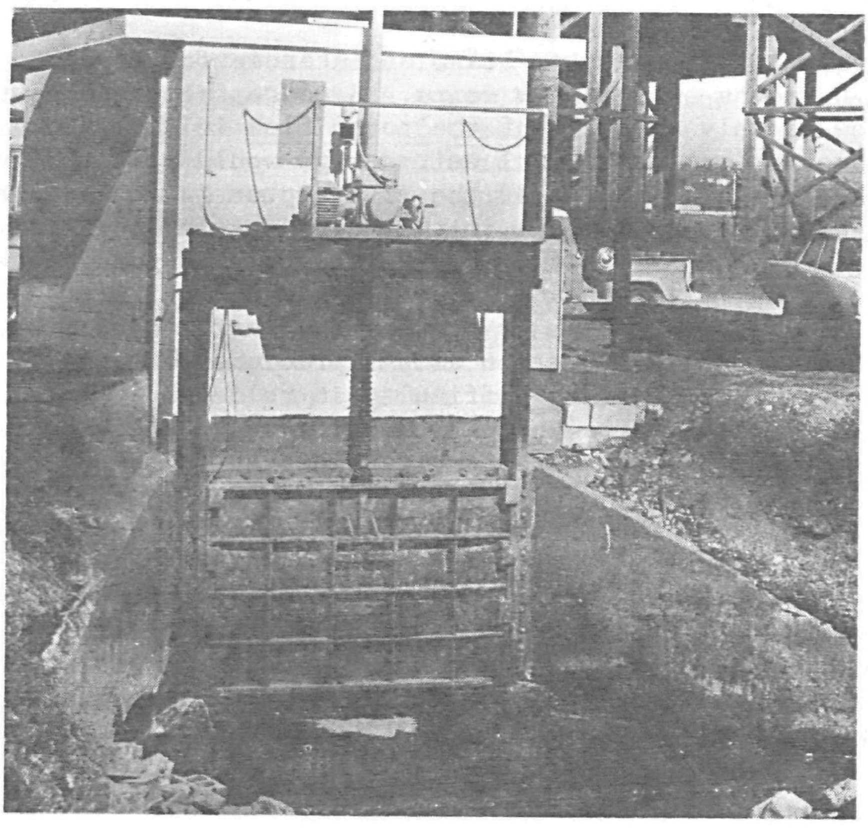


Figure 7. Typical Gate Regulator

TABLE 2

CATAD Storage Potential

I. Trunk Storage

Station	Maximum Safe Storage (MG)	Average Dry-Weather Flow (MGD)	Maximum Storage Time (hours)[a]
Eighth Avenue South	0.5	0.8	15.0
West Michigan Street	-	0.9	0.2
Chelan Avenue	0.4	3.0	3.2
Harbor Avenue	-	0.9	0.5
Norfolk	0.4	5.8	1.7
Michigan	1.2	1.0	28.8
Brandon	0.5	1.3	9.2
Hanford	3.8	4.6	19.9
Lander	1.4	1.5	22.4
Connecticut	0.8	1.6	12.0
King	0.1	2.0	1.2
Denny Way	0.8	2.5	7.7
Lake City Tunnel	6.5	10.0	15.8
II. Interceptor Storage Upstream from Pump Stations			
West Marginal	0.3	3.6	0.8
East Marginal	1.2	16.8	1.7
Duwamish	2.0	24.0	2.0
Interbay	9.3	35.0	6.4
Matthews Park	2.6	8.0	7.8

[a]For DWF only--Storage will reduce as average flow increases

The regulator station at each combined trunk sewer to be intercepted is provided with two automatically operated sluice gates of the modulating type. Figure 8 illustrates the typical underground regulator stations which were first constructed where the Elliott Bay Interceptor meets the Norfolk Street, Michigan Street, and Brandon Street trunk lines.

The location and function of these gates are as follows:

1. Regulator Gate. This gate is located on a line connecting the trunk to the interceptor. It is designed to regulate flow from the trunk so as not to exceed a selected depth in the interceptor. Under dry-weather flow conditions, the gate is fully opened and all sewage flow in the trunk is diverted to the interceptor. Under stormflow conditions, the gate is closed to the extent necessary to maintain the preset water level in the interceptor.

2. Outfall Gate. This gate is located on the stormwater overflow line from the trunk. It is designed to retain sewage in the trunk to utilize the full potential for storage. Thus, when the flow in the trunk is equal to or less than that being diverted to the interceptor through the regulator gate, the outfall gate remains closed. As the flow in the trunk increases, the gate remains closed until the preset water level in the trunk is reached, at which time it opens as necessary to maintain this level. Under peak storm conditions, the gate will be fully open. An overriding control prevents the gate from opening when the tidal elevation exceeds the water surface elevation in the trunk.

Control of the gates is based on water level elevations in the incoming trunks and in the interceptor. Air bubblers or other level sensors are used to sense the water level. This information is then transmitted to a controller which converts the pneumatic signal to an electronic signal. The gates are then actuated, either to close or open in increments, in response to changes in the water surface elevation in the trunk or interceptor. Electric motor drives or hydraulic cylinders are used to move the gates.

Benefits From Sluice Gate Regulators

An example of the effectiveness of the sluice gate regulator in reducing overflows is demonstrated by an engineering study (30) performed in 1969, which recommended construction of this type of regulator station at Dexter Avenue. The upstream trunk has a capacity of roughly 162 mgd. Downstream of the 30-foot-long side spill weir, the interceptor sewer has a capacity of 38 mgd. Overflow begins to occur when sewer flow reaches about 32 mgd and all flow in excess of the capacity of the downstream pipe is discharged to Lake Union at the foot of Galer Street. The 1969 study assumed a regulator station would be constructed near the side weir to store, if necessary, in the large (84-inch) interceptor upstream of the existing weir.

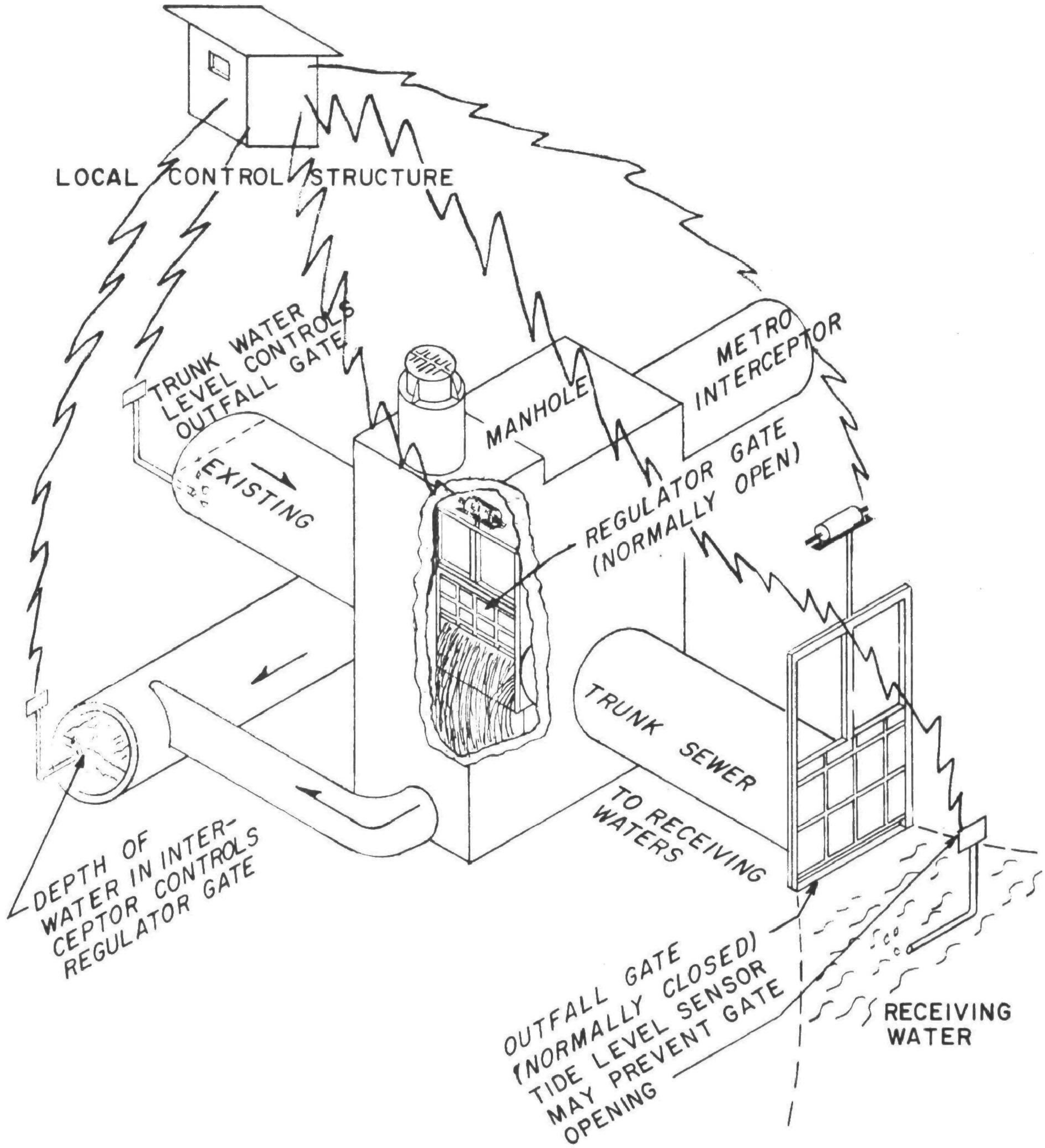


Figure 8. Underground Regulator

Depth of flow in the interceptor was monitored just upstream from the overflow site; the results of these measurements are plotted in Figure 9. During the study period, the flow exceeded the 38-mgd capacity of the downstream section eight times on five separate days and overflowed more than 6.4 million gallons of combined sewage into Lake Union. The mass hydrograph diagram was then constructed from flow calculations, assuming that a regulator station would be allowed to store all flows in excess of 38 mgd, up to the capacity available in the upstream trunk assuming a 4-foot surcharge at the regulator. All volumes in excess of this amount would be overflowed to Lake Union. The mass hydrograph showed that a gated regulator station would have eliminated all but one overflow, a reduction in frequency of 87.5%. The quantity overflowed to the lake would have been reduced to 2.7 million gallons or 42% of the quantity released over the existing simple weir. These percentages cannot be applied indiscriminately to all locations because of dissimilarities in sewer capacities, overflow levels, upstream sewer reaches, and the characteristics of the tributary area.

West Duwamish Interceptor System

The West Duwamish Interceptor system is an example of how regulator storage might be increased by constructing regulator gate structures that provide no storage themselves but, by controlling trunk flow, allow extra capacity at other stations within the system. The West Duwamish system, shown schematically in Figure 10, consists of four regulators, one pump station, and interceptor sewers that serve about 6,200 acres of residential area and 1,400 acres of industrial area. Table 1 indicates that the four main tributary trunk sewers have a hydraulic capacity in excess of 250 mgd. However, interceptor design was based on sanitary flow, which was computed as 36 mgd. Either separation or regulation was necessary to divert excessive stormflow to nearby receiving waters. The final enginneering design allowed for either or both of these alternatives at each regulator station. When separation has been completed in tributary drainage areas, connections can be made to existing pipe stubs to bypass the then unnecessary regulator stations, or the stations could continue to function as merely an emergency release point in cases of sewer line damage or plugging and to regulate flow during dry weather for peak flow attenuation.

The Eighth Avenue South regulator, also shown in Figure 10, was constructed to divert sanitary flow from two outfalls at 8th Avenue and 10th Avenue into the interceptor. Some 15 hours of storage time at dry-weather flow is available at this regulator, as shown by Table 2. The Chelan Avenue regulator also has a relatively flat tributary drainage area where considerable storage is available. The system design between the Harbor Avenue regulator and Chelan Avenue regulator is unique in that the interceptor passes through the latter after being regulated at Harbor Avenue. This unusual design

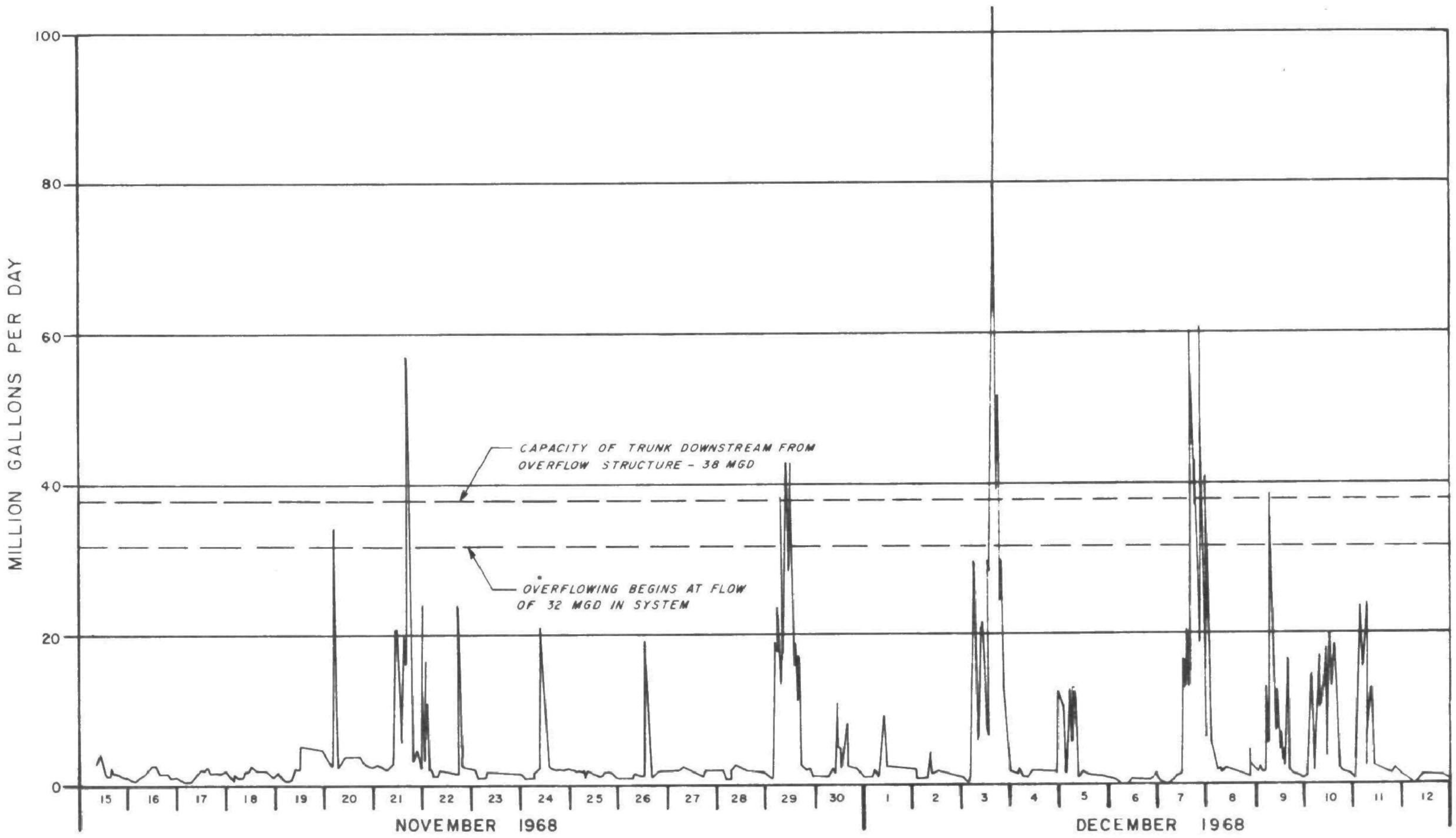


Figure 9. Dexter Overflow Reduction Hydrograph

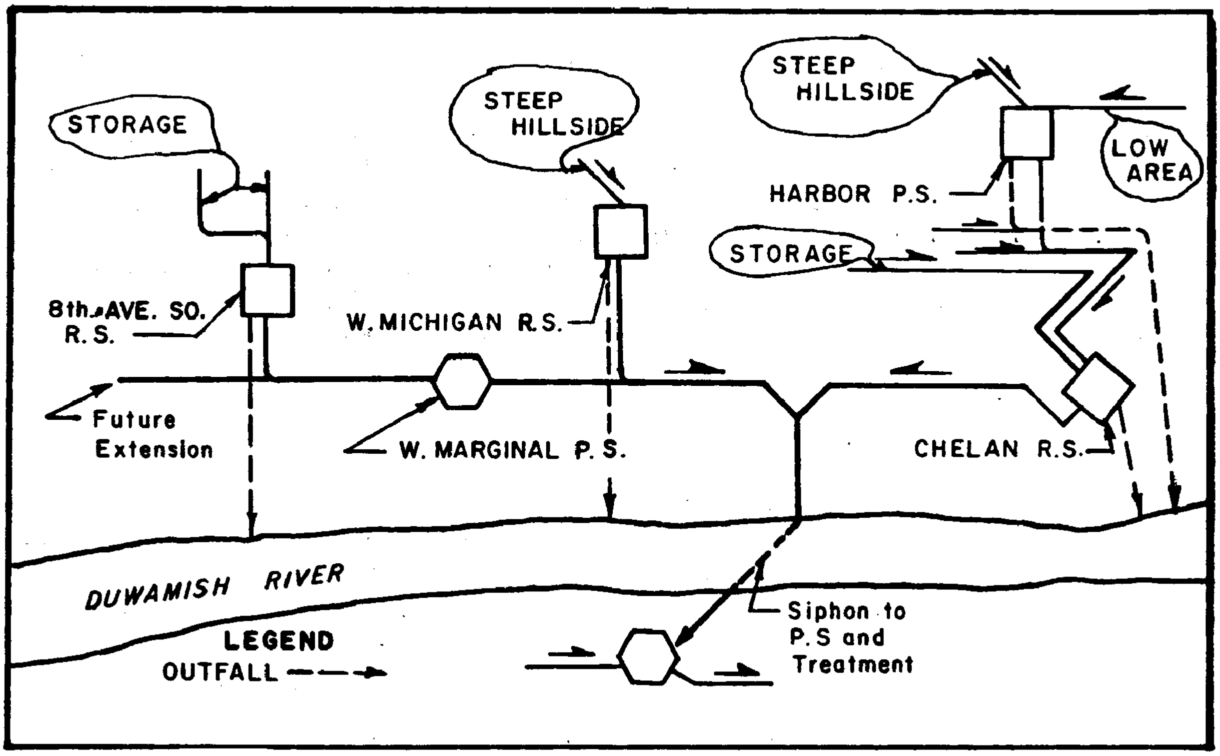


Figure 10. West Duwamish System Schematic

was brought about because engineers found that existing combined sewers could be tapped and could adequately handle flow from Harbor Avenue without requiring the construction of a new interceptor line the entire distance between the two stations. Both the Harbor Avenue and West Michigan Street regulator stations are located at the bottom of relatively steep hillsides where essentially no storage is available. Mechanically operated gates at these two locations could reduce overflows during a local storm in either of the watersheds. This would be accomplished by storing behind other regulators, thereby allowing greater flows into the interceptor from either of these two locations where no storage is available. Because of the limited storage upstream at Harbor Avenue and West Michigan Street, periods of frequent overflows often result. Therefore, to justify construction of these control stations, the overall optimum storage within a total system must be considered. Other factors may affect such a decision. For example, at Harbor Avenue, a regulator was also needed because of the low residential area lying directly north where flooding would occur if a combined sewer relief point were not provided.

It was decided that each of the four regulators would have mechanically operated regulator and outfall sluice gates so that precise computed flow measurements could be made in the future at all four points, even though computer control was not contemplated at West Michigan or Harbor Avenue. Also, tidal effects at three stations require that outfall gates be constructed. At West Michigan an outfall gate was not required for tidal purposes, but was installed mainly to reduce the amount of grit and other inorganic materials that otherwise would contribute to pipe damage and reduced treatment process efficiencies. Each station was provided with a bypass line which is used mainly when heavy maintenance is being done on sluice gates; the bypass lines are also available for use in the future when sewer separation is completed.

Gate Station Storage

It was previously pointed out that the new interceptor system construction shown in Figure 1 had been built with sufficient size to adequately carry the ultimate flow of the tributary drainage area. At no point in the Metro sewage collection system is this more evident than in the Lake City tunnel system, shown schematically in Figure 11.

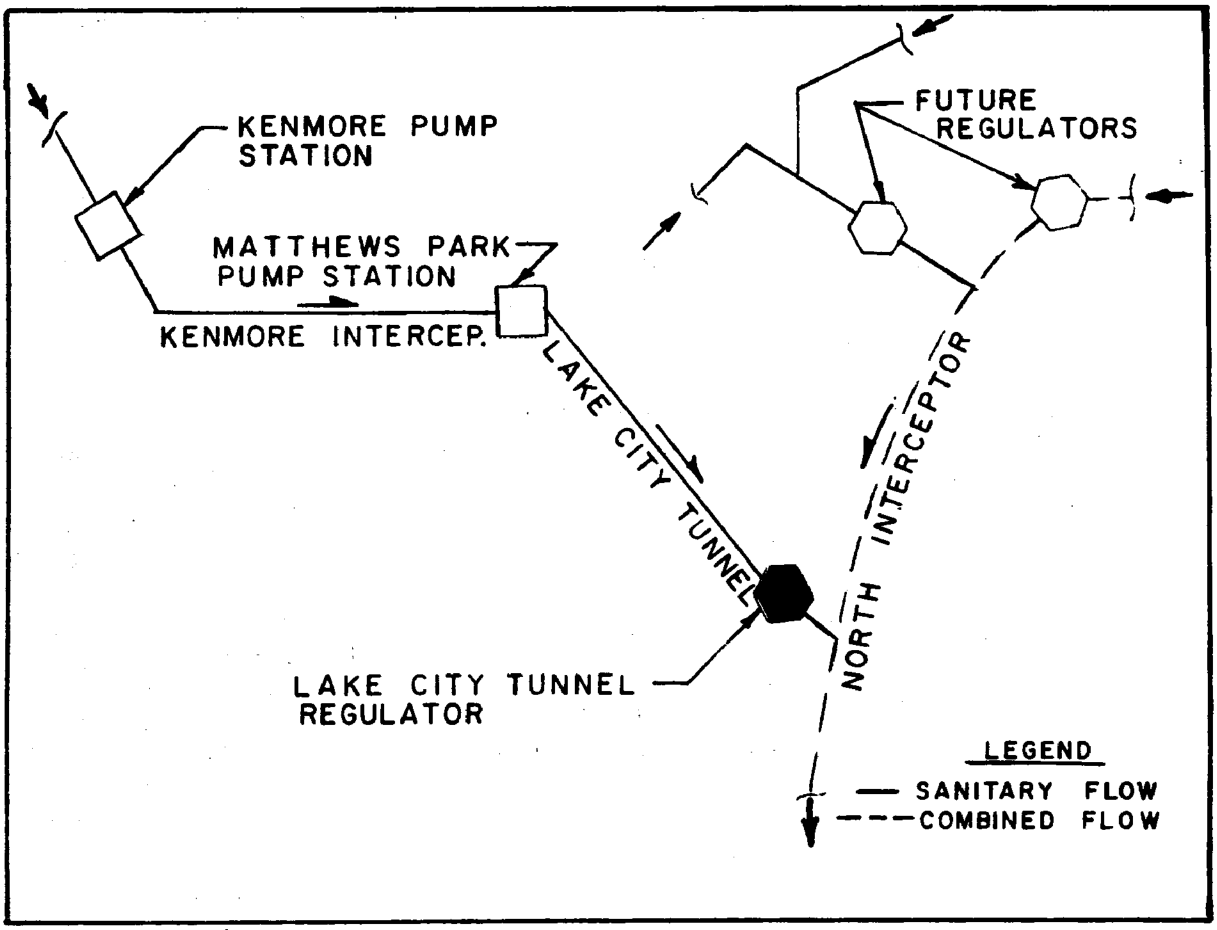


Figure 11. Lake City Tunnel Schematic

The Lake City tunnel was completed in 1968 to accept separate sanitary flow from the tributary area north and northwest of Lake Washington. Extending for 17,200 feet, the 96-inch-diameter tunnel has a hydraulic design capacity of 160 mgd, but actually now carries only 40 mgd at peak wet-weather flow and an average 10-mgd dry-weather flow. Thus three-fourths of its capacity is unused, making in effect a long narrow reservoir that could be used for temporary storage of sanitary sewage, when necessary.

At present flows, by closing the regulator gate at the south tunnel portal and making use of the 6.5 million gallons of available storage, all 10 mgd of dry-weather flow through the tunnel can be stored for approximately 16 hours without making use of other available upstream storage. By shutting down the two pump stations upstream of the Lake City regulator, storage times of 45 hours and 74 hours can be obtained. Such storage times would be more than adequate to allow the downstream interceptor to return to normal flow levels following a storm, thereby reducing the probability of overflows in that downstream interceptor.

With these facts in hand, Metro approached the FWQA in July of 1967 with a request to use demonstration grant contingency funds to construct the Lake City gate control structure at the south end of the tunnel. The station is now in operation.

The North Interceptor provides additional storage potential, and, on the basis of a detailed hydraulic study of that system (30), design of four additional sluice gate regulator stations has been authorized. Construction is expected within the next 5 years.

STORAGE FROM REDUCED STORM INFLOW

Through system expansion and optimum application of regulation techniques, it has been demonstrated that engineers have extracted a great deal of storage out of the existing Seattle combined sewer system. However, the improvements that have been discussed thus far have mainly affected the large trunk lines and interceptor lines, which now are the responsibility of Metro. The City of Seattle owns and operates the many small trunk lines and collector sewers, many of which have points of overflow that have not been affected by the improvements made to the system. Overflows still are common from the smaller systems at many points; therefore, all the innovative design and optimum operation and maintenance efforts are somehow dulled by subsequent adverse effects on the receiving water. It follows then that any effective plan to eliminate or reduce the frequency of combined sewer overflows throughout the entire city must provide additional capacity in the sewage system by eliminating all possible sources of storm drainage through a combination of infiltration reduction methods and some degree of sewer separation. Any effort to reduce storm inflow to the combined sewer system will improve the storage availability in both the local sewer area and the metropolitan collection system, thereby benefitting the entire population by reducing or even preventing these overflows.

Sewer Separation

Construction

Seattle voters in 1968 approved a bond issue to provide for separation of sanitary sewage and storm drainage in the city's combined sewer system over an area of 18,000 acres. The approved separation area covered about half the total combined sewer system and slightly less than a third of the city's total land area of 52,000 acres (31). The areas to be separated are shown on Figure 12. Cost details for 1958 for two different areas can be found in Appendix D. Design of additions was predicated on, as a minimum, the City of Seattle Standard Plans and Specifications. (32)

Present Status

About 330 miles of storm drains will be installed. Of the 35 construction contracts awarded since the program began, 23 are complete. Of the 35 contracts, the city prepared plans for 9 and design consultants, 26. Cooperation among the agencies and private businesses involved has aided progress. (33) The present status of individual projects is summarized in Figure 13.

The new storm drains are sized to carry 100% of the design storm, even though the partial separation now being done intercepts only 70% of the stormflow. For a cost increase of 12%, storm drains will have sufficient capacity to pick up the remaining 30% of stormflow from roof and foundation drains, if studies indicate this action is necessary. However, the cost to connect these individual drains is estimated to be equal to or greater than the cost of the project now under way.

Beginning in 1953, the City of Seattle has enacted a series of ordinances that require all new construction or modernization of existing structures to provide for separation of storm and sanitary drainage. Therefore, as land use changes, complete separation will gradually be accomplished.

While the separation program is in progress, studies are being planned to investigate whether it is possible to raise or plug various combined sewer overflow weir points as a result of the decreased stormflow following completion of partial separation.

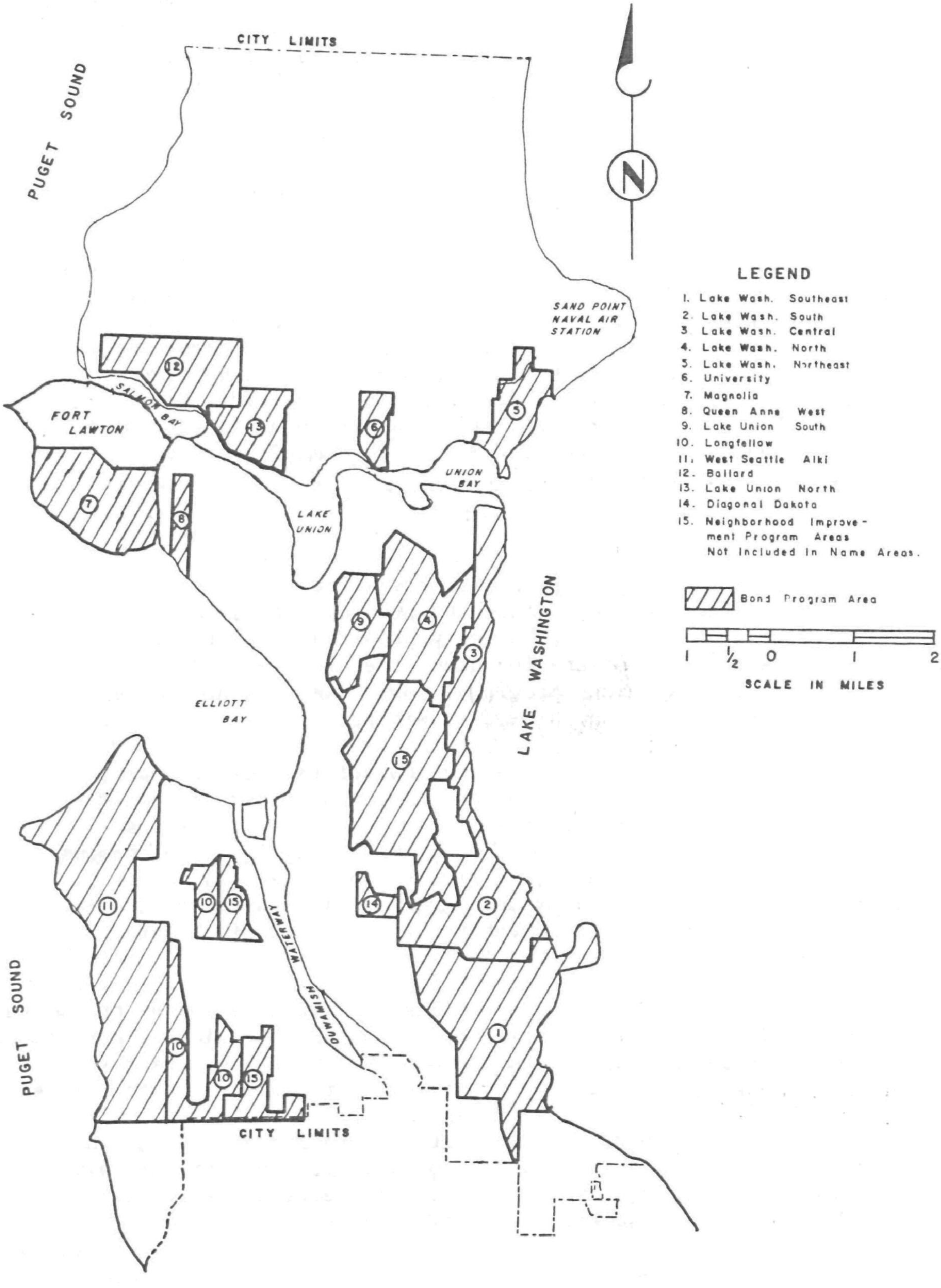


Figure 12. Combined Sewer Separation Areas

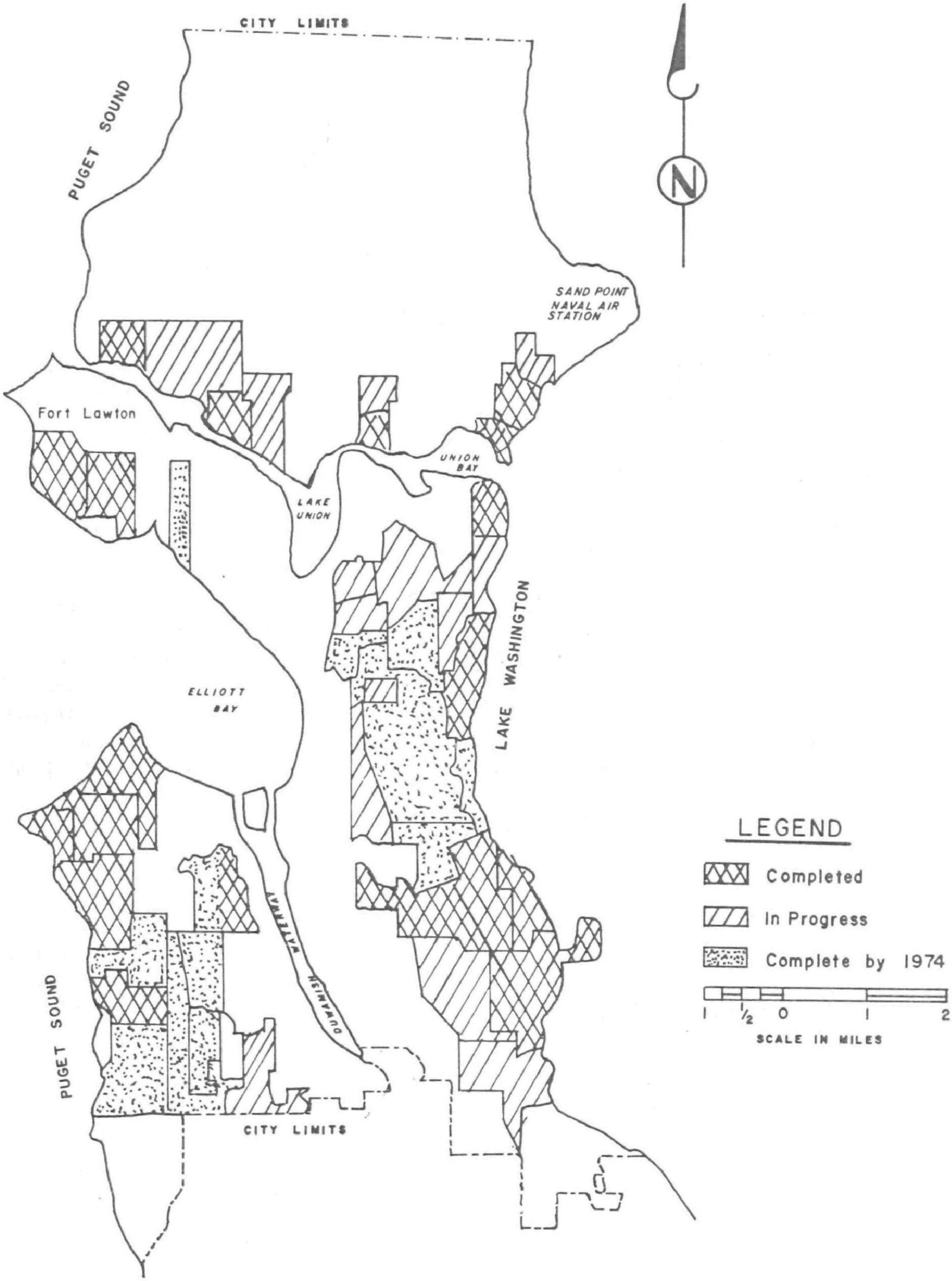


Figure 13. Separation Construction Status (March 1971)

Infiltration Reduction

The Problem Defined

Sewer system designers have long provided surplus capacity for ground water infiltration whether the capacity be provided in the form of an allowance based on an acreage of area served or the length of the line and its cross-sectional size. Typical infiltration specifications are presented in Table 3 from the book Sewers for a Growing America. (34) Permissible infiltration rates are the result of a balance between the cost of requiring tighter joints in a small sewer and the cost of a larger sewer with leaking joints. Actual infiltration rates are estimated based on the type of sewer pipes and mechanical joints, and are influenced by the age and physical state of repair of the pipeline and the number of illegal stormflow connections to a sanitary sewer. Figure 14 shows excessive infiltration that can lead to collapse of a sewer.

On an acreage basis, the Seattle metropolitan area has a wide variety of storm inflow and infiltration rates into various sanitary systems. The Bothell area of about 5,000 acres has an infiltration of about 5 gallons per acre per day (gpad) under the worst storm and runoff conditions. On the other end of the scale, the Lake City sewer area has an infiltration rate of as high as 2,000 gpad. Improved materials and quality control largely account for the improved infiltration experience of the former system, which was built about 10 years after the Lake City system. Metro experience indicates tighter joint specifications can be attained in practice, as modern construction techniques often limit infiltration to rates far below those allowed. Present Metro design allowable rates are stated as 300 to 600 gpad for infiltration and 0 to 500 gpad for stormwater inflow (lower of the two rates is for summer conditions; higher, winter).

Obviously, the waste of sewer capacity by excessive infiltration is a serious matter not only because overflows and sewer backups may result but also because allowances for infiltration require the use of larger and more expensive sewer lines and will result in more expensive pumping and treatment costs. The first problem then is to locate the source of excessive infiltration in a combined or sanitary sewer system.

Most infiltration and storm inflow enters sewers through loose joints and abandoned house connections, leaky manholes and manhole covers, and illicit sewer connections. Inspection on new construction work will generally limit illicit stormwater connections; older illicit connections have often been found using smoke tests and dye release tests. Such studies located many sources of illicit storm connections to the Lake City sanitary sewer. Corrections have already been made. A regular program of inspection, either by specially trained inspectors or film or television cameras, depending on sewer size, will locate other sources of storm or ground water infiltration to the sewer system.

TABLE 3

Infiltration Specifications

Source	Conditions	Allowable infiltration (gal./mi./24 hr.) Per in. dia.	8-in. pipe	10-in. pipe	12-in. pipe	24-in. pipe
(A) Consulting Engineers						
Greeley & Hansen	Average ground	-	5,000	5,000	5,000	5,000
	Wet, perv. ground	-	10,000	10,000	10,000	10,000
Metcalf & Eddy	Average	500	4,000	5,000	6,000	12,000
	Any short section	1,000	8,000	10,000	12,000	24,000
Havens and Emerson	-	500	4,000	5,000	6,000	12,000
Consoer, Townsend & Assoc.	-	200	1,600	2,000	2,400	4,800
Gannett, Fleming, Corddry, & Carpenter	-	500	4,000	5,000	6,000	12,000
William A. Goff	-	-	5,000	6,300	7,500	15,000
Buck, Seifert and Jost	-	-	7,000	8,800	10,500	21,000
Whitman, Requardt & Assoc.	-	250	2,000	2,500	3,000	6,000
O'Brien and Gere	-	-	1,400	1,750	2,100	2,450
John Baffa	Average[a]	-	4,000	5,000	6,000	12,000
Nussbaumer, Clarke & Velzy	-	500	4,000	5,000	6,000	12,000
(B) Cities and Districts						
Miami, Fla.	-	1,000	8,000	10,000	12,000	24,000
Milwaukee, Wis.	-	-	5,800	7,250	8,700	17,400
Minneapolis, Minn.	-	-	3,500	3,500	3,500	3,500
Portland, Ore.	-	0.5[b]	5,100	6,350	7,600	15,200
Seattle, Wash.	-	-	3,200	3,800	4,400	10,000
Syracuse, N. Y.	-	200	1,600	2,000	2,400	4,800
Tampa, Fla.	-	-	10,000	10,000	10,000	10,000
Tulsa, Okla.	-	-	25,000	-	-	-
Topeka, Kans.	-	1,500	12,000	15,000	18,000	36,000
Stamford, Conn.	-	-	1,160	1,300	1,600	-
Allegheny County (Pa.) San. Auth.	-	150	1,200	1,500	1,800	3,600
Washington (D.C.) Suburban San. Commission	-	-	5,000	6,000	7,000	12,000
Nassau County (N. Y.)	-	0.4[b]	4,000	5,000	6,000	12,000

[a]Short sections may be 100 per cent in excess.

[b]Per 100 feet.

Reference: Sewers for a Growing America (34)

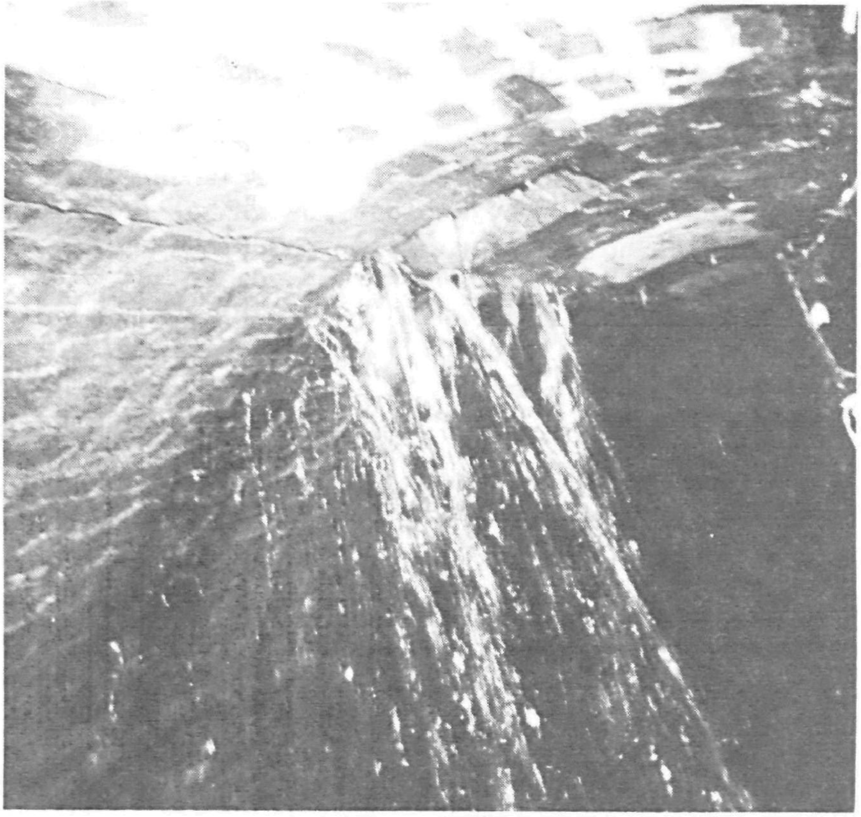


Figure 14. Sewer Infiltration from Broken Brick Arch Section

It has been found that as much as 150 gallons per minute may leak through a manhole cover. (35) Until recently the standard city manhole lid in Seattle contained as many as 30 separate ventilation and lifting holes, which allowed as much as 0.1 million gallons per day (mgd) of stormwater to enter the sewer from each lid with a depth of only 1 inch of water above the lid. (30)

Clean-Up Still Incomplete

Even with the sewer projects thus far accomplished, including the original local sewer system, the recently expanded interception lines and treatment plants, advanced automatic regulator operation, and stormwater separation projects, some pollution sources still remain today. Heavy localized storms continue to cause overflows, even within the larger Metro collection system. Power outages and other mechanical failures periodically result in a bypass of combined sewage to a nearby receiving water.

Storm drainage pollution, even in separated areas, may assume greater significance as the combined sewer overflow problem is reduced. Chlorination plants such as those being installed by the City of New Orleans (36), and methods of screening, sedimentation, and chemical-biological treatment are being studied for the Seattle area.

One large reservoir of system storage that may be utilized to prevent overflows still remains intact. The technique that must be used to obtain this last measure of storage is becoming known as "total system management." The simplest method of describing these small unused pockets of storage within a large combined sewer system is to describe the dynamic situation of an intense storm localized in one small drainage area within the system. The drainage area beneath the cloudburst is immediately saturated so that the regulator that transfers sewage from the full trunk line to the interceptor is forced to overflow to relieve the combined sewer system. Meanwhile, the adjacent drainage area with only partially full trunk lines is transmitting its entire flow to the nearly full interceptor.

Theoretically, by either routing flow from the saturated area to the dry drainage area before regulation or by making use of storage in the dry area, thereby allowing additional flow from the wet area into the interceptor, it will be possible to make maximum use of all storage within the system and minimize overflow to nearby waters. The difficulties in manually locating these pockets of storage within a total sewer system and of making flow calculations and predictions followed by manual adjustments of mechanical equipment are nearly insurmountable. Metro is now engaged in a 6-year study to determine whether a real-time computer and highly instrumented automatic pumping and regulation network will solve this problem of total system management and in effect maximize the storage available within a combined sewer system. This federally sponsored demonstration grant is described in following sections of this report.

SECTION V
MAXIMIZING STORAGE BY COMPUTER

REVIEW OF EXISTING CONTROLS

A review of the control procedures for motor-driven sluice gate regulator stations in the Seattle area will help to explain how storage within the combined sewer system can be maximized. The relationship between interceptor and trunk water levels and regulator outfall gate positions is outlined in Section IV, "Sluice Gate Regulators." Setpoint control elevations were also briefly discussed. The important point here is that the trunk setpoint is being manually established at a regulator station so that at the worst possible combination of high tide, heavy stormflow in the trunk, and a fully laden interceptor line would still permit combined flow from the trunk line to escape from the sewer system via a fully opened outfall gate without any resultant flooding or backup conditions upstream in the trunk sewer drainage area. Once the setpoint has been established, it remains essentially fixed through the various seasons, unless manually altered.

It would be difficult and time-consuming to have a person or persons visit each of the widely separated regulator sites to make adjustments in the setpoint to compensate for the dynamically changing water level conditions occurring during each storm. But if it were possible to do this, adjustments in the setpoint could allow a higher water elevation in many instances so that additional storage could be gained and overflows reduced or prevented.

By enlarging upon some basic rainfall information, it can be shown how computer control of an entire sewage collection system might be applied to gain additional internal storage. Figure 15 is a bargraph of actual rainfall data for two summer storm types that occurred in the Seattle area during 1967. Storm A illustrates the traveling storm. Notice that although the total rainfall is fairly uniform over the five districts, the peak intensity (most critical for overflows) struck initially in the southwest and occurred nearly 2 hours later in the northeast. Storm B illustrates the localized storm, where rainfall was measured in the southeast and southwest districts only.

Figure 16 is a schematic explanation of how storage is maximized in a representative system of three regulators, assuming that rainfall intensities vary considerably from one drainage area to another. All regulators would normally appear physically nearly alike, but only one outfall line is shown for clarity. The illustration exaggerates storm conditions by concentrating all rainfall in the drainage area tributary to only one trunk. But, the theory can be logically extended to cover any situation where rainfall intensities are significantly different over separate drainage areas.

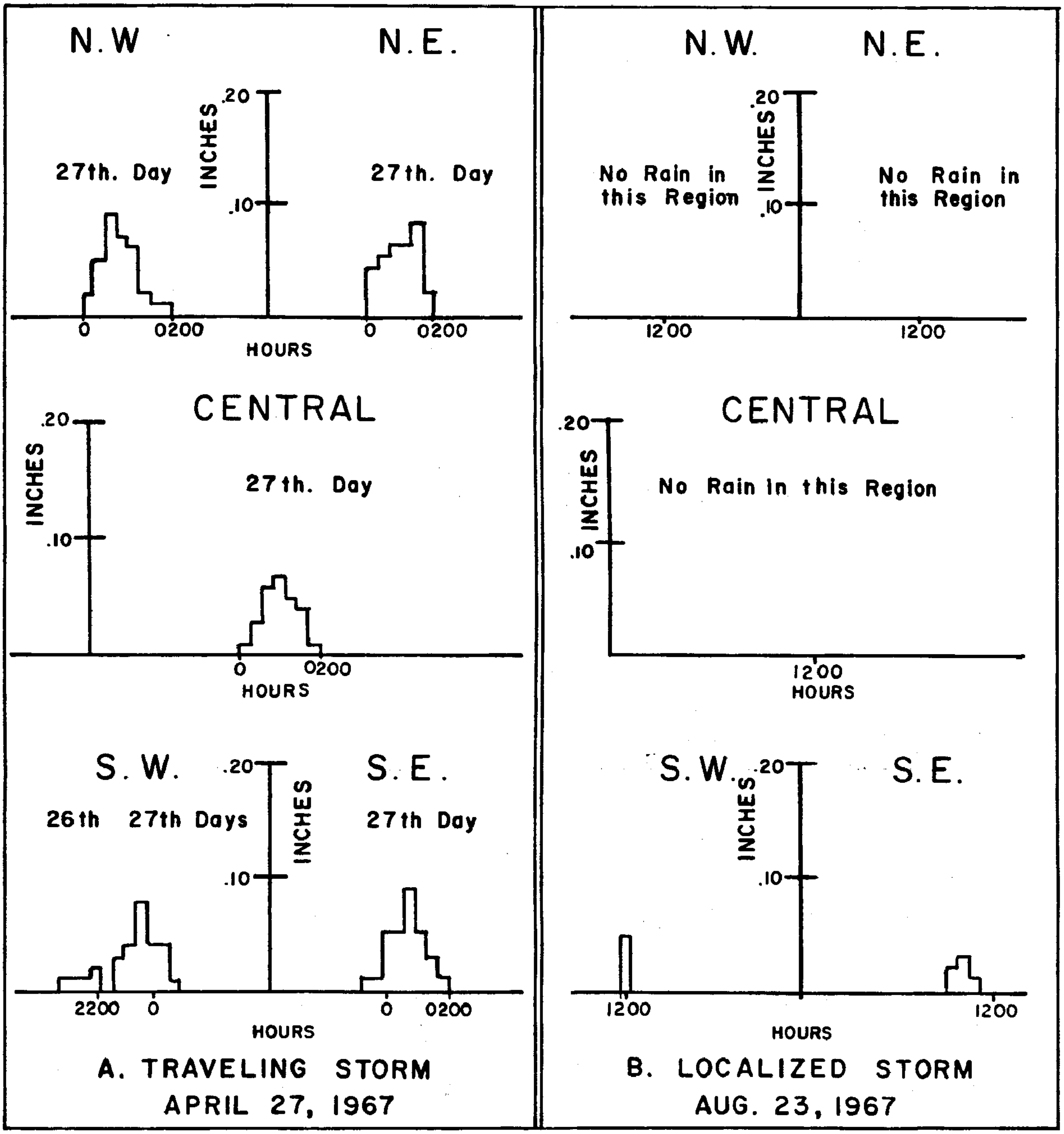


Figure 15. Summer Rainfall Distribution Patterns

Part 1 of Figure 16 shows a storm concentrated in one area. Under local control, gates operate to permit all trunks connected to the interceptor to divert the flow from each trunk into the interceptor and gradually fill the interceptor until storage is exhausted, resulting in an overflow from the trunk that is filled by the increased stormflow. With the proper application of computer control demonstrated by Part 2 in Figure 16, the regulator gates in all trunk lines not affected by increased stormflow are closed to store water in the trunks, thereby

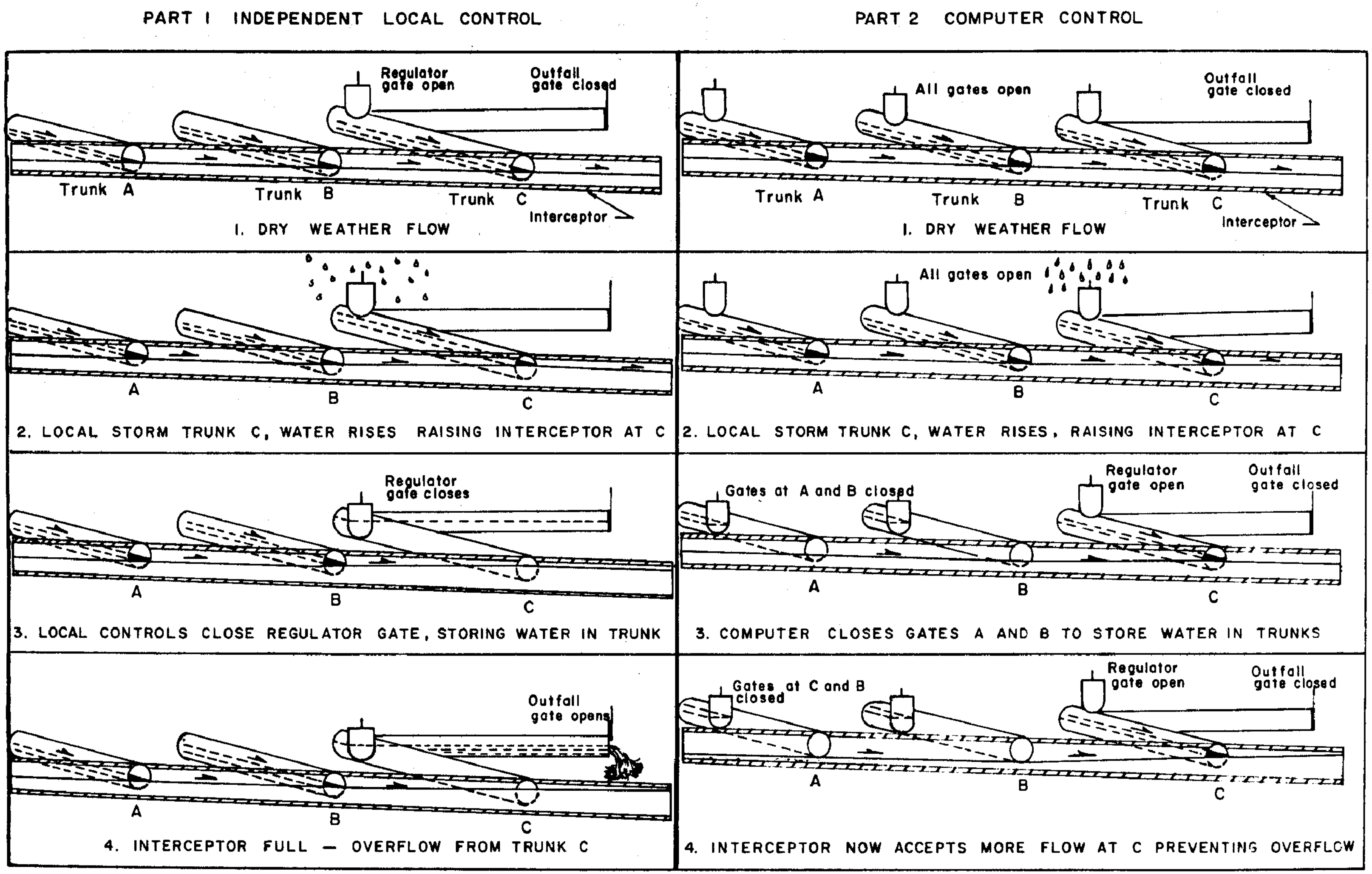


Figure 16. CATAD Theory

reducing flow into the interceptor and allowing greater amounts of sewage and storm water to drain from the trunk that is filled with storm runoff. The effective use of storage thus reduces or prevents overflow from trunk lines that carry the largest portion of stormflow to the interceptor.

This concept of maximizing storage throughout the system can be extended to interceptor lines where substantial storage capacity has been made available because the basic collection system is designed for ultimate projected sanitary flows. By considering the interceptor system as a number of trunk lines emptying into a common point, each of the branch interceptors could be gated so that sewage is stored in areas where total flow is small. The end result is the same as that suggested in Figure 16.

The Metro system is designed so that in some instances motorized gates and control structures have actually been installed in interceptor lines. However, storage can also be generated by controlling the pump stations that lift sewage from a low elevation to a higher elevation on a pipeline to allow continuation of gravity flow. By slowing or stopping the pumps at a station, the effect is the same as if a gate were being modulated to control flow and maximize storage within the interceptor itself.

Thus, with the proposed system of computer control of regulator station gates, interceptor gates, and pump station flow, it should be possible to make the ultimate maximum use of all storage within a combined sewer system. All these promising ideas were ultimately incorporated in the federal demonstration grant program proposed in 1966.

DEVELOPMENT OF CATAD SYSTEM

Mr. A.M. Rawn, former chief engineer with the Los Angeles County Sanitation Districts, has been credited with the original ideas for the use of trunk storage in combined sewer systems. His idea included a central console with pushbuttons to control some 50 storm gates in the Los Angeles County area to gain additional storage and prevent overflows.

Although the Rawn plan to gain storage through centralized control was not incorporated in the Metro first-stage, 10-year construction program begun in 1961, engineers did take into consideration the potential for future centralized controls. Considered during design of one of the first Metro construction projects (the Elliott Bay Interceptor south of the deactivated Diagonal Avenue sewage treatment plant) was a proposed plan for a small IBM 1620 computer (in a control room to be located near the construction site). The computer was to monitor and control the three regulators and one pumping station upstream of the treatment plant. However, engineers were skeptical about the costs and reliability of computer process control systems, then in their infancy. After much deliberation, the computer system idea was shelved, and pneumatic controllers were built into each station with provisions made for future remote control.

The plan to develop a system of computer-controlled mechanical regulators to make the maximum use of storage within the Elliott Bay-Duwamish River combined sewer system was formulated in 1965. The primary features of the Computer Augmented Treatment and Disposal system (CATAD), at that time, included the following: (1) five automatic regulator stations, (2) a central computer, (3) central command console, (4) water quality monitoring equipment, and (5) controls and wiring for an automatic storage and regulation system. The proposed plan was presented to various federal agencies for possible grant consideration. In late 1966, the newly formed Federal Water Pollution Control Administration approved the grant proposal and awarded federal funds totaling $1.4 million.

Since the original proposal, many improvements have changed the appearance of the original CATAD demonstration grant concept. In June 1967, a plan for obtaining additional interceptor storage was formulated with the request to use demonstration grant funds to construct the Lake City tunnel regulator gate station to develop large amounts of storage in the Lake City tunnel.

Another important influence on the CATAD control system was the rapid development taking place in the computer and instrumentation field. During this period, vastly improved third-generation computers were being developed, and the improvements were incorporated in the design of the central computer for the Metro control system. The new, improved computers allow Metro to consider a large and rapid system that can function as both a real-time process control computer and a background business and engineering type of computer. Such a dual-purpose application could not have been considered if the CATAD system had been built as few as 5 years earlier. The outstanding features available with the new generation computers provide Metro with a great deal of additional computer capacity and many potential uses that are just beginning to be realized.

In 1968, consultants completed the design specifications for the computer-controlled regulator system, incorporating provisions for additional future stations. The future additions are shown in Figure 17. They consist of: (1) the West Seattle system of five pump and regulator stations and a small primary treatment plant, and (2) the Renton system, including nine pump stations and one major secondary treatment plant. A primary feature was the main central console, which was to cover the entire wall of a large control room with a separate cathode ray tube for displaying operating data from each station within the CATAD system.

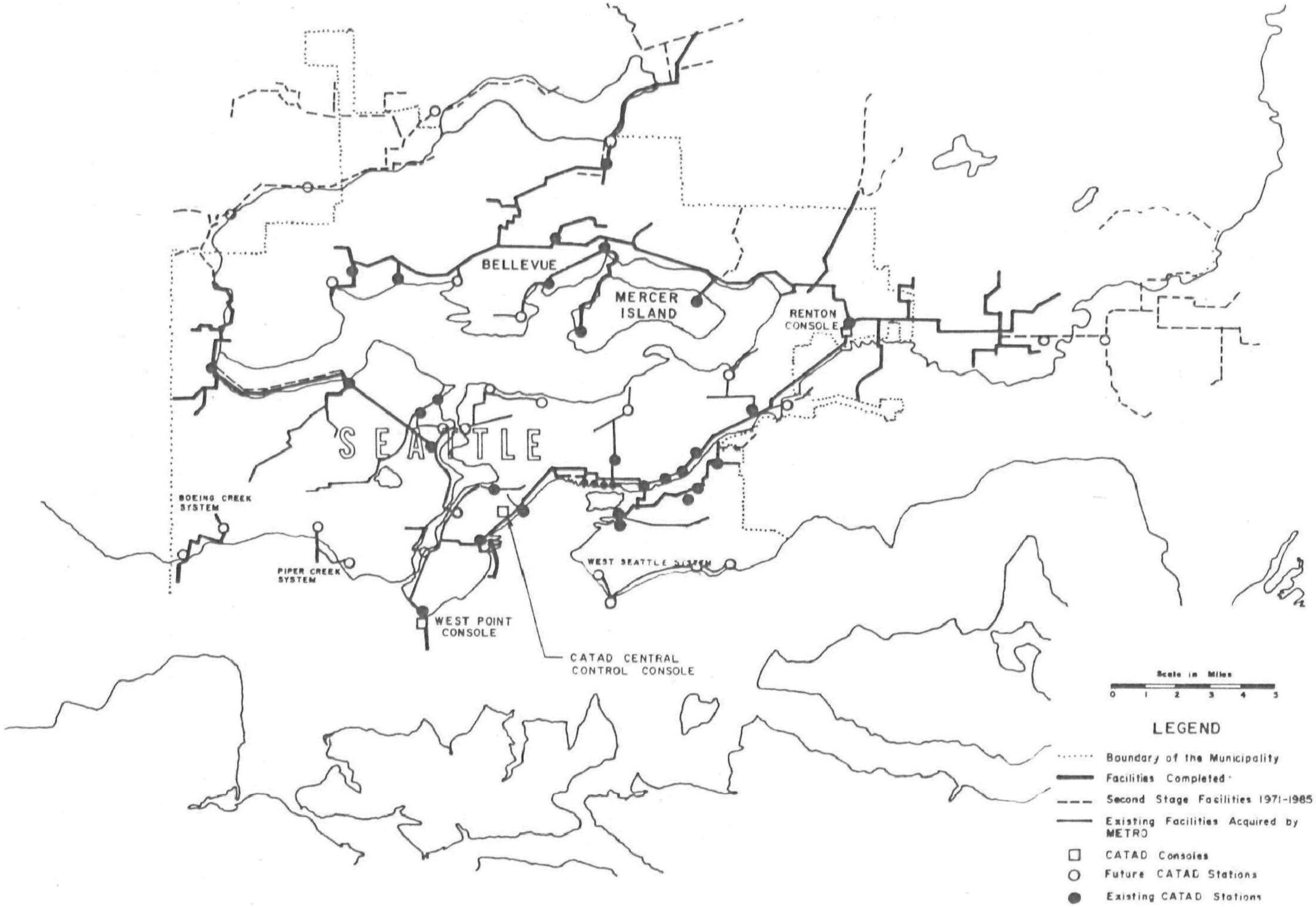


Figure 17. Computer Terminal Locations

The final and most visible changes took place during 1969 when the contractor who undertook the construction of the CATAD system proposed additional design changes and improvements. Metro accepted a number of these suggestions; as a result, the CATAD system now includes an outstanding command control console similar to a console complex built for the NASA Houston Space Center. The main features of the console are shown in Figure 18. They consist mainly of an active lighted wall map display and operator console. The map display graphically shows the entire Metro sewage collection system and its operating facilities. Now, data from seven or fewer stations is being displayed on the CRT's at any given time. An operator seated at the control console, immediately in front of the map display, can observe data output from the various stations, manually enter control commands, and quickly order a hard copy record of all operating information from the 37 regulator and pump stations in the CATAD system. (Refer to Appendix E.)

Basically, the CATAD system has not changed to any degree since the 1968 contract was awarded and initial change orders approved, though some stations originally labeled "future" are now operating within the system. The extreme flexibility of CATAD, as it was originally designed, has allowed Metro to include many features that at first were not even envisioned. The features of the system as it exists and is operated at this time are detailed in succeeding sections of this chapter.

COMPUTERIZED TOTAL SYSTEM MANAGEMENT

Real-Time Control

The development and implementation of computers within sewage collection and treatment agencies and municipal public works is small in comparison to other industries, even though objectives are similar and management processes are nearly the same. Many unrelated industries have placed primary emphasis on computer control in a determined effort to improve product quality and reduce production costs. Such industries as petroleum, gas, chemicals, cement, power, iron and steel, and paper have made tremendous strides in the use of computer process control for automating and managing their plants. (37)

The sewage collection and treatment field, although entering the realm of computers relatively late, is now beginning to make use of this tool in the management and control of plants and personnel. Computer applications in this industry are rapidly expanding as a result of increases in federal funding, growing concern over water quality conditions, and partly as a result of the tremendous success other industries have had with real-time control systems.

The term "real-time control" is worthy of some additional explanation. Real-time can be defined as the method of processing data so fast that virtually no time passes between inquiry and result. Real-time process control implies, or more correctly requires, the use of a digital

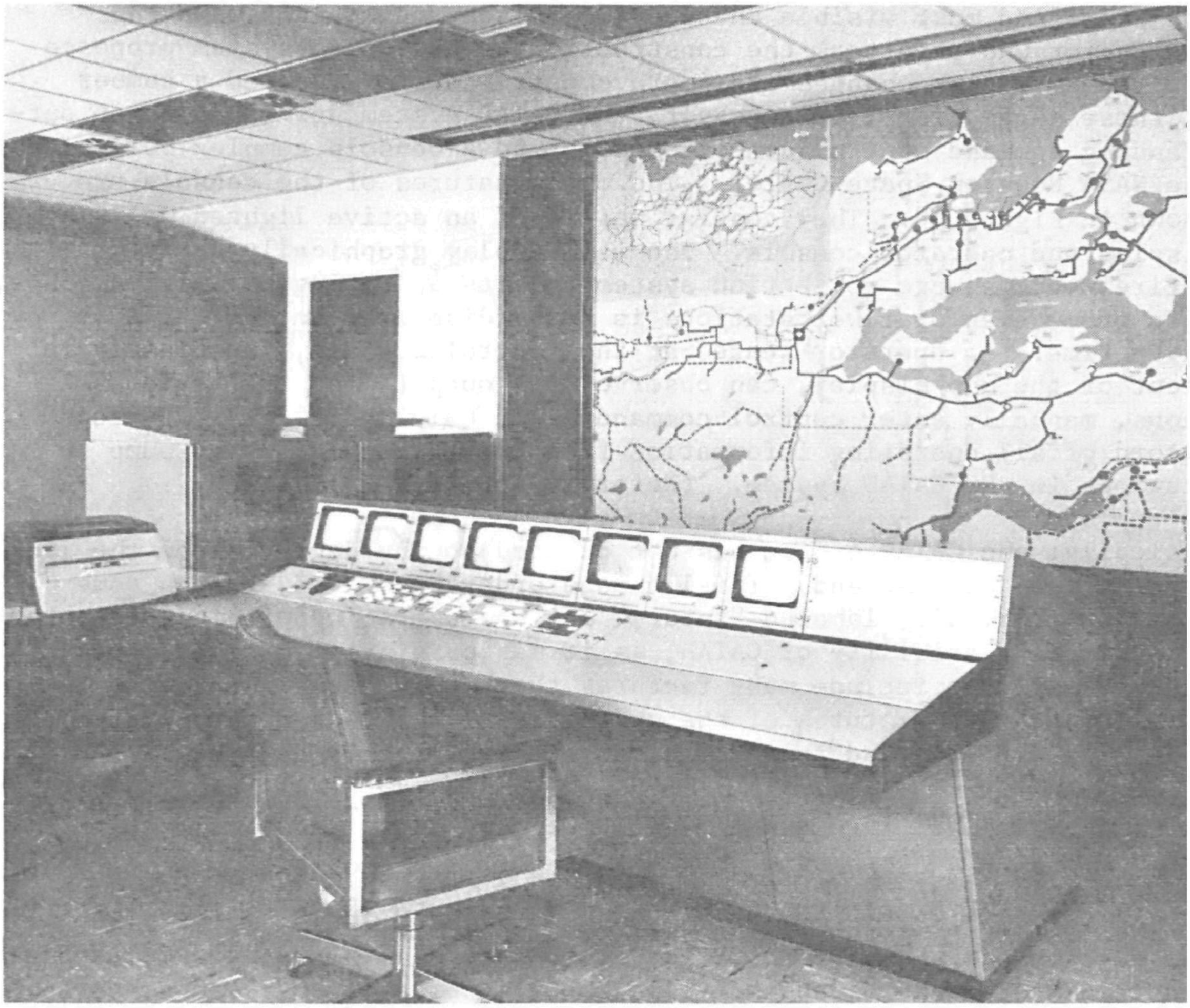


Figure 18. CATAD Console

computer in the control loop, as pictures in Figure 19. The three diagrams in Figure 19, adapted from the APWA report Feasibility of Computer Control of Wastewater Treatment (38), show the progressive development of a real-time or immediate responding control system from off-line computers to on-line computers to actual computer control.

Metro CATAD Control System

Metro is in the process of assembling a real-time process control system with the primary objective of maximizing storage within the sewage collection system and minimizing combined sewage overflows. The CATAD system can be divided into the following main components:

1. A central digital computer and internal control program.
2. A console where human-oriented information is communicated.
3. A series of remote terminals where information is generated and control functions are accomplished.

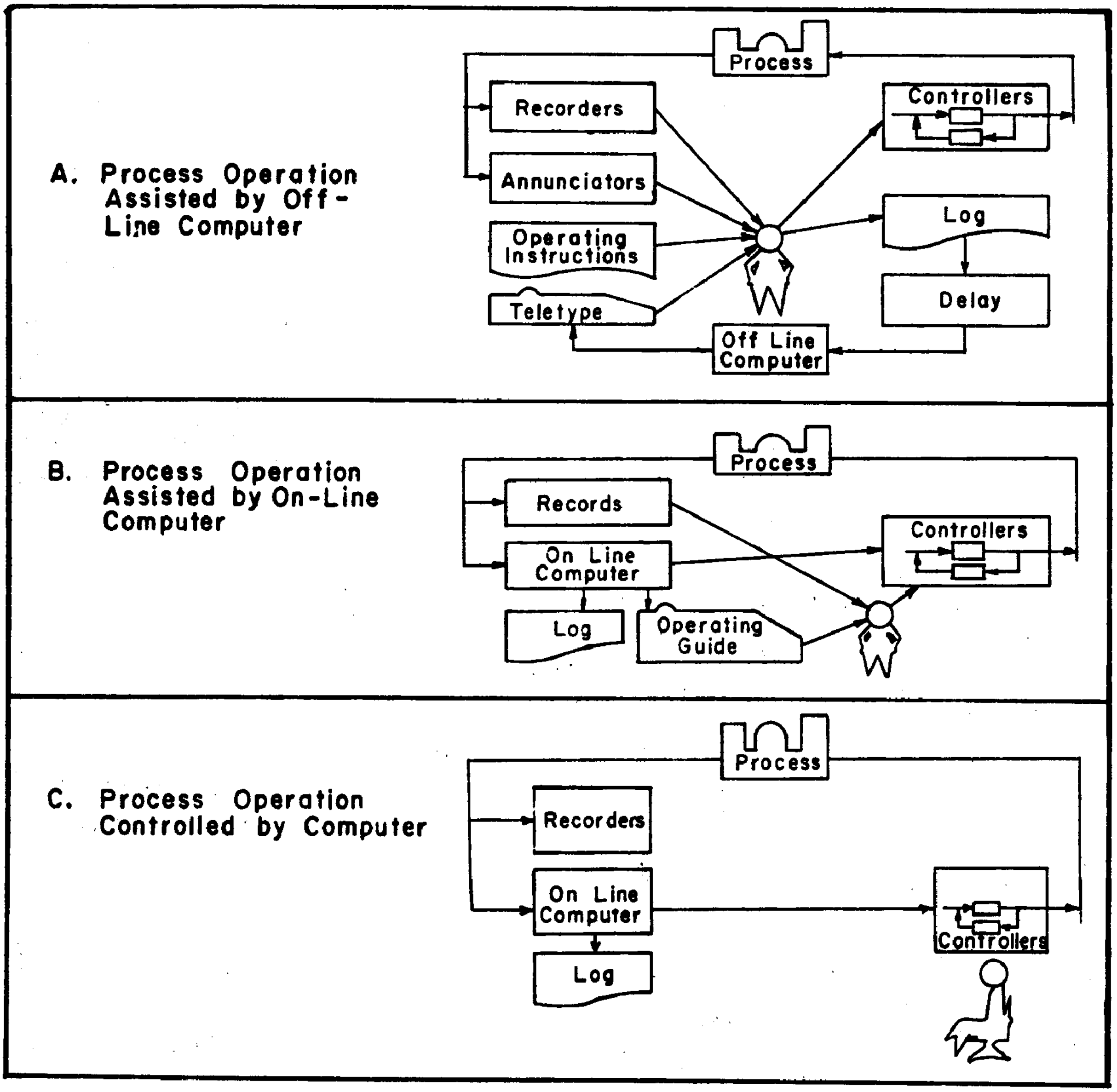


Figure 19. Real-Time Process Control Implementation

4. A telemetry network for high-speed transmission of data between the computer and the remote terminals.

Figure 20 shows schematically how the various components relate to each other in the basic CATAD operating system. Information will first be generated at block 1 on the diagram, from a bubbler, rain gage, or other sensor. Spread throughout the Metro area are various analog sensors and alarm contacts that develop information about water levels or equipment status in the form of varying voltages or contact positions. At block 2 in the diagram, information from block 1 is converted to digital data,

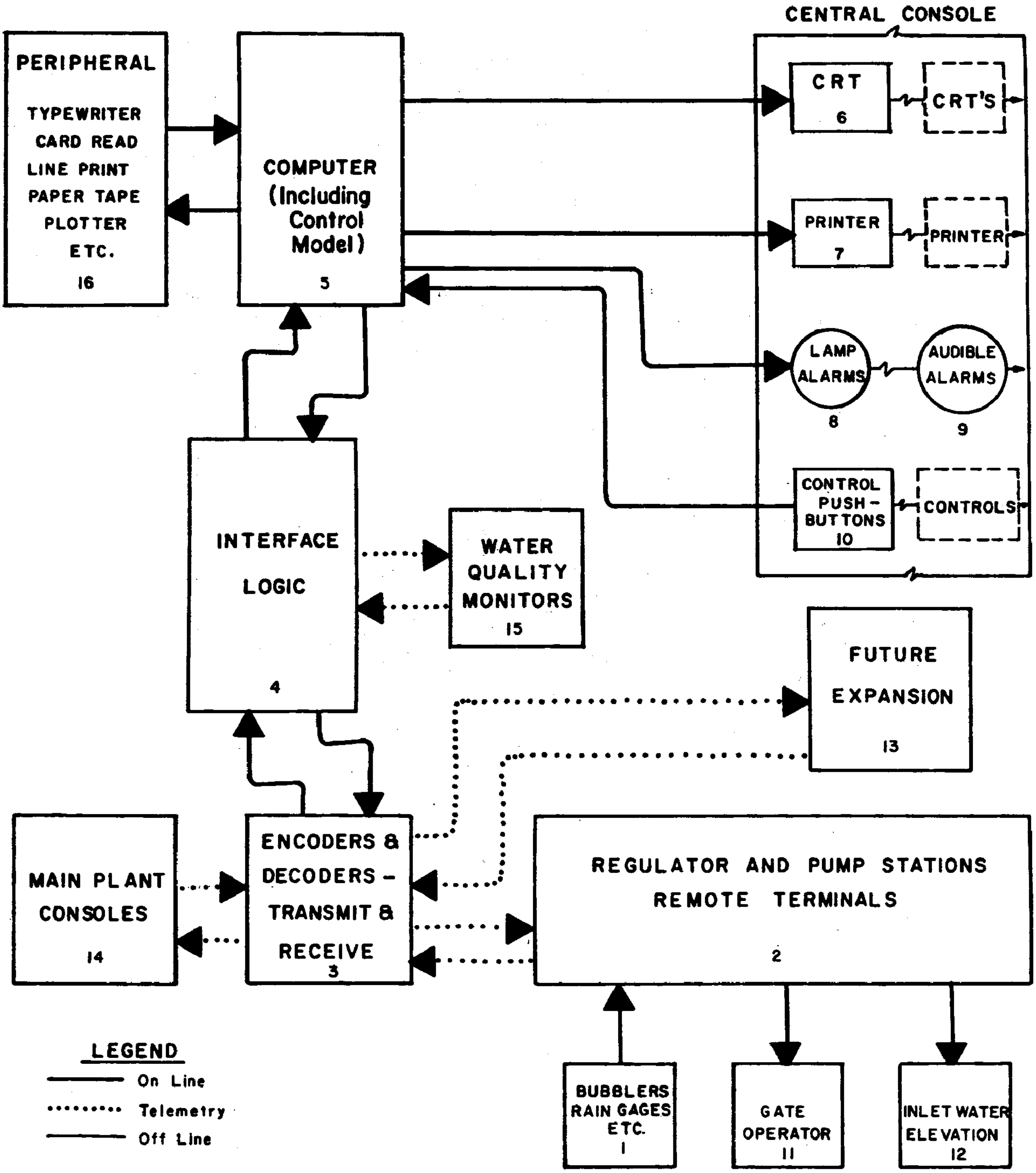


Figure 20. CATAD System Schematic Diagram

placed in a coded message, and converted to frequencies suitable for transmission over the telemetry system.

The telemetry system consists of duplex voice-grade phone lines with special security procedures and conditioning added to minimize the type of electrical interference that might destroy or alter the coded message between central and remote terminals. Following successful transmission, at block 3, receivers and encoders convert the coded message to data that can be transmitted through special interface logic at block 4 to the main digital computer at block 5.

Once inside the computer, the data is acted upon by a series of coded instructions (or programs) that convert the data into information suitable for output to either a visual display represented by a cathode ray tube (CRT), shown as block 6, or a logging type printer, shown by block 7. At the same time, programming within the computer generates alarms in the form of flashing lights, printed messages, or audible alerts (blocks 7, 8, and 9). Once information or alarms have been output at the central console, an operator can respond to the conditions through the control pushbuttons, labeled block 10 in the diagram. His instructions are transmitted to the computer, then back through interface logic, encoders, and the telemetry system to remote terminals where blocks 11 and 12, which symbolize control operations, react to the control command. Information about the manner and speed of equipment reaction is transmitted back over the same lines to restart the cycle.

In addition to the main features of the CATAD system, Figure 20 also includes some additional features to illustrate the capacity and flexibility of a computer system. Block 13 is a general reference to some of the future remote process control functions currently under consideration. Water quality information is transmitted to the central computer over phone lines from monitors at five separate locations along the Duwamish River, as symbolized by block 15. In case of mechanical or electronic problems with the central console or during periods when the central console is not being operated, monitoring and control is transferred to the two main plant consoles, symbolized by block 13. The last operation represented on the diagram is the peripheral equipment listed in block 16. Initially, the computer will be occupied with its process control tasks for only 30% of the available processing time. Therefore, it is expected that considerable use will be made of available background time for common managerial applications such as information reporting, accounting, engineering, and mathematical problems. Block 16 lists some peripheral devices that will be physically attached to the computer for these purposes.

Computer Learning Process

The development of a complex computer control system can be likened in many respects to the development of intelligence or its equivalent within the animal kingdom. The more complex the animal brain and physical system is, the longer it takes for the animal to achieve its full mental potential. The same situation exists in computer systems; a large, complicated computer system intended to control many interrelated functions requires many weeks and months of engineering and programming time to fully implement its potential. This in part explains the projected length of the 6-year development period for the Metro CATAD control system.

The developmental phases of the CATAD system can be compared with the development of intelligence within the human species. The digital computer is initially provided with the basic "instincts" for inputting and outputting information in some form. The computer manufacturer has provided the computer with a basic form of intelligence that allows it to control the input and output of data and interpret the various forms the data may take. Memory cells are provided so that the computer can accept prepared instructions and data and store this information temporarily or permanently in various forms of storage. At this point the computer might be compared with a new-born infant.

An instrumentation and electronic contractor, Philco-Ford Corporation, Western Development Laboratories, is presently taking the CATAD system through what might be termed its "childhood" phase. Programs have been written and are being integrated to instruct the computer in how to interpret specially coded information transmitted over telemetry lines and convert this basic data into dot patterns that form visible letters on cathode ray tubes or hammer instructions that will print information on teletype printers. These programs enable the computer to energize relays, turn on lights and other signals, and interpret pushbutton patterns, which are instructions from a human operator. In effect, the computer is being taught how to read, write, and communicate with both instruments and human operators.

The last phase in the CATAD system development will be the "adult" or final application stage. Metro's consulting engineers are preparing to guide the computer system through this final control stage. Very complex and sophisticated control, calculation, and simulation programs have been designed and are being written so that in the next 2 years, it is expected that the computer will be fully educated and, in effect, have its "college degree" as a completed on-line process control computer.

SYSTEM COMPONENTS AND PROBLEMS

In the computer control field, there is a boundary or interface between hardware and software. Software consists of programs made up of computer instruction sequences and data to be used by these instructions in the performance of some action. Hardware comprises the physical circuitry equipment and electronic components that make up the computer. A typical program (200 instructions) using both hardware and software during execution will be finished about one-thousandth of a second after it is started.

Also in process control systems, but on the other end of the spectrum, are what might be termed "slow-ware," which comprise the motors, sensors, gages, and other devices that, when compared to computer hardware and software, are extremely slow-acting equipment. With slow-ware, minutes or seconds may pass before discernible differences can be detected. The timing problem is complicated because the central computer, operating at extremely high rates of speed, is necessarily communicating with a multitude of relatively slow-acting devices.

Central Computer

The heart of the CATAD system is a high-speed digital computer manufactured by Xerox Data Systems and called the Sigma 2. Detailed information about the computer is presented in Appendix L.

The Sigma 2 computer system was selected because of its fine record in process control applications and its excellent hardware and software protection features. For the CATAD application, the computer is divided into foreground and background areas by a boundary that can be automatically adjusted when program size requires this change. The computer system is continuously performing one of three tasks:

1. Foreground data acquisition or control tasks.
2. Background programs and input-output operations.
3. Idling in a state awaiting foreground or background job requests.

Foreground operations consist of such tasks as scanning all stations for data at timed intervals, printing a complete system log each hour, or checking on a common operation to generate alarms in case of failure. Each of these operations is started by a countdown clock that is unique for each foreground task. Each countdown clock is initially set to some value, then is decremented by a master real-time clock that keeps time for the system, until the countdown clock reaches zero, triggering the foreground task and resetting the triggered clock to its initial value. Foreground tasks are all assigned a higher priority than background jobs and are also protected by hardware and software so that background problems cannot affect any of the foreground operations.

Because of the extreme high speed of the computer system, the amount of core memory, and the high-rate input-output equipment available, foreground tasks occupy only about a third of the available computer time. Therefore, the computer can be assigned many background jobs such as accounting or engineering problems.

One useful feature is that, in cases where both foreground and background programs take up the entire available core memory, the background job can be interrupted and its program status and all register contents instantly written onto the bulk memory device. The foreground operation is then completed and the background job replaced in core memory and restarted, all in such a short time as to be nearly unnoticed by the computer operator. This background interruption procedure is called checkpointing.

Background programmers have many alternative peripheral devices to select from. Figure 21 illustrates some of the main computer units on the control room floor. Additional details about these units can be found in Appendix L.

Universal Computer Startup Problems

Problems and delays in getting computer systems operational are universal. The CATAD system probably has had more than its share of these problems, but possibly the experience gained from this system can be helpful to other agencies contemplating a similar computer control project. Difficulties can be categorized as either physical (hardware) problems or programming (software) problems.

CATAD hardware has had a fine record of operation in the 2 years since it was initially assembled. Electronic components have failed, but such failures have been average or less frequent than normal, considering the state of the art of solid-state electronics. Surprisingly, the most vexing problems have been that of heat removal, air conditioning, and simple physical installation considerations. Failures with circulating fans have caused some electronics overheating and subsequent failure. The air conditioning system for the computer room itself has been revised and reinstalled twice by the contractor; even now, modifications are needed to satisfy insurance requirements. Size and weight of the equipment contributed to two additional problems. First, the computer system could be moved into its permanent location, an office building, only by removing a building window and lifting components by crane through the opening (see Figure 22). Once inside the building, certain computer elements were of such extreme weight that they had to be located over structural beams so that floor damage would not occur. The maze of signal and power cables required construction of a special combination equipment platform and cableway to enclose the cables and conduits.

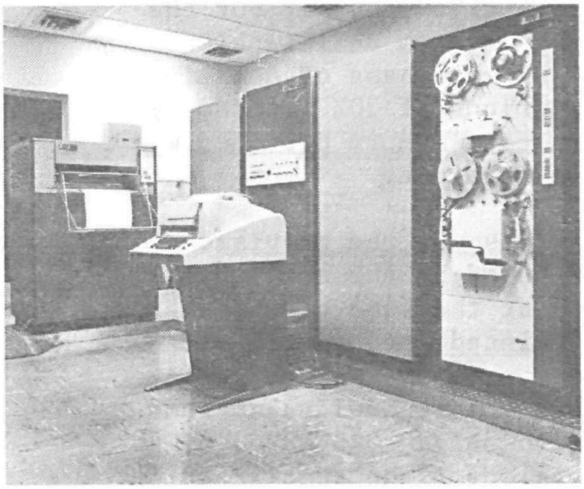


Figure 21. Central Computer and Equipment

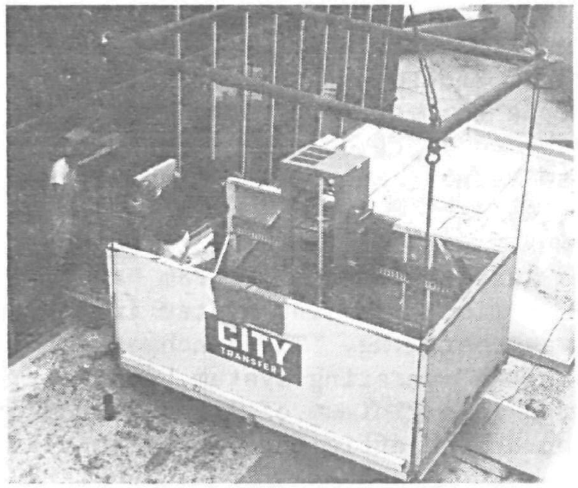


Figure 22. Computer Delivery Through Second-Floor Window

The problem of maintenance responsibility for equipment from different suppliers is a difficult one to resolve. Even if it were possible to assign the maintenance responsibility for all equipment initially purchased to one firm or individual, later additions to the computer system or to the total control system will increase the maintenance requirements, and responsibilities will overlap and conflicts will develop. Metro requested bids for a maintenance contract as part of the original CATAD specifications. As a result, the prime contractor has assumed responsibility for essentially all of the computer, communication, and interface equipment. However excluding the two telephone companies, ten different agencies are performing some level of maintenance on parts of the CATAD system, four groups act as subcontractors to the prime contractor.

Contrary to most business computer systems provided by manufacturers to commercial firms or large industries, CATAD, as with many other real-time applications, became enmeshed in complicated programming problems that forced delays in planned schedules. One of the major contractor problems was that very few experienced and competent real-time system programmers were available. Those who are competent are often attracted to other firms, and the resulting turnover has undesirable effects on control system schedules. The CATAD experience was that programmer turnover led to a delay in completion of at least 1 year.

Another problem in computer control systems is that few manufacturers provide executive programs that are particularly directed to real-time process control systems. The contractor on the CATAD system found it necessary to develop an executive program to augment the basic foreground-background operating system provided by the computer manufacturer. The computer manufacturer would not allow his customer (the contractor) to modify the basic executive program, but the contractor still had to overcome certain system deficiencies. This led to extensive programming time and purchase of additional core to meet foreground time use restrictions of 30% imposed by the contract specifications. The extra core memory provided was to Metro's benefit, but the time delays were not.

One important feature of the specifications was the provision that a large benchmark program had to be executed by the contractor-supplied operating system in background at the same time foreground was operating. The benchmark program pointed out deficiencies in the operating system because the same program that could be run in a minimum of 14,000 words of core memory could also run on a more efficient executive system with only 8,000 words of core memory. Because of the benchmark provision of the specifications the contractor had to provide the larger core memory.

One problem that affected both software and hardware was the requirement that the CATAD system be able to restart itself automatically in case of a power failure. Some elaborate programs had to be written and certain hardware modifications incorporated to provide an automatic restarting capability. Emergency power was not contemplated for the CATAD system because all remote terminals being controlled have emergency power systems and, in case of power failure to the central computer or telemetry failures between the computer and any remote stations, provisions were made so that remote terminals will automatically return to local control systems until power is restored to the central computer. In designing future systems similar to CATAD, a consideration should be given to providing emergency power to a central computer and developing 100% reliable communications systems, thereby reducing control systems required at remote terminals, and the interfacing problems that result directly from these complex independent control systems.

Operator's Console

Immediately adjacent to the computer equipment is the operator's console and wall map display, which will serve as the interface between the human operator and the control system. The relationship between the console and computer areas is illustrated by the floor plan in Figure 23.

The operator's console consists of three main parts: a desk-type control console, alarm and events teletype printing units, and lighted wall map display. These combine to enable the human operator to either control or strictly observe the various functions of each of the remote stations. The various control and display sections of the console are pictured in Figure 24. At the front of the console, proceeding from left to right, are the following functional areas:

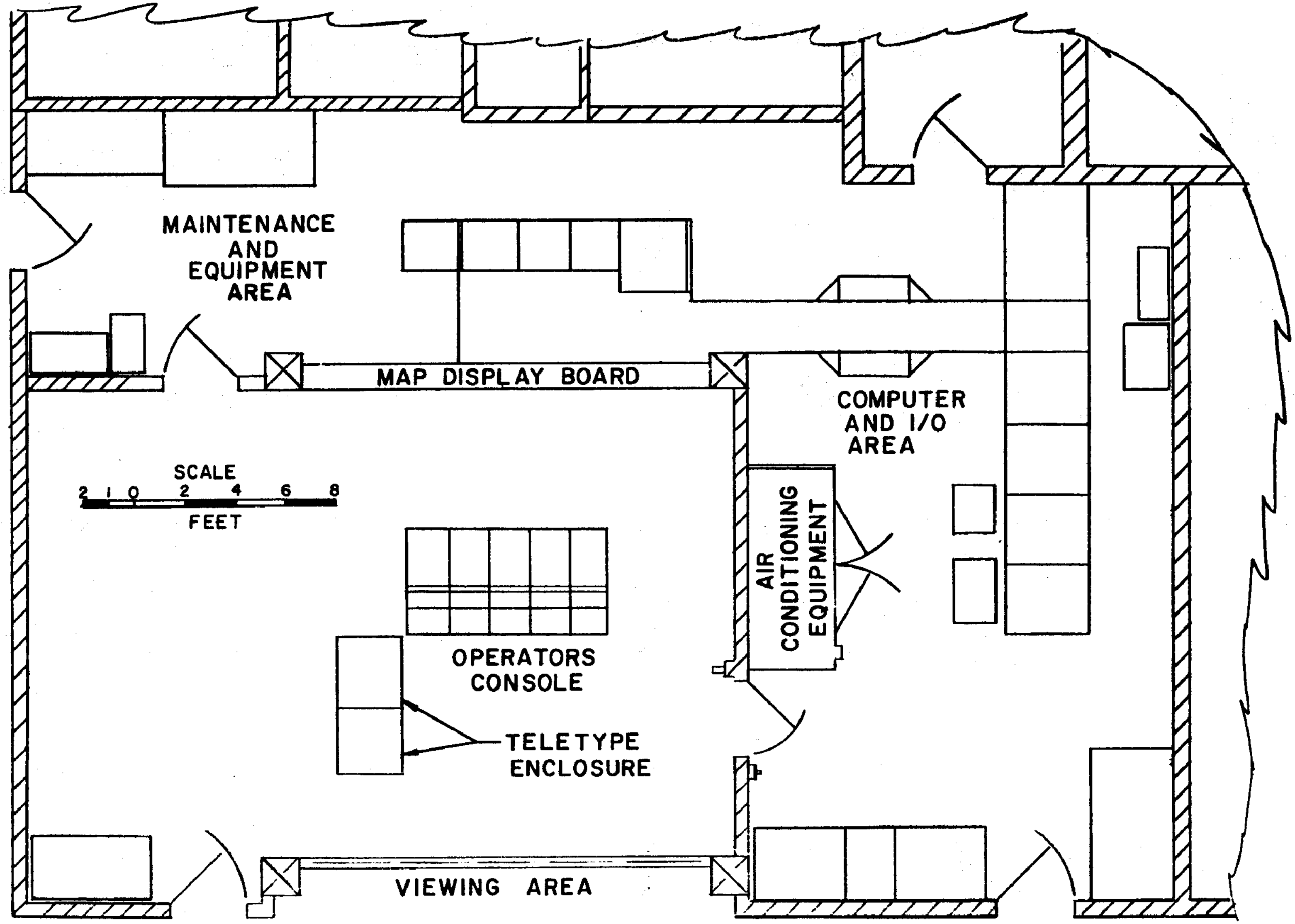


Figure 23. CATAD Central Control Floor Plan

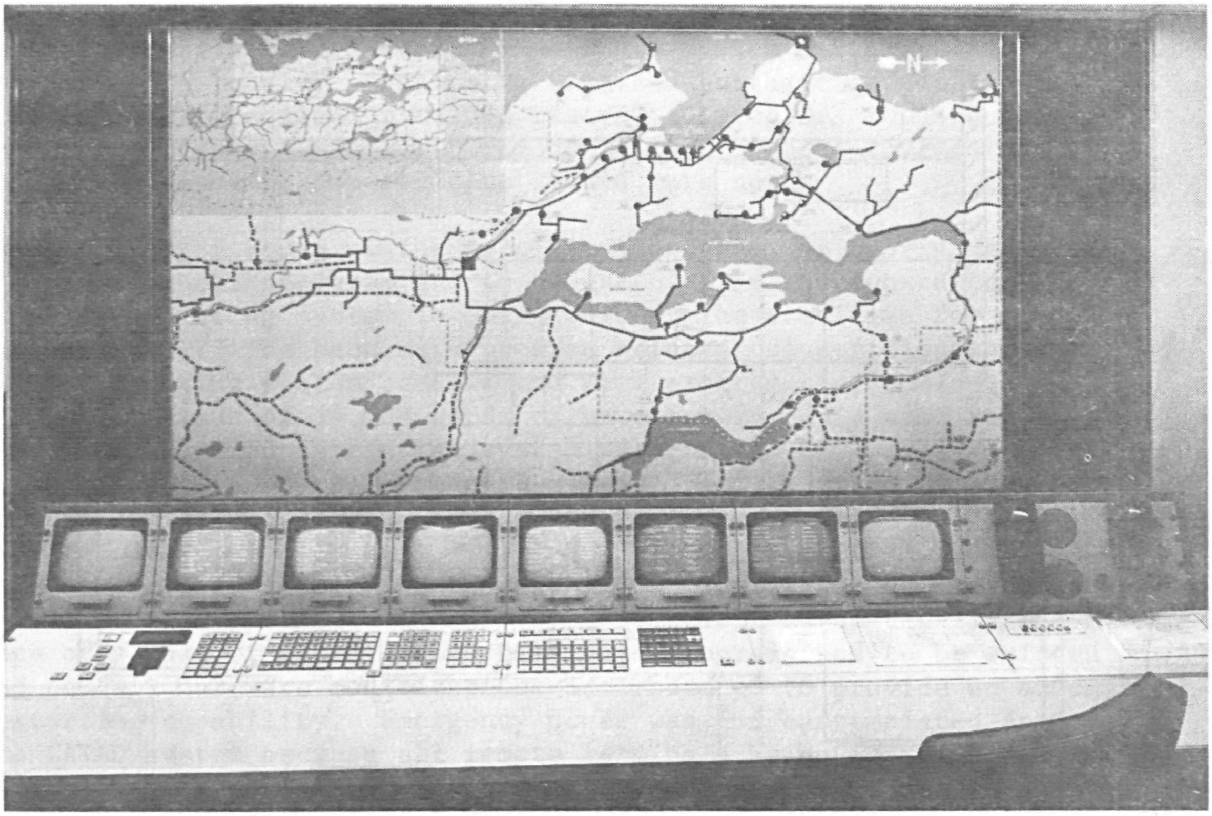


Figure 24. Console Sections

1. The control panel, for entering or cancelling various types of commands.

2. The command panel, for selecting the type of command desired.

3. The West Point station selector, for selecting the station to which the command will be directed.

4. The alarm panel, which displays the type of alarm or alarms at any selected station.

5. The status panel, which indicates the status of all commands in progress.

6. The Alki and Renton station selectors, which function similar to the West Point selector.

7. The segment selector, which is used to select which part of the total CATAD system will be displayed on the seven operating cathode ray tubes immediately above the control panel. (Only seven of the 37 total stations can be displayed at any one time. One cathode ray tube is a spare and is not wired into the system.)

8. The last section on the far right of the console is the communication section, where radio and telephone communication can be maintained with mobile units and other maintenance and operation personnel.

Above the console area is the bank of seven cathode ray tubes, which display quantitative data from the pumping and regulator stations. The seven or fewer stations displayed at any one time are located within a common area and are operationally related. Displayed data will include such information as water levels and gate positions plus computed information such as sewage flow rates and storage volumes. Formats for these information displays are flexible, but an example of typical formats for the different types of stations is shown in Figure 25.

Visible also in Figure 24 is the wall map display, which pictures the Metro collection system and future extensions to the system within the entire drainage area. The wall map supplements the operator's console by associating each cathode ray tube (CRT) display and each alarm with its geographic location. Within the symbol for each regulator or pump station is a four-segment lamp to indicate the condition at each station. An explanation of the wall map and lamp features is outlined in the wall map legend shown in Figure 26.

Figure 27 illustrates one important extension to the central operator console. This is a photograph of the West Point remote console. The CATAD system was designed to permit operator attendance at the control center for a single 8-hour shift on weekdays. During these normal working hours, the majority of system observations, modifications, and maintenance will be accomplished. At other times, the system will be monitored at satellite terminals installed at the two main sewage treatment plants, which are operated twenty-four hours a day. The remote consoles will receive all system alarms as a visual display and a printed hard copy from the teletype. The plant operator will be able to request a display on the cathode ray tube of the conditions at any selected remote station. A limited number of control actions can also be accomplished from the remote consoles pictured in Figure 27.

Telemetry System

In any real-time process control system, a method of communicating between the control computer and remote points must be decided upon. Construction and operating costs, ownership, and security factors will influence the final selection of a hard-wired, telephone line, telegraph line, microwave, or radio wave system. After a thorough analysis of the different communication alternatives and numerous discussions with telephone company personnel regarding security precautions, it was decided that the telephone system would be used for CATAD. Metro consultants recommended that a high degree of security be maintained in message telemetry and that remote stations be specially controlled to prevent unnecessary overflows in case of telemetry failures. In the normal scanning operation, a command is issued sequentially to each remote station from the central computer to begin transmission of the coded message groups from the remote site. A list of typical data transmitted is presented in Table 4.

LANDER ST. REGULATOR STATION

INTERCEPTOR		TRUNK	
INTERCEPTOR LEVEL	00.0	LEVEL UP-STREAM	00.0
REGULATOR SET-POINT	00.0	REGULATOR SET-POINT	00.0
FLOW SET-POINT	00.0	TRUNK IN-FLOW	00.0
DIVERTED FLOW	00.0	STORED FLOW	00.0
FLOW DOWNSTREAM	00.0	BY PASSED FLOW	00.0
		TIDE LEVEL	00.0
REGULATOR POSITION	00.0	OUTFALL GATE	00.0

INTERBAY PUMPING STATION

STATION		PUMPS	
INFLOW 1	0000	MODE	0000
INFLOW 2	0000	SPEED 1	0000
OUTFLOW	0000	SPEED 2	0000
INLET CHANNEL LEVEL	00.0	SPEED 3	0000
STORAGE RATE	0000	SPEED 4	0000
SETPOINT LEVEL	00.0	SPEED 5	0000
CONTROL LEVEL	00.0	SPEED 6	0000
CONTROLLER OUTPUT	00.0		

Figure 25. CRT Display Formats

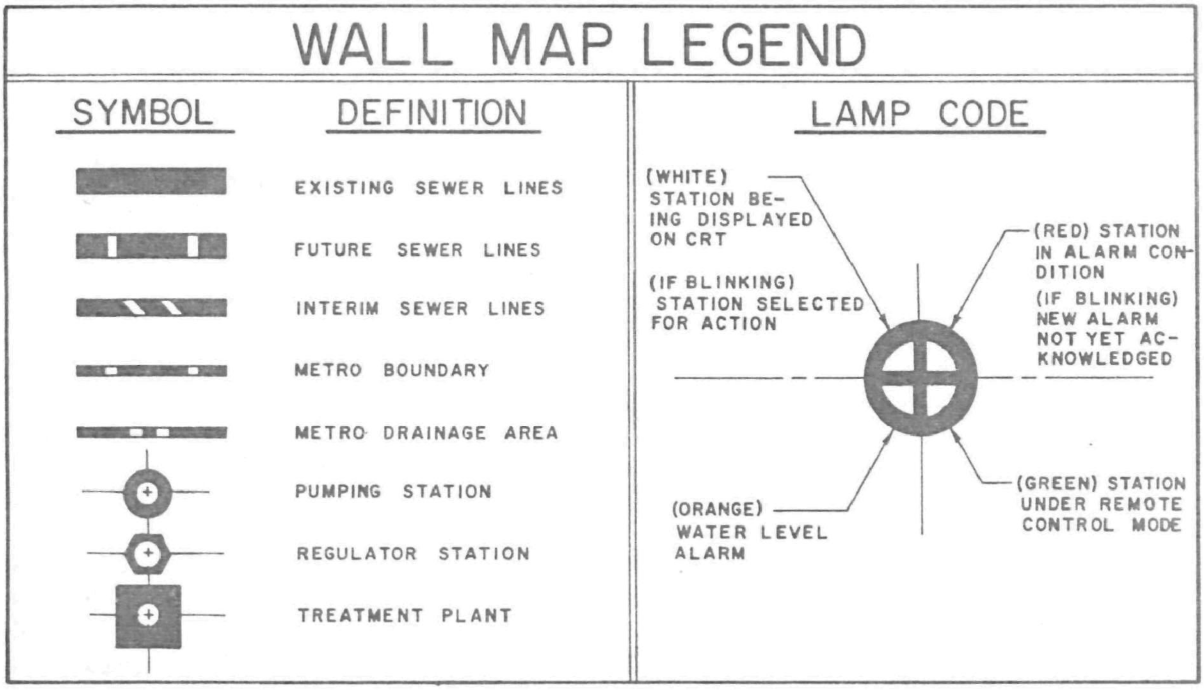


Figure 26. Wall Map Legend

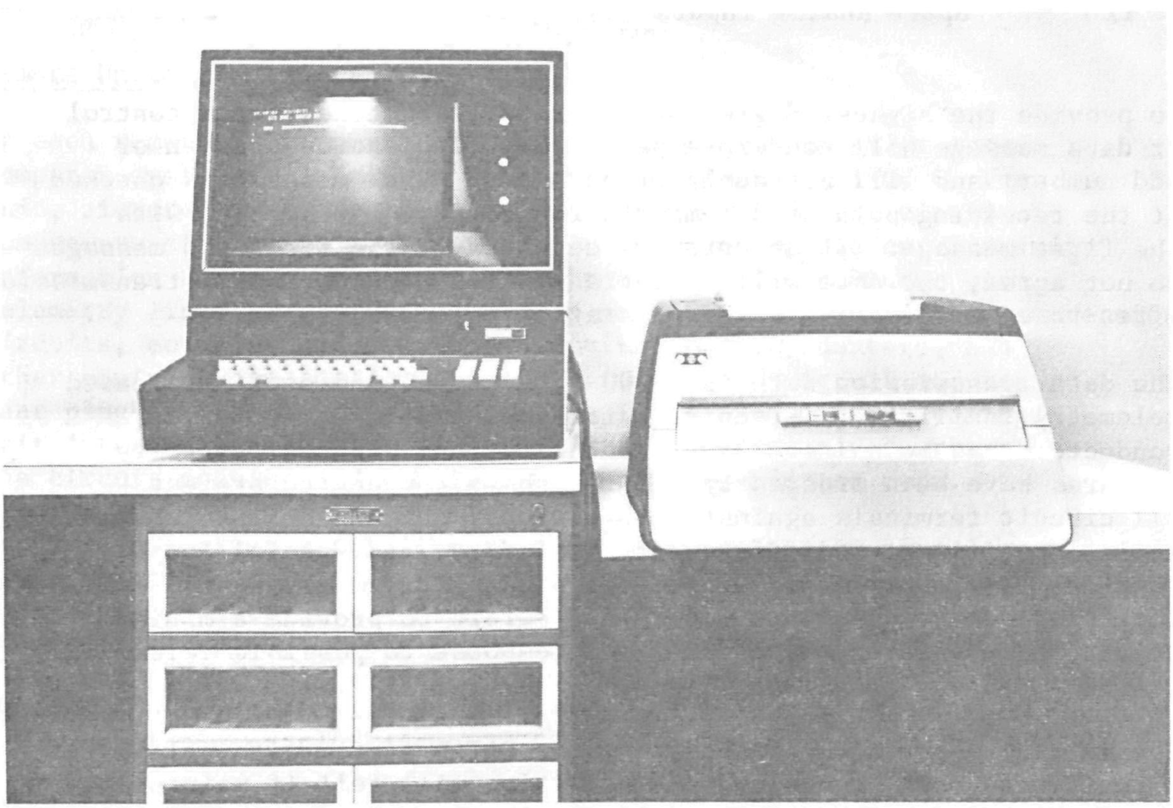


Figure 27. West Point Remote Console

TABLE 4

Typical Telemetry Scan Message Content

Item	Description	Number of Similar Items
1	Command status relays	12
2	Power on/off relays	2
3	Equipment status or alarm	6
4	Spare contact inputs	60
5	Pulse counters	2
6	Spare pulse counters	2
7	Reference voltage	1
8	Water levels	3
9	Equipment operating position	4
10	Operating levels	2
11	Spare analog inputs	2

To provide the highest degree of security, each telemetered control or data message will contain a parity bit (indication of even or odd number) and will be doubly transmitted. Each message is checked at the receiving point and compared for parity, bit by bit, with the first message. If an error is detected or the first two messages do not agree, the data will be retransmitted. Unsuccessful transmission after three tries will trigger a station telemetry alarm.

The data transmission rate is 1,200 bits per second over the leased telemetry facilities. A separate transmit and receive pair of conductors has been installed to each station. Special security measures have been ordered by the telephone company to protect all circuit terminals against unintentional disconnections. Balancing coils, amplifiers, radio frequency isolators, and special loop-back devices have been incorporated into the telemetry system by the telephone company in a determined effort to provide a minimum amount of interference and a maximum response to possible telemetry problems.

The initial experience of operating the CATAD system with telephone circuits has been promising, and only time will tell if maintenance responsibility and ownership boundaries between phone companies and those using the service will eventually result in disputes and operating problems. As an example of the reliability and high speed of the CATAD system, the entire sequence from beginning to end of a scan of all 37 stations takes about 40 seconds. Scan intervals can be ordered from the operator console at any interval from 1 to 10 minutes. It is expected that scan intervals will be widely spaced during the summer dry season in contrast to winter storm periods when scanning may be as frequent as 1-minute intervals.

Parallel Alarm System

Since 1966, Metro has had an operating telemetering alarm system to each remote station in the collection and treatment system. The system, called "Metrotel," now includes some 60 remote transmitters that send three general alarms, using a frequency shift principle, via voice-grade telephone lines to two receiving and recording stations located at the West Point and Renton treatment plants.

When the reliability of the CATAD system has been proved over a period of time, perhaps a year or two, it is planned to remove the Metrotel station alarm system at facilities where CATAD monitors are being installed. The Metrotel system will continue to function at smaller stations and other points within the collection system where the investment for a CATAD telemetry terminal is not warranted. In the distant future, this parallel system may be interfaced to feed directly into the CATAD system.

Remote Units

At each remote station, an additional element of the high-speed computer system is labeled a telemetry control unit (TCU). The unit, pictured in Figure 28, is built with solid-state electronic components similar to the computer. It converts data and transmits information between the station equipment and the computer via telemetry lines. The TCU contains a modem, analog-to-digital conversion circuits, encoding and decoding circuitry, pulse counters, and other equipment in the form of small integrated circuit modules that plug into a terminal board. The TCU design makes any single unit interchangeable with any other station by simply rearranging the circuit modules and changing a hard-wired address code.

Problems can exist within the station that may not be sensed by the telemetry control unit and subsequently by the computer. Any operator or maintenance man who observes a serious problem within the station can, by simply throwing a single switch on the TCU, disconnect the computer system from station control, thereby returning the station to the local control system to manually override computer commands at the station site.

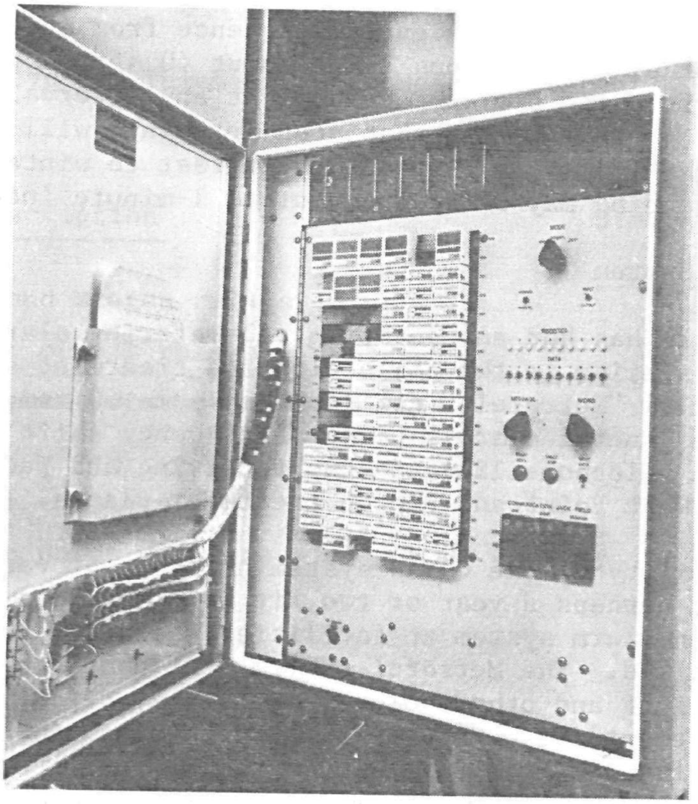


Figure 28. Telemetry Control Unit

Maintenance Considerations

One other important feature is visible at the telemetry control unit. At the bottom of the equipment box is the computer maintenance responsibility boundary. Computer systems specialists are not familiar with sewage collection pumping and regulator stations, just as sewage treatment specialists are unfamiliar with computer electronics. Therefore, a boundary had to be decided upon; it was placed at the bottom on the TCU box where a plug connected to station equipment meets with a socket receptacle permanently installed in the TCU. The description and reason for the seven separate cables interfacing at this point will be explained in the next section of this report. Except for the telephone and power plugs, which enter the top of the TCU box, this is the point where the computer system terminates and local station electronics and controls begin.

REMOTE TERMINAL MODIFICATIONS REQUIRED

Interfacing

Construction of the sewage collection system, including pipelines, regulator stations, and pump stations, has been described in this report as well as the computer control system and telemetry system that will transmit monitored data and commands between the two elements. However, it is not a simple task to take information developed at each station and merely plug data cables into a transmitter and expect to have any type of logical information develop. A given signal voltage representing a gate position or water elevation must be converted through various electronic devices into information that can be understood and relayed to the computer for further operation. This "mating" of station signals to computer signals, called interfacing, is no simple task. Switching between various voltages, common ground requirements, and analog-to-digital and pneumatic-to-electronic conversions are difficult even under the most advantageous conditions. The situation in the Metro system was even further complicated because of the many differences in the remote stations; many changes in instrumentation had been made during the 8-year period between 1962 and 1970.

Although there are experts in the computer control field and design engineering experts in the sewage collection control station field, there are few highly qualified experts at interfacing these two systems together. Any agency starting out on a similar system should be ready to accept the trials and mistakes that will arise when attempting this phase of a process control system. Of prime importance are the qualities of understanding the systems being interfaced, of coordination, both written and oral, between the various personalities and agencies involved, and of an honest awareness of the difficulties in attempting such a project. Supervisors must be prepared to accept a flexible deadline because unforeseen problems in interfacing are the rule rather than the exception. Although the continual delays are frustrating, the end rewards are sufficiently gratifying to justify the money and effort expended.

Space Considerations

When much of the coordination and preliminary engineering requirements have been established, space considerations become a serious limitation, as illustrated by Figure 29. The photograph shows the Brandon Street regulator station and shows a congested appearance caused by the many instrument cabinets required to interface a regulator station to a computer many miles away. The Brandon Street station is one of the earlier regulator installations constructed within the Metro system, and, although future centralized control was allowed for, there was very little awareness of the amount of instrumentation that might be required. In newer stations, all the electronics are being installed in spacious instrument panels, resulting in much less difficulty in the operation and maintenance of these local control systems.

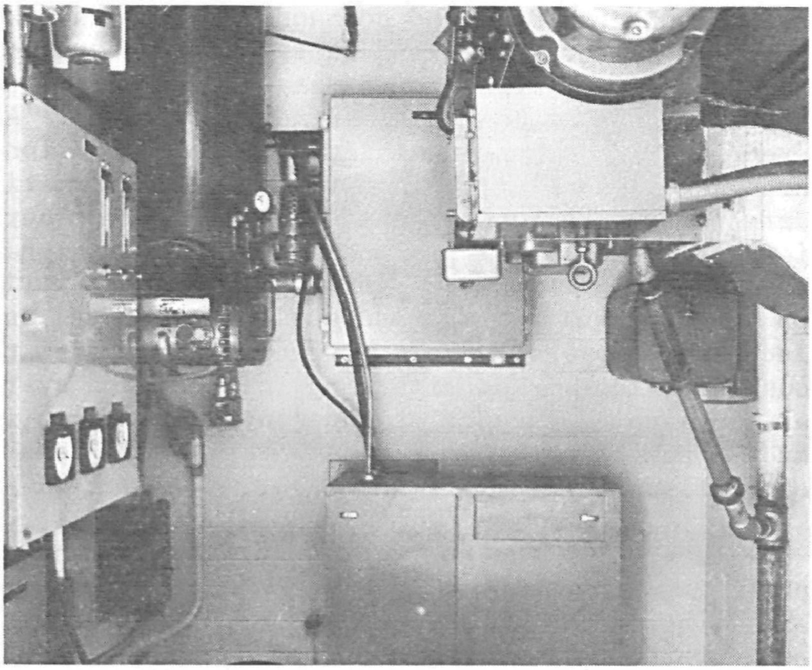


Figure 29. Congested Regulator Station

Changes to Station Controls

CATAD system control procedures are well documented in an article published in Water and Waste Engineering. (39) In summary, electronic equipment was needed in each remote station to perform several system control functions:

1. All remote control is done indirectly. That is, the computer or operator will impose a calculated water level setpoint elevation, which the station local control system will follow with its own control sequences.

2. Remote control of the setpoint is accomplished by transmission of a contact command signal to the remote terminal. The signal operates a contact in a circuit from a variable-rate pulse generator to a stepping motor. The stepping motor drives a potentiometer, which produces a proportional voltage output signal. The voltage, an analog signal, is transmitted back to the computer until it reaches the desired voltage level, whereupon the computer terminates the process.

3. A control-restoring sequence is provided in case of loss of signal from the computer. The restoring circuit equalizes the remote control setpoint with a constant signal from a manual setpoint device at a prescribed rate through a closed-loop balancing circuit.

4. Three-pen chart recorders provide a basis for comparing station operation and responses to information available at the computer and for recording events that transpire when a station is in local control and computer logs cannot be generated.

To obtain the signal quality and precision needed in keeping with the computer process, some modifications were required to existing station controls and sensors. The goal was to obtain signal quality that would have a minimum of interference or noise while maintaining a tolerance of 2% or less from the point the signal is generated to its storage and output location at the central computer terminal. Such precision can be obtained in many cases only by replacing existing signal cables with larger shielded cables or by replacing gate position indicators with newer, more sensitive devices. Cables and connectors were specified to provide a path for some 184 separate conductors (including an average of 22 spares for future applications) between the station control system and the telemetry control unit. Figure 30 illustrates the differences between interfacing equipment required at a regulator station and that at a pumping station.

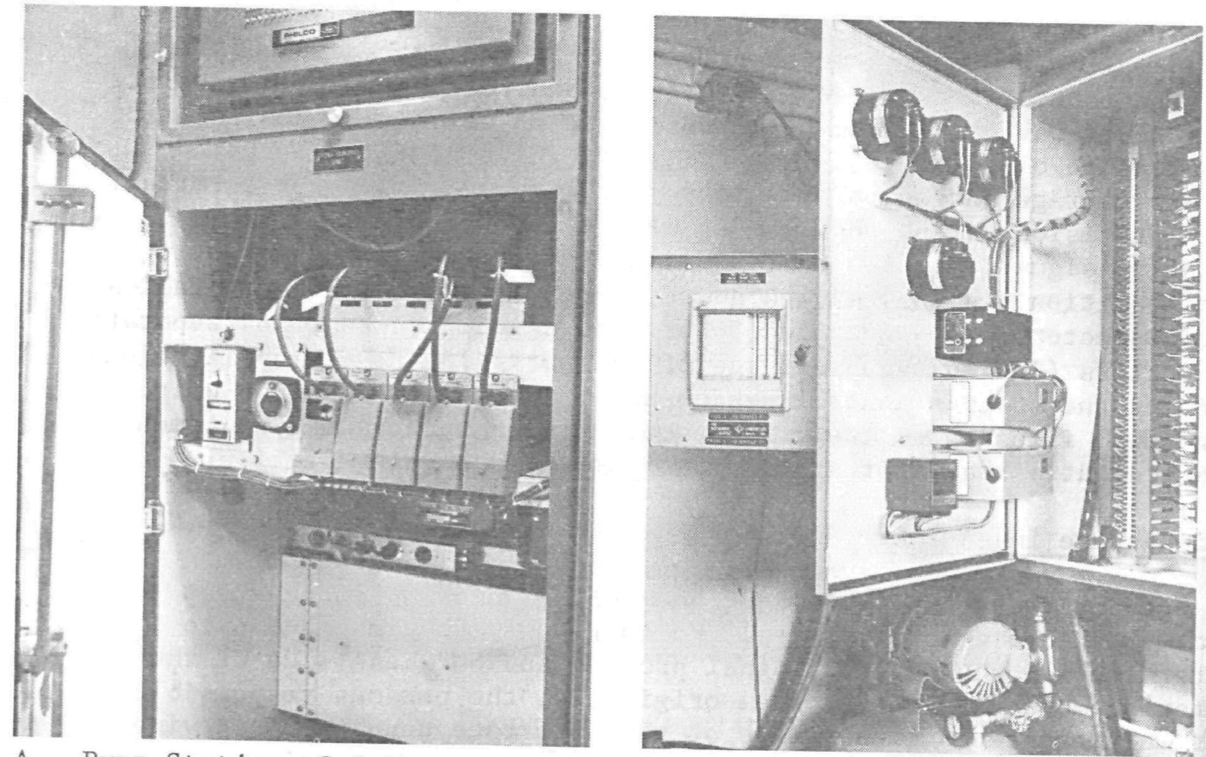
Maintenance Inventions

To prevent the age-old habit of one person pointing a finger at another when a problem exists, and to reduce the time needed to determine the source of a signal problem and on whose side of the interface boundary the problem originated, the persons responsible for maintenance on either side of the interface developed a device to isolate any potential problems. By quickly disconnecting the seven cables that link the computer system to the station controls, an instrument technician can reconnect the cables to a special instrument, called a simulator, and quickly locate the source of any problem. Because there is no guarantee that an instrument technician will arrive first at a troubled station, Metro maintenance personnel have a similar device to isolate problems in their system. Figure 31 shows the two different simulator units in operation.

The simulation equipment has been an invaluable tool in the location and correction of problems in both the computer system and the remote station control systems prior to the physical connection of the two systems. It would appear that some duplication of effort exists in the two simulator devices and that some funds and personnel might be saved by combining the two maintenance functions. At this time, Metro and its consultants feel that the technicians and engineers responsible for the computer controls and those responsible for local station controls are unprepared to assume maintenance responsibility for the entire system. The initial period of dual maintenance responsibility possibly will indicate whether a single maintenance group can gradually take on the maintenance responsibility for the entire system as technology develops.

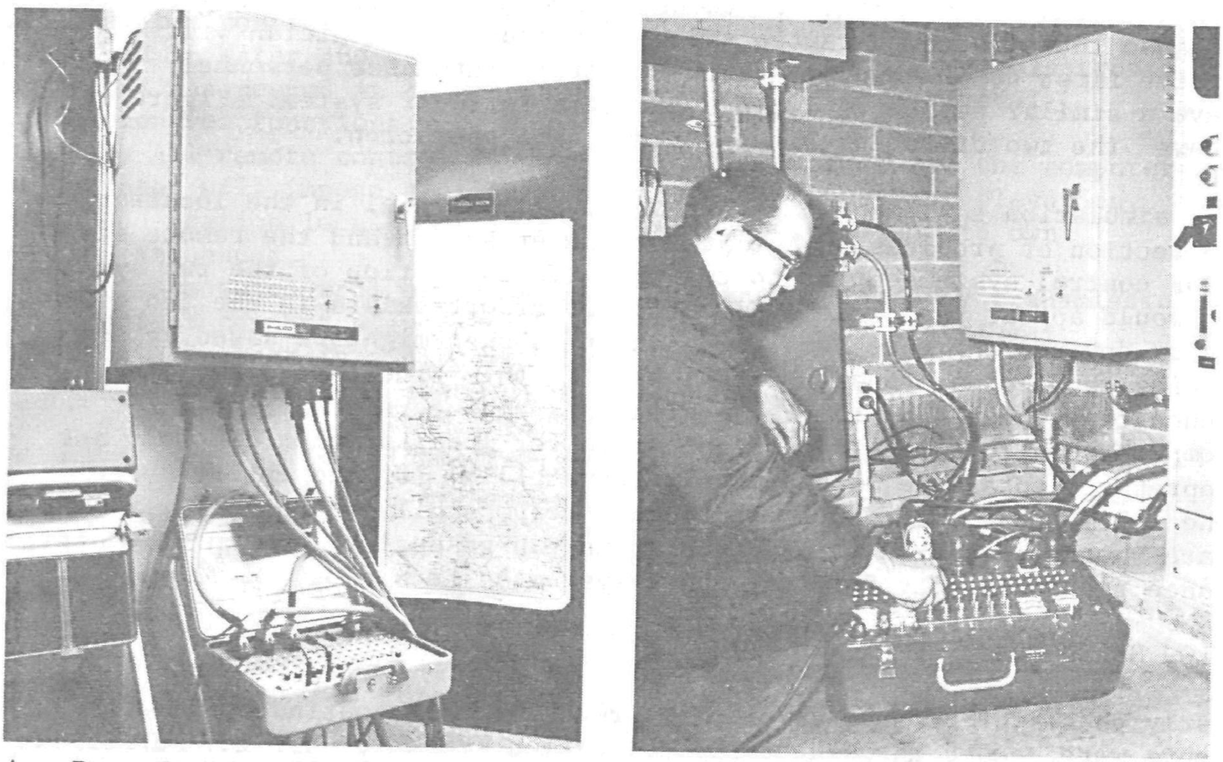
FLOW MEASUREMENT STUDIES

Early phases of program development revealed that continuous flow measurements were needed throughout the collection system to provide sufficient data input to a simulation model for use by the computer to properly control the CATAD system. The Metro collection system was analyzed to



A. Pump Station--C.C.U.   B. Regulator Station--A.C.U.

Figure 30. Remote Transmitting Terminals



A. Pump Station Simulator   B. Telemetry Unit Simulator

Figure 31. Interface Testing Equipment

determine where flow data could best be acquired. Many of the existing structures in the system provided convenient locations for the gathering of flow parameters. Remote depth telemetering stations are being considered at critical points where flow data cannot otherwise be continuously obtained.

Available Measuring Points

One group of structures being used to transmit flow data are the existing regulator stations. In a regulator, sewage passes control devices such as weirs and gates where flow can be determined with sufficient accuracy by using the appropriate weir or orifice discharge formula and knowing the depth of flow at these control sections. The data collection system provides the needed depth of flow.

The existing pumping stations provide another location where flows can be calculated. By combining pump speed and head data, both supplied by the data collection system, with manufacturers' certified pump curves, which are available for every pump in the system, a flow can be determined fairly accurately for a newly installed pump. However, a number of factors have reduced the accuracy of the pump curves. Because this is a combined sewage system, grit and other materials in the sewage have caused wear of the impellers. Also, repairs and other adjustments have been made to the pumping equipment after installation. Thus, the certified pump curves are no longer a satisfactory method by which flow can be calculated.

Force Main Calibration

The pump station force main can be used as a primary device for flow measurements. The problem is selecting a satisfactory and flexible method to calibrate the force mains. One means of calibration is the total count method using radioisotopes. This method was decided against because of the frequent difficulty in obtaining a usable range of flows in the force mains. Sufficient flow is dependent upon rainstorms in the area and would tie up a radiological safety officer or some other person trained in the use of isotopes for a long period of time. The highly trained individuals and elaborate equipment needed indicated that total count procedures would not be readily repeatable by the Metro maintenance crews. The method finally selected was an adaptation of the "Allen Salt Velocity Method of Water Measurements." (40)

The use of the salt velocity method requires that the force main head be kept constant between the time salt is injected until it is sensed at the discharge end of the force main. In many cases, this requires a period of half an hour or longer. The rate of flow can be calculated by dividing the volume of water displaced in the force main by the length of time that passed while displacing the known volume. The volume is computed from "as-built" drawings. The time is determined by injecting salt into the suction side of the pump and then measuring with a conductivity meter at the discharge end of the force main to determine when the salt slug has reached the end of the pipe. Stop watches are used to measure the time for the salt slug to travel between the two known reference points. The salt is injected into the sewage pump suction from a container holding five to seven pounds of salt. The container is pressurized with compressed air, and a quick-acting valve is actuated, blowing the dry salt into the pump suction.

Force main pressure is held constant during a calibration run by the use of a pressure sensing system that has been calibrated to acceptable limits. This system consists of a pressure transmitter having an accuracy of 0.15% of full scale, a range of zero to 100 pounds per square inch gage (psig) with an output signal of zero to 5 volts dc proportional to the pressure. The recorder is a laboratory model with an equivalent accuracy. Conversion of the raw data results in a calibration chart such as that shown in Figure 32. These calibration techniques are being used on all CATAD pumping station force mains. The data collection system will transmit force main pressures to the central computer for flow calculation.

Additional Flow Measurements

Other structures in the system provide locations that would yield flow information. One such point is the Fremont Siphon on the North Interceptor. It is believed that knowledge of the head on this inverted siphon can lead to calibration of flow through the siphon. Figure 33 shows the design of the depth recorder to be used. A sonic sensor, accurate to $\pm$ 1% of scale, relays water depth to an above-ground enclosure where telemetry equipment sends a modulated signal over a standard voice-grade line to a nearby regulator station. At this location, the analog input is converted to digital output to the data collection system. Similar flow depth recording equipment is being contemplated at other points in the Metro system. The cost of one of these self-contained depth recording stations is estimated to be $8,500.00.

WEATHER ANALYSES

A series of weather analyses were begun late in 1969 to determine what types of meteorological quantities would provide the best information for predicting storm intensities and actual wet-weather flows in the combined sewer system. Theoretically, with a lead time in excess of 2 hours, any excess storage being used in the Seattle collection system to level sewage load to the major treatment plants could be quickly released and the system drawn down to the fullest extent possible to gain the maximum amount of storage in preparation for the predicted rainfall. The study was divided into two main sections. The first was based on precipitation data only and covered a 3-year period from 1965 through 1967. The second section considered wind speed and direction data in addition to precipitation. Weather data was provided by observers at three airfields in the Puget Sound Basin: (1) Seattle-Tacoma International, 10 miles south of the center of Seattle, (2) McChord Air Force Base, 22 miles south-southwest of Seattle-Tacoma International, and (3) Paine Field, 32 miles north of Seattle-Tacoma International.

Analyses Performed

Precipitation studies to correlate data from the three airfields indicated that between 40% and 50% of all storms greater than 0.10 inch began at either of the two distant stations, McChord and Paine Fields, between 2 and 3 hours before rainfall began in the Seattle area.

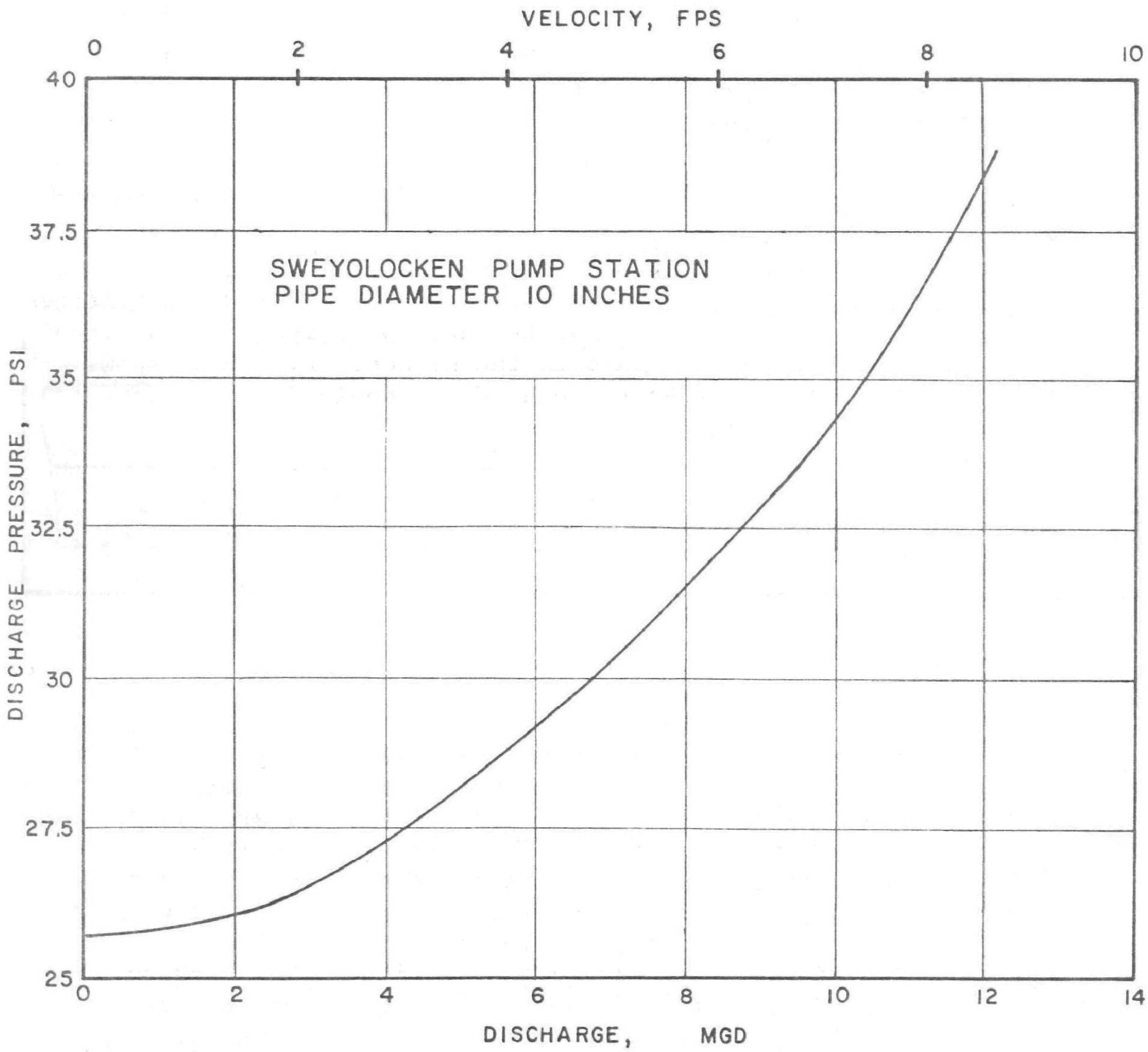


Figure 32. Force Main Calibration Chart

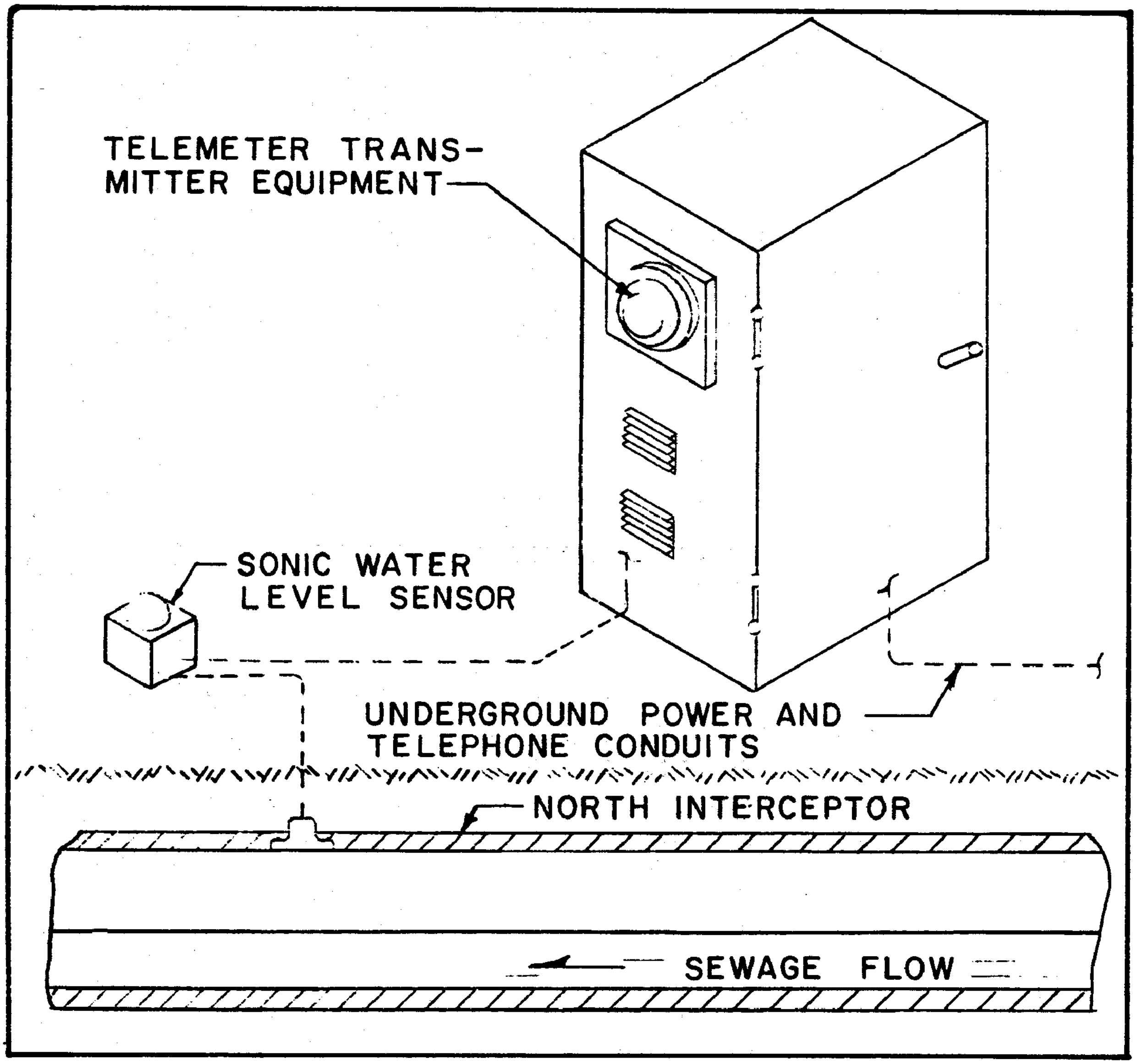


Figure 33. Remote Telemetering Depth Sensors

A second study was performed to determine the relationships between the peak storm intensity and the total volume of rainfall during a storm. Statistical analyses indicated a definite mathematical relationship between these two factors. By gaining the earliest information available on the peak intensity of the storm, the total rainfall volume could be readily estimated. In over half of the storms analyzed, the peak intensity was reached within 4 hours after the beginning of the storm period. By continuously checking the intensity values from distant or local raingages, the computer would be able to estimate storm volumes and predicted flows for each drainage area tributary to the Metro system.

Wind directions were next analyzed to see if they could be associated with rainfall patterns to provide even better predictions of storm potential. It was found that during certain months in summer, every storm with a total rainfall of 0.10 inch or more was preceded by windshifts from a northerly to southerly direction. Studies of wind directions for 1965 showed that consideration of wind shift not only increased lead times on many storms but also predicted two storms during the test period when rainfall began first in Seattle. One additional finding was that persistence of wind from a particular direction was definitely related to total volume. Heaviest storms were associated with long periods of southerly winds, while light storms occurred in conjunction with a high percentage of northerly winds. The end conclusion was that the combination of wind direction and rain gaging from remote stations would provide advance information to enable the CATAD program to determine optimum flow regulation and storage levels within the sewage collection system.

Actions Taken

Rather than duplicate much meteorological work being accomplished by the weather bureau, Metro decided to reduce the weather sensing portion of the CATAD program to the three following procedures:

1. Long-range precipitation forecasts would be entered into the computer program by obtaining the chance of rain (COR) prediction issued by the weather bureau at 6-hour intervals. This COR prediction would be incorporated into the model so that higher COR percentages would reduce allowable storage factors within the collection system.
2. Medium-range raingage data would be provided by rain gages at Metro stations located to the farthest north or south extent of the collection system. The first amount of rain detected by these gages would signal the immediate release of all stored sewage and draw down of those trunks and interceptors in a manner described at the beginning of this chapter.
3. Short-term weather prediction would be obtained by rain gages located throughout the Metro drainage area at points indicated in Figure 34.

The map shows locations for the six telemetering rain gages initially planned for the Metro CATAD system. Each rain gage is located adjacent to a pump or regulator station. A tipping bucket signals a counter inside the telemetry control transmitter unit within the nearby station. Figure 35 shows rain gage equipment at a remote terminal site. The computer senses changes in the counter during the next scan and computes rainfall intensity.

It is planned to run correlation studies in the future to determine if the six locations are sufficient to establish relationships between rain intensities and drainage areas. If it appears that the six stations are not sufficient, additional stations may be purchased or a parallel manually controlled raingage system owned and operated

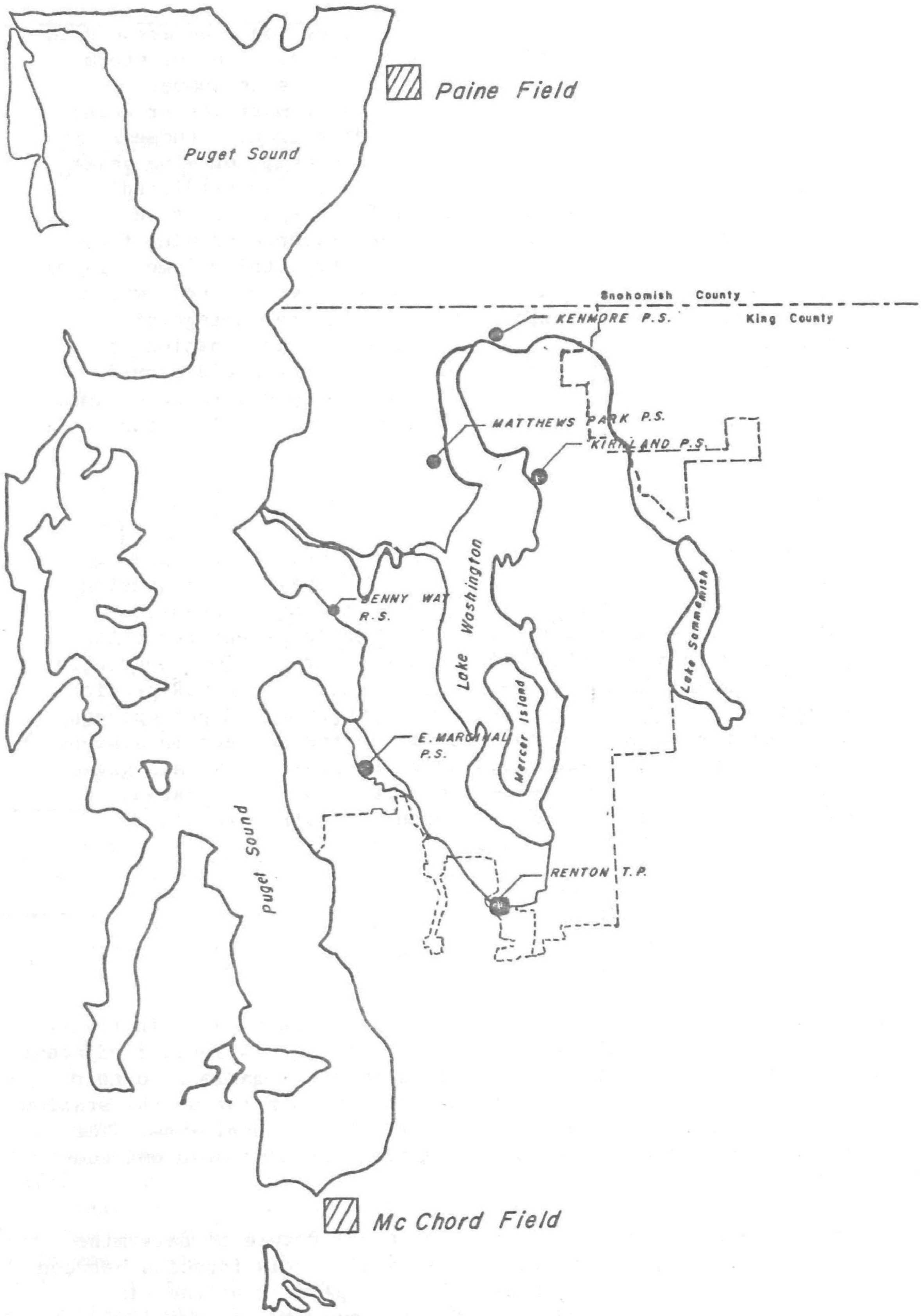


Figure 34. Metro Rain Gaging Sites

Figure 35. Rain Gage Equipment

by the City of Seattle and consisting of 27 stations (41) may be tied to the Metro computer to expand its sources of rainfall data. Three raingages are provided and checked by the Seattle Engineering Department as well as being tied directly to the Metro CATAD computer system. Data collected by the two agencies from these cooperatively operated gages will be compared and checked for accuracy. All meteorological data is being processed and forwarded to the U.S. Weather Bureau for further analysis and distribution. Rainfall data from selected Seattle stations for recent years is summarized in Appendix K.

PROGRAM FOR A SYSTEM MODEL

General Theory

At the same time equipment was being built and installed, there was need for a parallel effort in the development of computer executive programs, which are designed to make the hardware work properly. That is, all equipment must operate according to specifications; the console must respond to operator command actions; and the map display must light, blink, and otherwise function as specified. Most important, Metro-provided data from stations in the field must be brought without modification to a specific location in computer memory so that further programming actions can take place. When station data has been monitored, transferred to the central computer, and placed in a specific addressable location, another series of system programs, generally called the mathematical model, take over to calculate and combine various bits of information to simulate the system and issue control commands that the executive program must execute properly. The executive program also provides the Metro programs with a means of interrupting other less critical computer functions so that tasks can be accomplished in the order of their priority relationship to other system functions.

Hydraulics and Hydrology

Regulation of storage by the CATAD system controls will be accomplished by the use of rule curves, which define the permissible storage volume in relation to time. This technique is used extensively in river system storage regulation in which storage reservoirs are drafted and refilled in accordance with rule curves. The reservoirs are drawn down prior to a seasonal flood to a level that provides adequate space for anticipated flood flows; at the end of the flood period, the reservoirs are permitted to refill. Rule curves are initially based on past records. The curves are not inflexible but serve as a guide in effective use of available storage. The mathematical model will be used to study system operation with different rule curves under various runoff conditions and the effect of this operation on the volume and duration of overflows.

The task remains of developing storm hydrographs for the various trunk lines. At first a synthetic unit hydrograph, perhaps triangular in shape, will be used. Monitoring of the sewer system by the CATAD system is expected to furnish information that will permit refinement of the initial hydrographs. Storm hydrographs will be routed through the sewer system by a procedure similar to that used for routing floods down a river as suggested by B.R. Gilcrest in Chapter X of Engineering Hydraulics. (42)

Programming Requirements

Computer programs and subroutines needed to effect computer-directed remote control of regulator and pumping stations are currently being prepared and compiled by consulting engineers specializing in hydraulic and control systems. Two main computer programs are required: a modeling and a control program. The modeling program simulates the operation of the system based on a rule curve or inflow hydrograph selected by the engineer.

The control program will operate the system under an assumed rule curve based on measured variables. Under this program, the trunk inflow is calculated from measured variables. Thus, the program can be used to accumulate inflow hydrograph data for correlation with precipitation data. Many program routines will be common to both the simulation and control models.

Control Model

The method of controlling the CATAD system during periods of storm conditions is illustrated in the block diagram in Figure 36. The approach uses a mathematical model of the Metro interceptor system to simulate the movement of sewage from selected entry points to final disposal in the receiving waters of Puget Sound.

Four different types of inflow are considered, as shown in Figure 36. They are: (1) sanitary flow, which includes sanitary wastes and seasonal ground water infiltration; (2) infiltration, which represents ground water inflow resulting from recent rainfall; (3) measured rainfall, as determined by the Data Collection System; and (4) forecast rainfall, which may be a combination of operator input and information provided by the data collection system. Pump stations and regulator gates represent hydraulic devices used to inhibit the progress of sewage toward its ultimate treatment and disposal. Because the volume of flow in the system depends to a great extent on the nature and extent of rainfall, the need to inhibit flow and store sewage behind regulator gates varies proportionately to the amount of rainfall. Hence, forecast and measured rainfall data are used to prepare rule curves to govern the behavior of various pump and regulator stations in the system.

The rule curves provide a master plan for operating the system during periods of rainfall. It is also necessary to monitor the actual progress of the storm to optimize the available capacity of the system. Hence, rainfall, infiltration, and sanitary flow are combined into unit hydrographs, which are relationships of equivalent rainfall against time for the various tributary drainage areas. The unit hydrographs can readily be converted into projected runoff entering the system at the 50 or so flow entry points. The projected runoff for 30 minutes from a given point in time can be checked with the

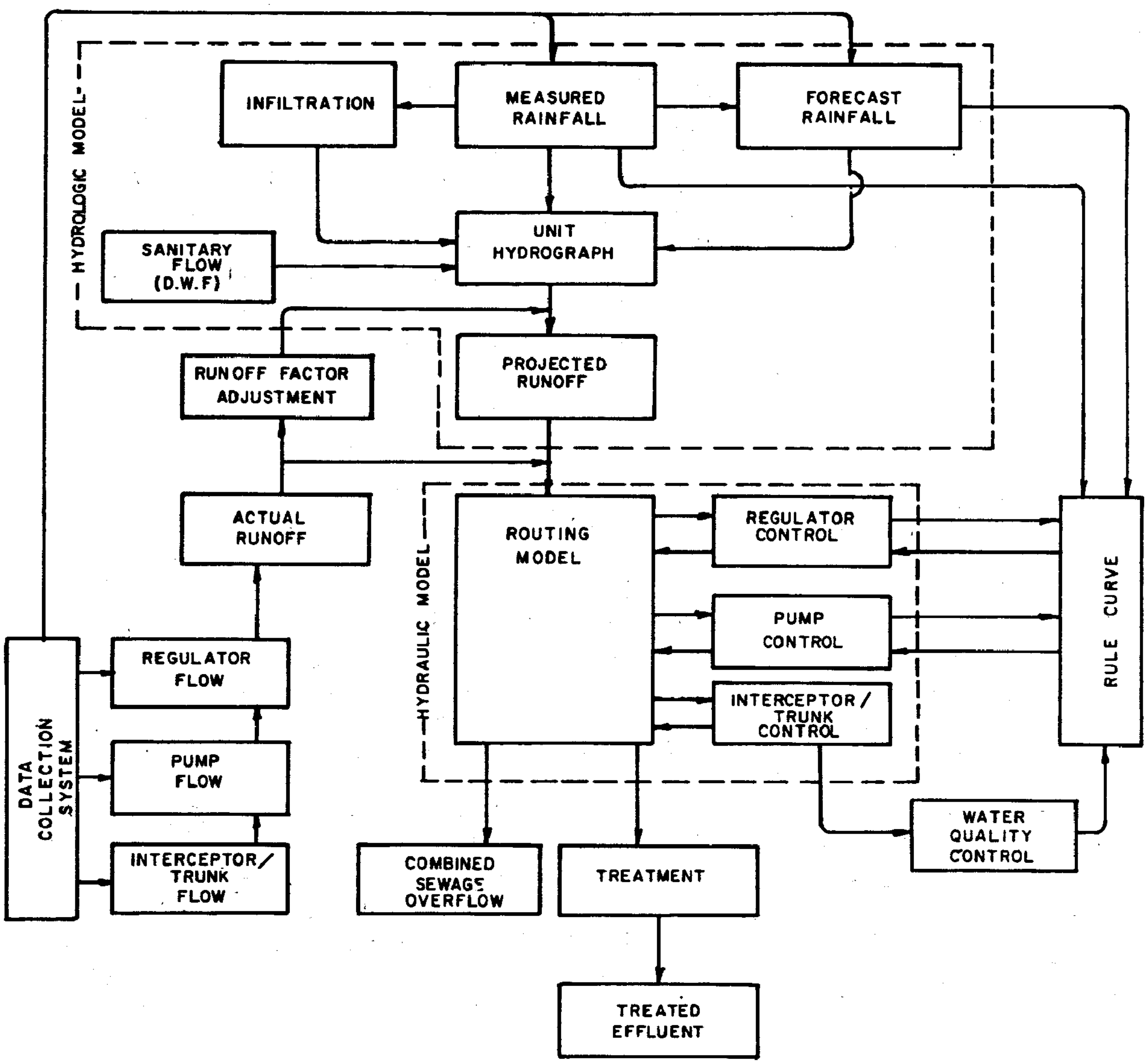


Figure 36. CATAD Control Model Block Diagram

actual recorded runoff after the 30 minutes have elapsed. The recorded value can be used to modify future values of the projected runoff.

Runoff entering the system is routed through the system by the routing model to eventual discharge either through the treatment plant or, if necessary, through outfalls directly to the receiving waters as combined sewage overflow. The progress of the sewage is subject to regulator control, which, where possible, follows the selected rule curve of storage against time. In a similar fashion, flow to a pump station is controlled by pump control.

From time to time, levels in the trunks or interceptors may exceed the maximum safe level allowed. In this event, it will be necessary to amend one or more of the rule curves to relieve the condition. It is the task of the interceptor trunk control program to detect such occurrences. The water quality control program will then modify the appropriate rule curves to provide optimum usage of the system storage and also establish a priority system for planned overflows. In theory, at some time in the future, the water quality control program may be adjusted automatically by the data collection system, which could be sensing such physical data as river flow, tide level and direction, dissolved oxygen concentration, and other water quality parameters for which sensors can be obtained.

Simulation Model

A block diagram of the simulation model showing control of the CATAD system under programmed storm conditions is shown by Figure 37. Rainfall from a simulated storm is combined with infiltration and normal sanitary flow into a unit hydrograph at various points in the Metro region. Drainage area characteristics such as inlet time, runoff coefficients, and acreage will determine the projected runoff at each entry point in the collection system.

Flow entering the interceptors through regulator stations is modulated by regulator control to follow a preset rule curve (the rule curve is developed from data about the storm). High water levels in the trunk or interceptor, detected by interceptor/trunk control, will point out program faults. Water quality control will amend the appropriate rule curve to provide optimum use of the system storage and establish a priority system for planned overflows.

A thorough engineering analysis of the system along with tne flow calibration and weather analyses previously described can lead to a period of trial testing and program modification to develop refined rule curves for use in actual control of the system during precipitation events. Alternatively, the model can be used to rerun previous storms and to refine the accuracy of the routing model to provide better flow projection for future storms.

Present Status

CATAD mathematical model programming has been proceeding in parallel with the executive system programming by using a separate computer so that the two programming groups would not interfere with each other. Coordination between the two program teams has been less than perfect so that some delay is a result of not having the two programming groups working in harmony on the same computer. For example, the prime contractor scheduled his software development in such a sequence that an executive program which was required by the consultants writing the control model, was one of the final programs to be finished. This scheduling could not be modified, and, as a result,

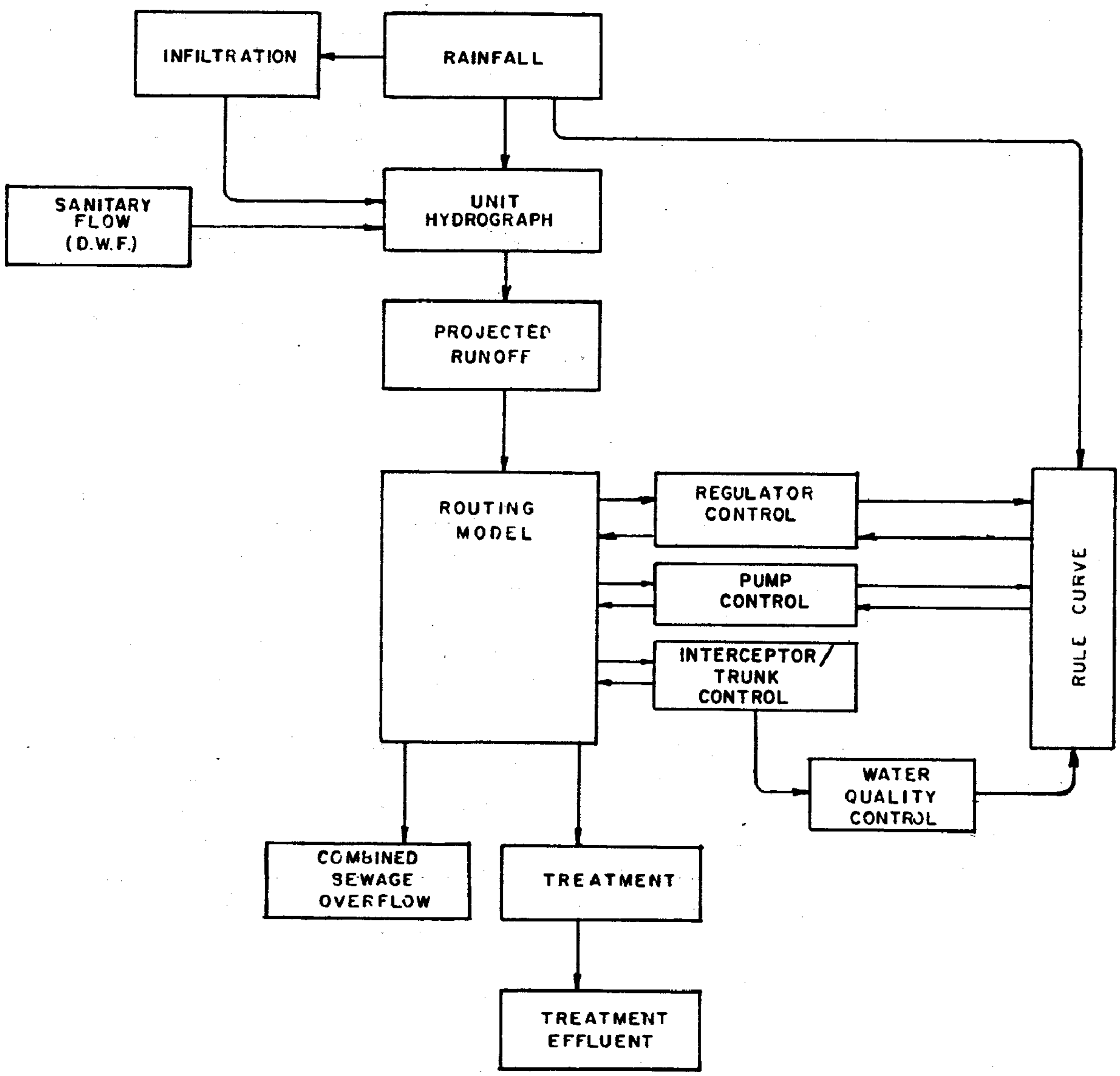


Figure 37. CATAD Simulation Model Block Diagram

early completion of the model was impossible. It is unreasonable to expect complete cooperation and coordination between different persons working on parts of a single program, so delays can be expected irrespective of the size of the programming group.

At this time, model subroutines (described in Appendix F) are being compiled and tested on the Metro CATAD computer. It is expected that in the late summer of 1971, the mathematical model can begin to run in a simulation mode while system reaction to various supervisory commands and storm conditions is monitored and analyzed for use in updating rule curves and other model programs. If weather conditions provide enough different types and intensities of storms so that most conditions can be predicted based on actual monitored data, it is expected that the control program can begin to direct collection system stations beginning with one station and proceeding deliberately until there is sufficient confidence to place the entire system under computer control. Each step of the assumption of this control will be closely monitored both at the central command console and at remote station terminals where physical observation will verify whether proper equipment responses are taking place and whether central console information displays match what is observed at the site itself.

SECTION VI
WATER QUALITY STUDIES

Since 1963, the Municipality of Metropolitan Seattle (Metro) has been engaged in a comprehensive water quality monitoring program throughout the entire metropolitan drainage area. At the inception of the computer demonstration grant in 1967, additional specialized water quality monitoring studies were added to the existing program to concentrate on certain areas within the collection system that contribute to combined sewer overflows. The portion of the comprehensive monitoring program and the special studies relating to the purpose of the demonstration grant will be described in this section.

The objectives of the demonstration grant water quality studies were two-fold. First, new water quality studies were begun or old programs modified to show how receiving water quality and other dynamic system parameters have changed during the periods of expansion, interception, regulation, and separation. A second objective was to establish a base level for various parameters that could be used as a tool for measuring the results of the CATAD demonstration project. The studies have been divided into two general areas related to either the collection system itself or the receiving waters adjacent to the municipality. Weather and other pertinent environmental factors are correlated with data from the two main study categories.

STUDIES ORIENTED TO COLLECTION SYSTEM

Collection system studies for the demonstration grant centered upon combined sewer overflows. Because of the importance of the storm water portion of combined sewage and the potential impact of the large sewer separation program being undertaken by the City of Seattle, two parallel studies have been included in this report section: (1) a 3-year study of the effects of sewer separation and (2) a short preliminary study of the quality of freeway drainage. The map in Figure 38 locates the sampling stations referred to in the discussion of the collection system studies.

OVERFLOW SAMPLING

Scope of Study

A demonstration project to reduce overflow frequency and volume and to improve receiving water quality, all as a direct result of some special new device or technique, must by its own nature include a detailed analysis of combined sewer overflow physical, chemical, and biological measurements. This concentrated study of overflows is generally intended to determine relationships of overflows to various rainfall and other meteorological factors, how overflow characteristics change with respect to time, rainfall intensities, and historical data such as dry periods before a storm or the intensity of the last previous storm. Another objective is to establish the

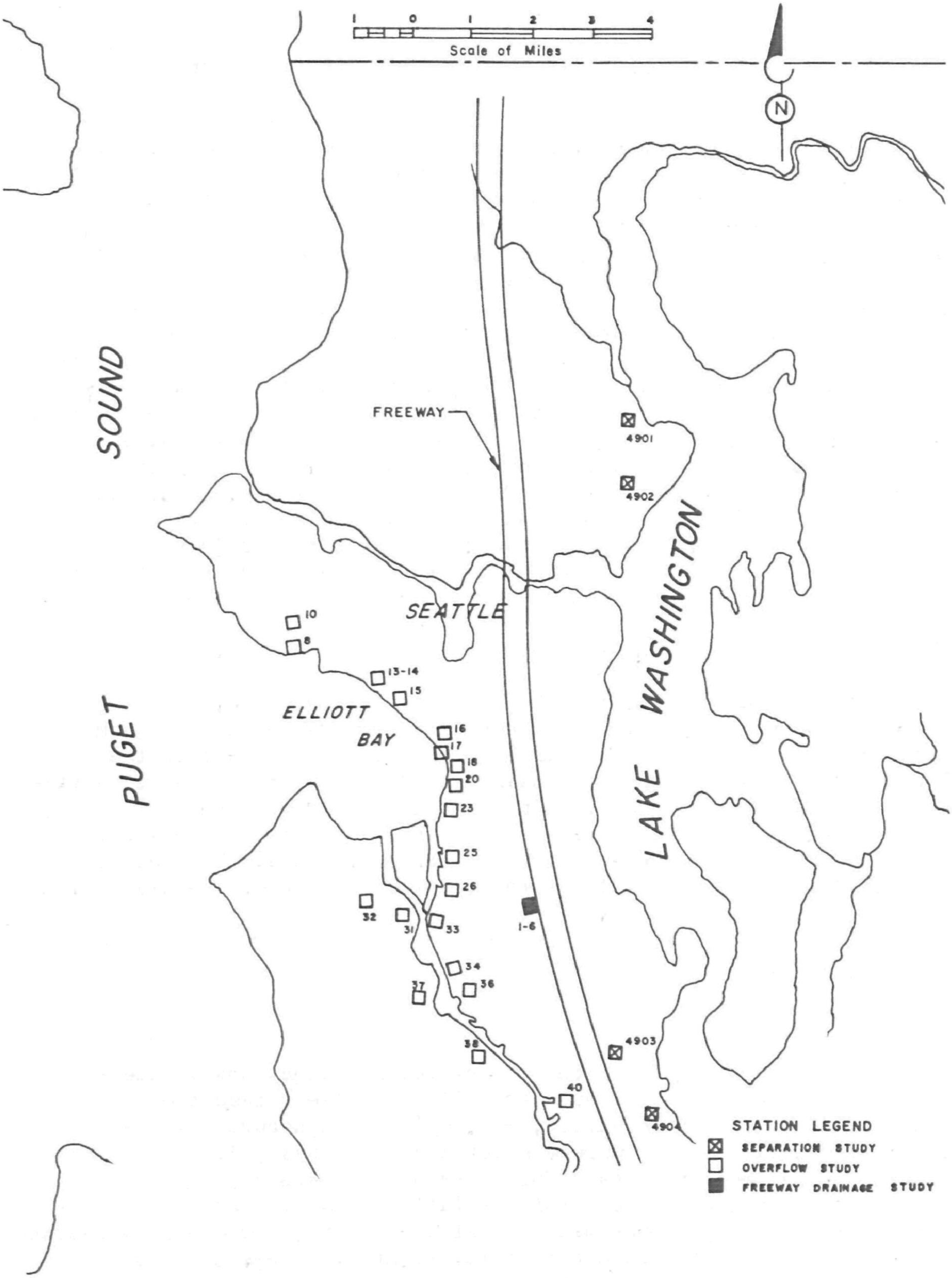


Figure 38. Overflow and Storm Sampling Stations

loading value of various pollution indices to nearby receiving waters and relate this information to water quality data from routine receiving water sampling information. The last comparison to be made will relate different overflows to the characteristics of the tributary drainage areas and collection system features.

Overflow sampling was divided into three categories: physical and chemical sampling, bacteriological sampling, and overflow volume computation. Figure 38, summarizes all overflow sampling stations included in the study. Physical and chemical sampling stations numbered seven when the study began in 1969 and were expanded to 13 in 1971. Samples were automatically taken by either a composite or sequential automatic sampler installed at each regulator station. Bacteriological sampling was accomplished at 16 stations during manual sample collection runs by water quality teams, which were on call during areawide storms. Volume measurements were taken initially at six stations. The number of volume stations was increased to 12 in 1971 and will be expanded to 13 by 1972 with the addition of the Norfolk Street Regulator Station. Volume measurements were based on three-pen recorder charts, which indicated tide level, trunk level, and gate opening from which volume is calculated by a computer program. Table 5 summarizes all the overflow sampling and monitoring stations.

Equipment and Analyses

Programmed automatic refrigerated samplers were designed and built as part of the demonstration grant to simplify the sample collection tasks at the widely separated overflow stations in the project. Six compositing and seven 24-bottle sequential samplers were installed to operate whenever the adjacent outfall gate is in the open position. The samplers all operate on a vacuum principle drawing overflow samples up as much as 17 feet to a bottle of at least 1-liter volume. Samples are then refrigerated until a technician collects samples and replaces the full sample bottles. Figure 39 shows the main features of the two different types of samplers. With either sampler, a section containing programmers, timers, and other control devices rests above a refrigerator section. The enclosure is heated and contains air circulation fans to reduce interior corrosion from condensation. Additional details are available from the equipment manufacturer's instruction manual. (43)

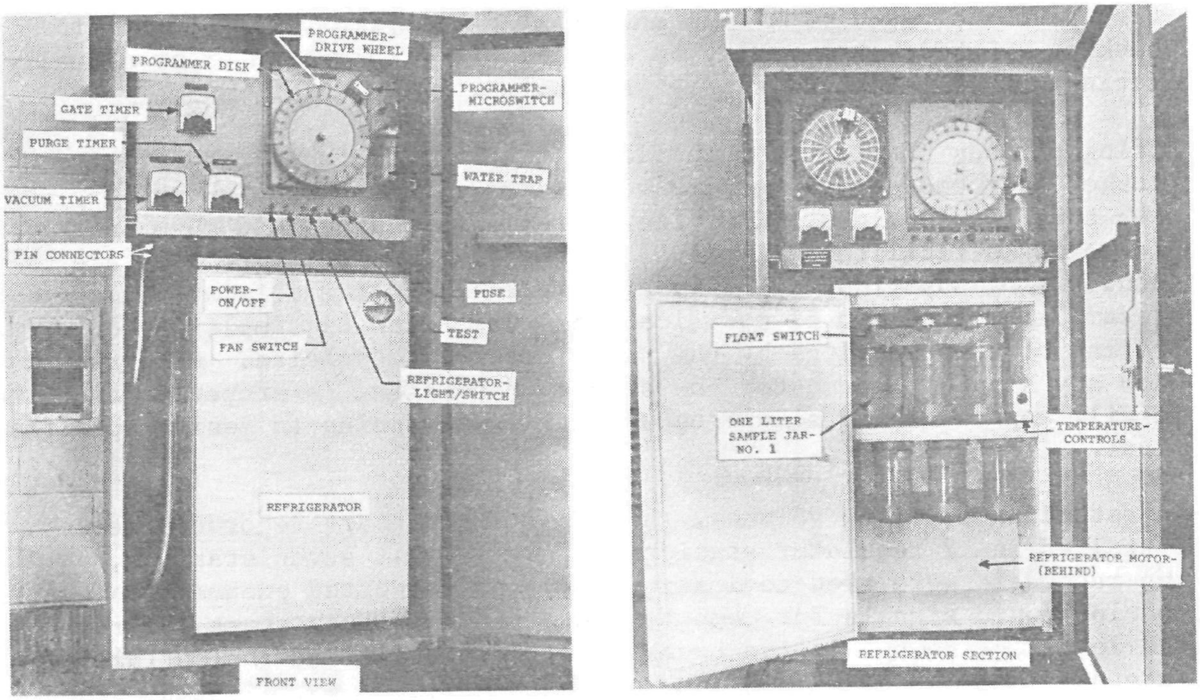
The connotation of the term "automatic" used to describe these samplers is somewhat deceiving; considerable manual effort is involved in collecting samples, replacing bottles, and testing and repairing the various electrical components. Originally the samplers were supervised, maintained, and serviced by different personnel. On the newly designed samplers, there was a 6-month period during which the samplers were broken in and various parts changed or modified. During 1970, a single technician was assigned the supervision, servicing, and some maintenance responsibility for each of the automatic samplers and since then the performance record of these units has been satisfactory.

TABLE 5

Overflow Sampling and Monitoring Stations

No.	Station Name	Type	Automatic Sampler	Regulation by: Orifice	Regulation by: Mech. Gate
8	Magnolia	Combined	None	x	
10	32nd Avenue	Storm	None	-	-
13	Denny-Elliott	Combined	Composite		x
14	Denny-Lk. Union	Combined	Sequential		x
15	Vine	Combined	None	x	
16	University	Combined	None	x	
17	Madison	Combined	None	x	
18	Washington	Combined	None	x	
20[a]	King	Combined	Composite		x
23[a]	Connecticut	Combined	Sequential		x
25[a]	Lander	Combined	Composite		x
36[a]	Hanford	Combined	Sequential		x
30	Harbor	Combined	Composite		x
31	Chelan	Combined	Sequential		x
32[a]	Longfellow	Storm	None	-	-
33	Diagonal	Storm	None	-	-
34	Brandon	Combined	Composite		x
36	Michigan	Combined	Sequential		x
37	W. Michigan	Combined	Composite		x
38	Eighth South	Combined	Composite		x
40	Norfolk	Combined	Sequential		x

[a]New station 1971



A. Composite B. Sequential

Figure 39. Automatic Overflow Samplers

An average of 30 samples are collected and analyzed each week. All analyses throughout this report were performed according to "Standard Methods." (44) The following tests are performed on each sample: settleable, suspended, and volatile suspended solids; ammonia and total nitrate nitrogen; total phosphate; and biochemical and chemical oxygen demand. This information is transferred to punch cards for computer statistical analyses.

At least twice a week, each sampler is visited to collect samples and perform minor maintenance. Most sampler malfunctions have been caused by conditions that were simple to correct; rarely has the manufacturer been called in to make major repairs.

A number of sampler problems might be explained to assist others in the specification and purchasing of sampler equipment. The electrical system on these samplers was complicated; on the first model, wiring was difficult to maintain. Fuses were often inadequate and, for a period of time, required frequent replacement. A number of electrical components have been found to be relatively marginal and have failed during continuous operation. Such things as timers, microswitches, relays, and reed switches have had to be replaced by instrument technicians. In sequential samplers, a float switch frequently failed to turn off the vacuum pump, resulting in water being drawn up into the pump even though water trap protection was provided. Despite an automatic purging feature, the 3/8-inch-diameter sampling tubes often become plugged with rags and other debris, requiring constant checking. Debris can usually be cleaned off with a hose or by manually lifting and cleaning the sampler tubes.

During periods of extreme high flows, the sampler tubes are often flushed over emergency overflow weirs and left hanging high and dry when the flow subsides. Guy wires were installed to hold them in place and to facilitate retrieval of sample tubes whenever they are found out of position. Shortly after purchasing the initial set of samplers, a number of modifications were added to simplify the testing of these devices by the water quality technician. As a rule, when any sampler, no matter how simple or complex, is properly maintained, it will work well and sample each overflow according to design specifications.

To establish overflow volumes, three-pen strip chart recorders were installed in 12 regulator stations. In the first seven stations, the recorders were tied to instruments that converted pneumatic signals to electronic signals for computer interfacing. Each chart records the levels of sewage in the trunk, the tide level, and the outfall gate opening, as shown by a sample chart on Figure 40. A computer program was written to determine the volume of sewage that escapes during an overflow by treating the gate as an orifice that may become submerged due to tidal action. The flow can be computed according to King's hydraulic handbook (45) by the equation:

$$\text{Flow} = (\text{constant}) \times (\text{area}) \times \sqrt{(\text{head})}$$

or

$$Q = k\,A\,\sqrt{H}$$

The volume of overflow is the rate of flow multiplied by the duration of the overflow. The computer program (described in Appendix F) must take into account the level and scale factors that are necessary for converting strip chart readings to levels relative to the invert of the outfall sewer. Strip charts are graphically divided into uniform areas and transferred to a worksheet (see Table 6 for sample data) for punching onto data cards to be read by computer programs that integrate these areas into a flow computation.

Operating experience with these recorders was similar to the sampler equipment in that after a specific individual had been assigned the duty of overseeing and servicing the recorders the units have proved reliable and helpful in determining operational problems at various stations. Several sample charts that indicate regulator instrumentation problems have been included in Appendix H.

The chart recorders have been useful in regulator stations. Their first use and the reason they were initially installed is to record

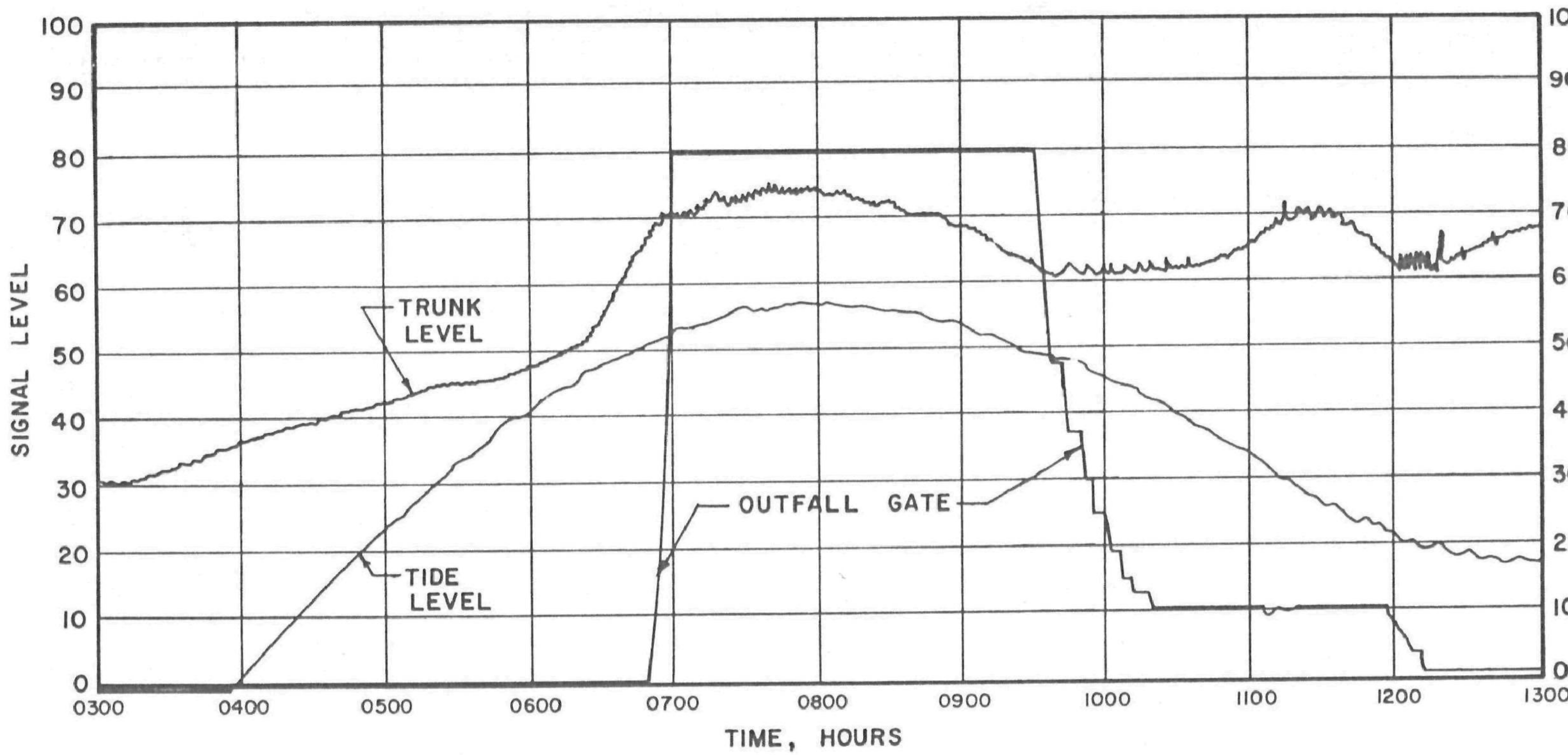


Figure 40. Sample Overflow Chart

TABLE 6

Volume Calculation Program--Sample Output Data

	Station	Date	Time Overflow Began	Duration (hours)	Volume (gal. x 1,000)	Flow (cfs)	
	36	70- 9-17	12	0.1	61.8	28.7	
	36	70- 9-17	12	0.1	110.7	51.4	
	36	70- 9-17	12	0.1	120.2	49.7	
	36	70- 9-17	12	0.1	105.3	48.9	
	36	70- 9-17	12	0.1	85.3	39.6	
	36	70- 9-17	12	0.1	74.4	30.7	
	36	70- 9-17	12	0.1	47.5	22.1	
	36	70- 9-17	12	0.1	28.6	13.3	
	36	70- 9-17	12	0.1	31.7	13.1	
	36	70- 9-17	12	0.1	9.4	4.4	
	36	70- 9-17	12	0.1	10.7	4.4	
	36	70- 9-17	12	0.2	29.9	4.5	
	36	70- 9-17	12	0.2	30.2	4.5	
	36	70- 9-17	12	0.2	29.9	4.5	
	36	70- 9-17	12	0.1	9.5	4.4	
Michigan	36	70- 9-17	12	1.7	785.1		Total
	36	70-11- 8	3	0.1	9.9	4.6	
	36	70-11- 8	3	0.1	19.8	9.2	
	36	70-11- 8	3	0.1	33.8	14.0	
	36	70-11- 8	3	0.2	92.7	13.8	
	36	70-11- 8	3	0.2	92.1	13.7	
	36	70-11- 8	3	0.2	92.7	13.8	
	36	70-11- 8	3	0.2	123.3	18.3	
	36	70-11- 8	3	0.3	203.1	22.9	
	36	70-11- 8	3	0.1	58.9	27.4	
	36	70-11- 8	3	0.1	77.7	32.1	
	36	70-11- 8	3	0.2	244.5	36.4	
	36	70-11- 8	3	0.2	154.2	35.8	
	36	70-11- 8	3	0.1	74.4	30.7	
	36	70-11- 8	3	0.1	31.7	13.1	
Michigan	36	70-11- 8	3	2.3	1309.0		Total
	36	70-11-19	18	0.1	9.3	4.3	
	36	70-11-19	18	0.1	18.8	8.7	
	36	70-11-19	18	0.1	21.0	8.7	
	36	70-11-19	18	0.1	18.4	8.6	
	36	70-11-19	18	0.2	57.1	8.5	
	36	70-11-19	18	0.2	56.6	8.4	
	36	70-11-19	18	0.2	54.8	8.2	
	36	70-11-19	18	0.2	54.3	8.1	
	36	70-11-19	18	0.2	53.3	7.9	
	36	70-11-19	18	0.2	51.9	7.7	
	36	70-11-19	18	0.1	9.4	3.9	
Michigan	36	70-11-19	18	1.9	405.2		Total
	36	70-11-23	15	0.1	6.0	2.8	
	36	70-11-23	15	0.1	12.4	5.7	
	36	70-11-23	15	0.1	21.9	9.0	
	36	70-11-23	15	0.1	20.0	9.3	
	36	70-11-23	15	0.1	20.2	9.4	
	36	70-11-23	15	0.1	23.0	9.5	
	36	70-11-23	15	0.2	66.2	9.8	
	36	70-11-23	15	0.2	68.5	10.2	
	36	70-11-23	15	0.2	72.1	10.7	
	36	70-11-23	15	0.1	36.7	11.4	
	36	70-11-23	15	0.1	40.7	11.6	
	36	70-11-23	15	0.1	25.0	7.7	
Michigan	36	70-11-23	15	1.6	412.6		Total

information for accurate manual or computer determination of overflow volumes and durations. A second asset is that the recorders have assisted operations personnel in locating station instrumentation problems and solving these problems before a long period of unnecessary overflow or further equipment damage transpires. Lastly, the recorders will have a use even after the computer automatically determines overflow volumes; they will provide information to check computer computations and also to continue the data base in case of telemetry or other computer failures that might cut off the automatic source of overflow volume information.

Data and Results

This section presents the results of laboratory tests performed on storm water and combined storm water and sewage taken from the sampling stations of Figure 38. Although some water quality data is available from as early as January 1970, for the purpose of this report, the analysis summary will cover the period of October 1969 to December 1970 when flow data from most stations became available for comparison. These concentrations are based on the average of each event sampled from the 16 test areas.

Bacteriological

The membrane filter technique (44) was used for the total coliform, fecal coliform, and fecal streptococci tests. Bacteria samples were taken manually during overflow conditions and on a less frequent basis than the other parameters, collected by automatic samplers. Table 7 gives the summary for this data. Stations 8 and 33 are the only storm drains being sampled. Station 8 (Magnolia) is the only truly separated storm sewer and is the lowest in coliform density. The high densities recorded from station 33 (Diagonal) reflect frequent combined sewage overflow into this "storm" sewer from the Metro Hanford Street No. 1 regulator and three City of Seattle regulators. Stations 15 through 18 drain the Seattle Central Business District and indicated low coliform averages when compared to other overflow points. Station 31 at the Chelan Street regulator has shown only one overflow since the start of the project, and this overflow was not sampled for bacteriological analysis.

Organic

Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were measured to show organic concentrations of the overflows. This data is summarized in Table 8. Station 36 (Michigan) had, by far, the highest BOD and COD concentration. The most likely explanation for this is the design of this particular station. At Michigan Street, the outfall gate and the regulator gate are about 800 feet apart. This situation creates a stagnant condition in this section of line along with a high buildup of solids. As the regulator gate closes and the outfall gate opens the stagnant sewage flushes out first,

TABLE 7

Bacterial Density Summary--Overflows
(October 1969 to December 1970)

Station Number	Total Coliform/100 mls Mean	Min.	Max.	Fecal Coliform/100 mls Mean	Min.	Max.	Fecal Streptococcus/100 mls Mean	Min.	Max.
8	18000	1500	59000	6000	800	10000	40000	1900	46000
10	2400000	1600	16000000	340000	250000	710000	51000	24000	350000
13	6500000	4700000	38000000	320000	150000	4200000	29000	23000	790000
14	4400000	1500000	6600000	540000	7000	4200000	43000	21000	110000
15	34000	2300	3100000	3600	20	140000	500	380	85000
16	1300000	16000	8600000	110000	500	280000	6000	150	46000
17	500000	2000	1000000	18000	1000	35000	3800	1600	6000
18	140000	26000	1100000	7500	1800	340000	34000	650	260000
30	2000000	1100000	5000000	410000	2500	1000000	23000	100	100000
31	-	-	-	-	-	-	-	-	-
33	1400000	120000	7100000	24000	16000	600000	29000	270	65000
34	700000	425000	1100000	46000	7800	93000	12000	8100	30000
36	4400000	850000	6900000	530000	290000	4400000	54000	18000	90000
37	4600000	850000	7900000	780000	290000	5400000	24000	24000	74000
38	980000	590000	2600000	320000	36000	590000	42000	7500	380000
40	7000000	4200000	8200000	340000	250000	2800000	150000	28000	210000

TABLE 8

BOD and COD Summary--Overflows
(October 1969 to December 1970)

Station Number	BOD mg/l Mean	BOD mg/l Min.	BOD mg/l Max.	COD mg/l Mean	COD mg/l Min.	COD mg/l Max.
8	27	10	41	266	56	842
10	79	17	228	295	16	860
13	62	81	73	196	120	272
14	68	3	200	353	37	1389
15	34	18	216	371	110	936
16	51	4	318	288	10	542
17	148	148	148	736	736	736
18	27	11	39	100	56	296
30	49	6	198	210	28	1200
31	15	15	15	160	160	160
33	42	17	330	96	16	440
34	33	7	129	250	32	1320
36	236	5	2700	817	20	3472
37	66	6	366	211	40	1184
38	19	18	20	200	200	200
40	66	1	264	272	20	1555

followed by high concentrations of solids that had built up in this section. Samples are taken at the outfall gate at station 36 and reflect this condition in their BOD and COD values.

A similar outfall configuration exists at station 34 (Brandon); however, the distance separation is less and the drainage area is considerably smaller in size and different in other characteristics.

Corrective action to alleviate the stagnant sewage condition is planned at both of these stations. A low weir will be built in the outfall line at the regulator and the outfall sewer relined to provide a rising invert from the regulator gate to the outfall gate.

Station 17 also indicates relatively high BOD and COD values, but this is the result of only one observation so should not be considered as representative when comparing all stations.

The average BOD concentrations from the 16 sampling stations ranged from a low of 15 mg/l at station 31 to a high of 236 mg/l at station 36. Average COD concentrations ranged from a low of 96 mg/l at station 33 (storm drain) to a high of 817 mg/l at station 36.

Solids

Three solids categories were measured including settleable, suspended, and volatile suspended solids. Averages of these categories can be found in Table 9. Considerable variation is found in all three categories. Settleable solids ranged from a low of 0.1 ml/l from the storm drains of station 16 and 33 to a high of 8.8 ml/l at station 14 (Denny-Lake Union). Station 14 was also highest in suspended solids (1464.0 mg/l). Diagonal storm drain was the lowest at 34 mg/l. Michigan Street regulator, station 36, had the highest percentage of volatile suspended solids concentration, with a value of 85.2%. Station 8 (Magnolia storm drain) had the lowest percentage of volatile solids, with a value of 18.4%, indicating that solids from this storm drain are essentially of a non-organic sandy nature. This is also an indication of good separation construction with few if any cross connections.

Nutrients

Average values for three nutrients are given in Table 10. They include ammonia-nitrogen, nitrate-nitrogen, and total soluble phosphate. Ammonia-nitrogen ranged from a low of 0.23 mgN/l at station 8 to a high of 6.25 mgN/l at station 40. Station 31 had the lowest nitrate-nitrogen value of 1.52 mgN/l. Total soluble phosphate ranged from 0.34 mgP/l at station 8 to 3.46 mgP/l at station 40. As with the solids analyses, nutrients tests pointed out the reduced loading from storm drains.

Volume of Overflow

There was enough acceptable overflow data collected during 1969 and 1970 to run a stepwise regression analysis on overflow volume and rainfall information from four regulator stations. The volume figures were used as the dependent variable and were correlated with seven independent rainfall variables including: volume of rain, duration of rain, duration of antecedent rain, and intensity of antecedent rain. These rainfall measurements accounted for 85% of the variability in overflow at station 41, 73% at station 30, 92% at station 36, and 86% at station 37. Volume of rain, as expected, in each case correlated the highest with volume of overflow, with values as shown in Table 11.

TABLE 9

Solids Constituent Summary--Overflows
(October 1969 to December 1970)

Station	Settleable ml/l			Suspended mg/l			Volatile Suspended mg/l			
Number	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	% Volatile
8	0.8	0.1	3.0	339.6	26.0	1305.0	62.6	8.0	255.0	18.4
10	3.3	2.5	5.5	168.0	31.0	580.0	86.2	24.0	230.0	51.3
13	1.0	0.5	1.5	212.0	148.0	276.0	80.0	64.0	96.0	37.7
14	8.8	2.0	19.0	1464.0	90.0	11105.0	553.3	60.0	8965.0	37.8
15	0.2	0.1	2.5	53.0	38.0	575.0	34.0	10.0	145.0	64.2
16	0.1	0.1	1.2	64.0	15.3	148.0	30.0	4.0	144.0	46.9
17	0.9	0.1	1.7	280.0	280.0	280.0	105.0	105.0	105.0	37.5
18	0.2	0.1	0.3	90.0	34.0	180.0	19.0	8.0	86.0	21.1
30	4.0	0.1	35.0	207.1	2.0	970.0	103.7	2.0	760.0	50.1
31	5.5	5.5	5.5	200.0	200.0	200.0	90.0	90.0	90.0	45.0
33	0.1	0.1	2.0	34.0	14.0	1350.0	17.0	4.0	220.0	50.0
34	2.7	0.1	40.0	194.2	16.0	952.0	101.0	8.0	736.0	52.1
36	3.8	0.1	241.0	777.4	5.0	8099.0	662.0	4.0	6102.0	85.2
37	3.4	0.1	34.0	313.2	20.0	1620.0	135.5	20.0	1350.0	43.3
38	1.4	0.3	1.8	191.8	66.0	293.0	50.4	24.0	66.0	26.3
40	6.3	0.7	33.0	244.9	2.0	1290.0	129.0	0.1	792.0	52.7

TABLE 10

Nutrient Concentration Summary--Overflows
(October 1969 to December 1970)

Station Number	Ammonia Nitrogen mg N/1			Nitrate Nitrogen mg N/1			Total Soluble Phosphate mg P/1		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
8	.23	.03	.76	.27	.12	.40	.34	.14	.76
10	1.87	.20	3.60	.58	.30	.86	2.38	1.60	3.60
13	1.98	1.20	2.75	.34	.34	.34	2.45	2.40	2.50
14	5.08	1.50	10.80	.51	.26	.86	3.29	.35	9.20
15	.78	.05	2.20	.54	.39	.70	1.36	.85	2.10
16	1.36	.08	3.10	.54	.42	1.20	.52	.15	2.40
17	1.34	1.34	1.34	1.52	1.52	1.52	1.10	1.10	1.10
18	.36	.09	.60	.84	.70	.98	.73	.28	1.00
30	2.18	.30	6.80	.44	.06	.64	1.54	.11	6.40
31	.91	.62	1.20	.21	.10	.32	1.72	.44	3.00
33	.38	.04	.71	.33	.24	.42	.55	.32	1.08
34	2.75	.60	10.00	.22	.10	.38	1.31	.45	3.60
36	3.00	.04	18.23	.33	.02	2.66	1.56	.10	5.63
37	2.50	.60	9.80	.82	.04	4.54	1.80	.25	7.90
38	1.58	.70	3.90	-	-	-	1.13	.26	2.70
40	6.25	.50	22.20	.42	.04	2.20	3.46	.30	22.00

TABLE 11

Regression Correlations Between Rainfall Volume and Overflow Volume

Station	"r value"[a]
14	.5467
30	.5633
36	.6664
37	.7241

[a]See Glossary (Section X) for explanation of "r value".

The equipment problems referred to in the preceding "Equipment and Analyses" section prevented the gathering of sufficient amount of volume data with corresponding overflow quality data for 1969 and 1970. These statistical analyses will be given in the final report.

Sequential Sampler Findings

The sequential samplers at stations 14, 36, and 40 have generated a fair amount of information on concentration versus time. Some of this data has been plotted with flow and rainfall intensity. Figures 41 through 44 show this sequential data.

The next three charts show an overflow that occurred on November 23, 1970, at station 36. Nutrient values are plotted on Figure 41. All nutrient values have an apparent direct relationship with overflow volume; that is, they are gradually diluted as storm runoff enters the combined sewer system. Dilution effects are more pronounced with ammonia than with other nutrients. The highest volume peak in the overflow occurred approximately 1 hour after the greatest rainfall intensity.

Solids have an initial "first flush" peak after the flow reaches a maximum, followed by gradual dilution of solids concentrations, as illustrated in Figure 42. Studies of longer sequentially sampled overflows indicate that, following the surge, solids levels diminish to baseline levels as slower wastewater velocities probably promote upstream sedimentation. Analysis of dry-weather flow concentrations would be helpful to describe differences in amplitude of solids levels following overflow conditions and during dry-weather flows.

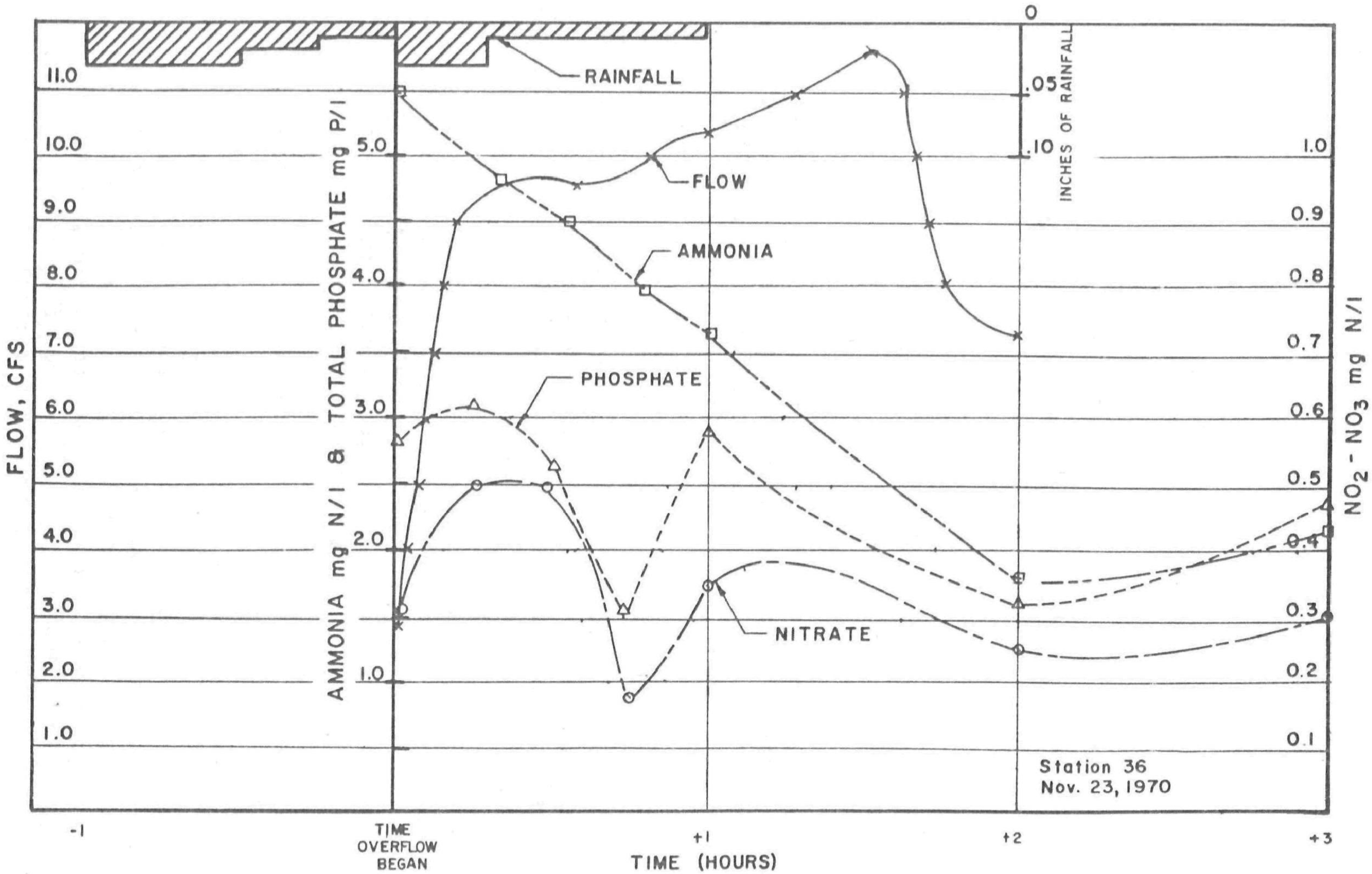


Figure 41. Flow and Nutrient vs. Time

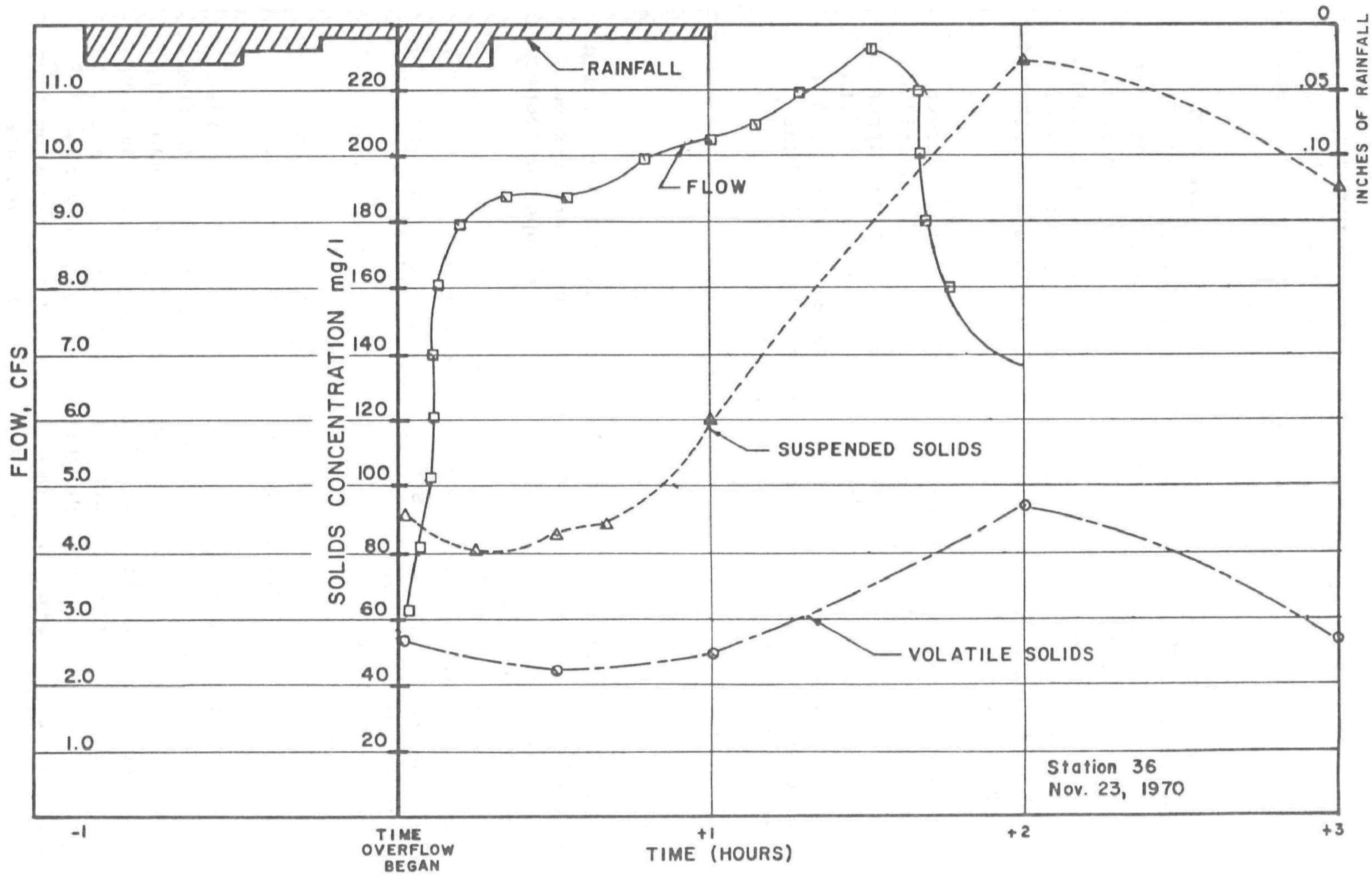


Figure 42. Flow and Solids vs. Time

BOD and COD concentrations shown in Figure 43 show a similar inverse relationship to flow. One interesting observation showed a high correlation of nutrient data with tide level at some sequential sampling stations. This discovery may indicate the possibility of a "salt wedge" of sea water backing up into the trunk and being sampled during overflow periods when outfall gates are wide open.

Nutrient parameters measured during an extended 15-hour overflow are shown in Figure 44. This overflow occurred at station 40 (Norfolk regulator) on October 12, 1970. Placement of the rainfall intensity is impossible as there is no way of measuring the time of overflow nor overflow volume at this station. Because of space limitation inside this underground station and because the regulator is scheduled to be rebuilt above ground within 2 years, a flow chart was not built in this station.

Table 12 presents a summary of laboratory analyses from confirmed over-flows along with rainfall information and sample and overflow volumes for 1970. Similar overflow data for other stations appears in Appendix I. As can be seen from these tables, more volume data is needed. A flow chart has not yet been installed at station 40. Data being collected in 1971 is more complete and will give the needed matching of overflow volume and laboratory analyses.

SEWER SEPARATION STUDY

Scope of Study

In March 1968 shortly after the City of Seattle passed a $70 million bond issue to partially separate all of the combined sewer system tributary to Lake Washington, Metro decided to embark upon a cooperative study with the City of Seattle to:

1. Determine the present effect of combined sewer overflows and storm drainage on Lake Washington receiving waters.
2. Record changes in combined sewer quality, volumes, and overflows as separation progresses.
3. Predict the future effect on the receiving water as partial separation is completed.
4. Determine the impact of separation projects throughout the city on the CATAD computerized storage management system.

As partners in this separation study, the City of Seattle provided access to sampling sites in addition to detailed rainfall data from areas tributary to the sites, and Metro provided manpower, sampling equipment, and laboratory facilities. Four representative sampling sites were selected as the primary sampling locations. Table 13 points out certain details about each sampling site (the sites are shown in Figure 38). Sand Point and Cooper Street sampling stations are on storm sewers draining small areas that have been separated for many years. Windemere and Henderson Street are sample

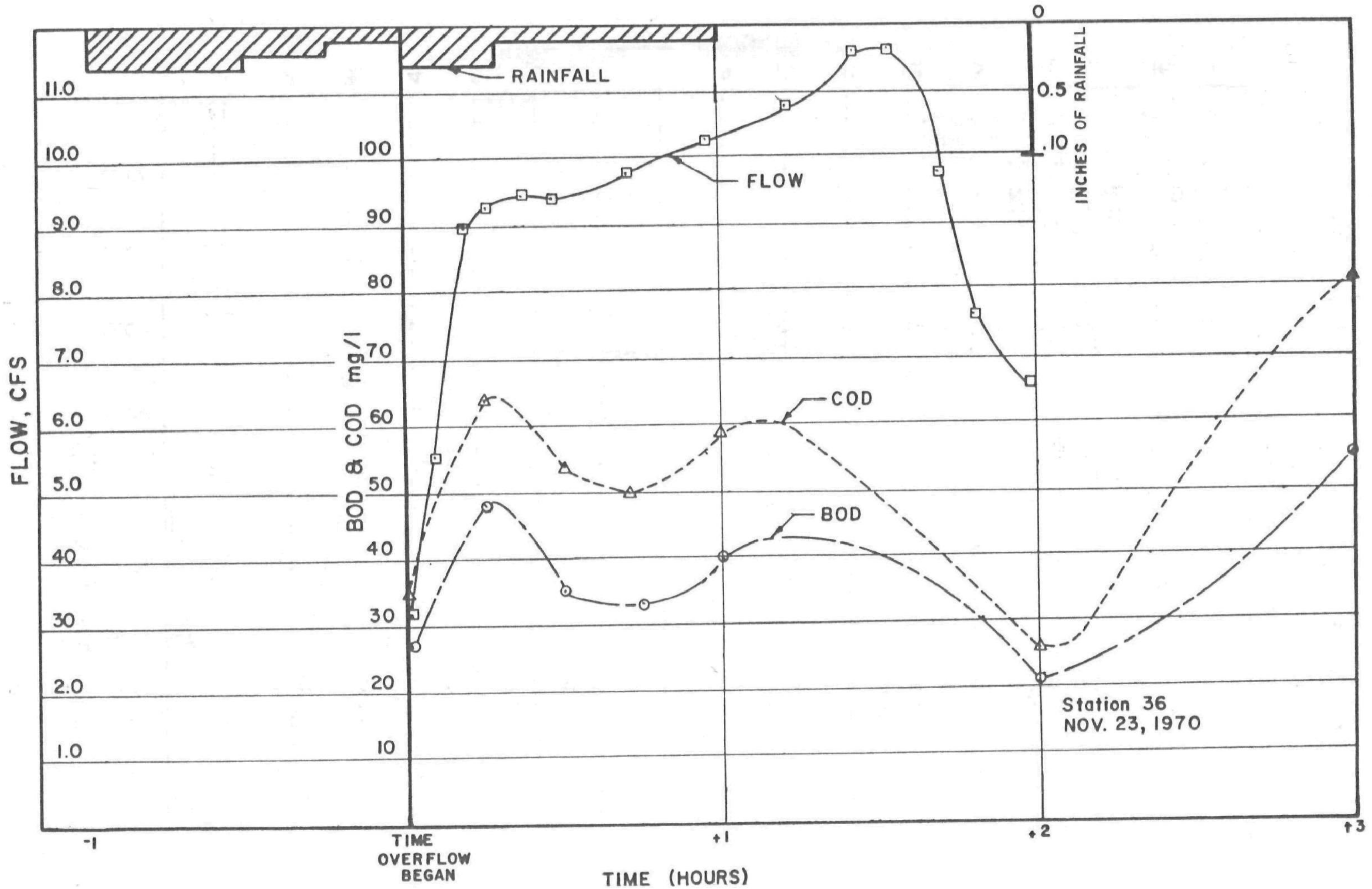


Figure 43. Flow, BOD and COD vs. Time

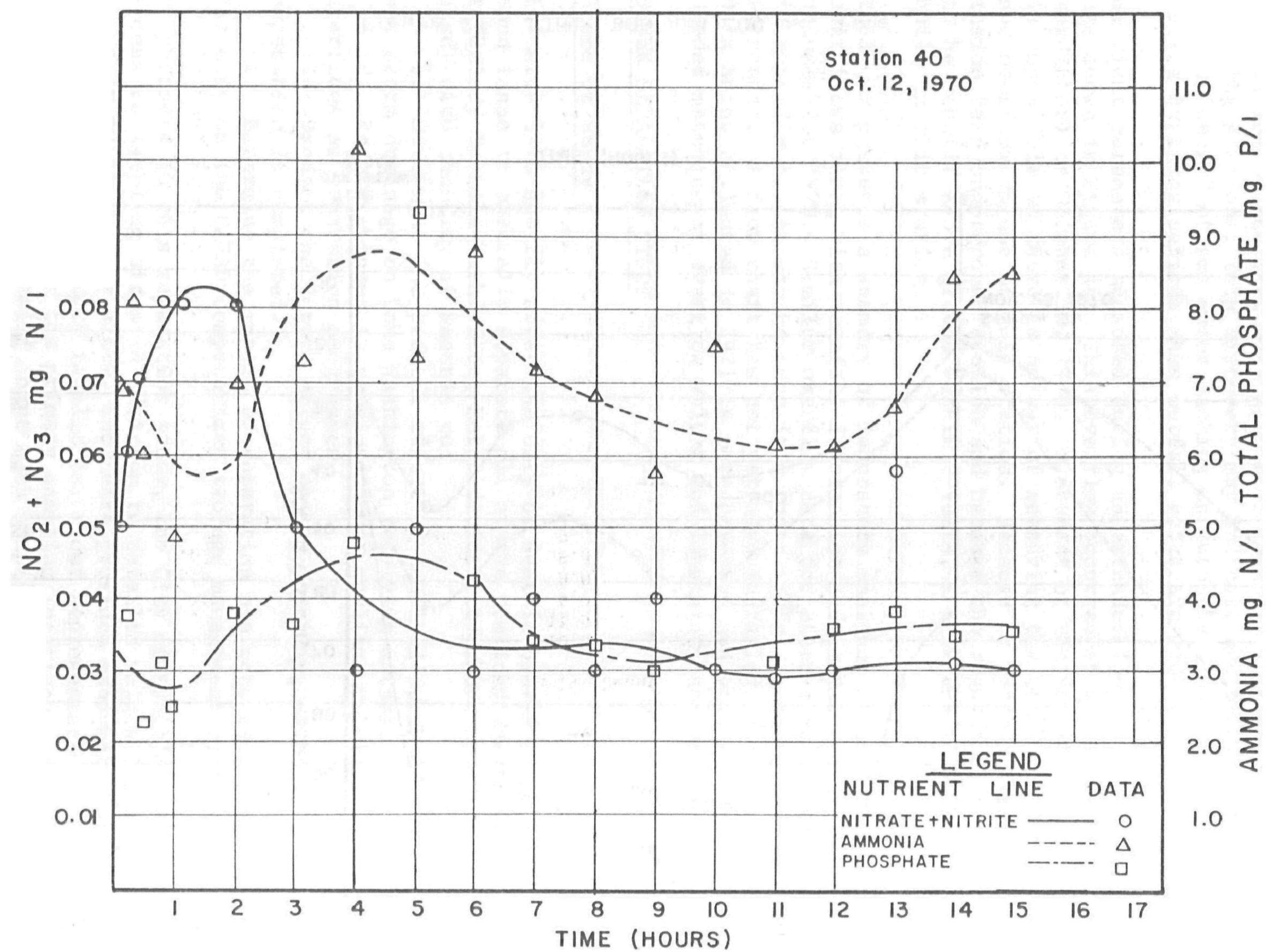


Figure 44. Nutrient Concentration vs. Time

TABLE 12

Regulator Station Overflow Data (1970)

Date	Rain Total (in.)	Rain Max. Rate (in./hr.)	Sample Volume (liters)	Overflow Volume (gal. x 1000)	Solids Settleable (ml/l)	Solids Suspended (mg/l)	Solids Volatile (mg/l)	BOD (mg/l)	COD (mg/l)	NH_3 (mg N/l)	NO_2+NO_3 (mg N/l)	PO_4 (mg P/l)
Station 13 Denny Way - Elliott Bay												
4-19	0.37	0.10	4		1.5	276	96	84	272	1.20	0.25	2.50
12-28	0.66	0.13	4		0.5	148	64	62	120	2.75	0.23	2.40
Station 14 Denny Way - Lake Union												
10-12	0.05	0.05	2	255.7	10.3	1580	92	12	105	4.35	0.30	0.37
11-19	0.14	0.03	1		11.5	370	320	200	210	6.40	0.49	9.20
11-30	0.23	0.07	1		4.0	180	175	191	480	6.60	0.37	4.57
12- 6	1.69	0.16	3	-	8.0	400	252	110	758	4.67	0.49	3.38
12-19	0.24	0.07	10	35651.0	8.8	2273	1874	32	264	5.20	0.27	3.23
12-28	0.64	0.09	4	55768.8	9.4	425	260	70	419	3.69	0.37	2.66
Station 30 Harbor Avenue												
1- 9	0.19	0.09	6		3.0	210	114	72	248	3.40	0.50	1.60
1-13	1.50	0.22	12		1.8	200	100	54	119	1.60	-	1.45
1-19	0.61	0.11	12		2.1	142	60	-	136	0.50	0.55	1.10
1-26	1.18	0.13	12		0.6	152	54	-	-	0.60	0.91	0.57
2- 5	0.16	0.04	10		20.0	200	106	76	504	3.90	0.55	2.90
2-15	1.08	0.12	7		3.0	120	46	36	344	1.90	0.55	0.70
3- 6	1.20	0.16	12		4.0	308	128	51	368	1.80	0.20	1.50
3-12	0.34	0.13	12		2.0	142	44	42	120	2.00	0.40	1.10
4- 9	0.80	0.12	12		4.0	154	82	42	216	1.50	0.30	1.00
4-24	0.19	0.07	6	-	1.5	106	32	18	112	0.30	0.01	0.50
4-27	0.28	0.18	8	-	2.0	280	80	54	184	2.00	0.05	1.30
6-29	0.47	0.28	12	1126.2	3.0	160	140	63	224	5.00	0.27	2.50
10-17	0.26	0.21	8	297.0	11.5	36	-	20	128	2.25	0.27	-
11- 8	0.53	0.10	10		1.2	50	20	6	335	1.00	0.19	0.35
11-15	0.22	0.06	4		3.5	2	2	-	838	1.70	0.25	1.30
11-19	0.30	0.06	12		1.5	295	170	10	140	1.85	0.37	6.40
11-23	0.80	0.09	12	1164.4	0.3	108	86	26	28	2.35	0.39	0.75
11-30	0.21	0.06	12	1315.9	1.3	198	128	41	168	1.80	0.26	1.15
12- 3	0.20	0.05	8	75.6	3.2	550	305	32	207	2.50	0.24	1.40
12-28	0.48	0.09	12		2.5	294	120	48	223	2.55	0.28	1.95

TABLE 13

Separation Study—Station Data

Station Number	Station Name	Drainage Area Type	Drainage Area Acres	Pipe Diameter (inches)
4901	Sand Point	Separated	183	36
4902	Windemere (overflow)	Combined[a]	448	36
4903	Henderson (overflow)	Combined	539	84
4904	Cooper	Separated	103	60

[a]Includes 215 acres served by separated sewers.

stations located at side-spill weirs where combined sewage frequently overflowed to Lake Washington and where separation was being planned in the near future.

It was not planned so initially, but the separation study turned into an extended research project into the efficiency of various types of samplers and flow recorders. It also was a large drain on manpower because the study, which extended from April 1968 to May 1971, required generally at least three persons for any manhole entry (samplers were located in manholes), extensive safety equipment and attention to safety procedures, plus considerable travel time; all this added up to a great deal of manpower during the 3-year life of the study.

Equipment and Analyses

Equipment used in the study can be divided into two groups: that used during the research period, and equipment finally selected to complete the study. Initially, one vacuum-operated sequential sampler and three battery-driven compositing samplers were combined with specially designed compressed air bubbler depth recorders and installed at the four manhole sampling sites. For the 12 months following the first installation in May 1968, the sampling equipment and recorders were studied and found to have serious problems that required correction. The compositing samplers needed frequent battery changes and were continuously becoming plugged with solids from the sewers. The bubbler-type depth recorders, after an extended calibration period, were found to be insufficiently sensitive for the minimal changes in sewer depth that were found to occur.

During the summer of 1969, the separation project was expanded. Additional personnel were added and three more vacuum-operated sequential samplers were purchased. A float-type, direct-reading level recorder was installed at each station and connected to a scow float that rode on the surface of the rapidly moving sewage stream. Two more changes occurred. The scow float was replaced by a plastic ball float, which operated much more effectively, and the vacuum-operated samplers had a special clock starter device attached so that entry to the manhole was not required to initiate a sequential sampler cycle. As has been indicated by others (9) sampling equipment must be designed to cope with the violence and unexpected flooding conditions that occur in sewer lines.

As it was finally established, the sampling procedure began at the onset of rainfall in the Seattle area. Water quality technicians would rapidly travel to each sampler site, remove a manhole cover, and release a pneumatic device to start the clock motor on the sequential sampler. At the same time, the technician would take a manual sample for bacteriological examination. The day following the storm, technicians would visit each sampler site and remove the sequential sampler from the manhole. The four samplers would be transferred to the central laboratory for solids and chemical nutrient tests. Samplers would then be recharged and returned to their manhole locations in preparation for the next storm.

Each week, another crew would replace the sewage level recording chart at each site. These charts were then converted into punch card data for computer calculation and volume computation using Mannings' formula. The sharp peaks shown on a typical level recording chart, reproduced in Figure 45, 49, show how difficult it is to convert these data into elevations and then volumes. However, even with these limitations, the calculated volumes correlate well with recorded rainfall information as indicated by the data presented in the following sections. Figure 46 shows the installation and sampling equipment used during the sewer separation study.

In addition to the volume calculation, study parameters included such physical analyses as settleable solids and total suspended solids. Volatile suspended solids tests were added following a preliminary study report issued in April 1970 (46) that indicated high solids loading from storm sewers. Biochemical and chemical oxygen demand tests were also added following the preliminary report. Chemical analyses included total phosphate and ammonia nitrate. Total and fecal coliform and fecal streptococcus bacteriological counts complete the list of analyses performed as part of the study.

Data and Results

Analyses performed on overflows and storm drainage are summarized in Tables 14 through 17. As stated, stations 4901 and 4904 are storm sewers, whereas stations 4902 and 4903 are combined overflows.

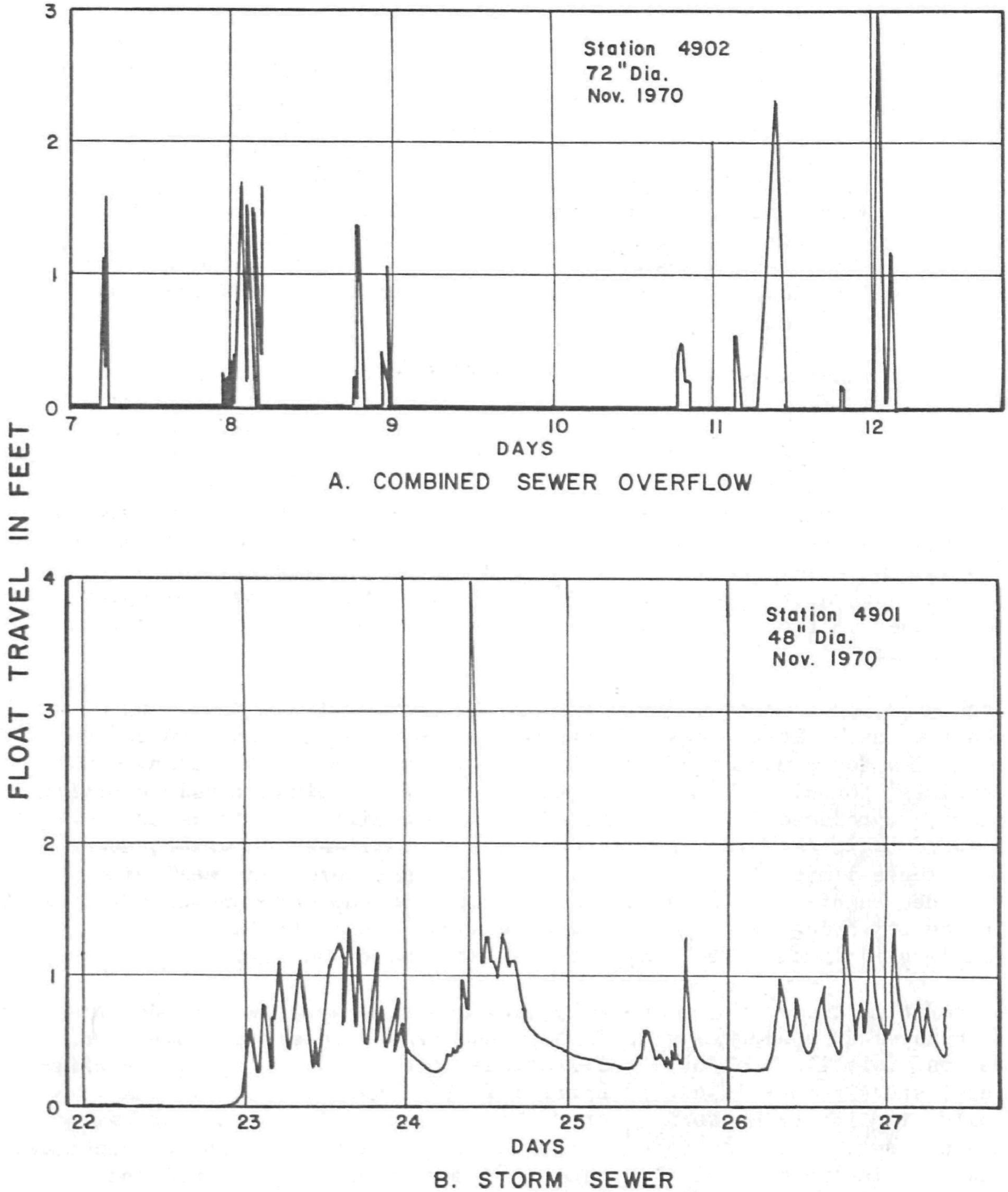
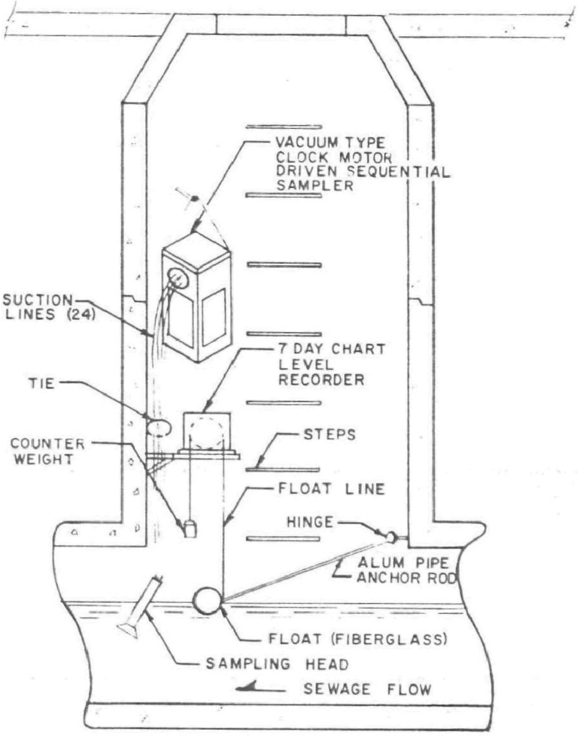
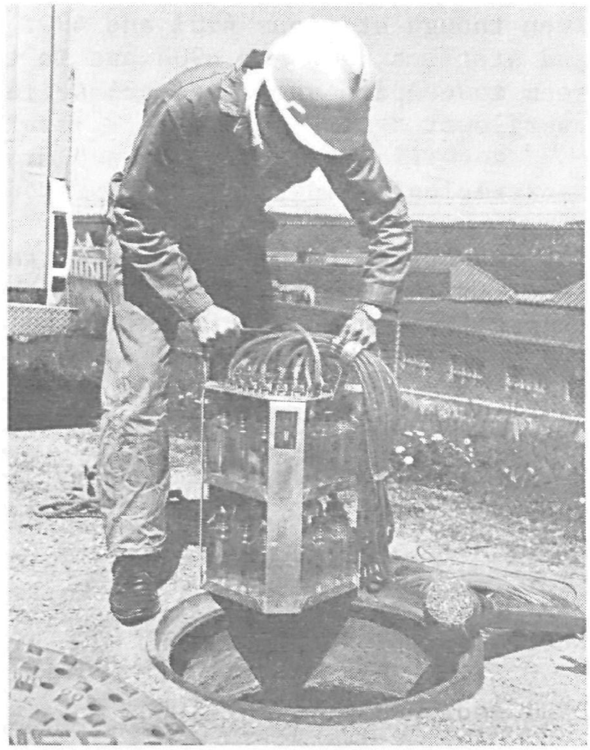


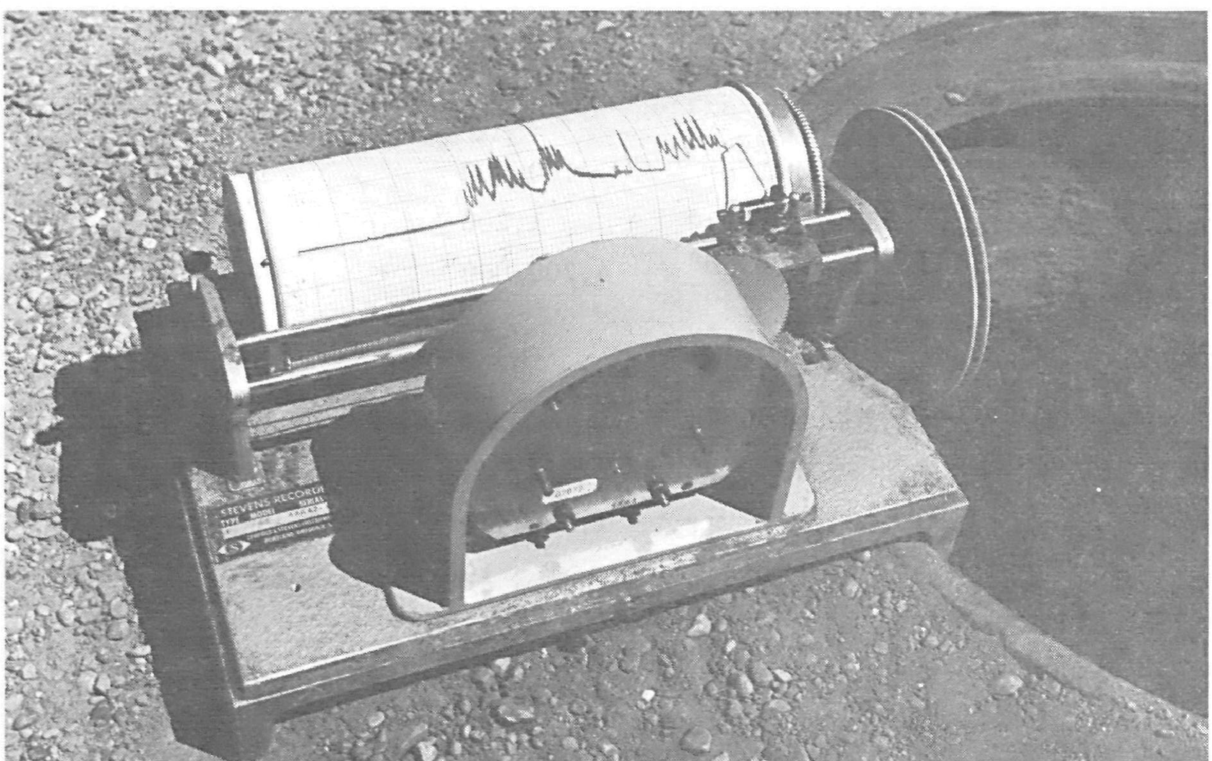
Figure 45. Sample Separation Charts



A. Site



B. Sampler



C. Recorder

Figure 46. Typical Equipment and Setup for Separation Study

Even though stations 4901 and 4902 are in the north end of Seattle and stations 4903 and 4904 are in the south end, both storm sewers seem to compare relatively close in concentrations, as do the combined overflows.

Bacteriological

The reduction in coliform concentration in going from a combined sewer to a storm sewer can easily be seen in Table 14. The reduction ranges from 60 to 140 times.

TABLE 14

Bacterial Density Summary--Storm Sewers
(October 1969 to December 1970)

Station Number		Total Coliform/100 mls	Fecal Coliform/100 mls	Fecal Streptococcus/100 mls
4901	median	24,000	3,200	2,400
	min.	20	20	20
	max.	1,900,000	110,000	12,000
	n[a]	40	38	20
4902	median	1,400,000	150,000	180,000
	min.	130,000	1,200	7,600
	max.	4,400,000	4,200,000	570,000
	n	24	25	16
4903	median	1,200,000	160,000	46,000
	min.	60,000	35,000	2,000
	max.	10,000,000	1,300,000	380,000
	n	18	19	10
4904	median	8,800	2,300	7,600
	min.	180	20	1,200
	max.	380,000	68,000	720,000
	n	41	39	24

[a]n = number of individual tests

Nutrients

A nutrient summary is given in Table 15. Here again the difference in storm and combined overflows is evident. Ammonia-nitrogen is seven to eleven times lower in the storm overflow, nitrate-nitrogen 1.3 to 2.0 times lower, and total phosphate five to eight times lower.

Organics and Solids

Tables 16 and 17 summarize BOD, COD, and solids. Storm sewer data compares favorably with findings of other researchers. Pollution indices in combined sewers are generally 2 to 5 times larger than for similar parameters in storm overflow. One exception is found at station 4901 in suspended solids. Suspended solids at this storm drain were three times higher than the nearby combined station 4902. This results from a fine clay silt that drains from a sidehill into the storm drains and from construction of a new apartment house in the area, which washed large amounts of clay and construction materials into the storm drain after the slightest rainfall. Unusually low volatile percentages reinforce this conclusion.

TABLE 15

Nutrient Concentration Summary--Storm Sewers
(October 1969 to December 1970)

Station Number		Ammonia Nitrogen mg N/l	Nitrate Nitrogen mg N/l	Total Soluble Phosphate mg P/l
4901	mean	.18	.66	.35
	min.	.02	.21	.12
	max.	1.80	1.80	1.54
	n	319	158	317
4902	mean	2.05	.87	1.97
	min.	.14	.06	.36
	max.	7.00	2.40	8.10
	n	75	46	75
4903	mean	1.26	1.11	1.78
	min.	.22	.09	.54
	max.	3.70	5.70	4.10
	n	73	51	73
4904	mean	.18	.51	.20
	min.	.01	.02	.06
	max.	.98	2.40	.69
	n	121	86	123

Estimates of Pollutional Loadings

The pollutional loading values in Table 18 were computed from average concentrations and total overflow volume from each station for 1970. Flow data and, therefore, loadings are unreasonably low at station 4904 because the sewer slope is rapidly changing from 0.0142 to 0.168 at the point where depth measurements are being recorded. Unfortunately, there was no alternate sampling site. By estimating the slope effect in Manning's formula flow calculations, one could increase computed flows by a factor of two to four.

By averaging together the above data from each separated area and repeating the procedure for the combined sewer areas, and making adjustments based on data from other references, such as Storm Water Pollution from Urban Land Activity (26), some estimates can be made about the effects of separation on the receiving waters (Lake Washington, in this case). The following assumptions were made and should be taken into consideration when referring to the estimates presented in Table 19: (1) The basic data are representative of the entire area. (2) Since separation diverts an estimated three-fourths of total storm flow west to saltwater, overflow contribution to the lake will be reduced to one-third of previous levels (Note: no data are available to verify this assumption. We expect overflow volume to decrease to about one-fourth, but because sewage would be less dilute, we selected a value of one-third.) (3) A hypothetical 500-acre drainage area is being considered; to estimate total effect on the lake, multiply loading figures as follows:

$$\begin{pmatrix}\text{loading} \\ \text{from} \\ \text{500-acre} \\ \text{area}\end{pmatrix} \times \frac{\text{(total tributary separation area, acres)}}{\text{(500 acres)}} = \begin{pmatrix}\text{New loading} \\ \text{from} \\ \text{separated} \\ \text{areas}\end{pmatrix}$$

or

$$L_o \times \frac{(7,724)}{(500)} = L_1$$

(4) To gauge the total effect to the lake, in addition to the above, other existing pollutant sources must be totaled and factored into the equations.

In light of all the previously discussed factors, Table 19, shows that separation should be expected to reduce essentially all pollution loadings to less than half their former levels, with the exception of COD, which is diminished by only 37%.

TABLE 16

BOD and COD Summary--Storm Sewers
(October 1969 to December 1970)

Station Number	BOD (mg/l) Mean	Min.	Max.	COD (mg/l) Mean	Min.	Max.
4901	05.5	0.3	34.5	76.5	8.0	398.0
4902	39.0	3.8	96.0	124.2	14.0	364.0
4903	41.5	1.8	264.0	164.6	53.0	344.0
4904	09.6	0.1	70.5	56.9	15.0	273.0

TABLE 17

Solids Summary--Storm Sewers
(October 1969 to December 1970)

Station Number	Settleable Solids ml/l Mean	Min.	Max.	Suspended Solids mg/l Mean	Min.	Max.
4901	0.8	0.1	15.8	305.3	2.8	3390.0
4902	2.0	0.1	7.5	93.4	8.0	260.0
4903	1.7	0.1	11.5	285.8	11.6	1300.0
4904	0.3	0.1	3.5	53.8	0.3	675.0

Station Number	Volatile Solids mg/l Mean	Min.	Max.	% Volatile
4901	46.7	3.6	570.0	15
4902	53.2	0.1	140.0	57
4903	110.4	-0-	550.0	38
4904	15.4	0.1	140.0	28

TABLE 18

Pollution Loading to Lake Washington
(Representative sample stations - data in pounds per year)

Station Number	Susp. Solids	BOD	COD	Ammonia Nitrogen	Nitrate Nitrogen	Total Phosphate
4901	54,000	970	13,500	32.0	117.0	62.0
4902	55,800	19,100	60,900	1,010.0	430.0	970.0
4903	144,200	20,900	83,100	640.0	560.0	900.0
4904[a]	205	128	760	2.4	6.8	2.7

[a]Flow data is questionable at this station. See text for explanation.

TABLE 19

Estimated Effects of Separation in a Combined Sewer Area[a]

Source	Type	Loading in Pounds to Lake Washington: Before Separation	Loading in Pounds to Lake Washington: After Separation	% Decrease (increase)
Combined Sewer	BOD	20,000	6,700	67
	S.S.	100,000	33,000	67
	COD	70,000	23,000	67
	NH_4	820	270	67
	NO_3	500	170	67
	PO_4	950	320	67
Storm Sewer	BOD	-	3,000	-
	S.S.	-	3,000[b]	-
	COD	-	21,000	-
	NH_4	-	45	-
	NO_3	-	62	-
	PO_4	-	32	-
Total	BOD	20,000	9,700	52
	S.S.	100,000	36,000	64
	COD	70,000	44,000	37
	NH_4	820	315	62
	NO_3	500	232	54
	PO_4	950	352	63

[a]See text for assumptions made in preparation of this table.

[b]Data based on reference (25)

Sequential Sampler Data

Figure 47 shows how nitrate nitrogen at station 4901 varies when plotted against time, flow, and rainfall intensity. As soon as the overflow begins, a relatively high amount of nitrate nitrogen is flushed off. There also appears to be some dilution, as shown by the peaks in overflow and corresponding depressions in nitrate nitrogen. As the storm continues, nitrate nitrogen declines on a gradual scale. Other sequential sampler data show that a pollution parameter will finally reach a baseline concentration from which it will fluctuate very little if rainfall intensity remains relatively constant.

Combined overflow (station 4902) sequential sampling results are illustrated in Figure 48. Ammonia nitrogen was plotted against time, flow, and rainfall intensity. Here, concentration takes on an inverse relationship to flow. As shown in the statistical analysis that follows, ammonia has an "r value" of -0.643 when correlated to flow at station 4902. This means that an increase in flow would result in a corresponding decrease in ammonia about 64% of the time, a strong correlation.

Pollution Parameter Correlations

Nutrient data was available in sufficient quantity for valid statistical analysis. Therefore, it was possible to run a series of stepwise regression analyses to determine single and multiple correlation values with overflow and rainfall characteristics. Ammonia-nitrogen, nitrate-nitrogen, and total phosphate were the dependent variables. The independent variables were:

1. Air temperature
2. Wind direction
3. Volume of overflow
4. Duration of overflow
5. Intensity of overflow
6. Time since last overflow
7. Volume of antecedent overflow
8. Duration of antecedent overflow
9. Intensity of antecedent overflow
10. Volume of rain
11. Duration of rain
12. Intensity of rain
13. Time since last rain
14. Volume of antecedent rain
15. Duration of antecedent rain
16. Intensity of antecedent rain

Results of individual correlations are summarized in Table 20. A large "r value" indicates a significant correlation. Negative "r values" show inverse relationships. The table shows that seemingly unrelated factors such as nutrient concentration and wind direction

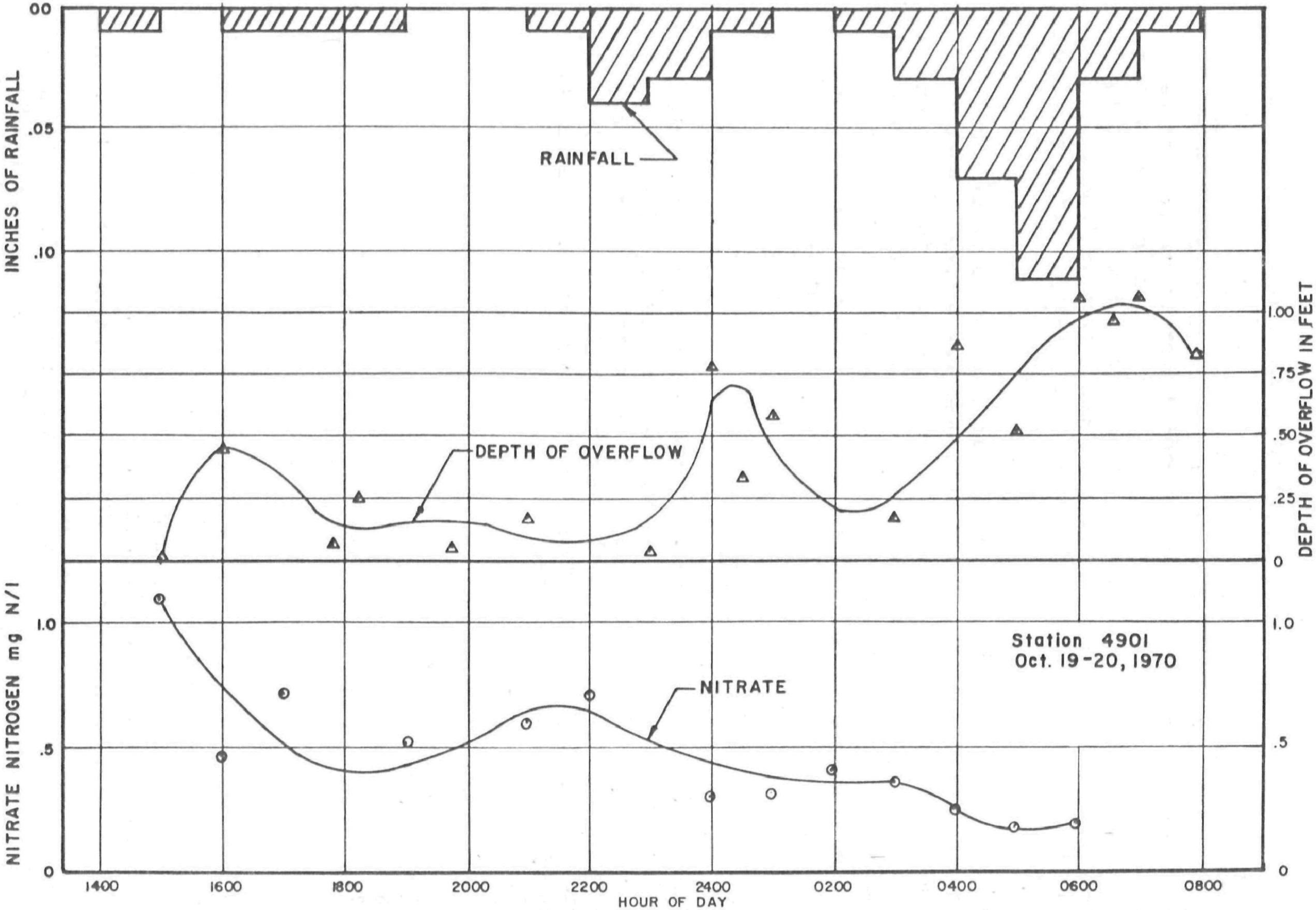


Figure 47. Storm Runoff with Rainfall and Nitrate Nitrogen

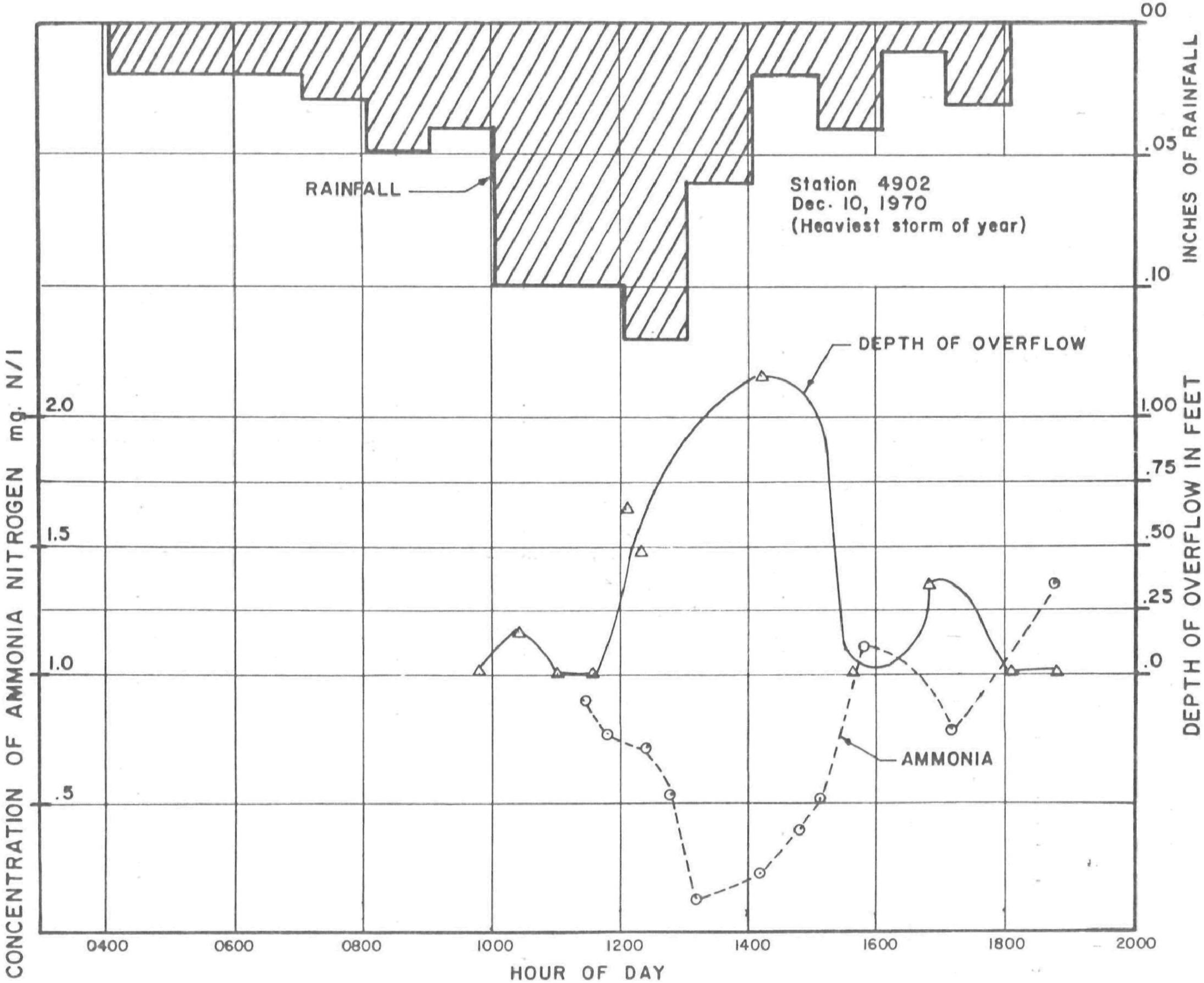


Figure 48. Overflow with Rainfall and Ammonia Concentration

TABLE 20

Individual Correlations

Nutrient Parameter	Station	Overflow or Rainfall Characteristic	"r value"
Ammonia-nitrogen	4901 (storm)	Air temperature	0.397
		Time since last storm flow	0.485
		Volume of antecedent storm flow	-0.490
		Time since last rain	0.463
	4902 (overflow)	Volume of overflow	-0.638
		Time since last overflow	0.420
		Duration of antecedent rain	-0.455
	4903 (overflow)	Time since last overflow	0.378
		Intensity of rain	-0.375
	4904 (storm)	Wind direction	-0.452
		Volume of antecedent storm flow	0.516
Nitrate-nitrogen	4901 (storm)	Air temperature	0.441
	4902 (overflow)	Air temperature	-0.472
		Volume of overflow	-0.305
		Intensity of overflow	-0.389
		Intensity of rain	-0.484
	4903 (overflow)	Wind direction	-0.451
		Duration of overflow	0.451
		Volume of rain	0.375
	4904 (storm)	Wind direction	0.415
		Time since last storm flow	0.467
		Volume of rain	-0.346
Total phosphate	4901 (storm)	Time since last storm flow	0.334
		Volume of antecedent storm flow	-0.474
		Intensity of antecedent storm flow	-0.377
		Time since last rain	0.467
	4902 (overflow)	Volume of overflow	-0.423
		Volume of rain	-0.365
		Duration of rain	-0.355
	4903 (overflow)	Time since last overflow	0.507
		Volume of rain	-0.337
	4904 (storm)	Wind direction	-0.471
		Duration of antecedent storm flow	0.368
		Intensity of antecedent rain	-0.339

or air temperature often correlate well. This is likely the result of the high correlation in the Seattle area between storms and various meteorological factors.

Data derived from the stepwise regression analyses can be found in Appendix J. The statistical analyses show that by taking all significant independent variables into account, 50% to 85% of the nutrient variation is explained at the storm drain stations (4901 and 4904). At the two combined sewer overflow stations (4902 and 4903) analysis of the independent variables explained between 55% and 98% of the nutrient variation.

The most significant independent variables for each nutrient in the regression analyses are the same as those presented in Table 20. All the above statistical analyses were done using standard "Biomedical" programs on the University of Washington CDC 6400 computer.

FREEWAY DRAINAGE STUDY

As part of the overall Metro study of the effects of separated stormwater on environmental water quality, a preliminary survey (47) was initiated in February 1970 to assess the quality of stormwater drainage from the Seattle freeway system. An elevated portion of Interstate 5 was chosen (see Figure 38) based on the relative noninterference from outside drainage sources.

Essentially, only two complete periods of rainfall could be sampled during the time allotted for the study. One of these periods was preceded by a rather lengthy dry spell (12 days) while the other was preceded by 3 days of dry weather. The latter storm was characterized by a much higher rainfall intensity.

Runoff samples were analyzed for settleable solids, chemical oxygen demand (COD), biochemical oxygen demand (BOD), nitrate-nitrogen (NO_2 + NO_3 as N), total hydrolyzable phosphates (P), free ammonia (NH_3 as N), oil, and gasoline additives.

Findings

A summary of the data collected is presented in Table 21. Mean concentrations of the constituents analyzed are listed in relation to time after start of runoff. Because of the short duration of the study, it is necessary to consider the data presented as only preliminary, and conclusions should be drawn with this in mind.

The "first-flush" contained relatively high concentrations of contaminants, particularly suspended solids, COD, BOD, and oil. Nutrient levels were relatively low.

TABLE 21

Urban Freeway Drainage Water Quality

Date	Time Since Last Rain	Time After Start of Runoff	Suspended Solids mg/l	Settleable Solids mg/l	COD mg/l	BOD mg/l	NO_2+NO_3 Nitrogen mg N/l	Total PO_4 Soluble mg P/l	Free NH_3 mg N/l	Oil mg/l
2-17-70	3 hrs.	0-15 min.	559	0.8			0.56	.51	.51	56.8
3- 2-70	12 days	0-15 min.	1494	31.0	1617	198	2.52	.37	.01	55.0
		15-30 min.	25	<0.1	909	181	2.50	.18	.01	16.0
		30-40 min.	11	<0.1	893	162	2.45	.16	.01	18.0
3- 3-70	-	16-16.5 hrs.	60	0.2	384	44	1.85	.14	.44	25.0
3- 6-70	3 days	0-20 min.	504	1.1	222	22	0.58	.33	.18	55.0
		4 hrs.	177	0.2	185	21	1.00	.28	.20	47.0
		8 hrs.	228	0.7	150	9	0.38	.20	.09	27.0
		12 hrs.	141	0.2	103	12	0.51	.16	.11	30.0

The concentrations of these contaminants show a high correlation to rainfall intensity and duration as well as antecedent rainfall. Concentration levels diminished rapidly in the first 15 to 30 minutes. Nutrient concentrations were also lower under conditions of a shorter antecedent dry spell and more intense rainfall.

Gasoline additives probably contribute to stormwater contamination. One such byproduct was found and identified as calcium bromide, which originates in the gasoline additive ethylene bromide. This particular byproduct turned the samples a yellow color.

In general it appears that some effect on receiving water quality can be expected from freeway drainage, particularly in regard to aesthetic effects. Even though the stormwater does not carry a high level of nutrient concentration, its first-flush flow does contain rather high levels of other contaminants. This warrants a closer look to determine the need for separation or treatment, especially of the first-flush contaminants. On-site rain gaging should be performed in any future studies to provide more accurate rainfall data for volume and loading figures.

STUDIES ORIENTED TO RECEIVING WATERS

Metro's comprehensive monitoring program has included many analyses of all waters that receive drainage from the Seattle metropolitan area. Additional details about the entire program can be found in various reference reports (48) (49). Two principal receiving water bodies are being studied as part of this demonstration grant. They include the Green-Duwamish River and Elliott Bay. Sampling stations include shore stations, surface stations, and automatic river monitoring stations, as indicated on the map in Figure 49. The analyses discussed in this section of the report include bacteriological, physical, chemical, and ecological analyses.

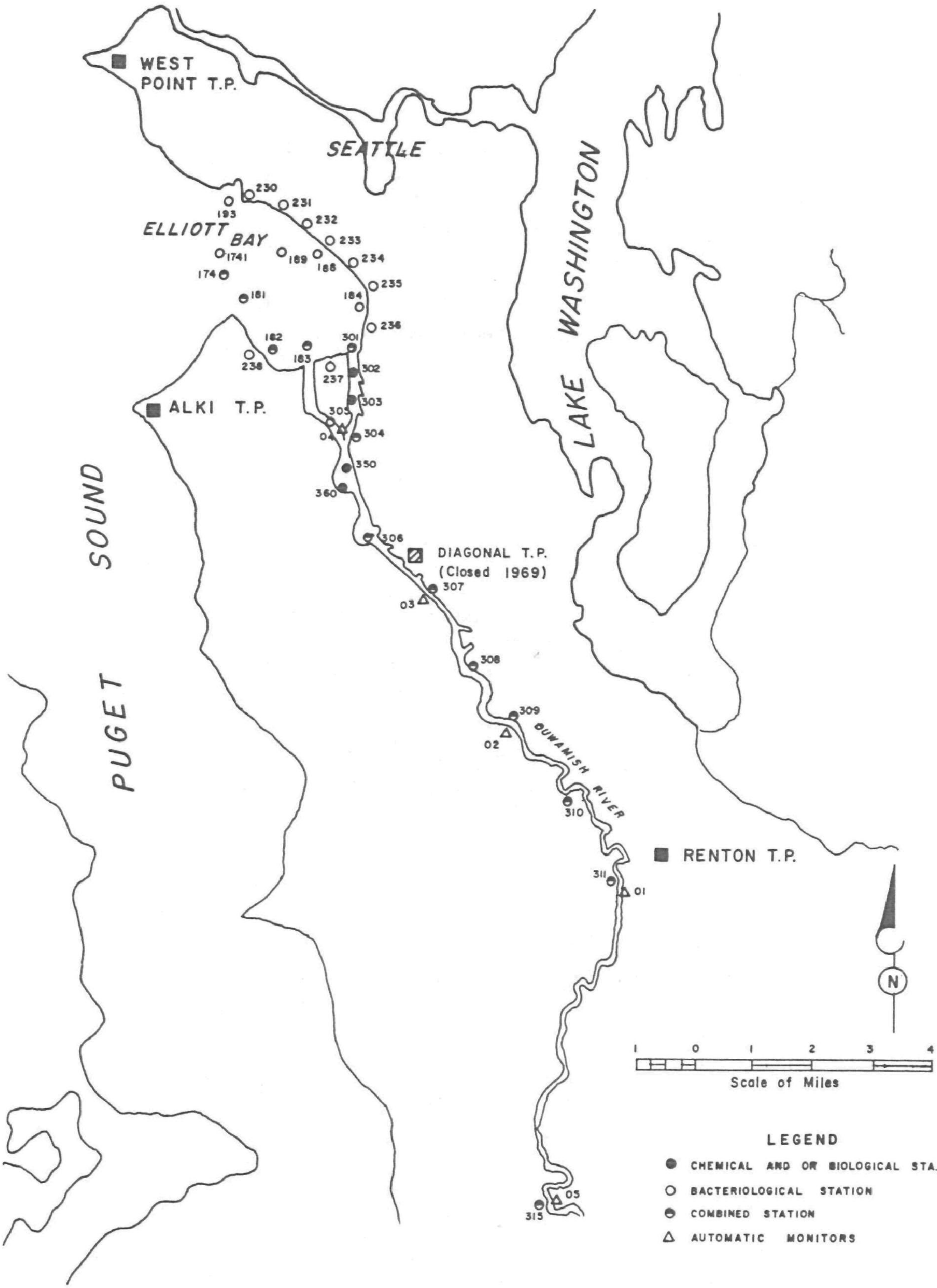


Figure 49. Receiving Water Sampling Stations

Elliott Bay Sampling

Scope

The objectives of the Elliott Bay sampling are mainly to show how the expansion and interception of trunks by Metro has improved the local receiving waters and also to demonstrate to regulatory agencies the degree of local compliance with their established water quality standards. On a weekly basis, sampling runs are made along shore stations. Biweekly, offshore sampling runs are made by a sampling boat operated under a cooperative agreement with the United States Geological Survey. Samples are taken for analysis of total and fecal coliform, dissolved oxygen, temperature, transparency, and chloride content. Figure 50 shows the boats and typical tests used by Metro crews in sampling the receiving waters.

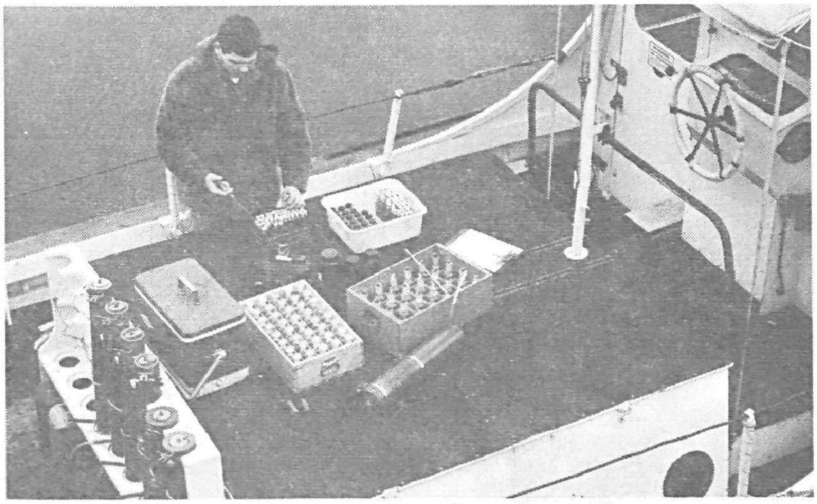
Automated Wet Chemistry Analyses

To speed the analysis of the many samples being brought to the Metro laboratory, a Technicon autoanalyzer was purchased in 1969. This unit was tested out during a 6-month period and found to give extremely reliable results from the automated analysis procedure. Unfortunately, a scarcity of available information resulted in inadequate planning, and an autoanalyzer was purchased with a single-channel recorder and a number of interchangeable "plattered manifolds" (tubing arrangements specific for each chemical test). This meant that the autoanalyzer could be used for a variety of tests, but it required a time-consuming change of the manifolds to run a second test. It was found that, for the rate that samples requiring multiple analyses were brought to the lab, it was easier and less time consuming to run chemical analyses in the standard manual manner rather than calibrate and set up the autoanalyzer for each test.

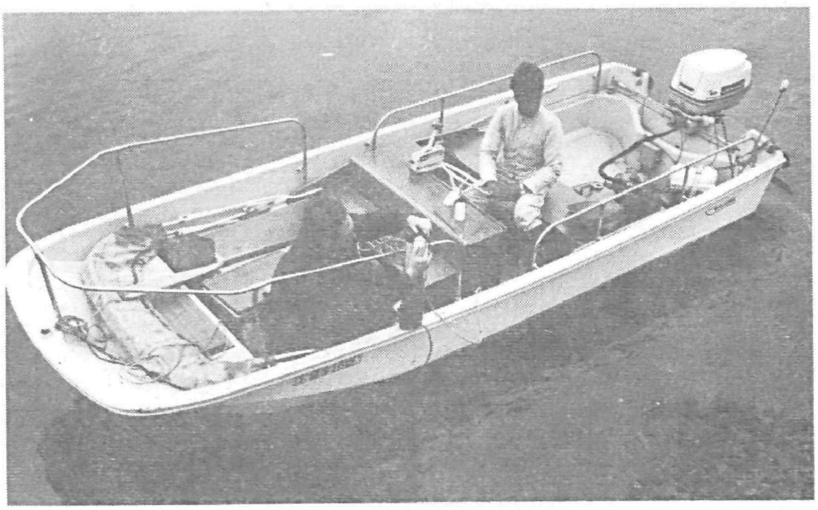
After the trial period at the Metro central laboratory, the autoanalyzer was transferred to the Renton Treatment Plant, where a different demonstration grant was in progress. This demonstration grant required multiple repetitions of total phosphorous tests on many samples, and the autoanalyzer proved ideal for this application. (50) Figure 51 shows the autoanalyzer being operated at the Renton Treatment Plant. The Minneapolis Sanitary District has also found much success with the autoanalyzer in their analyses of sewage samples (51). It is expected that as tests multiply and the Renton Treatment Plant purchases an analyzer for plant use, the Metro central laboratory will add accessories to the original autoanalyzer for use specifically on the CATAD demonstration grant.

Bacteriological

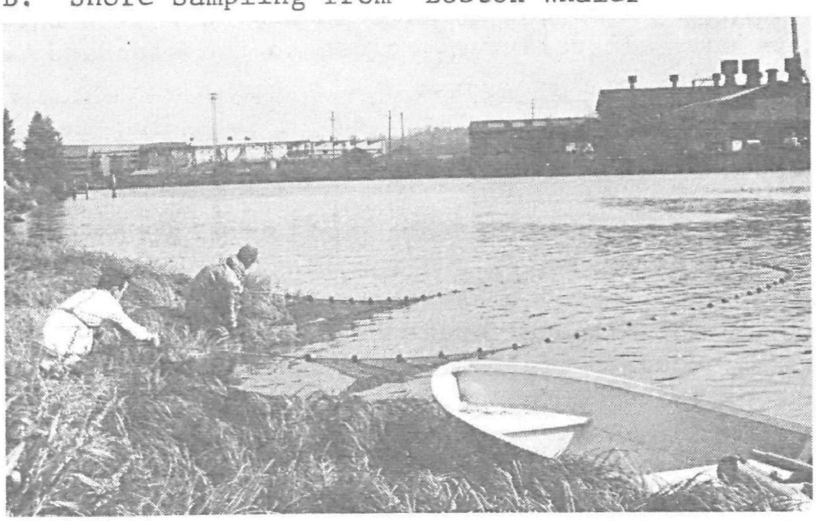
Probably the most striking improvement found in the receiving water of Elliott Bay is in the total coliform concentration resulting from diversion of several large raw sewage outfalls from the bay



A. Chemical and Biological Sampling Equipment in the "Hydor"



B. Shore Sampling from "Boston Whaler"



C. Trawl-Caught Fish Counts Using 16-Foot Craft

Figure 50. Metro Sampling Boat Fleet

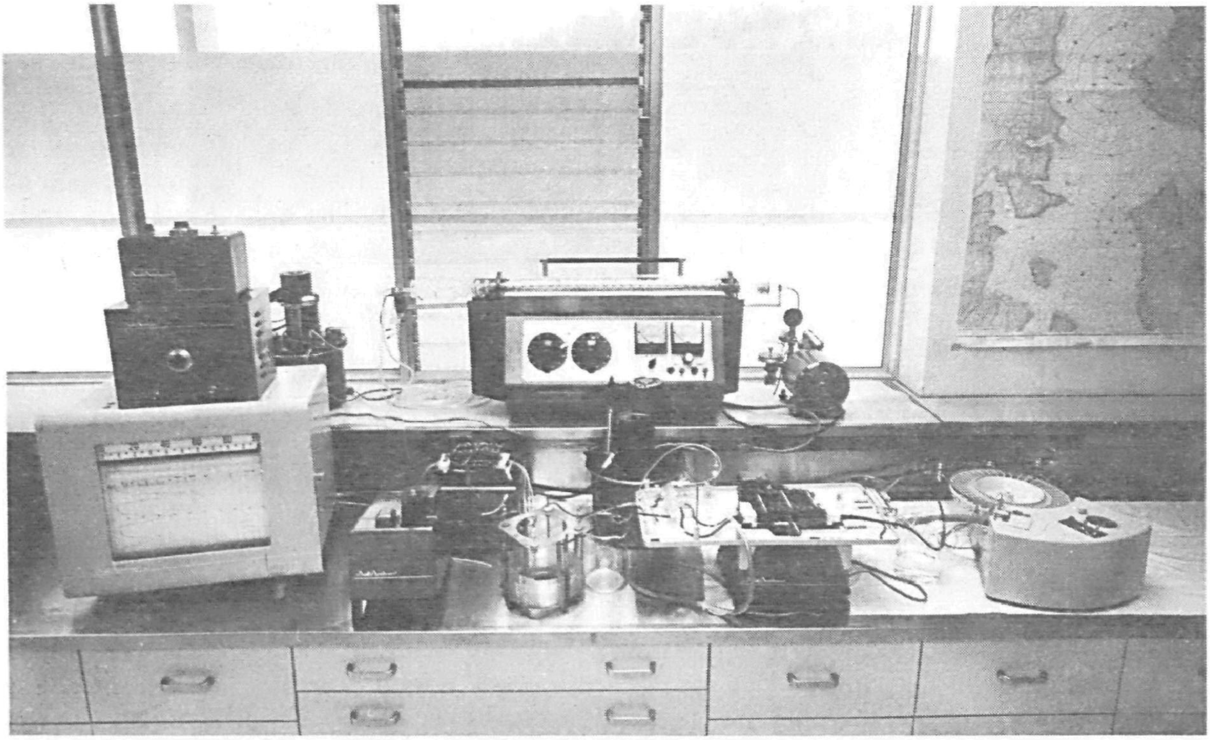


Figure 51. Autoanalyzer in Operation

to the West Point Treatment Plant. Table 22 shows median coliform concentrations of shore and offshore stations both before and after diversion. August 1969 to March 1970 represents the condition before interception and August 1970 to March 1971 represents the conditions after. This same data is graphically presented in Figure 52. The data plotted in Figure 53 compares total coliform counts during summer periods (quarters) of 1968 and 1970. Figures 52 and 53 show that coliform counts now fall relatively close to the standard, even during winter periods.

Dissolved Oxygen

Low dissolved oxygen has never been a problem in Elliott Bay, which experiences good tidal flushing and the flushing effect of the Green-Duwamish River. Some improvements can be seen, however, as a result of the closure of the Diagonal Treatment Plant and the diversion of all major raw sewage outfalls from Elliott Bay. Stations 301 and 184 are geographically the closest offshore stations to the old raw sewage outfalls. Figures 54 and 55 show both the surface and bottom dissolved oxygen levels from 1968 through the beginning of 1971. This data reveals several small changes. Saline waters near the bottom often had higher DO values than the less saline surface waters until about November 1969. This may be explained partially by high biochemical oxygen demand of the effluent from

TABLE 22

Total Coliform Concentrations--Elliott Bay
(Before and After Raw Sewage Diversion
to the West Point Treatment Plant)

Median Total Coliform Concentration (Organisms per 100 mls)

Station	August 1969 to March 1970	August 1970 to March 1971
230	4800	1800
231	4900	1500
232	5000	1200
233	12000	2200
234	11000	2500
235	20000	2600
236	28000	6400
237	1800	200
238	260	180
301	19000	2800
305	16000	6400
181	430	64
182	540	63
183	7000	230
184	13000	450
188	17000	1400

the Diagonal Treatment Plant, which depressed oxygen levels in surface waters where it was principally being carried. Most of this water then flows through the East Waterway and into Elliott Bay, flowing over the more dense salt water in the bay and creating lower DO concentrations in the surface waters. After the Diagonal plant was closed, surface DO concentrations then exceeded concentrations on the bottom.

DO values on the surface at both stations were higher in the August-to-November period of 1970 (following diversion of raw sewage outfalls in the East Waterway) when compared to the same periods of 1968 and 1969. At station 184, the difference was about 2 mg/l, and at station 301, the difference was 2 to 3 mg/l. Bottom values at station 301 were not significantly different in 1970 compared to 1968 and 1969. DO values from 50-meter depths at station 184 were slightly higher in the August-to-November period of 1970 than the same periods

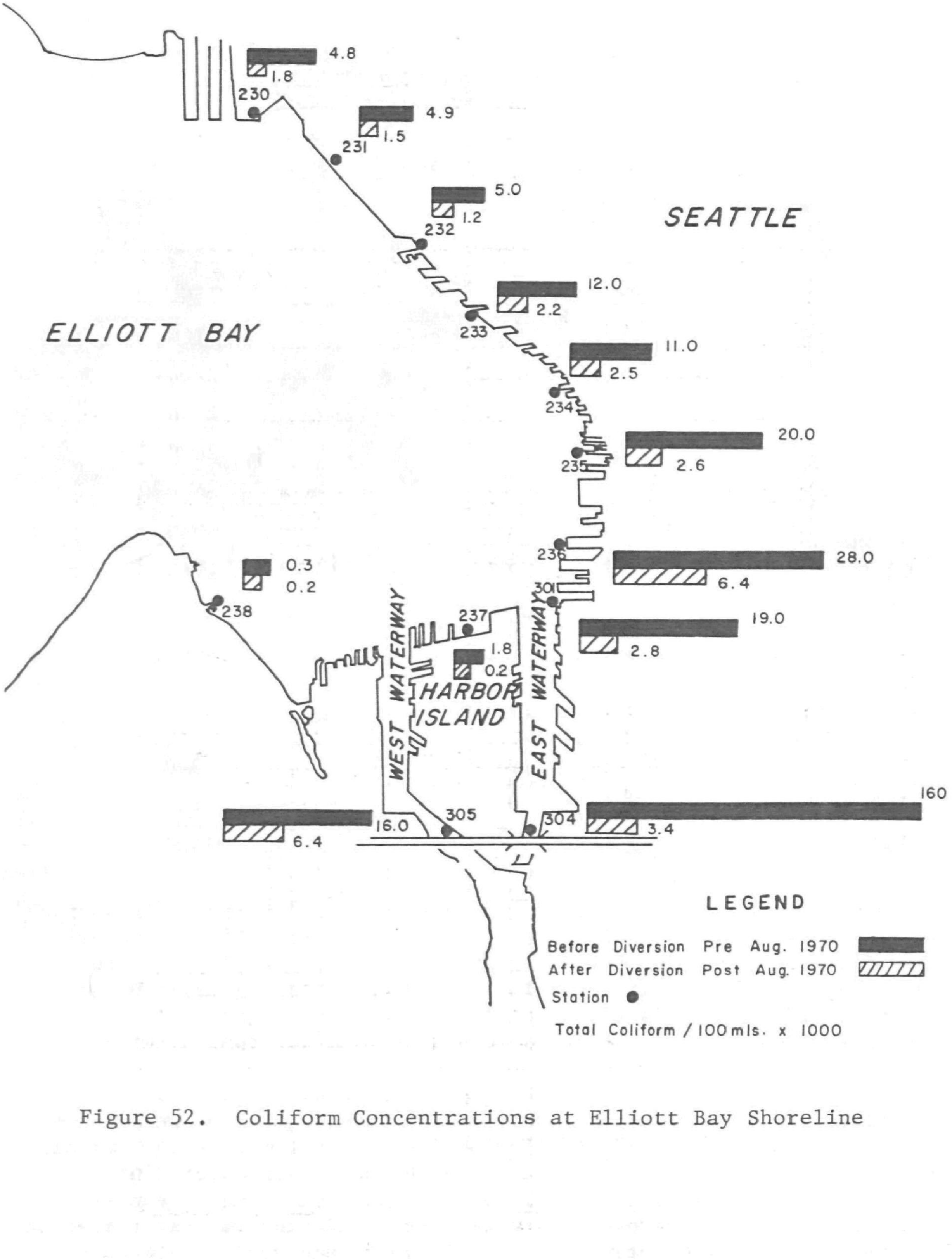


Figure 52. Coliform Concentrations at Elliott Bay Shoreline

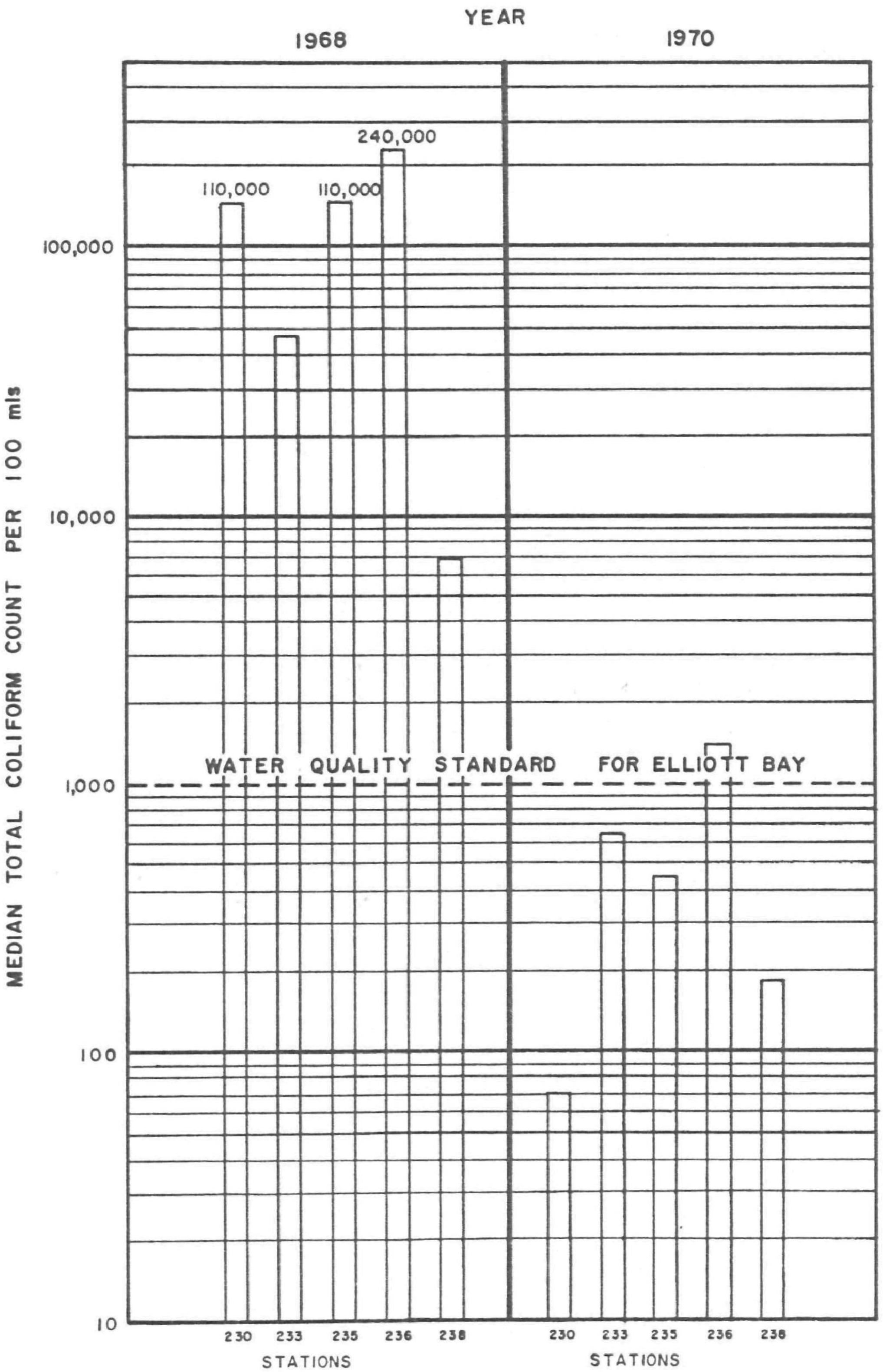


Figure 53. Coliform Levels and Standard

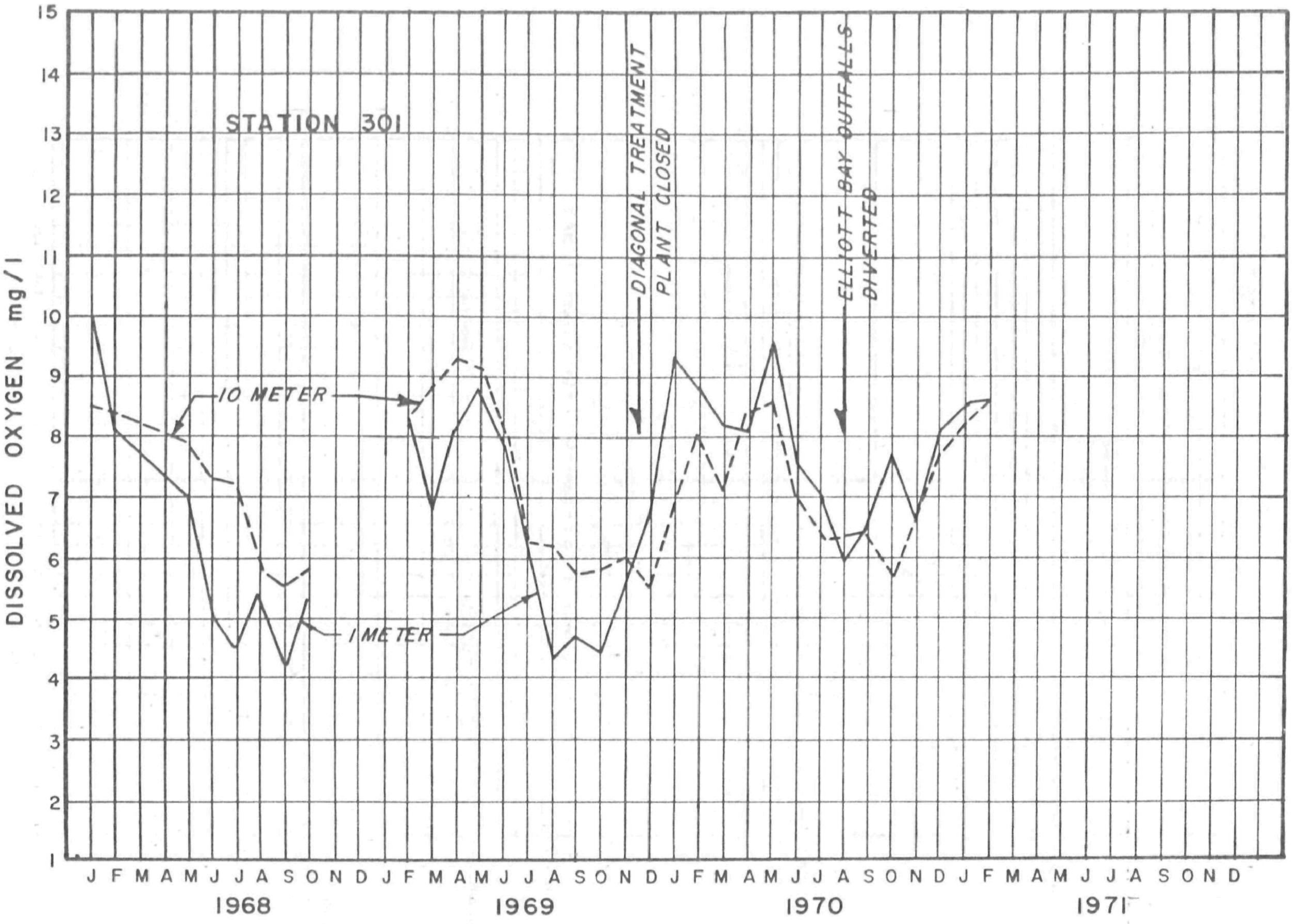


Figure 54. Dissolved Oxygen Levels in Bay at River Mouth

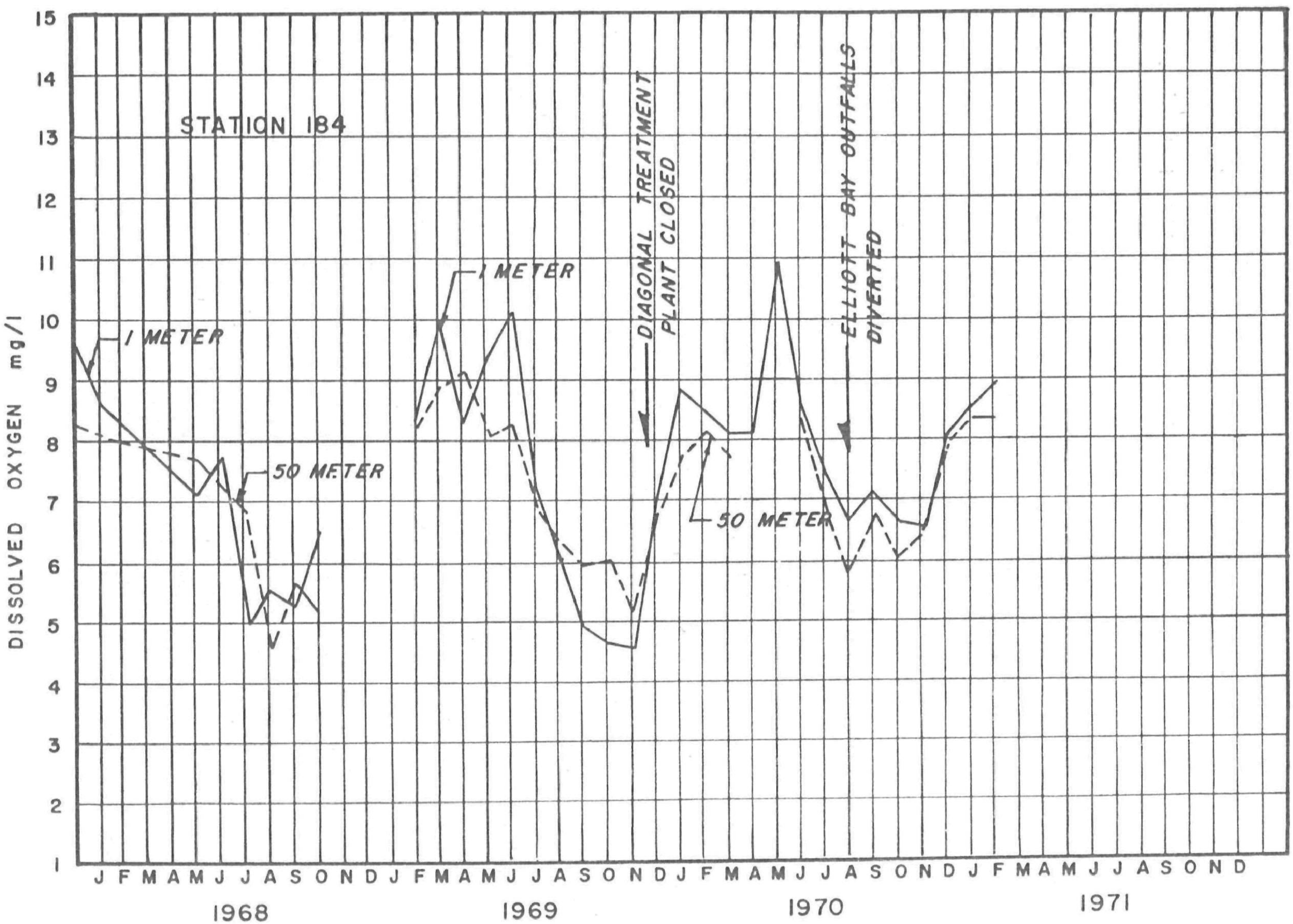


Figure 55. Dissolved Oxygen Levels in Elliott Bay

of 1968 and 1969. The slightly higher DO values at 50 meters at station 184 in 1970 may be the result of lower oxygen demand of bottom waters in the area as a result of less settling of particulate matter from surface waters, specifically as a result of the removal of raw sewage discharges.

Water Transparency

Unfortunately, secchi disc readings were not taken prior to 1970, which leaves no historic base for comparison. Water transparency readings were taken in 1970; Table 23 gives monthly averages for three Elliott Bay stations.

Based on visual observations and comments from people working along the Seattle waterfront, it can be stated that there has been a major improvement in water transparency during the summer of 1970 as compared to previous years.

Further improvement in all water quality indicators of Elliott Bay is expected as the CATAD system permits better regulation of combined sewage and stormwater overflows.

TABLE 23

Water Transparency Readings--1970
(All depths in feet)

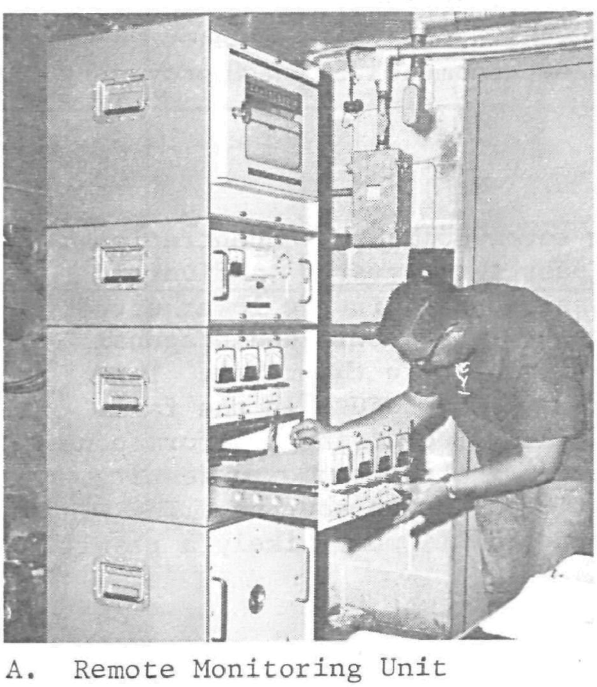
	Station 188	Station 184	Station 301
January	4.9	8.7	5.4
February	7.7	8.2	8.8
March	17.5	18.6	7.7
April	9.5	11.6	4.4
May	8.7	8.2	3.4
June	16.8	14.7	9.8
July	11.8	12.3	8.3
	(diversion completed)		
August	21.5	18.0	8.6
September	24.2	22.6	16.1
October	24.3	27.5	17.7
November	19.7	26.2	18.0
December	15.1	19.7	19.5

Duwamish River Studies

Scope

The major objective of the Duwamish-Green River studies is to maintain a continuous surveillance of water quality conditions as they relate to the migration and propagation of fish life. (The name of the river changes about 11.5 miles upstream from the mouth. The lower portion is the Duwamish; upper reaches are known as the Green.) Another objective is to demonstrate compliance with state water quality standards and to observe improvements in water quality conditions as brought about by Metro construction or operational adjustments. Metro is a partner with United States Geological Survey in a cooperative study of the Duwamish River using continuous monitoring stations at five strategic points on the river. At each remote site, an automatic monitoring unit, shown in photograph A of Figure 56, telemeters information over phone lines to a central receiving data logger, shown in photo B. Information, which is transmitted hourly, is converted to punch card or tape storage for further statistical analyses.

In addition to the automatic monitoring stations, an extensive manual sampling program is being carried out to augment the automatic equipment. Data is collected from 18 shore and river sampling stations shown in Figure 49.



A. Remote Monitoring Unit

B. Central Data Logger

Figure 56. Automatic Water Quality Monitor System

Equipment and Analyses

Automatic monitoring equipment measures dissolved oxygen, pH, temperature, solar radiation, turbidity, and conductivity. The other manual sampling stations add BOD and nutrient investigations to the list of analyses.

Data and Results

Riverflow, water temperature, and conductivity have not changed significantly from their normal fluctuations and ranges. Riverflow in cubic feet per second is illustrated through 1970 in Figure 57.

Dissolved Oxygen

The first major change in dissolved oxygen observed since Duwamish River monitoring began in 1961 occurred in the summer of 1970. This change was noted in bottom waters at the 16th Avenue South automatic monitor site. As demonstrated in Figure 58, the bottom dissolved oxygen level did not drop as low in the late summer of 1970 as in previous years. Minimum values in 1970 approached maximum values in 1969. The fall in DO during July was caused by diversion of raw sewage upstream to Diagonal Avenue during construction of the Hanford Street regulator.

One factor possibly contributing to the increased DO was the greater tidal exchange in 1970 than in previous years. The increase also correlates well with the interception of the raw and treated sewage outfalls previously discharging to the river estuary. Assuming normal tidal exchange, 1971 and 1972 records will demonstrate whether the increased DO is merely a tidal exchange phenomenon or an improvement trend resulting from interception.

Bacteriological

Figure 59 shows median fourth quarter total coliform concentrations for the Duwamish-Green River for the past three years. A fivefold reduction in coliform concentration was recorded in the lower estuary. This is primarily the result of closing of the overloaded Diagonal Treatment Plant, which discharged its effluent to the river. This reduction was noticed immediately after plant closure in the fall of 1969. The figure also shows a gradually increasing coliform concentration traveling downstream until reaching station 306, a result of numerous industrial and some domestic pollution sources. The reduced coliform between station 306 and 307 is most likely a result of salt water dilution.

Nutrients

The study of chemical nutrients in the river have included such parameters as ammonia-nitrogen, nitrate-nitrogen, and total hydrolyzable

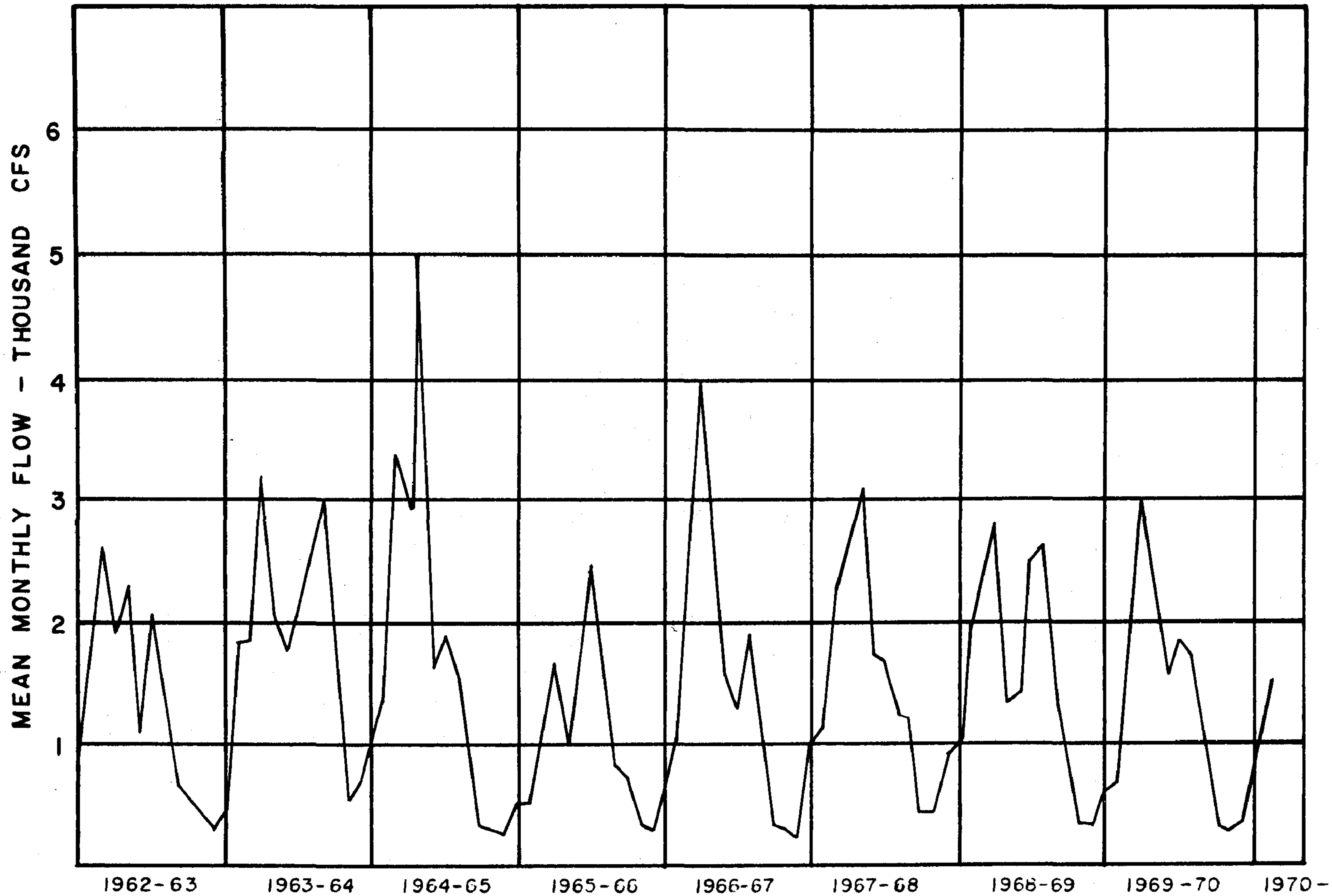


Figure 57. Duwamish River System Flow

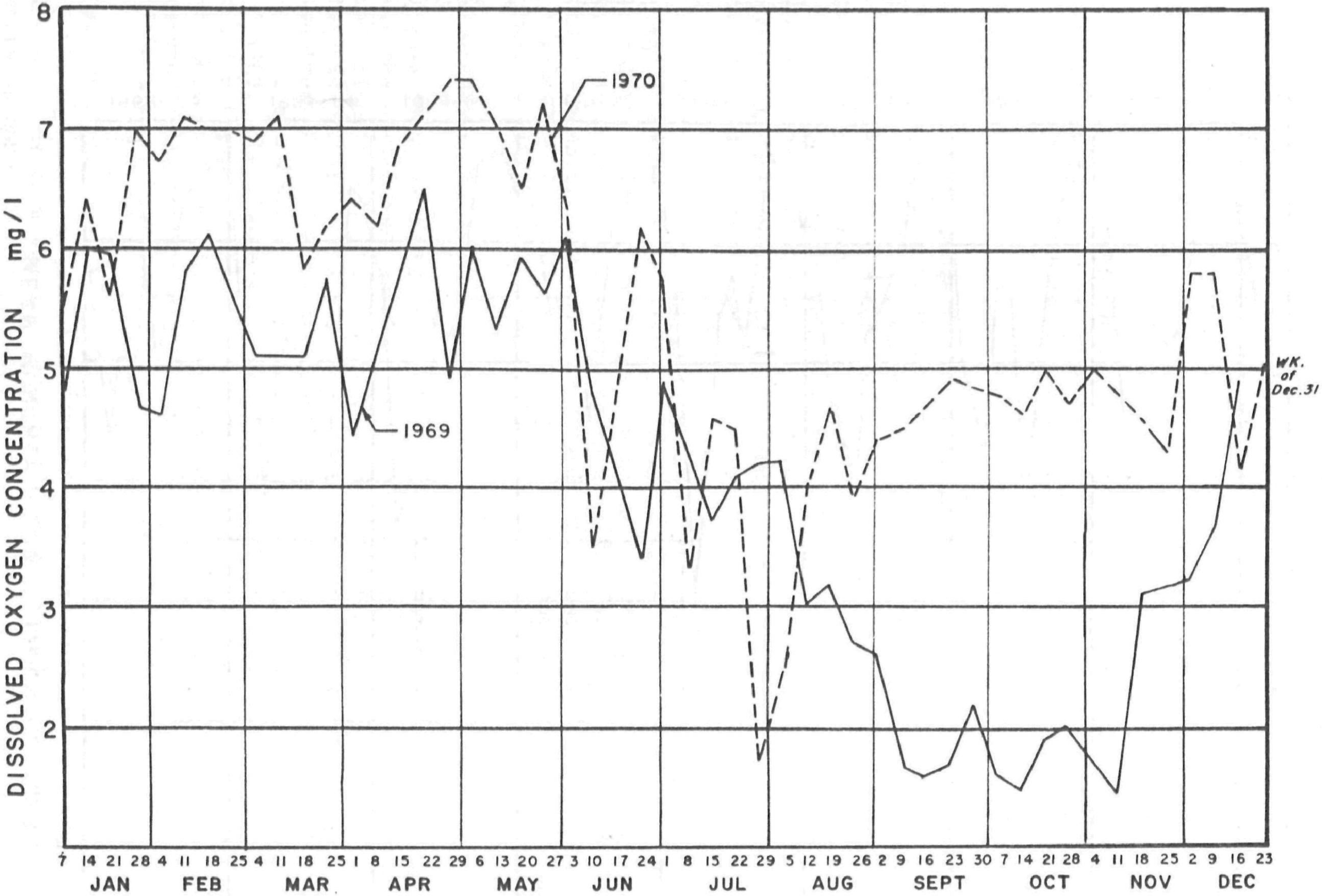


Figure 58. Minimum River Dissolved Oxygen

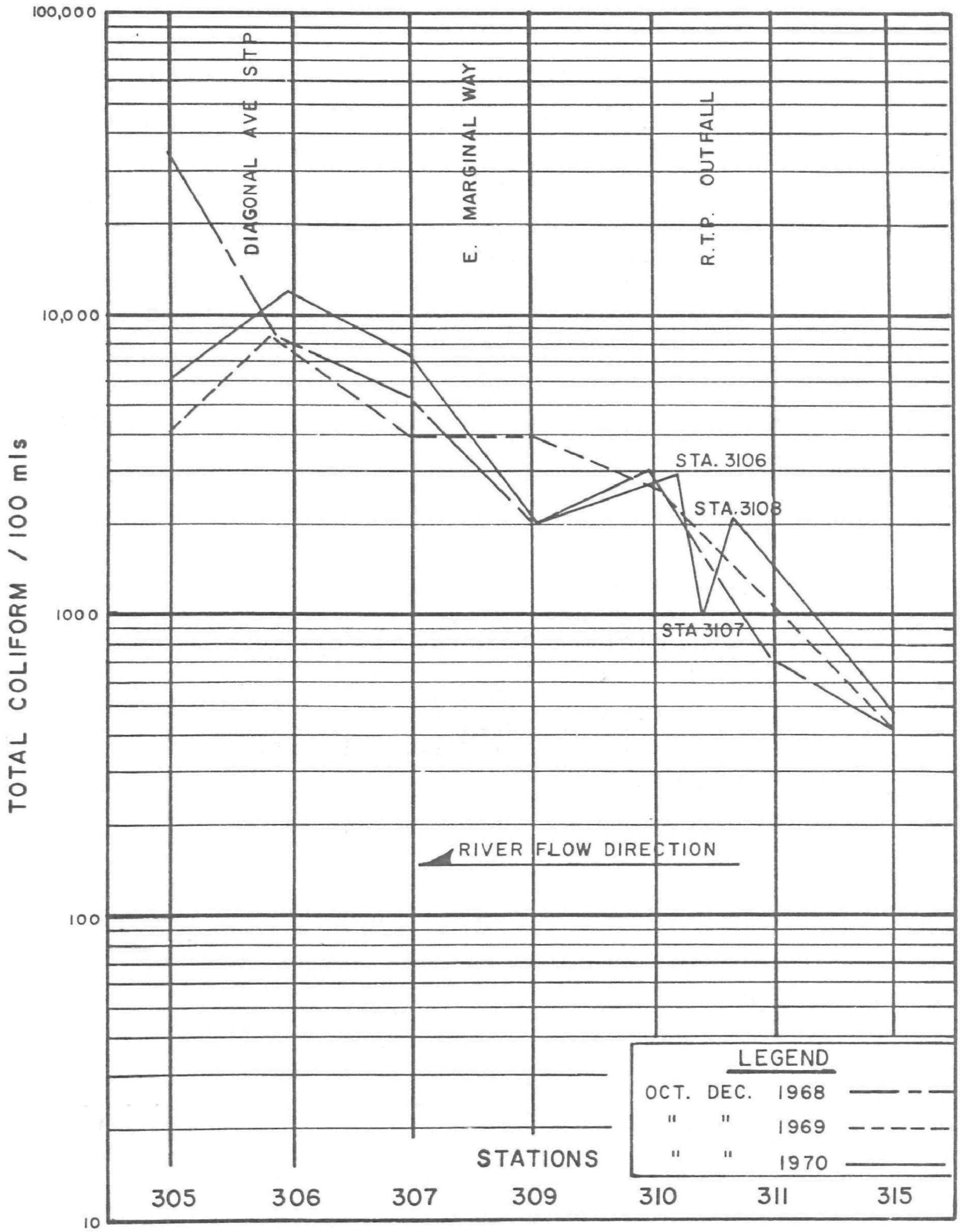


Figure 59. River Total Coliform Count

phosphate. In comparing 1970 with 1967, it was found that ammonia concentrations have decreased greatly at station 309 during the months of July, August, and September (Figure 60). The ammonia concentration at this station was lower than recorded in previous years because of modified plant operation which allows greater nitrification of the Renton Treatment Plant effluent (see Figure 49). Nitrification reduces the nitrogenous biochemical oxygen demand loading of the effluent. A slight decrease in ammonia is also apparent at stations 305 and 307 for the same time comparison. Similarly, phosphate-phosphorous concentrations were generally lower in 1970 than in 1967, but the pattern is not consistent or of as great a significance (Figure 61).

Biochemical Oxygen Demand

Recent biochemical oxygen demand studies of the river have been performed by the U.S. Geological Survey branch located in Tacoma, Washington, but the data has not yet been published.

Bottom Sediments

Studies of benthal deposits in the Duwamish River estuary have been continued to assess the changes resulting from increased effluent discharges from the Renton Treatment Plant and the removal of various raw and treated sewage outfalls in the lower Duwamish River estuary.

Physical characteristics of the stretch of river under study have not changed significantly since the start of the study in 1963. The upper undredged section of river has remained sandy, with corresponding low chemical oxygen demand (COD) values. This indicates that the Renton Treatment Plant has not contributed to any sludge buildup in this section of river.

In the lower dredged section of the river, a significant decrease in the COD of benthal sediments was recorded at the station (Figure 62) below the Diagonal Treatment plant between 1968 and 1969. During this period, a land filling project near the discharge point was in progress at the time of the plant closure. Observation of sediments during 1969 indicated that significant amounts of sand were mixed with the fine organic sediment usually found at this station. The sand presumably entered the river through erosion from the nearly filled site. Although the presence of the sand contributed to the decrease in benthal COD, it is safe to assume that the elimination of the Diagonal Treatment Plant discharge contributed to the decrease in COD levels at one station.

Aquatic Life

The Green-Duwamish River continues to support significant runs of salmon. Data from the Washington State Department of Fisheries (Green

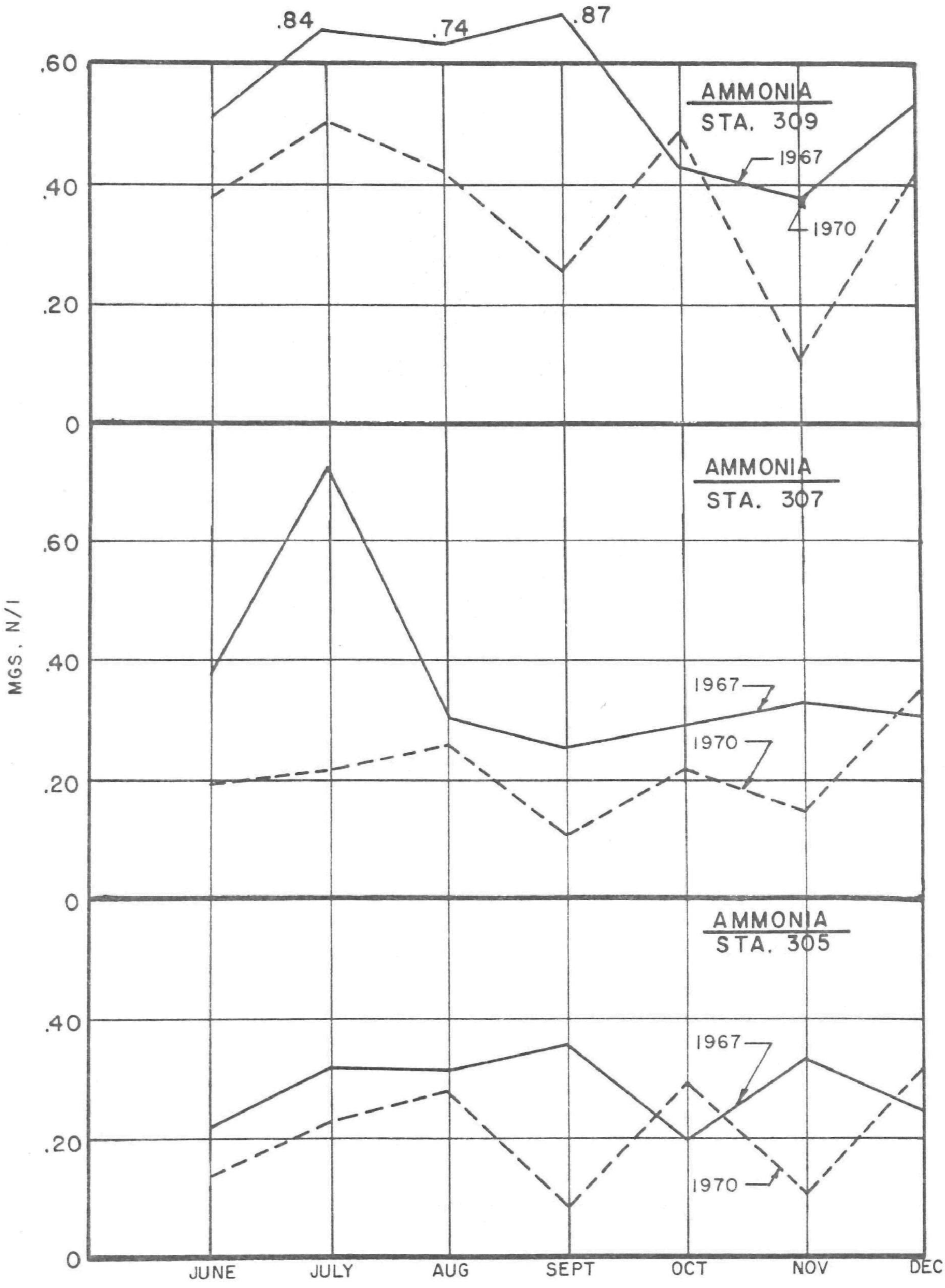


Figure 60. River Ammonia Concentration

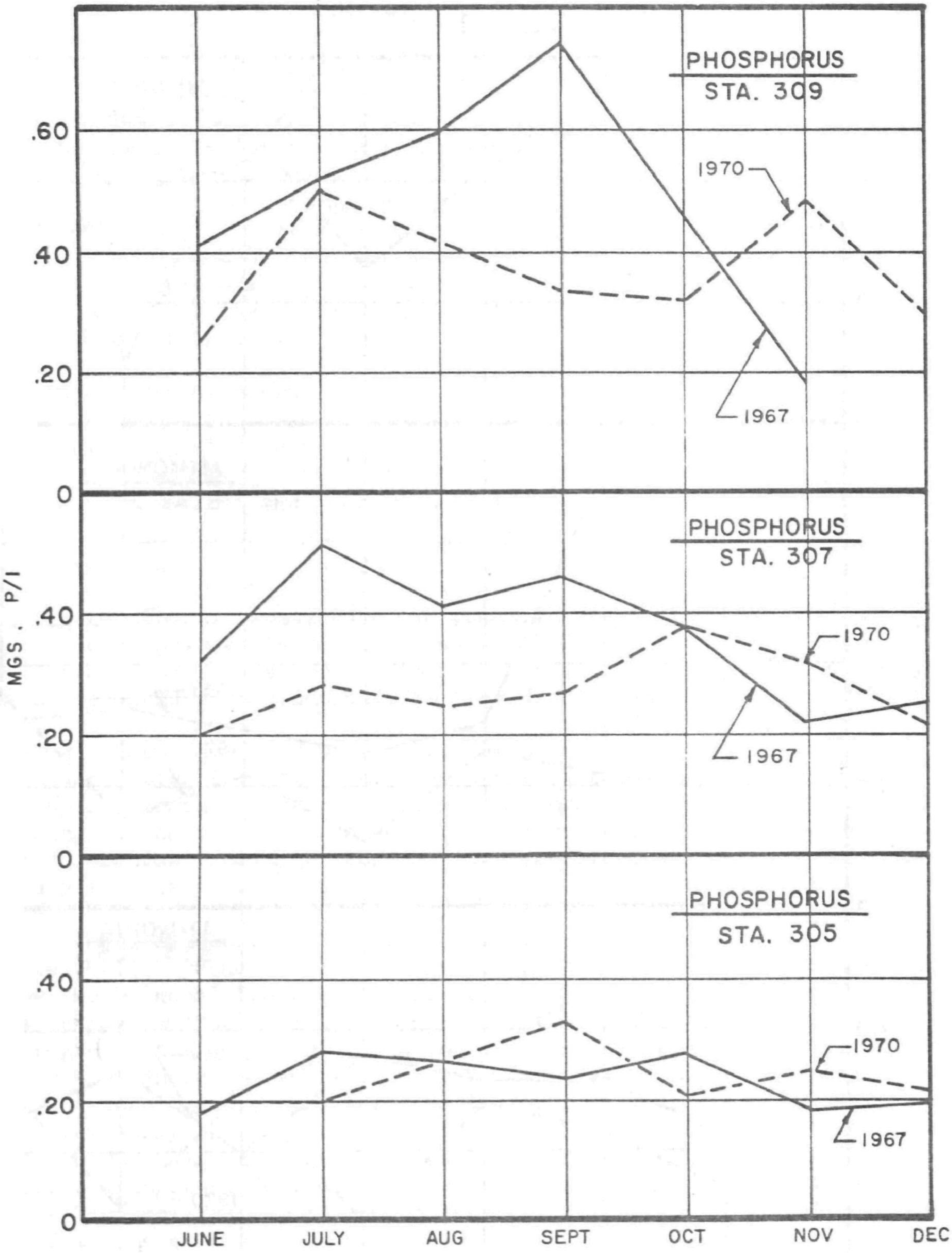


Figure 61. River Phosphorous Concentration

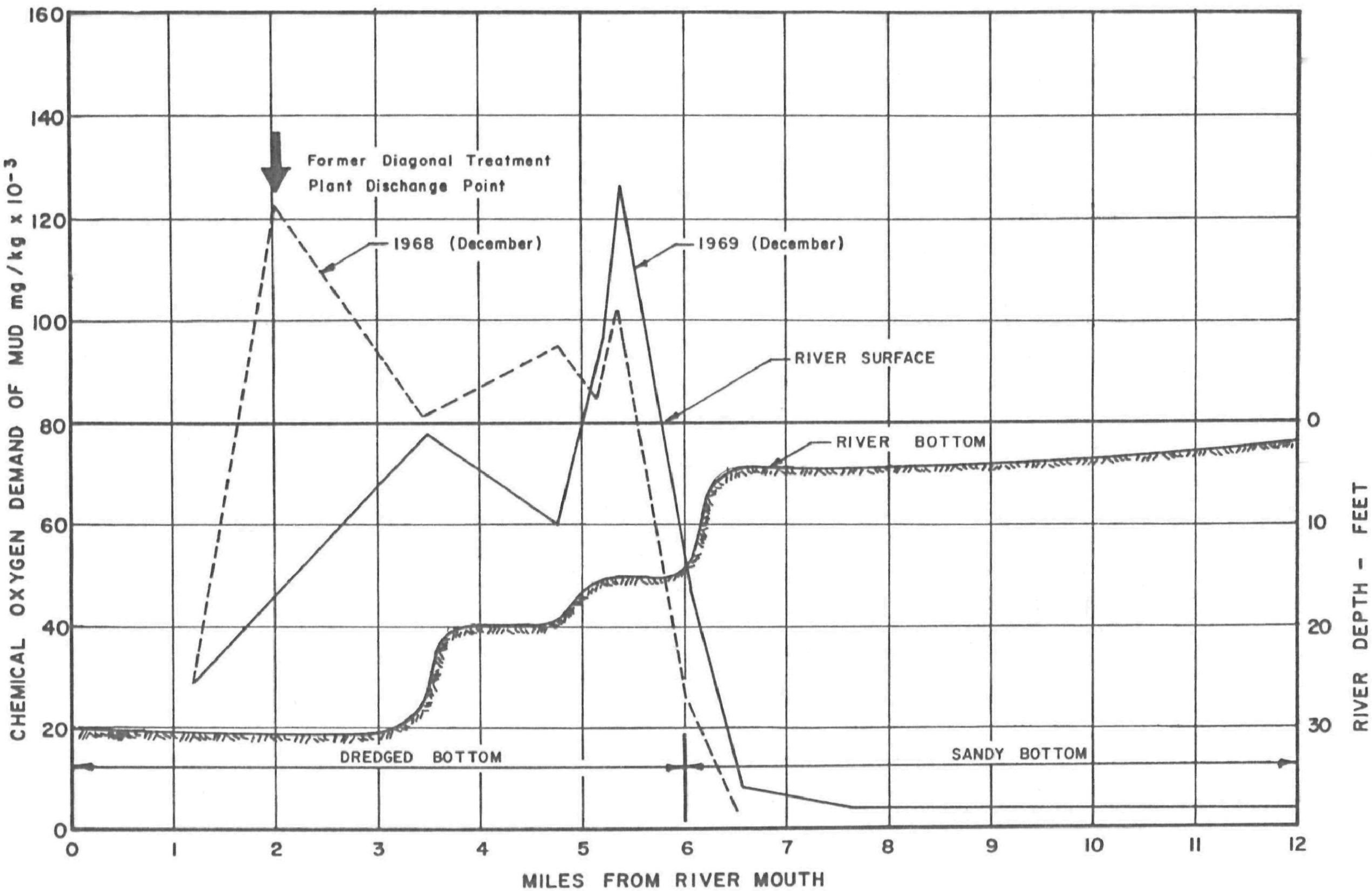


Figure 62. River Bottom Chemical Oxygen Demand

River Hatchery) for various years are shown in Table 24. These pollution-sensitive fishes have been able to maintain, and in one case apparently increase, their population during the past few years.

Another example of the effects of improved water quality on the increase in a fish population is shown in the Duwamish trawl study. The results are shown in Table 25.

These data illustrate the significant increase in the number of English sole at all three sampling stations. Small numbers of English sole are caught at station KW probably because the species is intolerant to large salinity changes; such changes occur at this station because of tidal fluctuations and the resulting effect on salt water intrusion into the estuary.

The removal of raw and treated waste discharges from the lower Duwamish River estuary has improved water quality and benefited the continued growth and survival of salmon and other aquatic life.

TABLE 24

Adult Salmon Returns
(Green River Hatchery)

Year	Chinook Salmon	Coho Salmon
1967	5,038	12,736
1968	8,114	50,856
1969	6,650	36,000
1970	9,000	70,868

TABLE 25

Trawl Catches of English Sole
(average number for various years)

Year	Station 1st Avenue So.	Station 16th Avenue So.	Station KW
1967	8.7	7.0	0.4
1968	15.5	2.4	0.4
1969	10.9	9.2	3.9
1970	32.6	50.2	11.7

SECTION VII
DEMONSTRATION GRANT PLANNING

IMPLEMENT THE CATAD SYSTEM

This report was prepared to indicate how the storage capacity of combined sewers can be maximized to prevent and possibly eliminate overflows. The progress of the Seattle area toward this goal has now been defined; therefore, the task remains to demonstrate whether the specific application of on-line computers to automatic control of a collection system is the ultimate solution to achieving this goal.

Figure 63 relates the planned schedule and the progress thus far attained toward implementing the Metro CATAD computerized total management system. Filled-in areas on the bar graph indicate work already completed. Unfilled areas show scheduled work. The planning chart shows that all facilities and hardware have been purchased and are in use. As of June 1971, the tasks remaining include: (1) continued sampling and monitoring of quantity and quality indicators, (2) refinements to the control and simulation model programs to allow a gradual change from local to supervisory to computer control (one station at a time), and (3) an evaluation of the merits of the system, including a final report.

MONITORING

Plans call for the receiving water monitoring program to continue at about the present levels with a few exceptions; these include an increase in Lake Washington Ship Canal sampling, where much regulator construction work is planned in the next 5 years. Collection system monitoring will show a major shift in emphasis as the separation and storm drainage studies are completed and more effort is diverted to overflow studies. More automation is planned, beginning with automatic chemical analyses and proceeding to automatic overflow volume calculations, river water quality plots, and possibly computer-directed overflow sampling operations.

MODELING

As pointed out in Section VI, the CATAD mathematical model is now passing through a transitional phase where monitored data, relating system response to measured rainfall and manual control actions, will be changing model program coefficients and algorithms (computational methods) until the model performs its duties without significant error. Further model revisions or additions are being studied.

Both the regional United States Geological Survey and River Basin Coordinating Committee--Water Resources Management Study (RIBCO-WRMS) are engaged in extensive research to develop water quality models for Seattle area river systems. For the Duwamish River estuary, this work is highly complicated because of the gradual mixing of fresh and salt water and the complex tidal variations, pictured in Figure 64, which range from -3 feet to +13 feet. When a model is finally available, it is

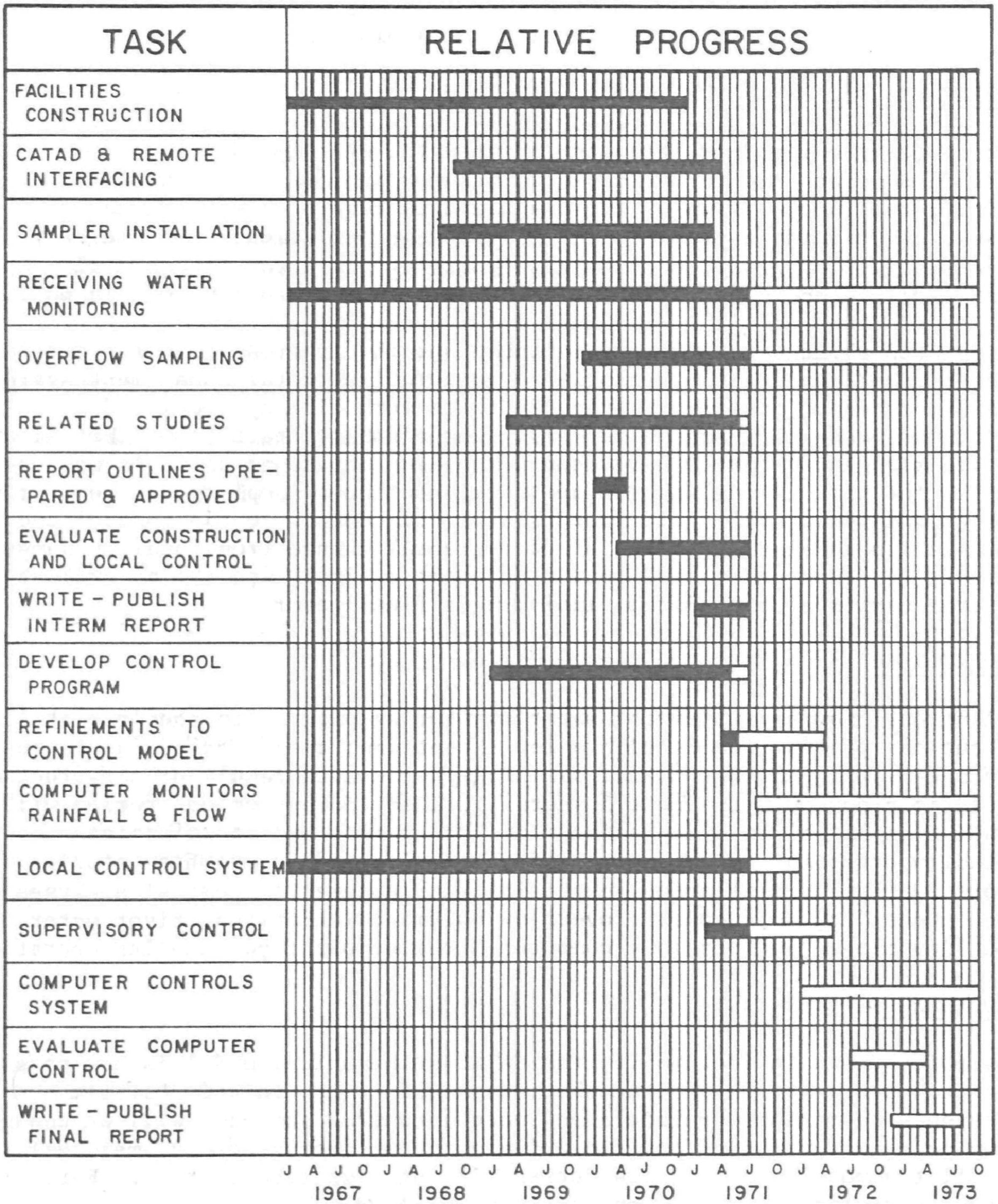


Figure 63. Planning and Progress Chart

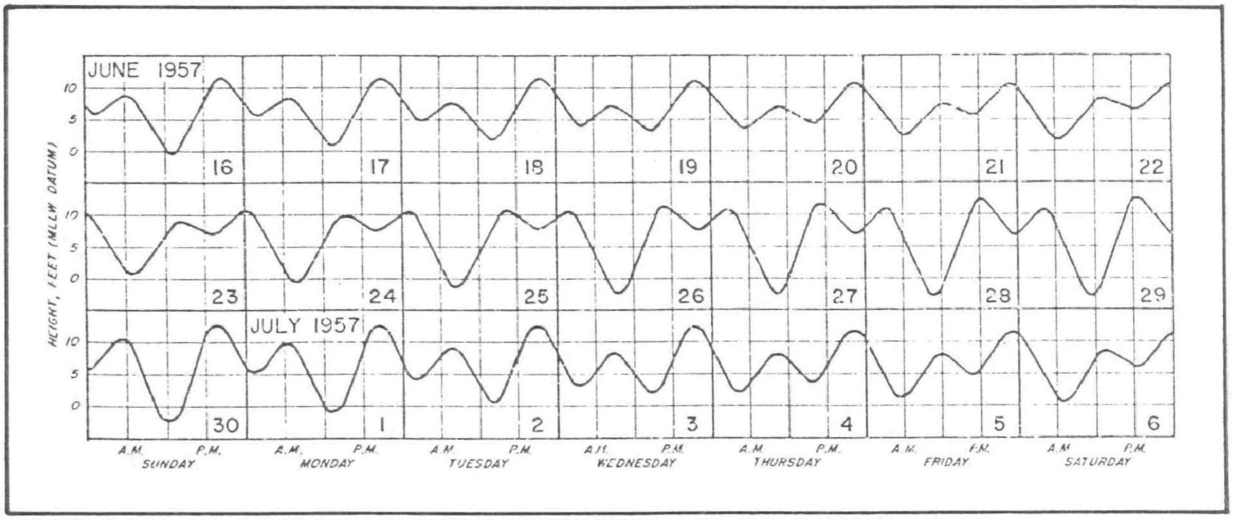


Figure 64. Tidal Variations in Puget Sound

to tie in some version of the Metro automatic river monitoring system so that effects of overflows or other stream loadings can be predicted and used to keep stream factors within established limits by automatically limiting or eliminating any discharge.

At the same time, new modeling techniques such as those recently completed by Lager, Metcalf, Eddy, et al. (52) and those being initiated by San Francisco and by Battelle for Cleveland (53) will be studied to determine whether refinements can be made to the CATAD system to further improve its ability to optimize all facets of the collection and treatment system, including operation and planning and design of additions to upgrade or expand the present system.

NEW APPLICATIONS

Also being planned are various ways to capitalize on the great number of alternative potential uses that become available as a result of Specifying a real-time computer system that can be time-shared by the foreground or background programs. For example, a remote terminal similar to the West Point console has been specified for the Renton Treatment Plant. (54) This terminal will have as a major component a mini-computer that will eventually allow development of a secondary treatment process control program. Other foreground applications include an on-line preventive maintenance management system and automatic receiving water quality monitoring, plotting, and alarming functions. The possible background uses for the new generation digital computers are too numerous to describe in this report.

SUMMARY

It would appear that municipal utility agencies are generally heading toward computer usage at some level to improve their service to the communities they support. Computer assistance can take the form of improved efficiency in record keeping and billing procedures or improved operating procedures to reduce costs. The Municipality of Metropolitan Seattle and EPA-WQO have made a large investment in an attempt to gain a foothold in the application of computers to real-time control of sewage collection systems. Regardless of the final results of this demonstration grant, many cities will profit from this research effort: Metro in that a highly adaptable computer system is available for many purposes and other cities in that such information will be on hand to serve as a starting point to begin the solution of their own unique problems.

SECTION VIII
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SECTION X
GLOSSARY OF TERMS AND ABBREVIATIONS

access time - time required by computer to locate a word in core memory and transfer the word to a register.

A.C.U.- auxiliary control unit: cabinet containing electronics, relays, etc. located between T.C.U. and station local control system.

address - name or number which identifies a particular storage location in the computer.

analog - the representation of a numerical quantity by some physical variable, e.g., translation, rotation, voltage or resistance.

as-built - engineering drawing completed after a facility is constructed, shows original design plus revisions made during construction.

autoanalyzer - copywritten term referring to equipment which automates chemical tests on samples. After initial set-up of equipment and sampling unit, no further human effort is needed other than interpreting a strip chart.

background - a low priority, unprotected processing area in a computer where batches of programs are compiled, tested and run without affecting other protected control and processing areas.

benchmark - a test program written to test the speed, performance and capacity of a computer and often to compare the results of a run on different computers.

benthal sediments - deposits on the bottom of a stream, often containing decaying material which removes oxygen from the stream.

binary - the representation of a numerical quantity by use of the two digits 0 and 1.

bit - abbreviation of binary digit: smallest possible unit of computer storage.

BOD - biochemical oxygen demand, a standard test used in assessing wastewater strength. The quantity of oxygen used in the biological-chemical oxidation of organic matter in a specified time under standard conditions.

CATAD - computer augmented treatment and disposal system.

C.C.U. - CATAD control unit: cabinet same as A.C.U but located at pumping stations.

cfs - cubic feet per second, unit of quantity of liquid flow checkpoint - a point in time where computer processing is stopped, all machine variables, registers and background area copied to a rapid magnetic storage device so that a large foreground program can temporarily use all or a part of what is normally called background area.

COD - chemical oxygen demand, a standard rapid test of the strength of a wastewater. The COD determination provides a measure of the oxygen equivalent of that portion of the organic matter in the sample that is susceptible to oxidation by a strong chemical oxident.

core - computer storage area where binary data is represented by the direction of the magnetic field in each unit of an array of tiny donut-shaped rings (generally).

Coliform - bacteria found only in intestines of mammals, therefore used as an indication of the pollution level of a sample or body of water.

composite - placing samples from a continuously changing stream into one common storage point to test for an average value.

C.P.U. - central processing unit: that portion of computer excluding input-output and external storage units, where arithmetic, logical, storage and control functions are centered.

CRT - Cathode Ray Tube: television, for visual data presentation.

DC - direct current, a form of electrical power.

DO - dissolved oxygen, the amount of gaseous oxygen dissolved into a liquid sample.

digital - the use of discrete numbers to a given base to represent all quantities in a problem or calculation. Most often all information is stored, transmitted or processed by a dual state condition; e.g. on-off, open-closed, true-false.

dwf - dry weather flow: normal sewer flow from domestic and industrial sources only.

executive - a program, often supplied with a computer, which controls loading and relocation of all software (much unknown to the programmer) required to execute a job entered by a programmer.

fecal coliform, fecal streptococcus - bacteria associated with humans, refinements to coliform tests to eliminate animal sources when assessing the pollution level of a water sample.

first flush - heavy load of material, previously settled in sewers, which is washed along by the initial flow resulting from a storm.

fps - feet per second, a measure of velocity.

force main - a pressure pipe joining the pump outlet at a wastewater pumping station with a point of gravity flow.

F value - a number corresponding to the degree of confidence of a certain statistical correlation. A correlation with an "F" less than one is generally discounted.

gpad - gallons per acre per day, a measure of infiltration or leakage between a pipeline and its surroundings.

hardware - the physical equipment and devices which comprise a computer or computer system component.

head - distance in feet from a free liquid surface to some reference point (which may be a different liquid surface).

hydrograph - a graphical representation of liquid flow versus time with time as the horizontal axis.

interceptor - sewer which receives water from various traverse sewers and carries water to a point for treatment and disposal.

interface - a common boundary between parts of a computer system.

interrupt - a special signal which temporarily halts the normal operation of some computer job for the purpose of accomplishing another more important short task, after which normal operation resumes.

loading - the dry weight, in pounds, of some material that is being added to a process or disposed of to a receiving water.

logic - the science of combining electronic components in order to define the interactions of signals in an automatic data processing system.

mathematical model - the characterization of a process or concept in terms of mathematics, which allows the simple manipulation of variables in an equation to determine how the process would act in different situations.

mg/l - milligrams per liter, or the concentration of some chemical in a liquid. If a letter appears after "mg" it represents the chemical symbol, e.g. N, for nitrogen; P, for phosphorous.

mgd - millions gallons per day, a common term for quantity of wastewater flow.

modem - device which converts between computer recognized signals and tones transmitted over telemetry lines.

NH_4, NO_3 - chemical shorthand for ammonia and nitrate in solution.

nutrient - is a major ingredient of a water or wastewater sample, e.g. ammonia nitrogen, nitrate-nitrite nitrogen, phosphate phosphorous, or silica which may serve as growth media for microorganisms, phytoplankton or zooplankton.

off-line - system and equipment under human operator control, not C.P.U. control.

O.G.C. - outfall gate controller: cabinet containing controllers and recorders relating to the outfall gate at a mechanical regulator station.

on-line - system and equipment under continuous automatic C.P.U. control.

orifice plate regulator - a machined hole in a metal plate (usually horizontal) allows a flow only slightly in excess of trunk dry weather flow to enter the interceptor.

overflow - undesirable emergency relief of sewer system by direct transmission to receiving water generally without treatment.

outfall - pipeline which carries raw or treated sewage from the collection system or treatment plant to the receiving body of water.

parity - a term relating to whether a given word or character (group of digits) is even or odd. A single bit denoting the parity of a word is usually attached to that word so that quick tests can be made as to the validity of the data.

partial separation - removal of some portion of all the elements of storm drainage into a combined sewer; e.g. streets and parking areas only, leaving roof and foundation drainage to enter the combined sewer.

peripheral - specialized machines connected electrically to the computer for converting between binary and other data forms, e.g. cards, tapes, typed pages.

pH - a measure of the degree of acidity or alkalinity of a solution.

PO_4 - chemical shorthand for phosphate in solution.

priority - degree of importance assigned to some computer task.

psig - pound per square inch, gage: a measure of the pressure of a fluid or gas based on atmospheric pressure.

purging - the act of reversing flow or using high pressure liquid or gas to clear a pipeline of a plug of solids.

rational method - a means of computing storm drainage flow rates by use of the formula Q=ciA; where c is a coefficient describing the physical drainage area, i is the rainfall intensity and A is the area.

real-time control - control of a system by using computers and timing such that the speed of response to the input information is fast enough to effectively influence the performance of that system.

register - device consisting of miniature electronic components including transistors, where a specific number of bits are stored and operated upon.

regulator - structure which controls amount of sewage entering an interceptor by storing in a trunk line or diverting some portion of flow to an outfall.

routing - storing, regulating, diverting or otherwise controlling the peak flows of wastewater through a collection system according to some prearranged plan.

rule curves - a set of curves which relate storage and discharge for a given reservoir under different control conditions.

r value - individual correlation value; indicates the degree of correlation between two variables.

R value - multiple regression value: the correlation value to many independent variables with a single dependent variable, e.g. air temperature and solar radiation on water temperature.

sag curve - a curve which describes the gradual drop to some minimum value followed by an increase to normal levels of the dissolved oxygen in a flowing stream following the addition of some oxygen demanding material such as sewage.

salt wedge - a wedge shaped volume of salt water beneath a body of fresh water.

secchi disk - a disk, painted in four quadrants of alternating black and white, which is lowered by rope into a body of water. The measured depth at which the disk is no longer visible from the surface is a subjective measure of relative transparency.

sequential - samples taken at known time intervals and stored in separate labeled containers.

side weir - a regulator which is essentially a long slot cut into the side of a sewer. Normal dry weather flow continues through the sewer while the increased depth during a storm will allow excessive flows to exit through the slot to some alternate point as an overflow.

scan - the collection and storage of data from all points at all stations in system by computer.

scan time - time set by operator which establishes the interval from the beginning of one scan to the next.

simulation - representation of physical systems and phenomena by computers, models and other equipment.

siphon - a u-shaped pipe used to carry wastewater under some obstacle such as a stream or another pipe.

sluice gate - a vertically sliding gate of any shape used to control or shut off flow in a sewer or other channel.

software - the programs or instructions which often control the hardware to perform some computer operation or extend the capabilities of the system.

stepwise regression - a statistical technique whereby a sequence of linear regression equations are computed in a stepwise manner, i.e. each independent variable is entered into the equation as it becomes the greatest remaining effect upon the variability of the dependent variable.

storage - unfilled, enclosed volumes within or connected to a sewer system capable of accepting and retaining wastewater for a period of time.

subroutine - a compact set of instructions to perform some repetitive task quickly and return to a main program.

telemetry - data transmission over long distances via telephone or telegraph lines by electro-magnetic means.

T.C.U. - Telemetry Control Unit: interchangeable electronic cabinets, convert between telemetry and station control signals (from A.C.U. or C.C.U.).

time sharing - use of a computer or device for two or more purposes during the same overall time interval, done by interspersing component actions in time.

trunk - large sewer which receives wastewater from tributary branch sewers serving generally one drainage area.

trawl - a fish catching technique using nets pulled along a river bottom (net sometimes also reaches to the surface) by boat.

wastewater - the spent water of a community, including domestic, industrial and commercial water-carried solids plus storm or other water sources. Replacing the term sewage.

word - a set of 16 or more bits stored and transferred as a unit by the computer.

SECTION XI

APPENDICES

Appendix A

Washington State Water Quality Standards

BEFORE THE WATER POLLUTION CONTROL COMMISSION
STATE OF WASHINGTON

IN THE MATTER OF PROMULGATING REGULATIONS RELATING TO THE ESTABLISHMENT OF WATER QUALITY STANDARDS FOR THE INTERSTATE AND COASTAL WATERS OF THE STATE OF WASHINGTON AND A PLAN FOR IMPLEMENTATION AND ENFORCEMENT OF SUCH STANDARDS	)	PROMULGATION OF REGULATION

I. INTRODUCTION

The Water Pollution Control Commission following the procedures set forth in Chapter 34.04 RCW and after giving notice as required by Chapter 42.32 RCW, and by virtue of the authority vested in it by Chapter 90.48 RCW, hereby promulgates the following regulation relating to water quality standards for the interstate and coastal waters of the State of Washington and a plan for implementation and enforcement of such standards as set forth in Section II through V hereof; said regulation remaining in effect until amended or rescinded. This regulation is promulgated to comply with Section 10 of the Federal Water Pollution Control Act as amended. (PL 84-660, as amended.)

II. CRITERIA AND CLASSIFICATION

The water quality criteria and the classification of interstate and coastal waters set forth in this section are established in conformance with present and potential water uses of said waters after giving due consideration to the natural potential and limitations of the same.

A. WATER QUALITY CRITERIA

The following criteria shall be applicable to the various interstate and coastal waters of the State of Washington:

1. Class AA Extraordinary

a. General Characteristic

Water quality of this class markedly and uniformly exceeds the requirements for all or substantially all uses.

b. Characteristic Uses

Characteristic uses include, but are not limited to, the following:

Water supply (domestic, industrial, agricultural)
Wildlife habitat, stock watering
General recreation and aesthetic enjoyment (picnicking, hiking, fishing, swimming, skiing and boating)
General marine recreation and navigation
Fish and shellfish reproduction, rearing and harvest

c. Water Quality Standards

Total Coliform Organisms shall not exceed median values of 50 (FRESH WATER) or 70 (MARINE WATER) with less than 10% of samples exceeding 230 when associated with any fecal source.

Dissolved Oxygen shall exceed 9.5 mg/l (FRESH WATER) or 7.0 mg/l (MARINE WATER).

Temperature No measureable increases shall be permitted within the waters designated which result in water temperatures exceeding 60°F (FRESH WATER) or 55°F (MARINE WATER) nor shall the cumulative total of all such increases arising from nonnatural causes be permitted in excess of $t = 75/(T-22)$ (FRESH WATER) or $t = 24/(T-39)$ (MARINE WATER); for purposes hereof "t" represents the permissive increase and "T" represents the resulting water temperature.

pH shall be within the range of 6.5 to 8.5 (FRESH WATER) or 7.8 to 8.5 (MARINE WATERS) with an induced variation of less than 0.1 units.

Turbidity shall not exceed 5 JTU.

Toxic, Radioactive or Deleterious Material Concentrations shall be less than those which may affect public health, the natural aquatic environment, or the desirability of the water for any usage.

Aesthetic Values shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch or taste.

2. Class A Excellent

a. General Characteristic

Water quality of this class exceeds or meets the requirements for all or substantially all uses.

b. Characteristic Uses

Characteristic uses include, but are not limited to, the following:

Water supply (domestic, industrial, agricultural)
Wildlife habitat, stock watering
General recreation and aesthetic enjoyment (picnicking, hiking, fishing, swimming, skiing and boating)
Commerce and navigation
Fish and shellfish reproduction, rearing and harvest

c. Water Quality Standards

Total Coliform Organisms shall not exceed median values of 240 (FRESH WATER) with less than 20% of samples exceeding 1,000 when associated with any fecal source or 70 (MARINE WATER) with less than 10% of samples exceeding 230 when associated with any fecal source.

Dissolved Oxygen shall exceed 8.0 mg/l (FRESH WATER) or 6.0 mg/l (MARINE WATER).

Temperature No measureable increases shall be permitted within the waters designated which result in water temperatures exceeding 65°F (FRESH WATER) or 61°F (MARINE WATER) nor shall the cumulative total of all such increases arising from nonnatural causes be permitted in excess of $t = 90/(T-19)$ (FRESH WATER) or $t = 40/(T-35)$ (MARINE WATER); for purposes hereof "t" represents the permissive increase and "T" represents the resulting water temperature.

pH shall be within the range of 6.5 to 8.5 (FRESH WATER) or 7.8 to 8.5 (MARINE WATER) with an induced variation of less than 0.25 units.

Turbidity shall not exceed 5 JTU over natural conditions.

Toxic, Radioactive or Deleterious Material Concentrations shall be below those of public health significance, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect any water use.

Aesthetic Values shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch or taste.

3. <u>Class B Good</u>

a. General Characteristic

Water quality of this class exceeds or meets the requirements for most uses.

b. Characteristic Uses

Characteristic uses include, but are not limited to, the following:

General recreation and aesthetic enjoyment (fishing, swimming, skiing and boating)
Fishery and wildlife habitat
Industrial and agricultural water supply
Stock watering
Commerce and navigation
Shellfish reproduction and rearing, and crustacea (crabs, shrimp, etc.) harvest.

c. Water Quality Standards

<u>Total Coliform Organisms</u> shall not exceed median values of 1,000 with less than 20% of samples exceeding 2,400 when associated with any fecal source.

<u>Dissolved Oxygen</u> shall exceed 6.5 mg/l (FRESH WATER) or 5.0 mg/l (MARINE WATER), or 70% saturation whichever is greater.

<u>Temperature</u> No measureable increases shall be permitted within the waters designated which result in water temperatures exceeding 70°F (FRESH WATER) or 66°F (MARINE WATER) nor shall the cumulative total of all such increases arising from nonnatural causes be permitted in excess of $t = 110/(T-15)$ (FRESH WATER) or $t = 52/(T-32)$ (MARINE WATER); for purposes hereof "t" represents the permissive increase and "T" represents the resulting water temperature.

<u>pH</u> shall be within the range of 6.5 to 8.5 (FRESH WATER) or 7.8 to 8.5 (MARINE WATER) with an induced variation of less than 0.5 units.

<u>Turbidity</u> shall not exceed 10 JTU over natural conditions.

<u>Toxic, Radioactive or Deleterious Material Concentrations</u> shall be below those which adversely affect public health during the exercise of characteristic usages, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect characteristic water uses.

<u>Aesthetic Values</u> shall not be reduced by dissolved, suspended, floating or submerged matter, not attributable to natural causes, so as to affect water usage or taint the flesh of edible species.

4. Class C Fair

a. General Characteristic

Water quality of this class exceeds or meets the requirements of selected and essential uses.

b. Characteristic Uses

Characteristic uses include, but are not limited to, the following:

Commerce and navigation
Cooling water
Boating
Fish passage

c. Water Quality Standards

Total Coliform Organisms shall not exceed median values of 1,000 when associated with any fecal source.

Dissolved Oxygen shall exceed 5.0 mg/l (FRESH WATER) or 4.0 mg/l (MARINE WATER), or 50% saturation whichever is greater.

Temperature No measureable increases shall be permitted within the waters designated which result in water temperatures exceeding 75°F (FRESH WATER) or 72°F (MARINE WATER) nor shall the cumulative total of all such increases arising from nonnatural causes be permitted in excess of t= 125/(T-12) (FRESH WATER) or t= 64/(T-29) (MARINE WATER); for purposes hereof "t" represents the permissive increase and "T" represents the resulting water temperature.

pH shall be within the range of 6.0 to 9.0 (FRESH WATER) or 7.0 to 9.0 (MARINE WATER) with an induced variation of less than 0.5 units.

Turbidity shall not exceed 10 JTU over natural conditions.

Toxic, Radioactive or Deleterious Material Concentrations shall be below those which adversely affect public health during the exercise of characteristic usages, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect characteristic water uses.

Aesthetic Values shall not be interfered with by the presence of obnoxious wastes, slimes, or aquatic growths or by materials which will taint the flesh of edible species.

B. CLASSIFICATION

Interstate and coastal waters of the State of Washington are classified as follows:

1. Columbia River Class A

Mouth to the Washington-Oregon border (River Mile 309)

Special Conditions

Temperature No measureable increases shall be permitted within the waters designated which result in water temperatures exceeding 68°F nor shall the cumulative total of all such increases arising from nonnatural causes be permitted in excess of t= 110/(T-15); for purposes hereof "t" represents the permissive increase and "T" represents the resulting water temperature.

Below Interstate Highway No. 5 bridge

Total Coliform Organisms shall not exceed median values of 1,000 with less than 20% of samples exceeding 2,400 when associated with any fecal source.

2. Columbia River Class A

Washington-Oregon border (River Mile 309) to Grand Coulee Dam (River Mile 595)

Special Conditions

Washington-Oregon border (River Mile 309) to Priest Rapids Dam (River Mile 397)

Temperature No measureable increases shall be permitted within the waters designated which result in water temperatures exceeding 68°F nor shall the cumulative total of all such increases arising from nonnatural causes be permitted in excess of t= 110/(T-15); for purposes hereof "t" represents the permissive increase and "T" represents the resulting water temperature.

3. Walla Walla River Class B

Mouth to Lowden (River Mile 15)

30. Quinault River Class AA
Mouth to River Mile 2

31. Queets River Class AA
Mouth to River Mile 3.0

32. Hoh River Class AA
Mouth to River Mile 0.8

33. Strait of Juan de Fuca and Puget Sound Class AA
Through Admiralty Inlet and South Puget Sound, South and West to Longitiude 122° 52' 30" W (Brisco Point) and Longitude 122° 51' W (Northern tip of Harstene Island), Hood Canal, Possession Sound south of Latitude 47° 57' N (Mukilteo) and all North Puget Sound West of Longitude 122° 39' (Whidbey, Fidalgo, Guemes and Lummi Island) except as otherwise noted.

34. Port Angeles Class A
South and West of a line bearing 152° true from buoy "2" at the tip of Ediz Hook

Special Conditions

Total Coliform Organisms - Shall not exceed a median value of 240 with less than 20% of samples exceeding 1,000 when associated with any fecal source.

35. Sequim Bay Class A
Southward of entrance

36. Port Townsend Class A
West of a line between Point Hudson and Kala Point

37. Port Gamble Class A
South of latitude 47° 51' 20" N.

38. Elliott Bay Class A
East of a line between U. S. Navy Supply Depot and Duwamish Head

Special Conditions

Total Coliform Organisms - Shall not exceed median values of 1,000 with less than 20% of samples exceeding 2,400 when associated with any fecal source.

39. Duwamish River Class B
Mouth south of a line bearing 254° true from the NW corner of Berth 3, Terminal No. 37 to the confluence with the Black River (Tukwila).

40. Duwamish River Class A

Upstream fron the confluence with the Black River to the limit of tidal influence.

Special Conditions

Total Coliform Organisms - Shall not exceed median values of 1,000 with less than 20% of samples exceeding 2,400 when associated with any fecal source.

41. Dyes and Sinclair Inlets Class A

West of Longitude 122° 37' W

Special Conditions

Sinclair Inlet and Port Washington Narrows West of Longitude 122° 37' W and south of Latitude 47° 35' 20" N

Total Coliform Organisms - Shall not exceed median values of 1,000 with less than 20% of samples exceeding 2,400 when associated with any fecal source.

42. Commencement Bay Class A

South and east of a line bearing 258° true from "Brown's Point" and north and west of a line bearing 225° true through the Hylebos Waterway light.

Special Conditions

Total Coliform Organisms - Shall not exceed median values of 1,000 with less than 20% of samples exceeding 2,400 when associated with any fecal source.

43. Inner Commencement Bay Class B

South and east of a line bearing 225° true through the Hylebos Waterway Light except the Port-Industrial and City Waterways south and east of south 11th street.

44. Port-Industrial and City Waterways Class C

South and East of south 11th street.

45. Puyallup River Class B

Mouth to River Mile 1 (from mouth)

46. Puyallup River Class A

River Mile 1 to limit of tidal influence

47. Chambers Creek Class A

Mouth to the limit of tidal influence.

48. Nisqually River Class A

Mouth to River Mile 9 (Muck Creek confluence)

C. GENERAL CONSIDERATIONS

The following general guidelines shall be applicable to the water quality criteria and classifications set forth in the sections II A and II B hereof:

1. At the boundary between waters of different classifications, the water quality criteria for the higher classification shall prevail.

2. In brackish waters of estuaries, where the fresh and marine water quality criteria differ within the same classification, the criteria shall be interpolated on the basis of salinity except that the marine water quality criteria shall apply for dissolved oxygen when the salinity is one (1) part per thousand or greater and for total coliform organisms when the salinity is ten (10) parts per thousand or greater.

3. The water quality criteria herein established, except for the aesthetics values, shall not apply within immediate dilution areas of very limited size adjacent to or surrounding a wastewater discharge. In determining the size of an immediate dilution area, consideration will be given to the quality of the effluent or wastewater discharged and the nature and condition of the receiving waters. No such areas will be established for a waste discharge unless authorized under a permanent permit:
   a. The wastewater discharge has been provided with all known, available and reasonable methods of treatment,
   b. The wastewater treatment facilities are operated and maintained to the satisfaction of the Commission and,

c. The treated wastewater is provided with initial diffusio. at the point of discharge into the receiving water to the satisfaction of the Commission.

4. The criteria established in Section IIA for any of the various classifications of this regulation may be modified by the Director for limited periods when receiving waters fall below their natural water quality condition due to natural causes which are unusual and not reasonably foreseeable if in the opinion of the Director the protection of the overall public interest and welfare requires such modification.

5. Regardless of the water quality criteria as herein established, wherever existing receiving waters of a classified area are of a higher quality than the criteria assigned for said area, the existing water quality shall constitute water quality criteria. Likewise existing water quality conditions shall constitute the criteria for interstate and coastal waters not specifically classified herein.

D. CHARACTERISTIC USES TO BE PROTECTED

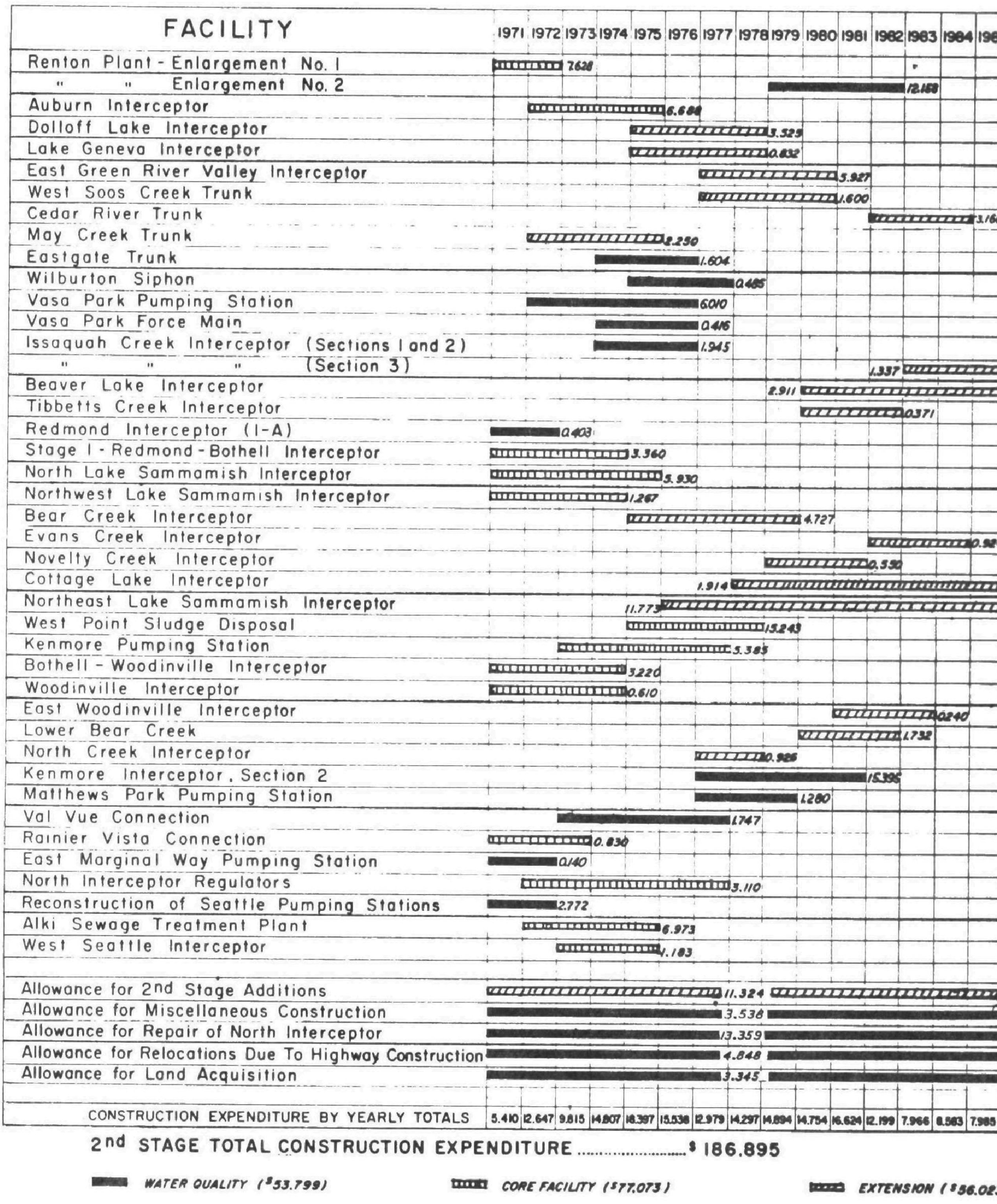
The following is a noninclusive list of uses to be protected by the various classifications:

USES	WATERCOURSE CLASSIFICATION AA	A	B	C
FISHERIES				
Salmonid				
Migration	F M	F M	F M	F M
Rearing	F M	F M	F M	
Spawning	F	F		
Warm Water Game Fish				
Rearing	F	F	F	
Spawning	F	F	F	
Other Food Fish	F M	F M	F M	
Commercial Fishing	F M	F M	F M	
Shellfish	M	M	M	
WILDLIFE	F M	F M	F M	
RECREATION				
Water Contact	F M	F M	F M	
Boating and Fishing	F M	F M	F M	F M
Environmental Aesthetics	F M	F M	F M	F M
WATER SUPPLY				
Domestic	F	F		
Industrial	F M	F M	F M	F M
Agricultural	F	F	F	F
NAVIGATION	F M	F M	F M	F M
LOG STORAGE & RAFTING	F M	F M	F M	F M
HYDRO-POWER	F	F	F	F

** F - Fresh Water
M - Marine Water

Appendix B

Metro Second-Stage Construction Program Costs



Appendix C

Combined Sewer Overflow Points

Table C-1

Overflow Points Within Separation Area

No.	Location	Diam. Size In.	Weir* Elevation
	Lake Washington South of Union Bay		
1	38th and Alaska	-	22.2
2	Cooper	20	25.6
3	Perry	15	19.5
4	Grattan (Lift Station)	12	-
5	57th Avenue South	16	15.0
6	Brighton & 57th	-	9.0
7	Alaska	-	-
8	Snoqualmie	12	17.5
9	Alaska	20	-
10	40th Avenue	-	-
11	50th Avenue	15	11.5
12	Lake Wash. Blvd.	72	10.3
13	Alaska and 38th	24	22.2
14	Horton	12	17.6
15	College	12	19.9
16	Massachusetts	16	15.0
17	Charles	20	18.8
18	Dearborn	12	16.7
19	Main	8	16.5
20	Blaine	12	14.2
21	Park	16	10.0
22	Alder	15	13.0
23	James	16	12.6
24	Pike	16	12.0
25	Pine	24	7.6
26	Denny	8	11.8
27	Lee	20	5.1
28	Lee	20	2.5

Table C-1 (cont'd.) Lake Washington S.

No.	Location	Diam. Size In.	Weir Elevation
29	Lynn	24	8.7
30	39th Avenue	-	1.4
	Lake Washington Ship Canal		
31	Brooklyn Avenue	12	7.2
32	Brooklyn Avenue (Pump Station)	15	9.5
33	Montlake Blvd.	84	17.2
	Lake Washington North of Union Bay		
34	55th & 40th	60	94.1
35	38th Avenue (Storm)	60	3.4
36	41st & 38th	-	19.7
37	Belvoir Place	21	10.0
38	N.E. 31st (Lift Station)	8	7.8
39	38th	30	17.4
40	43rd	10	16.8
41	Kenilworth	15	13.0
42	Windemere	36	13.5
43	Ambleside Road	15	8.0
44	60th	27	4.9
45	64th (Lift Station)	15	22.5
46	Park	18	7.5
47	Park	15	9.7
48	Park	12	8.8
	Henderson System		
49	Rainier North	72	14.1
50	Rainier South	36	18.3
51	50th	10	15.7
52	48th	8	17.4
53	46th	12	29.7
54	Renton	10	32.4
55	42nd	60	41.9

Table C-1 (cont'd.) Salmon Bay Waterway

No.	Location	Diam Size In.	Weir Elevation
56	Burke	12	-
57	Densmore	8	-
58	Woodland Park & 34th	24	16.7
59	Carr Place	8	-
60	Stoneway	30	15.4
61	2nd Avenue	30	11.6
62	1st Avenue	60x80	-
63	8th Avenue (Pump Station)	8	4.8
64	11th Avenue	60	9.0
65	45th & 8th	18	13.2
66	24th Avenue	30	25.0
67	24th Avenue	18	8.4
68	20th Avenue	36	8.0
69	28th Avenue	48	14.2
70	N.W. 57th (Pump Station)		
	Magnolia		
71	32nd	24	10.0
72	16th	16	10.0
73	17th	42	-
74	17th	30	-
75	Prospect	30	6.4
	Duwamish Waterway		
76	Spokane	15	1.2
77	W. Michigan	36	-
78	8th Avenue	36	-
	West Seattle		
79	104th	8	-
80	98th	10	-
81	Brace	10	22.0
82	Director	60	- 3.8

Table C-1 (cont'd.) West Seattle

No.	Location	Diam. Size In.	Weir Elevation
83	Cloverdale (Lift Station)	20	-5
84	Lowman Beach (Pump Station)	72	5.0
85	Alaska	54	-
86	Lowman Beach (Pump Station)	48	4.0
87	Bruce (Lift Station)	24	-1.3
88	Spokane	66	-5.8
89	Alki T.P.	42	-
90	53rd (Lift Station)	60	-1.6
91	23rd & Barton	12	326.0
92	Atlantic Street	20	-0.2
93	Jersey	24	-1.3
94	Jersey	10	-
95	California	30	-
96	Maryland Place	18	-4.8
97	Georgia Street	12	-0.0
98	Fairmont Avenue	42	-4.3
99	Myrtle & 24th	30	-
100	Webster & 28th	-	-

* City of Seattle Datum is 6.05 above MSL set USGS after 1947 adjusted.

Table C-2

Overflow Weir Elevation Outside the Separation Area

No.	Location	Diam. Size In.	Weir* Elevation
	N. of Sand Point		
1	Thornton (lift)	18	9.8
2	103rd	12	16.1
3	105th (Storm)	72	13.6
4	113th (Pump)	12	15.3
5	127th (Lift)	12	14.9
6	119th (Pump)	12	15.6
7	130th (Lift)	8	8.0
8	106th (Pump)	15	13.1
9	107th	12	14.0
10	144th	12	14.0
11	140th	12	14.0
12	126th	12	14.0
	N. of West Point		
13	Carkeek Park	33	-
14	Bedford Crt. (Pump)	8	4.0
15	N. Beach (Pump)	15	18.0
16	32nd (Lift)	8	-
17	71st (Lift)	8	2.7
18	68th (Lift)	8	-6.6
19	77th (Lift)	8	-5.6
	S. of West Point		
20	W. Raye	24	3.4
21	W. Raye	12	4.0
	Elliott Bay		
22	Denny Way	96	- .7
23	Denny Way	72	-1.2
24	Vine	48	1.3

Table C-2 (cont'd.) Elliott Bay

No.	Location	Diam. Size In.	Weir Elevat
25	University	49	-5.4
26	Madison	24	-1.8
27	Columbia	12	-4.3
28	Washington	24	-6.7
29	King	48	-1.4
30	Connecticut	72	-4.1
31	Massachussetts	12	0.8
32	Stacy (Raw)	12	-2.0
33	Lander	96	-6.0
34	Hanford	150x100	-6.8
35	Spokane (Raw)	16	-
	Salmon Bay		
36	Cramer	20	-5.8
37	Ewing	39x60	6.4
38	Aurora	8	-
	Ship Canal North		
39	Latona	18	9.31
40	Sunnyside (Pump)	8	8.0
	Duwamish River		
41	Oregon Siphon	36	-
42	Diagonal	30	-10.0
43	Oregon and Ohio	30	-.55
44	Diagonal and Colo.	30	.95
45	Diagonal and 1st	8	.87
46	8th and Hanford	96x84	-7.45
47	Brandon	50x78	-3.2
48	Michigan	70x102	-5.3
49	Brighton	30	-8.4
50	E. Marginal (Pump)	36	-10.9
51	Othello	24	-4.5
52	Norfolk	84	2.6

Table C-2 (cont'd.)

No.	Location	Diam. Size In.	Weir Elevation
	Harbor Island		
53	Spokane (Pump)	12	-1.5
54	E. Hanford	8	-
55	Massachusetts	8	-
56	13th	8	-1.6
57	W. Hanford	8	-
58	Lander	8	-
59	13th and Lander (Pump)	24	-
60	Florida	8	-
	Lake Union		
61	Crokett	8	-
62	Galer	42	27.8
63	Valley	18	9.2
64	Fairview	24	7.4
65	Yale	8	5.9
66	Garfield	18	16.3
67	Newton	8	4.2
68	Lynn	21	10.0
69	Louisa	8	8.0
70	Roanoke	24	29.1
71	Hamlin	10	34.7
72	Shelby (Pump)	8	3.3
73	Shelby (Pump)	18	8.9
74	Allison	8	5.12
75	Eastlake	10	43.4
76	Allison	8	6.1
77	16th	30	7.1
78	W. Park	18	9.5
79	Montlake	60	32.7
80	Shelby (Pump)	21	9.8
81	39th (Pump)	8	-1.4

*City of Seattle Datum is 6.05 above MSL set USGS after 1947 adjusted.

Appendix D

Separation Cost Examples

A. Southwest Seattle
   - Figure D-1
   - Table D-1

B. East Central Seattle
   - Figure D-2
   - Table D-2

Figure D-1

Separation Plan - Southwest Seattle District

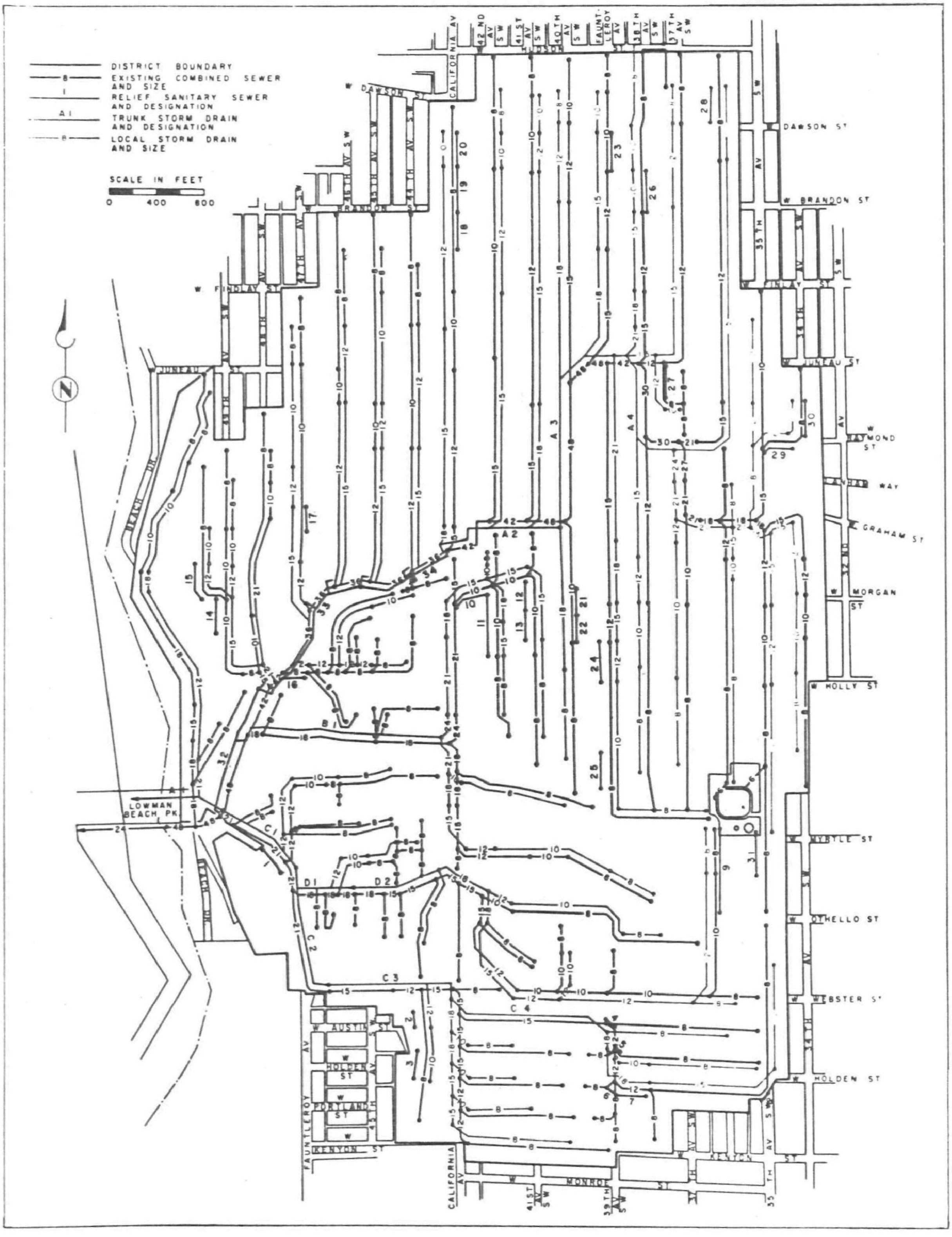


Table D-1

Estimated Construction Costs - Southwest Seattle

Number	Design flow, cfs	Description	Construction cost, dollars
Partial separation[a]			
Relief sanitary sewers			
1	15, 30[b]	300 ft of 21-in. RC at 1.0%	6,600
2	0.7, 2.8[b]	100 ft of 8-in. conc at 1.5%	800
3	0.5, 1.7[b]	230 ft of 8-in. conc at 1.0%	1,600
4	1.5, 6.5[b]	80 ft of 8-in. conc at 2.2%	500
5	0.5, 1.7[b]	70 ft of 8-in. conc at 1.0%	500
6	3.9	80 ft of 15-in. RC at 0.4% to replace existing 12-in.	1,100
7	1.5, 3.9[b]	260 ft of 10-in. conc at 0.5%	2,200
8	2.0	90 ft of 15-in. RC at 0.2% to replace existing 8-in.	1,600
9	0.3, 1.1 – 1.8[b]	690 ft of 8-in. conc at 0.4 – 0.6%	4,800
10	1.2, 5.2[b]	280 ft of 8-in. conc at 3.1%	2,600
11	0.4, 1.7[b]	610 ft of 8-in. conc at 0.3 – 0.9%	4,200
12	2.8, 4.1[b]	240 ft of 15-in. RC at 0.3%	3,300
13	0.9, 2.1[b]	240 ft of 10-in. conc at 0.3%	2,000
14	1.0, 3.1[b]	290 ft of 8-in. conc at 0.9%	2,000
15	0.5, 1.5[b]	340 ft of 8-in. conc at 0.7 – 1.0%	2,400
16	2.0, 6.2[b]	220 ft of 8-in. conc at 12.9%	1,200
17	1.4, 3.5[b]	370 ft of 10-in. conc at 0.9%	3,100
18	0.7 – 1.0, 2.7 – 3.0[b]	660 ft of 8-in. conc at 2.4 – 2.8%	7,200
19	1.3, 2.1[b]	380 ft of 10-in. conc at 0.4%	4,900
20	0.5, 1.4[b]	280 ft of 8-in. conc at 0.6%	3,000
21	0.8, 2.9[b]	240 ft of 8-in. conc at 0.9%	1,700
22	1.3, 2.7[b]	240 ft of 10-in. conc at 0.4%	2,000
23	0.3, 1.7[b]	300 ft of 8-in. conc at 0.4%	3,200
24	0.5, 4.3[b]	330 ft of 8-in. conc at 9.7%	2,300
25	0.4, 3.1[b]	290 ft of 8-in. conc at 4.8%	2,000
26	1.0, 2.1[b]	320 ft of 8-in. conc at 0.9%	1,800
27	0.2, 1.3[b]	340 ft of 8-in. conc at 0.8%	2,400
28	0.4, 1.0[b]	280 ft of 8-in. conc at 0.4%	1,900
29	0.4 – 0.8,[b] 1.6	300 ft of 8-in. conc at 0.4 – 0.9%	2,000
30	0.2, 1.0[b]	290 ft of 8-in. conc at 0.4%	2,000
31	0.9, 1.6[b]	360 ft of 10-in. conc at 0.4%	4,600
32	58 – 66	1,100 ft of 30-in. RC at 3.2 – 6.0% to replace existing 42 – 48-in. which is to be used as storm drain	26,000
33	50 – 55	1,200 ft of 27-in. RC at 3.0 – 15% to replace existing 36 – 42-in. which is to be used as storm drain	29,700
34	46 – 47	640 ft of 24-in. RC at 5.6 – 33% to replace existing 36-in. which is to be used as storm drain	13,300
–	–	Reconnect 80 house connections	3,200

Table D-1 (cont'd.)

Number	Design flow, cfs	Description	Construction cost, dollars
–	–	Reconnect 64 manholes	6,400
–	–	Reconnect 9 lateral sewers	1,800
Subtotal, relief sanitary sewers			161,900
Trunk storm drains			
A-1	220–225	600 ft of 54-in. RC at 1.8%	27,600
A-2	86–100	1,140 ft of 30-in. RC at 4.5 – 7.0%	21,300
A-3	80–83	1,560 ft of 48-in. RC at 0.3 – 0.6%	55,200
A-4	44–66	1,200 ft of 33-in. RC at 0.7 – 3.9%	27,300
B-1	32–36	1,680 ft of 21-in. RC at 5.6 – 10.5%	22,800
C-1	60	860 ft of 36-in. RC at 1.0 – 20%	21,800
C-2	32	1,170 ft of 27-in. RC at 1.2 – 18%	20,100
C-3	27–32	1,280 ft of 18-in. RC at 7.5 – 17%	14,100
C-4	15–17	1,260 ft of 18-in. RC at 2.6 – 5.1%	15,300
D-1	25–30	520 ft of 24-in. RC at 1.6 – 5.0%	8,300
D-2	23–25	710 ft of 18-in. RC at 6.2 – 15%	8,700
–	–	Connections to existing trunk to be utilized as storm drain	2,000
Subtotal, trunk storm drains			244,500
Local storm drains			
–	–	25,200 ft of 8-in.	125,800
–	–	17,600 ft of 10-in.	103,900
–	–	17,700 ft of 12-in.	148,200
–	–	24,200 ft of 15-in.	238,500
–	–	9,800 ft of 18-in.	113,500
–	–	5,700 ft of 21-in.	81,200
–	–	600 ft of 24-in.	9,600
–	–	227 intersection crossings, includes catch basin reconnections	80,900
Subtotal, local storm drains			901,600
Total contract cost, partial separation			1,308,000
Engineering and contingencies, 25 per cent			427,000
Total construction cost, partial separation			1,735,000
Complete separation[c]			
Relief sanitary sewers[d]			
–	3.0–4.5	2,940 ft of 15-in. RC at 3.0 – 33% to replace existing 36–48-in. which is to be utilized as storm drain	42,600
–	1.9–2.4	1,200 ft of 12-in. RC at 3.8 – 7.0% to replace existing 42 – 48-in. which is to be utilized as storm drain	13,100
–	1.5 – 1.9	1,480 ft of 12-in. RC at 0.3 – 0.6% to replace existing 48-in. which is to be utilized as storm drain	16,900
–	–	15 new house connections	4,500
–	–	Reconnect 18 lateral sewers	3,600
Subtotal, relief sanitary sewers			80,700

Table D-1 (cont'd.)

Number	Design flow, cfs	Description	Construction cost, dollars
Trunk storm drains			
A-1	365 – 375	600 ft of 63-in. RC at 1.8%	32,400
–	250 – 260	710 ft of existing 42 – 48-in.	–
–	60, 240[b]	390 ft of 30-in. RC at 3.2% to parallel existing 42-in.	8,300
–	215 – 225	670 ft of existing 42-in.	–
–	190 – 200	540 ft of 45-in. RC at 3.0% to replace existing 36-in.	16,800
–	170 – 190	630 ft of 39-in. RC at 5.6 – 9.2% to replace existing 36-in.	16,700
A-2	135 – 165	1,220 ft of existing 42-in.	–
A-3	100 – 135	1,750 ft of existing 42 – 48-in.	–
A-4	68 – 80	930 ft of 39-in. RC at 0.7 – 3.9%	25,300
B-1	45 – 50	1,680 ft of 27-in. RC at 5.6 – 10.5%	32,500
C-1	100	860 ft of 42-in. RC at 1.0 – 20%	45,300
C-2	55 – 100	1,170 ft of 33-in. RC at 1.2 – 18%	33,400
C-3	50 – 55	1,280 ft of 24-in. RC at 7.5 – 17%	20,300
C-4	28 – 30	1,260 ft of 24-in. RC at 2.6 – 5.1%	21,700
D-1	40 – 45	520 ft of 27-in. RC at 1.6 – 5.0%	10,600
D-2	35	710 ft of 21-in. RC at 6.2 – 15%	11,000
–	–	Connections to existing trunk to be utilized as storm drain	6,000
Subtotal, trunk storm drains			280,300
Local storm drains			
–	–	37,600 ft of 8-in.	226,700
–	–	11,800 ft of 10-in.	84,800
–	–	17,300 ft of 12-in.	170,100
–	–	19,300 ft of 15-in.	224,100
–	–	19,700 ft of 18-in.	264,600
–	–	6,000 ft of 21-in.	98,900
–	–	6,900 ft of 24-in.	125,500
–	–	240 ft of 27-in.	4,600
–	–	340 ft of 30-in.	7,900
–	–	227 intersection crossings, includes catch basin reconnections	80,900
–	–	3,825 new house connections	1,147,500
Subtotal, local storm drains			2,435,600
Total contract cost, complete separation			2,796,600
Engineering and contingencies, 25 per cent			699,200
Total construction cost, complete separation			3,495,800

a. Partial separation provides for removal of all street drains from sanitary sewers and for continued discharge of roof leaders and foundation drains to sanitary sewers. See Fig. C-1 for facility location.
b. First flow is required relief capacity, second is total design flow.
c. Complete separation provides for removal of all storm drainage, including roof leaders and foundation drains, from sanitary sewers.
d. Routes approximately same as above.

Figure D-2

Separation Plan - East Central Seattle

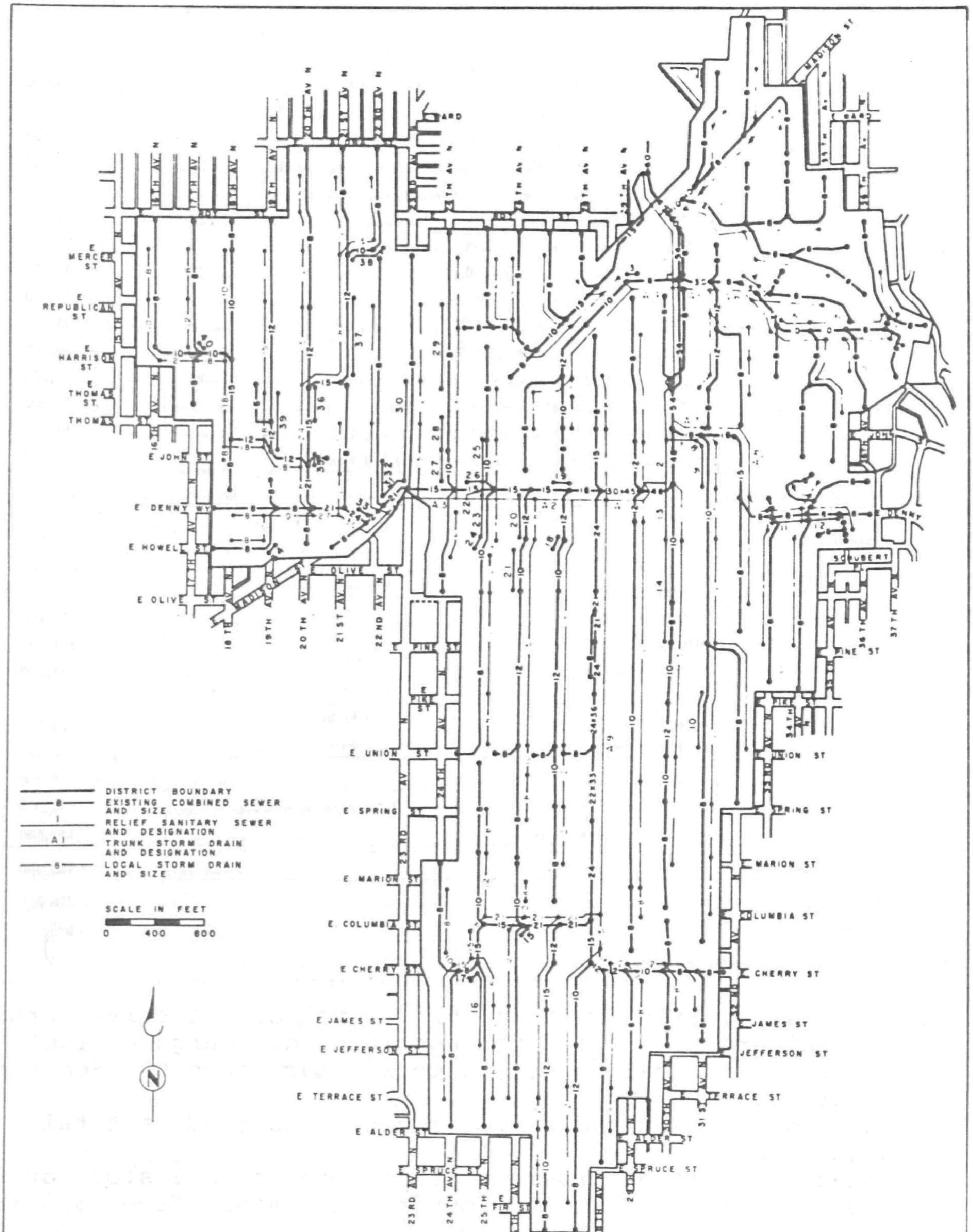


Table D-2

Estimated Construction Costs - East Central Seattle

Number	Design flow, cfs	Description	Construction cost, dollars
Partial separation[a]			
Relief sanitary sewers			
1	64 – 65	2,120 ft of 39-in. RC at 0.50 – 0.70%, to replace existing 54 – 60-in. which is to be used as storm drain	119,000
2	44 – 49	880 ft of 30-in. RC at 1.4 – 2.3%, to replace existing 48-in. which is to be used as storm drain, includes 880 ft of 8-in. lateral parallel to trunk to avoid making house connections to trunk	31,300
3	1.2, 2.7[b]	330 ft of 8-in. conc at 1.4%	2,000
4	1.7, 9.0[b]	210 ft of 10-in. conc at 1.3%	1,500
5	2.4, 7.0[b]	310 ft of 8-in. conc at 4.4 – 8.1%	1,900
6	0.4 – 1.0, 2.0 – 4.0[b]	720 ft of 8-in. conc at 1.0 – 4.0%	4,300
7	3.0, 13[b]	210 ft of 12-in. RC at 0.8%	3,900
8	5.3, 7.4[b]	60 ft of 15-in. RC at 0.9%	1,300
9	2.7, 6.0[b]	470 ft of 10-in. conc at 2.4%	6,200
10	0.7, 2.5[b]	320 ft of 8-in. conc at 2.1 – 3.3%	1,900
11	1.1, 4.0 – 5.3[b]	510 ft of 8-in. conc at 5.4 – 11.8%	3,100
12	2.8, 4.0[b]	270 ft of 12-in. RC at 1.0%	2,900
13	1.3, 3.4[b]	470 ft of 10-in. conc at 0.9%	6,200
14	0.7 – 1.3, 2.7 – 2.9[b]	850 ft of 8-in. conc at 1.0 – 1.4%	5,100
15	0.4, 2.0[b]	60 ft of 8-in. conc at 1.6%	400
16	0.3 – 0.6, 1.0 – 1.5[b]	690 ft of 8-in. conc at 0.4 – 1.1%	4,100
17	2.4, 3.7[b]	60 ft of 10-in. conc at 1.1%	400
18	2.4, 3.9[b]	80 ft of 12-in. conc at 0.4%	900
19	3.6, 28[b]	80 ft of 8-in. conc at 11.6%	500
20	1.1, 3.1[b]	390 ft of 10-in. conc at 0.30%	2,800
21	0.8, 2.6[b]	350 ft of 8-in. conc at 0.70%	2,100
22	0.4, 2.4[b]	60 ft of 8-in. conc at 0.80%	400
23	1.0, 2.2[b]	390 ft of 10-in. conc at 0.30%	2,800
24	0.4, 2.1[b]	90 ft of 8-in. conc at 0.60%	500
25	0.5 – 0.7, 1.7 – 2.0[b]	450 ft of 8-in. conc at 0.60 – 1.45%	2,700
26	3.5, 22[b]	100 ft of 8-in. conc at 7.7%	600
27	0.6, 2.2[b]	330 ft of 8-in. conc at 0.5%	2,300
28	1.2, 2.1[b]	230 ft of 10-in. conc at 0.6%	1,900
29	0.3 – 0.8, 1.0 – 1.6[b]	640 ft of 8-in. conc at 0.3 – 0.4%	4,500
30	0.6 – 0.8, 1.5 – 2.3[b]	890 ft of 8-in. conc at 0.8 – 1.5%	6,200
31	2.7, 18[b]	410 ft of 12-in. RC at 0.9%	5,000
32	0.4, 2.0[b]	230 ft of 8-in. conc at 1.9%	1,400

Table D-2 (cont'd.)

Number	Design flow, cfs	Description	Construction cost, dollars
33	11, 17[b]	170 ft of 30-in. RC at 0.06%, includes 170 ft of 8-in. lateral parallel to trunk to avoid making house connections to trunk	5,100
34	0.7, 1.1[b]	50 ft of 10-in. conc at 0.11%	400
35	6.9, 8.6[b]	60 ft of 27-in. RC at 0.07%	1,300
36	4.2, 8.6[b]	330 ft of 15-in. RC at 0.45%	4,600
37	1.2 – 1.6, 4.7 – 5.2[b]	660 ft of 8-in. conc at 1.2 – 1.6%	4,000
38	0.8, 2.0[b]	310 ft of 8-in. conc at 0.5 – 0.7%	1,900
39	1.7, 2.1[b]	600 ft of 12-in. RC at 0.25%	7,300
40	0.7, 1.7[b]	50 ft of 8-in. conc at 0.7%	300
–	–	Reconnect 132 house connections	6,500
–	–	Reconnect 89 manholes	8,900
Subtotal, relief sanitary sewers			270,400
Trunk storm drains			
A-1	100	320 ft of 36-in. RC at 2.2%	6,900
A-2	59 – 66	600 ft of 30-in. RC at 8.8 – 16.7%	10,500
A-3	42 – 53	1,020 ft of 30-in. RC at 7.7 – 16.7%	17,800
A-4	11 – 16	560 ft of 15-in. RC at 2.9 – 6.7%	5,700
A-5	22	250 ft of 24-in. RC at 0.80%	4,100
A-6	17	420 ft of 21-in. RC at 1.3 – 1.4%	5,700
A-7	26	270 ft of 27-in. RC at 0.8 – 5.8%	4,900
A-8	15	890 ft of 24-in. RC at 0.6 – 15.3%	13,000
A-9	34 – 37	3,600 ft of 24-in. RC at 2.3 – 10.0%	59,400
–	–	Connections to existing trunk to be utilized as storm drain	1,500
Subtotal, trunk storm drains			129,500
Local storm drains			
–	–	22,000 ft of 8-in.	102,100
–	–	19,000 ft of 10-in.	112,700
–	–	13,000 ft of 12-in.	106,300
–	–	17,000 ft of 15-in.	169,900
–	–	8,000 ft of 18-in.	91,300
–	–	1,000 ft of 21-in.	12,800
–	–	800 ft of 24-in.	13,100
–	–	700 ft of 27-in.	12,000
–	–	900 ft of 30-in.	17,400
–	–	212 intersection crossings, includes catch basin reconnections	74,700
Subtotal, local storm drains			712,300
Total contract cost, partial separation			1,112,200
Engineering and contingencies, 25 per cent			278,000
Total construction cost, partial separation			1,390,200

Table D-2 (cont'd.)

Number	Design flow, cfs	Description	Construction cost, dollars
Complete separation[c]			
Relief sanitary sewers			
–	3.5 – 4.5	1,940 ft of 15-in. at 0.48 – 0.70%, to replace existing 54 – 60-in. which is to be used as storm drain	62,300
Trunk storm drains			
–	180 – 210	490 ft of 54-in. RC at 0.8 – 1.45%	35,500
–	179	350 ft of 51-in. RC at 0.8%	23,400
A-1	163	320 ft of 42-in. RC at 2.2%	13,000
A-2, A-3	62 – 100	1,620 ft of 30-in. RC at 7.7 – 16.7%	32,200
A-4	19 – 28	560 ft of 18-in. RC at 2.9 – 6.7%	8,300
A-5, A-6	32	460 ft of 30-in. RC at 0.8 – 1.3%	10,500
A-6	26	210 ft of 24-in. RC at 1.4%	3,300
A-7	44	270 ft of 33-in. RC at 0.8 – 5.8%	6,700
A-8	22	890 ft of 24-in. RC at 0.6 – 15.3%	14,100
A-9	54 – 58	3,600 ft of 30-in. RC at 2.3 – 10.0%	100,300
–	–	Connections to existing trunk which is to be utilized as storm drain	1,500
Subtotal, trunk storm drains			248,800
Local storm drains			
–	–	34,100 ft of 8-in.	182,400
–	–	15,600 ft of 10-in.	97,300
–	–	15,600 ft of 12-in.	139,600
–	–	19,600 ft of 15-in.	210,400
–	–	10,100 ft of 18-in.	126,700
–	–	4,200 ft of 21-in.	57,000
–	–	1,600 ft of 24-in.	24,600
–	–	620 ft of 27-in.	11,000
–	–	1,000 ft of 30-in.	19,500
–	–	600 ft of 33-in.	13,300
–	–	170 ft of 48-in.	6,000
–	–	212 intersection crossings, includes catch basin reconnections	74,700
–	–	2,930 new house connections	879,000
Subtotal, local storm drains			1,841,500
Total contract cost, complete separation			2,152,600
Engineering and contingencies, 25 per cent			538,200
Total construction cost, complete separation			2,690,800

a. Partial separation provides for removal of all street drains from sanitary sewers and for continued discharge of roof leaders and foundation drains to sanitary sewers. See Fig. C-1 for facility location.
b. First flow is required relief capacity, second is total design flow.
c. Complete separation provides for removal of all storm drainage, including roof leaders and foundation drains, from sanitary sewers.
d. Routes approximately same as above.

Appendix E

CATAD Station Information

Table E-1

REGULATOR STATIONS

Station Name[a]	Facility No.	Segment Location	Computer Reference	Telemetry Circuit	Floor Space Square Feet	Construction Contract Cost-dollars	Yr. Compl.
Brandon (3)	220	S. Elliott Bay	10	2	180	68,200[b]	1964
Chelan	420	W. Duwamish	5	1	140	70,600	1967
Connecticut (2)	560	N. Elliott Bay	16	6	410	191,000	1971
Denny-Lk. Union[c]	620	N. Elliott Bay	19	6	390	240,000	1969
Denny-Local[c]	600	N. Elliott Bay	18	6	390	240,000	1969
Dexter Avenue	800	North Trunk	21	4	1530	454,000	1971
Eighth Avenue So.	470	W. Duwamish	1	1	170	63,700	1967
Hanford #1	500	Hanford-Elliott	13	6	190	110,000	1968
Hanford #2 (2)	530	N. Elliott Bay	14	6	480	343,000	1971
Harbor	400	W. Duwamish	4	1	200	75,400	1967
King Street	580	N. Elliott Bay	17	6	220	114,000	1971
Lk. City Tunnel(2)	710	Lake City	25	4	780	137,400	1969
Lander	540	N.Elliott Bay	15	6	800	305,000	1971
Michigan (3)	240	S. Elliott Bay	9	2	220	71,100[b]	1964
Norfolk	260	S. Valley	7	N/A	215	63,300[b]	1964
W. Michigan	450	W. Duwamish	3	1	130	56,700	1967

a. Numbers in parenthesis refer to no. of units, if station components are at multiple locations

b. Cost does not include facilities from 1935 construction, stations to be remodeled 1971-72.

c. Both stations at one physical site, cost and floor space allocated evenly.

Table E-1 (cont'd.)

REGULATOR STATIONS

Station Name	Connecting Sewer Diameter-Inches Trunk	Outfall	Interceptor	Transfer	Gate Size-Inches[c] Regulator	Outfall	Bypass	Drive Mechanism
Brandon	40x66[a]	50x78[a]	60	12	20x20	48x48	N/A	Motor
Chelan	54	54	42	36	36d	54x54	30x54[b]	Motor
Connecticut	72	72	96	36	36x36	84x60	72d	Hydraulic
Denny-Lake Union	60	60	102	21	21d	48x48	24x184[b]	Motor
Denny-Local	42	42	102	18	18x18	24x24	24x48[b]	Motor
Dexter Avenue	84	48	48	N/A	84x84	48x360[b]	84x66	Hydraulic
Eighth Avenue S.	48	36	36	24	24x24	36x36	28x36[b]	Motor
Hanford #1	150x100[a]	120	N/A	N/A	N/A	96x84	40x96[b]	Hydraulic
Hanford #2	150x100[a]	150x100[a]	96	48	48x48	144x96	96x84	Motor
Harbor	36	54	21	N/A	24x24	54x54	48x84[b]	Motor
King Street	48	48	96	30	30x24	60x36	24x120[b]	Motor
Lk. City Tunnel	96	N/A	108	N/A	96x96	N/A	N/A	Hydraulic
Lander	96	96	96	36	36x36	84x60	96x84	Hydraulic
Michigan	72x102[a]	72x102[a]	60	24	20x24	96x60	N/A	Motor
Norfolk	84	84	42	42	60x24	54x48	N/A	Motor
W. Michigan	24	24	42	10	10d	24d	24d[b]	Motor

a. Horseshoe shaped sewer cross-section

b. Dimension of opening - no gate

c. Gates are actually all rectangular. Size refers to opening behind gate which is the critical dimension for computing flows.

Table E-2

PUMPING STATIONS

Station Name	Facility No.	Segment Location	Computer Reference	Telemetry Circuit	Floor Space Square Feet	Construction Cost-dollars	Contract Yr. Compl.
Bellevue	1160	East Side S.	30	5	1020	160,000	1965
Belvoir Place	100	Green Lake	23	3	1500	374,000[a]	1971
Duwamish	200	S. Elliott Bay	11	2	4900	1,134,000	1969
E. Marginal	250	S. Elliott Bay	8	2	1790	192,100	1964
E. Pine	130	Green Lake	22	N/A	700[d]	62,000[b]	1932
Heathfield	1130	East Side S.	34	5	400	163,000	1965
Henderson	150	S. Valley	6	N/A	1000[d]	64,000[b]	1934
Interbay	650	N. Elliott Bay	20	6	9000	1,486,100	1967
Juanita Heights	1020	East Side N.	36	4	1480	259,000	1969
Kenmore	740	Lake City	27	4	500	207,500	1966
Kirkland	1090	East Side N.	37	5	1420	167,800	1966
Matthews Park	720	Lake City	26	4	20,000	3,493,000	1967
N. Mercer Island	1210	East Side S.	32	5	2700	712,900	1970
Rainier Avenue	140	Hanford-Elliott	12	N/A	1100	64,200[b]	1932
Renton S.T.P.	1230	East Side S.	29	5	30,000	3,500,000[c]	1965
S. Mercer Island	1220	East Side S.	33	5	940	179,800	1965
Sweyolocken	1150	East Side S.	31	5	1490	216,200	1965
Thirtieth Ave.N.E.	110	Green Lake	24	3	2100	385,000[a]	1971
W. Marginal Way	440	W. Duwamish	2	1	2080	262,000	1967
Wilburton	1140	East Side S.	35	4	940	154,900	1965
West Point S.T.P.	660	N. Elliott Bay	28	3	35,800	4,000,000[c]	1966

a. Cost includes estimated value of facilities constructed in 1940's.
b. Estimated cost plus value of new pumps not yet installed, stations to be remodeled 1971-73.
c. Estimated value of pumping facilities within sewage treatment plant.
d. Estimated floor space, drawings not available.

Table E-2 (cont'd.)

PUMPING STATIONS

Station Name	No. Pumps Installed Initial	Ultimate	Total Pumping Capacity - MGD Initial	Ultimate	Rated Pump Head, Feet	Bypass Dia.-Inches
Bellevue	3	3	13.8	13.8	90.0	24
Belvoir Place	3	3	15.0	15.0	23.0	36
Duwamish	3	3	150.0	150.0	17.5	2 @ 36
E. Marginal	2	3	20.0	44.0	16.4	36
E. Pine	2[a]	-	4.3	-	90.0	24
Heathfield	2[a]	-	6.0	-	180.0	8
Henderson	2[a]	-	7.2	-	19.0[b]	60
Interbay	3	3	180.0	180.0	39.0	72
Juanita Heights	3	4	11.0	16.0	122.0	N/A
Kenmore	3[a]	-	12.0	-	32.0	N/A
Kirkland	3	3	12.0	12.0	187.0	48
Matthews Park	3	6	93.0	186.0	77.0	5 @ 24x24
N. Mercer Island	3	4	7.8	10.5	149.0	24
Rainier Avenue	3[a]	-	11.8	-	30.0[b]	N/A
Renton S.T.P.	3	6	192.0	513.0	42.0	96
S. Mercer Island	3	3	18.0	18.0	63.3	24
Sweyolocken	3	4	20.4	27.2	75.0	30
Thirtieth Ave. N.E.	3	3	18.0	18.0	42.0	36
W. Marginal Way	3	3	24.3	24.3	20.0	N/A
Wilburton	2	3	8.0	12.0	110.0	24
West Point S.T.P.	4	4	432.0	432.0	17.7	2 @ 84

a. No ultimate data included, station due for remodeling

b. Estimated head, plans not available

Appendix F

List of Model Subroutines

The subroutines at present under development have the following functions to perform: storage, flow, regulation, and checking. Under storage functions the following subroutines are included: STRG1, CLOOO, FLOWP and FLOWR. Flow determination utilizes subroutines AREAH, AREA1, OTFL1, OTFL3, OTFL4 and INTER. Regulation involves subroutines PUMP1, OTFL2, FLOS1, PUMP2,STPT1 and REGL1. Checking subroutines include SBMR and CHECK.

A brief description of the functions of the various subroutines and the current status of the programs is shown below:

(1) Subroutine: STRG1

Function: Using the input of regulator (or pump) discharge and sewage level upstream of the regulator (or pump wet-well) this subroutine gives values of storage in the sewer and flow entering the sewer.

(2) Subroutine: AREAH

Function: This program calculates the area and wetted perimeter of horseshoe sections.

(3) Subroutine: AREA1

Function: This subroutine calculates the areas and wetted perimters of circular sewer sections.

(4) Subroutine: PUMPQ

Function: This subroutine provides a common means of calculating either pump speed or pump discharge, given a known static head and one of the other variables.

(5) Subroutine: CALDX

Function: This subroutine computes the length of sewer for which the sewage depth drops 0.2 feet.

(6) Subroutine: OTFL1

Function: This subroutine computes the free discharge from a rectangular gate opening.

(7) Subroutine: FLOWP

Function: This subroutine calculates flows and storage for a pump station.

(8) Subroutine: FLOWR

Function: This subroutine computes flow and storage for a regulator station.

(9) Subroutine: OTFL2

Function: This subroutine, using input of discharge and upstream sewage level, gives the gate opening appropriate for delivery of the required discharge.

(10) Subroutine: OTFL3

Function: This subroutine gives the outfall discharge including that from an overflow weir if used.

(11) Subroutine: OTFL4

Function: This subroutine gives an estimation of submerged flow through the regulator.

(12) Subroutine: INTER

Function: This subroutine computes the interceptor flow downstream of the regulator.

(13) Subroutine: SBMRG

Function: This subroutine furnishes a check of regulator submergence.

(14) Subroutine: FLOS1

Function: For regulator station without interceptors. This subroutine computes trunk inflow, storage, overflow, downstream flow and gate positions.

(15) Subroutine: FLOS2 (For Hanford No. 1 Regulator Station)

Function: This subroutine gives trunk inflow, level upstream, overflow, diversion flow and gate positions.

(16) Subroutine: CHECK

Function: This subroutine combines flows from several upstream tributary stations and compares their total flow (plus an allowance for interflow) with the observed flow at a downstream station. It alarms on an excessive discrepancy.

(17) Subroutine: PUMP2

Function: From the pump discharge pressure in the force mains this subroutine calculates the pump station discharge.

(18) Subroutine: REGL1

Function: This subroutine operates to control regulator or pump stations by a rule curve.

Appendix G

Flow Calculation Programs

1. Manning's Formula Program

Metro has installed Leupold & Stevens depth recording instruments in four sewers. The recorders plot depth of sewage vs. time on gridded graph paper. The purpose of this program is to calculate the volume of sewage that flows through the station during an overflow or a storm.

Manning's formula was used in the calculations. Rather than go into a detailed description of the formula (See King's Handbook of Hydraulics) suffice it to say that the slope, radius, and depth of flow are all that is needed to calculate the flow. The volume is, of course, the flow in a unit of time multiplied by the duration.

Since many of the overflows are recorded as spikes by the instrument, the depth and duration figures are often subjective. Also, Manning's formula is not meant to be used to calculate surge but rather steady state flows. Even with these limitations, however, the volumes calculated correlate well with recorded rainfall.

The program read the data from cards with the format shown on the sample data sheet of Table F-1. The stations numbers are:

4901	Sand Point	4903	Henderson
4902	Windemere	4904	Cooper

The date is a six digit number: Month, Day, Year: e.g. 032170 for March 21, 1970.

The time is expressed as a two digit military time number referring to the hour that the overflow started, for example: 13(00) means the flow started at 1:00 PM.

Duration is the length of time in hours that the overflow occurred. The decimal point must be punched.

The depth is the number of scale divisions in the vertical direction during an overflow. Again, punch the decimal point.

Referring to the chart for Sand Point (4901) on March 21st, the data card should read:

4901	032170	10	00.5	04.7
Duration	Date	Time	Duration	Depth

For the more complicated overflow occurring on March 23 beginning at 1600, two cards could be used:

```
4901 032370 16 1.75 07.5
4901 032370 16 5.00 15.0
```

Note that the time is the same on both cards. This indicates that only "one" overflow occurred. Also note the subjective nature of the parameters of depth and duration.

A copy of the program listing follows a sample of input and output.

Table G-1

Manning's Program-Input Data

STATION 1-4	MONTH 5-6	DAY 7-8	YEAR 9-10	TIME 11-12	DUR 13-16	DEPTH 17-20
4901	09	24	69	08	02.0	10.0
4901	09	25	69	14	02.0	05.0
4901	09	27	69	12	06.0	05.0
4901	09	29	69	04	06.0	04.0
4901	09	30	69	08	06.0	06.0
4901	10	07	69	14	06.0	05.0
4901	10	08	69	16	02.0	03.0
4901	10	09	69	08	02.0	03.0
4901	10	09	69	18	04.0	04.0
4901	10	27	69	01	12.0	03.0
4901	10	28	69	23	08.0	04.0
4901	11	02	69	23	05.0	04.0
4901	11	03	69	20	00.5	03.0
4901	11	04	69	03	48.0	05.0
4901	11	06	69	16	02.0	03.0
4901	11	15	69	04	20.0	05.0
4901	11	20	69	05	19.0	05.0
4901	11	23	69	02	24.0	05.0
4901	11	27	69	12	00.5	05.0
4901	12	03	69	01	10.0	04.0
4901	12	04	69	07	03.0	06.0
4901	12	08	69	04	12.0	04.0
4901	12	09	69	14	06.0	01.5
4901	12	10	69	14	04.0	01.5
4901	12	10	69	21	36.0	06.0
4901	12	12	69	08	36.0	05.0
4901	12	16	69	11	12.0	02.0
4901	12	17	69	18	08.0	03.0
4901	12	18	69	05	14.0	02.0
4901	12	19	69	10	10.0	03.0
4901	12	20	69	14	02.0	01.0
4901	12	20	69	23	24.0	03.0
4901	12	22	36	08	29.0	05.0
4901	12	23	69	14	08.0	03.0
4901	12	25	69	20	18.0	03.0
4901	01	08	70	12	12.0	04.0
4901	01	09	70	04	06.0	03.0
4901	01	09	70	09	16.0	05.0
4901	01	13	70	07	72.0	05.0
4901	01	17	70	03	21.0	04.0
4901	01	18	70	01	20.0	03.0
4901	01	18	70	21	26.0	05.0
4901	01	20	70	02	10.0	03.0
4901	01	21	70	01	14.0	04.0
4901	01	22	70	10	24.0	05.0
4901	01	24	70	05	48.0	04.0
4901	01	26	70	08	40.0	07.0
4901	01	31	70	04	18.0	03.0

```
      FUNCTION QQQQ(RK,R,BB)
      PI=3.14159
      E=BB/(2.0*R)
      THETA=ATAN2(2.0*SQRT(E-E*E),2.0*E-1.0)
      AREA=R*R*(PI-THETA+.5*SIN(2.0*THETA))
      PERIM=2.0*R*(PI-THETA)
      QQQQ=RK*AREA**1.6667*PERIM**(-.6667)
      RETURN
      END
0016 B  QQQQ        0003 D  RK          0004 D  R           0005 D  BB
0006 B  PI          EXTERN  M:PUSH      EXTERN  L:33L1      EXTERN  L:33R3
000A B  E           EXTERN  L:33L2      EXTERN  L:33M1      0008 B  TMP:00
EXTERN  L:33D3      0010 B  THETA       EXTERN  ATAN2       EXTERN  SQRT
EXTERN  L:33L3      EXTERN  L:33S1      EXTERN  L:33M3      EXTERN  L:33S3
EXTERN  L:3N        000C B  TMP:01      000E B  TMP:02      0012 B  AREA
EXTERN  SIN         EXTERN  L:33A3      EXTERN  L:33M2      0014 B  PERIM
EXTERN  L:33E3      EXTERN  L:33E1      EXTERN  M:POP       EXTERN  L:9P
* PROGRAM SIZE= 009B *
* DATA SIZE  =  0018 *
* COMMON SIZE = 0000 *
```

```
      INTEGER CR,LP
      INTEGER  NDATE(3),IDATE(3)
      REAL   RK(4),R(4)
      DATA CR,LP/105,108/
      DATA RK,R/8.0,30.7,40.5,12.9,2.,1.5,3.0,2.5/
      IPAGE=1
    1 WRITE(LP,2)IPAGE
    2 FØRMAT(1H142X,I2,////,
     1        43H  STATIØN  DATE    TIME DURATIØN      VØLUME/,
     1        25X,5HHØURS,5X,8HTHØU GAL//)
      IPAGE=IPAGE+1
      LINE=6
      READ(CR,5)NSTA,NDATE,NTIME,DUR,DEPTH
    5 FØRMAT(I4,4I2,2F4.0)
   10 TVØL=0.0
      TDUR=0.0
      ISTA=NSTA
      DØ 12 I=1,3
   12 IDATE(I)=NDATE(I)
      ITIME=NTIME
      I=ISTA-4900
      IF(I)28,28,14
   14 IF(I-4)15,15,28
   15 DEPTH=.05*DEPTH
      Q=QQQQ(RK(I),R(I),DEPTH)
      VØL=Q*DUR*26.9
      TVØL=TVØL+VØL
      TDUR=TDUR+DUR
      READ(CR,5)NSTA,NDATE,NTIME,DUR,DEPTH
      IF (ITIME-NTIME)18,16,18
   16 IF(NDATE(2)-IDATE(2))18,17,18
   17 IF(IDATE(3)-NDATE(3))18,15,18
   18 WRITE(LP,20)ISTA,IDATE,ITIME,TDUR,TVØL
   20 FØRMAT(4X,I4,1X,2(I2,1H-) ,I2,1X,I4,3X,F4.1,2X,F12.1,/)
      LINE=LINE+2
      IF(LINE-50)25,1,1
   25 IF(NSTA)30,30,10
   28 WRITE(LP,29)
   29 FØRMAT(15H1NØ SUCH STATIØN)
   30 WRITE(LP,31)
   31 FØRMAT(1H1)
      CALL EXIT
      END
0025 B  CR          0021 B  LP          0003 B  NDATE       0009    IDATE
000F B  RK          0017 B  R           001F B  IPAGE       EXTERN  M:RES
EXTERN  L:ØUT.      EXTERN  L:ARG       EXTERN  L:CBF       0023 B  LINE
EXTERN  L:INP       0027 B  NSTA        0029 B  NTIME       002B B  DUR
002D B  DEPTH       002F B  TVØL        EXTERN  L:33L1      EXTERN  L:33R3
0031 B  TDUR        0033 B  ISTA        0035 B  I           0037 B  TMP:00
0039 B  TMP:01      003B B  ITIME       EXTERN  L:33L3      EXTERN  L:33M1
003D B  Q           EXTERN  QQQQ        003F B  VØL         EXTERN  L:33M3
EXTERN  L:33A3      EXTERN  EXIT        EXTERN  L:ØP
* PRØGRAM SIZE= 017A *
```

```
 * DATA SIZE  =  0041 *
 * COMMON SIZE = 0000 *
  END

ET=000.23

 OLOAD
  $ROOT ,,GO
  END

ET=000.42

 KEG
```

Table G-2

Manning's Program-Output Data

STATION	DATE	TIME	DURATION HOURS	VOLUME THOU GAL
4901	9-24-69	8	2.0	180.1
4901	9-25-69	14	2.0	41.8
4901	9-27-69	12	6.0	125.3
4901	9-29-69	4	6.0	77.9
4901	9-30-69	8	6.0	184.6
4901	10- 7-69	14	6.0	125.3
4901	10- 8-69	16	2.0	14.0
4901	10- 9-69	8	2.0	14.0
4901	10- 9-69	18	4.0	51.9
4901	10-27-69	1	12.0	84.2
4901	10-28-69	23	8.0	103.9
4901	11- 2-69	23	5.0	64.9
4901	11- 3-69	20	.5	3.5
4901	11- 4-69	3	48.0	1002.8
4901	11- 6-69	16	2.0	14.0
4901	11-15-69	4	20.0	417.8
4901	11-20-69	5	19.0	396.9
4901	11-23-69	2	24.0	501.4
4901	11-27-69	12	.5	10.4
4901	12- 3-69	1	10.0	129.8
4901	12- 4-69	7	3.0	92.3
4901	12- 8-69	4	12.0	155.8

2. Sluice Gate Flow Program

Strip charts are installed in eight of Metro's regulator stations. On these charts are recorded the level of sewage in the trunk, the tide level and the outfall gate opening. The purpose of this program is to compute the volume of sewage that escapes during an overflow.

The outfall is treated as an orifice in these calculations. The tide level can become high enough so that the outfall becomes a submerged orifice; this is taken into account in computing the head. The flow through an orifice is given by the equation:

$$A = K \text{ x (Area) x } \quad \text{head}$$

The volume is, of course, the flow multiplied by the duration of the overflow.

The regulator stations and their numbers which have the recorders are:

	0013	Denny Local
	0014	Denny Lake Union
	0030	Harbor
	0031	Chelan
	0034	Brandon
	0036	Michigan
	0037	W. Michigan
and	0038	8th Avenue South

The outfall at W. Michigan is never influenced by the tide, hence, tide level is not recorded on its chart. The chart at Denny Local is scheduled to be installed in the summer of 1971 and no charts are available yet.

The programs read cards with the format shown on the sample data sheet of Table F-2. Time is a two digit military time referring to the time the overflow started. Trunk level, gate opening and tide level are all two digit numbers that correspond to the scale divisions on the strip charts. "Duration" must have the decimal point punched in the card.

If, during an overflow, the gate or trunk level changes, another card must be punched to reflect these changes. If the time the overflow started is not changed, the volume calculated will be the total volume of the overflow.

Internal to the program are many level and scale factors that are necessary for converting the strip chart readings to levels relative to the invert of the outfall. Factors are variable depending upon calibration but the accepted values are presented in Table F-3.

Typically, on the charts the tide level is red, the trunk level is blue and the outfall gate opening is green. The charts at Denny deviate from this scheme.

Table G-3

Chart Conversion Factors*

No.	Station Name	Tide Factor	Tide Corr.	Trunk Factor	Trunk Corr.	OG Factor
13	Denny Local	-	-1.8	-	.5	.04
14	Denny Lake Union	.15	.5	.17	.5	.05
20	King	.06	.5	.06	.5	.03
23	Connecticut	.12	.5	.12	.5	.05
25	Lander	.12	1.4	.12	.5	.05
26	Hanford #2	.12	-1.0	.12	.5	.08
30	Harbor	.06	- .75	.09	1.0	.045
31	Chelan	.09	2.25	.12	2.25	.045
34	Brandon	.15	-	.08	.5	.04
36	Michigan	.14	- .71	.08	.5	.05
37	W. Michigan	-	-	.05	.5	.02
38	8th Avenue	.1	.25	.1	2.05	.03

*Note: To compute differences in feet relative to invert:

$$D = (\text{factor}) \times (\text{Chart Reading}) + \text{Corr.}$$

Table G-4

Sluice Gate Program-Input Data

STATION 1-4	YEAR 5-6	MONTH 7-8	DAY 9-10	TIME 11-12	TRUNK 13-14	GATE 15-16	TIDE 17-18	DUR 19-21
0037	71	01	18	18	30	03	00	017
0037	71	02	12	20	42	00	00	.65
0037	71	02	14	08	35	08	00	013
0037	71	02	14	12	35	07	00	032
0037	71	02	14	19	34	22	00	016
0037	71	02	15	00	40	22	00	013
0037	71	02	15	03	32	17	00	029
0037	71	02	15	09	37	32	00	012
0037	71	02	15	12	41	13	00	028
0037	71	02	18	23	51	10	00	010
0037	71	02	24	05	52	25	00	009
0037	71	03	07	12	49	13	00	011
0037	71	03	10	13	37	22	00	.45
0037	71	03	10	13	36	12	00	014
0037	71	03	10	13	27	08	00	026
0037	71	03	10	13	32	12	00	018
0037	71	03	11	17	34	20	00	.70
0037	71	03	11	17	29	14	00	.75
0037	71	03	11	17	33	28	00	.75
0037	71	03	11	17	37	20	00	.75
0037	71	03	11	17	27	11	00	[illegible]
0037	71	03	11	17	30	09	00	032
0037	71	03	11	17	37	50	00	013
0037	71	03	11	17	37	14	00	015
0037	71	03	11	17	31	11	00	018
0037	71	03	22	05	27	03	00	[illegible]
0037	71	03	22	05	36	07	00	018
0037	71	03	23	03	34	07	00	013
0037	71	03	23	10	26	03	00	.75
0037	71	03	23	10	27	01	00	.80
0037	71	03	23	10	36	11	00	032
0037	71	03	23	10	32	22	00	016
0037	71	03	23	10	26	03	00	079
0037	71	03	26	03	31	21	00	.50
0037	71	03	26	03	29	03	00	040
0037	71	03	26	03	30	11	00	032
0037	71	03	26	03	31	04	00	062
0037	71	03	27	18	30	21	00	012
0037	71	03	29	01	32	07	00	011
0037	71	03	29	01	26	01	00	023
0037	71	03	30	22	26	18	00	[illegible]
0037	71	03	30	22	35	30	00	.55
0037	71	03	30	22	26	18	00	[illegible]
0037	71	03	30	22	30	02	00	[illegible]
0037	71	03	30	22	32	09	00	042
0037	71	03	30	22	35	28	00	023
0037	71	03	30	22	26	07	00	018
0037	71	03	30	22	28	11	00	019

```
      FUNCTION ASIN(X)
      PI2=1.570796326
      IF(X-1.)2,1,2
    1 ASIN=PI2
      RETURN
    2 IF(X+1.)4,3,4
    3 ASIN=-PI2
      RETURN
    4 ASIN=ATAN(X/SQRT(1.-X*X))
      RETURN
      END
0006 B  ASIN        0003 D  X          0004 R  PI2        EXTERN  M:PUSH
EXTERN  L:33L1      EXTERN  L:33R3     EXTERN  L:33L2     EXTERN  L:33S1
EXTERN  L:33L3      EXTERN  M:POP      EXTERN  L:33A2     EXTERN  L:3N
EXTERN  ATAN        EXTERN  SQRT       EXTERN  L:33M2     0008 B  TMP:00
000A B  TMP:01      EXTERN  L:33D3     000C B  TMP:02     EXTERN  L:9P
* PROGRAM SIZE= 0063 *
* DATA SIZE   =  000E *
* COMMON SIZE = 0000 *
```

```
      REAL WIDTH(12),GOFAC(12),TDFAC(12),TRFAC(12),TDCOR(12),TNCOR(12)
      REAL STANAM(4,12)
      INTEGER STAT,STA(12),DATE(3),XDATE(3),TIME,XTIME,CR,LP
      DATA STANAM/'    ',' DEN','NY L','OCAL','DENN','Y LA','KE U','NION',
     1'    ','    ','  HA','RBOR','    ','    ',' CH','ELAN','    ','    ',' BRA','NDON',
     2 '    ','    ','MICH','IGAN','    ','  8T','H A.','ENUE','   W','EST ',
     3 'MICH','ICAN','    ','    ','    ','KING','    ',' CON','NECT','ICUT','    ',
     4 '    ','  LA','NDER','    ','   H','ANFO','RD-2'/
      DATA CR,LP/105,108/
      DATA  STA/13,14,30,31,34,36,38,37,20,23,25,26/, PI2/1.5707963/
      DATA  WIDTH/2.00,4.00,4.50,4.50,4.00,6.00,3.00,2.,5.,7.,7.,12./,
     1 GOFAC /.04,.05,.045,.045,.04,.05,.03,.02,.03,.05,.05,.08/,
     2     TDFAC /0.,.15,0.06,0.09,0.15,0.14,00.1,00.0,.06,.12,.12,.12/,
     3     TRFAC /0.,.17,0.09,0.12,0.08,0.08,0.10,0.05,.06,.12,.12,.12/,
     4   TDCOR /-1.8,0.00,-.75,0.00,0.00,-.71,0.00,0.00,.5,.5,1.4,-1./,
     5     TNCOR /00.5,00.5,1.00,2.25,0.50,0.50,2.05,0.50,.5,.5,.5,.5/
      IPAGE=1
      READ(CR,5)STAT,DATE,TIME,TRLVL,GO,TDLVL,DUR
    5 FORMAT(I4,4I2,3F2.0,F3.1)
    1 WRITE(LP,2)IPAGE
    2 FORMAT(1H142X,I2,//  ,16X,
     1       43H  STATION  DATE    TIME DURATION     VOLUME,8X,4HFLOW,/,
     1       41X,5HHOURS,5X,8HTHOU GAL,9X,3HCFS,/ )
      IPAGE=IPAGE+1
      LINE=3
C USE DO LOOP INDEX AS KEY
C
C  1  DENNY LOCAL
C  2  DENNY LAKE UNION
C  3  HARBOR
C  4  CHELAN
C  5  BRANDON
C  6  MICHIGAN
C  7  8TH AVENUE
C  8  W. MICHIGAN
C
    7 DO 10 I=1,12
      IF (STAT-STA(I)) 10,11,10
   10 CONTINUE
      WRITE(LP,13)
   13 FORMAT(16H1NO SUCH STATION)
      GO TO 50
C SAVE INFORMATION ON CARD
   11 DO 12 K=1,3
   12 XDATE(K)=DATE(K)
      XTIME=TIME
C INITIALIZE PARAMETERS
      TVOL=0.0
      TDUR=0.0
C COMPUTE TIDE LEVEL,TRUNK LEVEL, AND GATE OPENING
   14 TDLVL=TDLVL*TDFAC (I)+TDCOR (I)
      TRLVL=TRLVL*TRFAC (I)+TNCOR (I)
      GO = GO*GOFAC (I)
```

```
C IF MICHIGAN THEN GO COMPUTE AREA FOR CIRCULAR ORFICE
      IF(I-8) 15,20,15
C RECTANGULAR ORFICES
   15 AREA=GO*WIDTH(I)
      GO TO 25
C CIRCULAR ORFICE AT W. MICHIGAN
   20 AREA=(GO-1.)*SQRT(GO*(2.-GO))+ASIN(GO-1.)+PI2
C COMPUTE EFFECTIVE HEAD
   25 IF(TDLVL-.5*GO) 27,27,28
C EXPOSED ORFICE
   27 HEAD=TRLVL-.5*GO
      GO TO 30
C SUBMERGED ORFICE
   28 HEAD=TRLVL-TDLVL
C COMPUTE FLOW (CFS)
   30 Q=4.81*AREA*SQRT(HEAD)
C COMPUTE VOLUME IN THOUSANDS OF GALLONS
      VOL=Q*DUR*26.9
      WRITE(LP,31)STA(I),XDATE,XTIME,DUR,VOL,Q
      LINE=LINE+1
   31 FORMAT (18X,I4,3X,2(I2,1H-),I2 ,1X,I4,3X,F4.1,2X,3F12.1,/)
C UPDATE TOTAL VOLUME AND DURATION
      TVOL=TVOL+VOL
      TDUR=TDUR+DUR
C READ ANOTHER DATE CARD
      READ(CR,5) STAT,DATE,TIME,TRLVL,GO,TDLVL,DUR
C IS IT A NEW OVERFLOW
      IF(TIME-XTIME)40,35,40
   35 IF(DATE(2)-XDATE(2)) 40,39,40
   39 IF(DATE(3)-XDATE(3))40,14,40
   40 WRITE(LP,41)(STANAM(J,I),J=1,4),STA(I),XDATE,XTIME,TDUR,TVOL
   41 FORMAT (2X,4A4,I4,3X,2(I2,1H-),I2,1X,I4,3X,F4.1,2X,F12.1,14X,
     1  5HTOTAL,/)
      LINE=LINE+2
      IF(LINE-45)44,1,1
   44 IF(STA(I)-STAT)45,11,45
C IF STATION IS BLANK -- EXIT
   45 IF(STAT)50,50,7
   50 WRITE(LP,51)
   51 FORMAT(1H1)
      CALL EXIT
      END
0003 B  WIDTH      001B B  GOFAC      0033 B  TDFAC      004B B  TRFAC
0063 B  TDCOR      007B B  TNCOR      0093 B  STANAM     011B B  STAT
00F3 B  STA        010B B  DATE       0111 B  XDATE      011D B  TIME
0133 B  XTIME      0119 B  CR         0127 B  LP         013D B  PI2
0117 B  IPAGE      EXTERN  M:RES      EXTERN  L:INP      011F B  TRLVL
0121 B  GO         0123 B  TDLVL      0125 B  DUR        EXTERN  L:ARG
EXTERN  L:COF      EXTERN  L:OUT      0129 B  LINE       012B B  I
012D B  TMP:00     012F B  K          0131 B  TMP:01     0135 B  TVOL
EXTERN  L:33L1     EXTERN  L:33R3     0137 B  TDUR       EXTERN  L:33L2
EXTERN  L:33M3     EXTERN  L:33A2     0139 B  AREA       EXTERN  SQRT
EXTERN  ASIN       EXTERN  L:33L3     EXTERN  L:33S1     EXTERN  L:33S3
0133 B  TMP:02     EXTERN  L:33A3     EXTERN  L:33M1     EXTERN  L:3N
```

```
013F B  HEAD          0141 B  Q              0143 B  V8L            0145 B  J
EXTERN  EXIT          EXTERN  L:0P
* PR0GRAM SIZE= 02AF *
* DATA SIZE  =  0147 *
* C0MM0N SIZE = 0000 *
 END

ET=090.52

0L0AD
 $R00T ,,30
 END

ET=090.63

XEQ
```

Table G-5

Sluice Gate Program-Output Data

	STATION	DATE	TIME	DURATION HOURS	VOLUME THOU GAL	FLOW CFS	
	36	70-10-22	23	1.0	206.8	7.7	
	36	70-10-22	23	7.0	3517.2	18.7	
MICHIGAN	36	70-10-22	23	8.0	3724.0		TOTAL
	36	70-11- 8	3	.7	458.3	22.7	
	36	70-11- 8	3	1.0	368.2	13.7	
	36	70-11- 8	3	.5	485.5	36.1	
MICHIGAN	36	70-11- 8	3	2.2	1312.0		TOTAL
	36	70-11-11	10	.8	485.3	22.6	
	36	70-11-11	10	.3	103.6	12.8	
MICHIGAN	36	70-11-11	10	1.1	588.9		TOTAL
	36	70-11-19	18	.8	170.7	7.9	
MICHIGAN	36	70-11-19	18	.8	170.7		TOTAL
	36	70-11-23	15	1.0	274.7	10.2	
	36	70-11-23	15	.3	92.3	11.4	
MICHIGAN	36	70-11-23	15	1.3	367.0		TOTAL
	36	70-11-24	9	.8	363.9	16.9	
MICHIGAN	36	70-11-24	9	.8	363.9		TOTAL
	36	70-12- 5	5	1.0	122.4	4.6	
	36	70-12- 5	5	.3	576.2	71.4	
	36	70-12- 5	5	1.0	5110.6	190.0	
	36	70-12- 5	5	1.0	8218.6	305.5	
	36	70-12- 5	5	1.0	8383.8	311.7	
	36	70-12- 5	5	1.0	1041.0	38.7	
	36	70-12- 5	5	.3	105.7	13.1	
MICHIGAN	36	70-12- 5	5	5.6	23558.2		TOTAL
	36	70-12-10	12	.6	280.0	17.3	
	36	70-12-10	12	.3	171.8	21.3	
MICHIGAN	36	70-12-10	12	.9	451.7		TOTAL
	36	70-12-30	7	2.5	1923.5	28.6	
MICHIGAN	36	70-12-30	7	2.5	1923.5		TOTAL
	36	71- 1-15	0	6.5	9587.7	54.8	

Appendix H

Chart Problem Examples

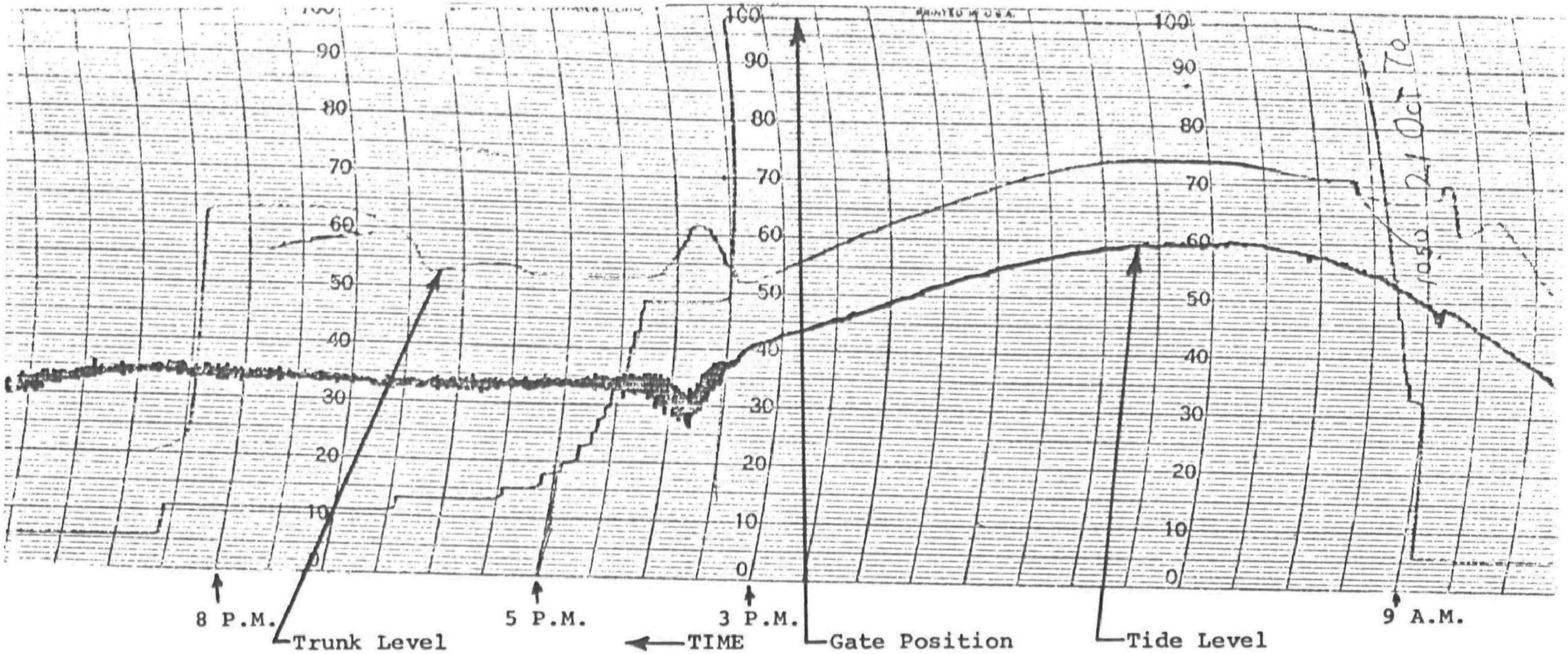


Figure H-1

<u>Denny Regulator</u>

Date: 10/21/70

Comment: Normal overflow. Outfall gate opened at 9 A.M. and remained open until about 8 P.M. Then the regulator gate (not shown) opened and the trunk level returned to normal. The tidal backwater effect is noticeable from 9 A.M. to about 3 P.M.

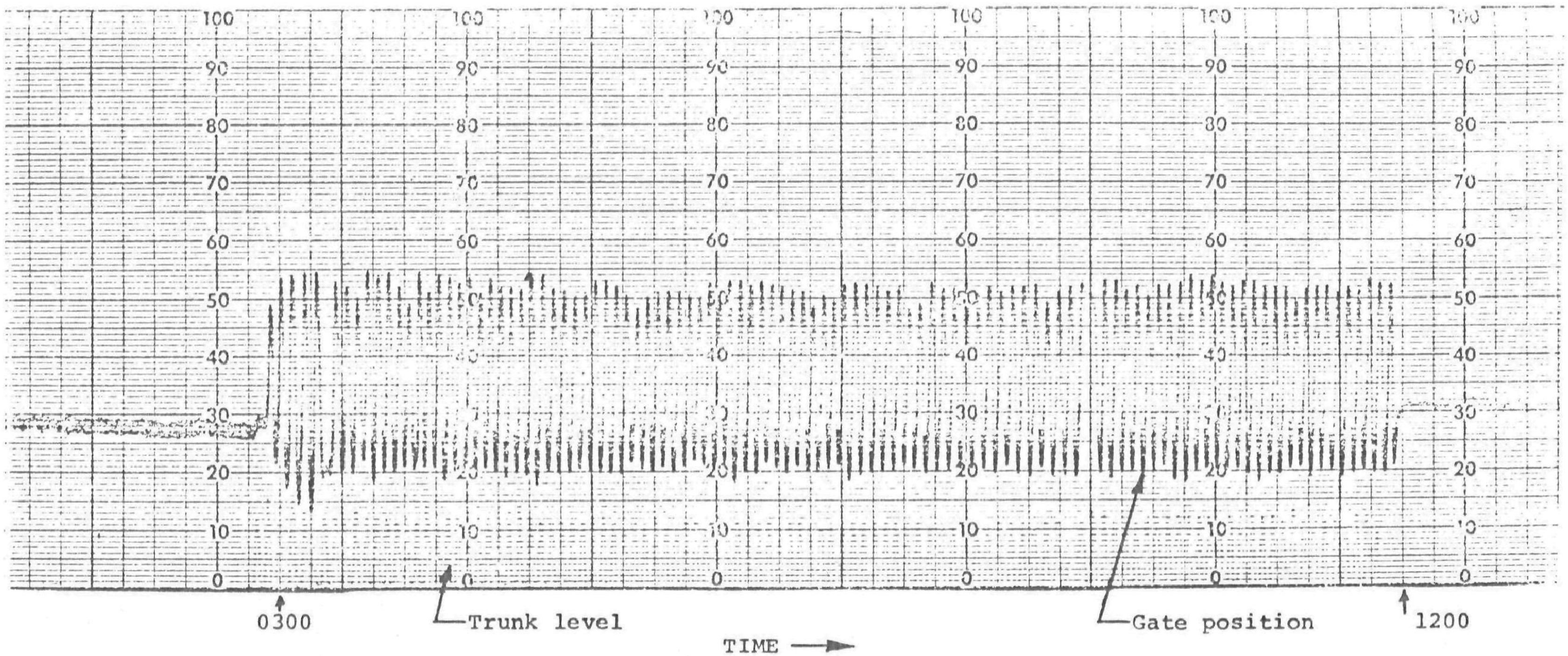


Figure H-2
<u>West Michigan Regulator</u>

Date: 01/17/71

Comment: Probably outfall gate controller malfunction which never repeated itself January 17, 1971.

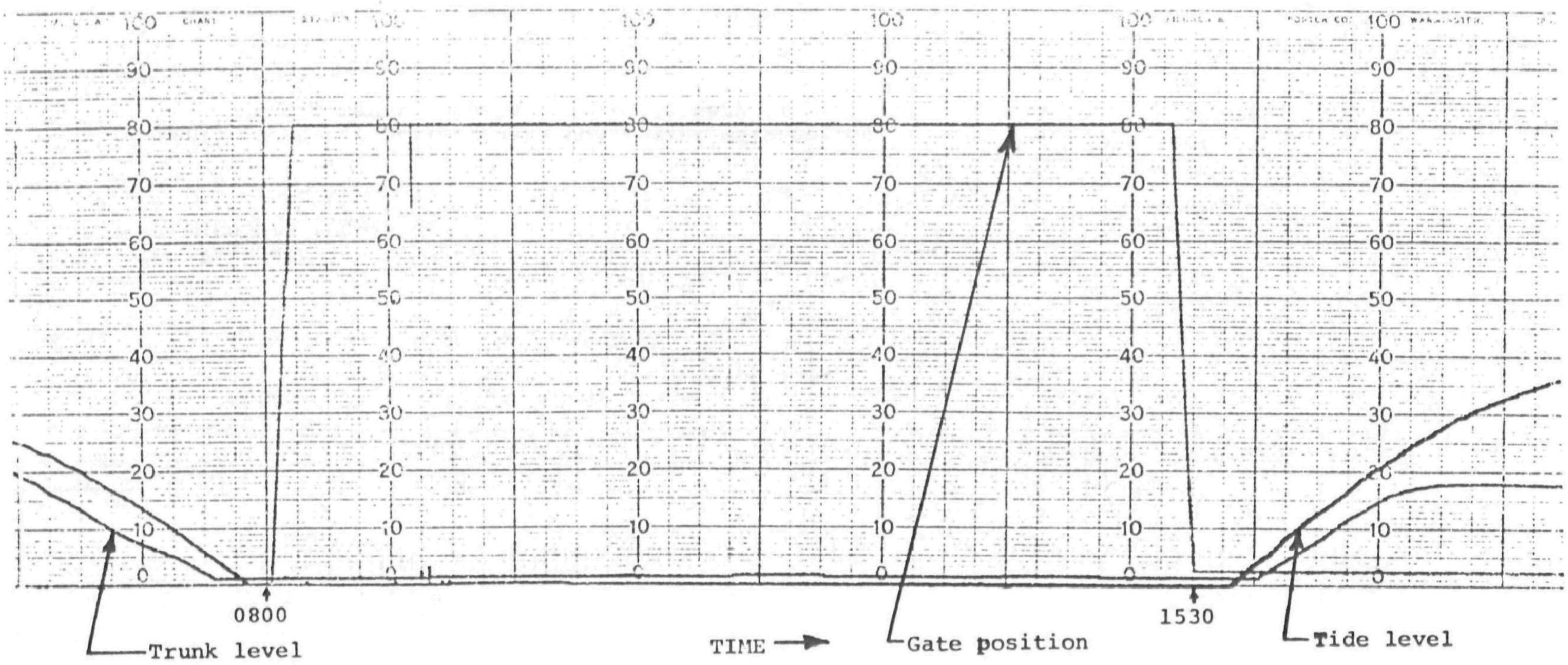


Figure H-3

<u>Michigan Regulator</u>

Date: 07/01/70

Comment: Emergency repair in July 1970.
Outfall gate was opened for eight hours
at a time to allow workmen to repair site.
Trunk flow stopped with sandbags.

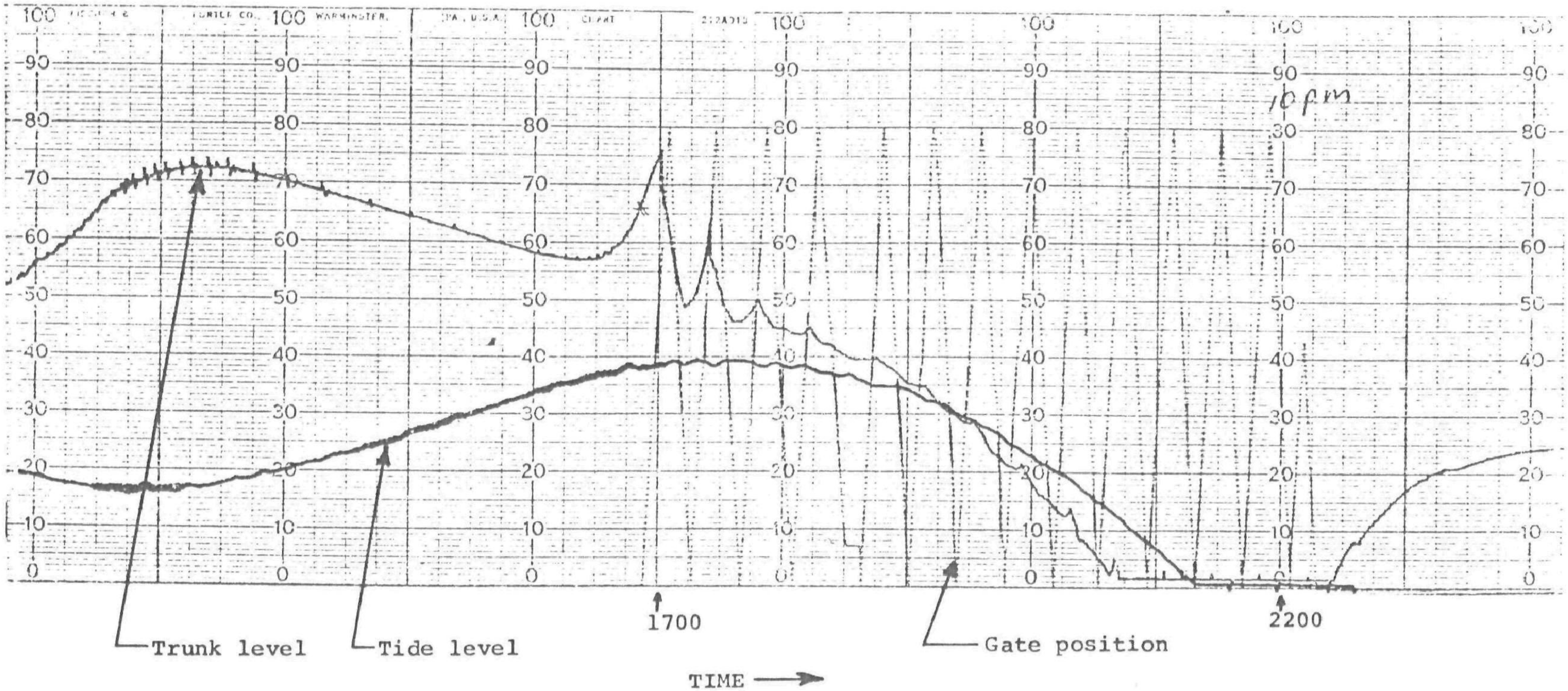


Figure H-4
Michigan Regulator

Date: 12/15/70

Comment: Probably an outfall gate controller malfunction that was never repeated. Regular checks indicate controller returned to normal operation.

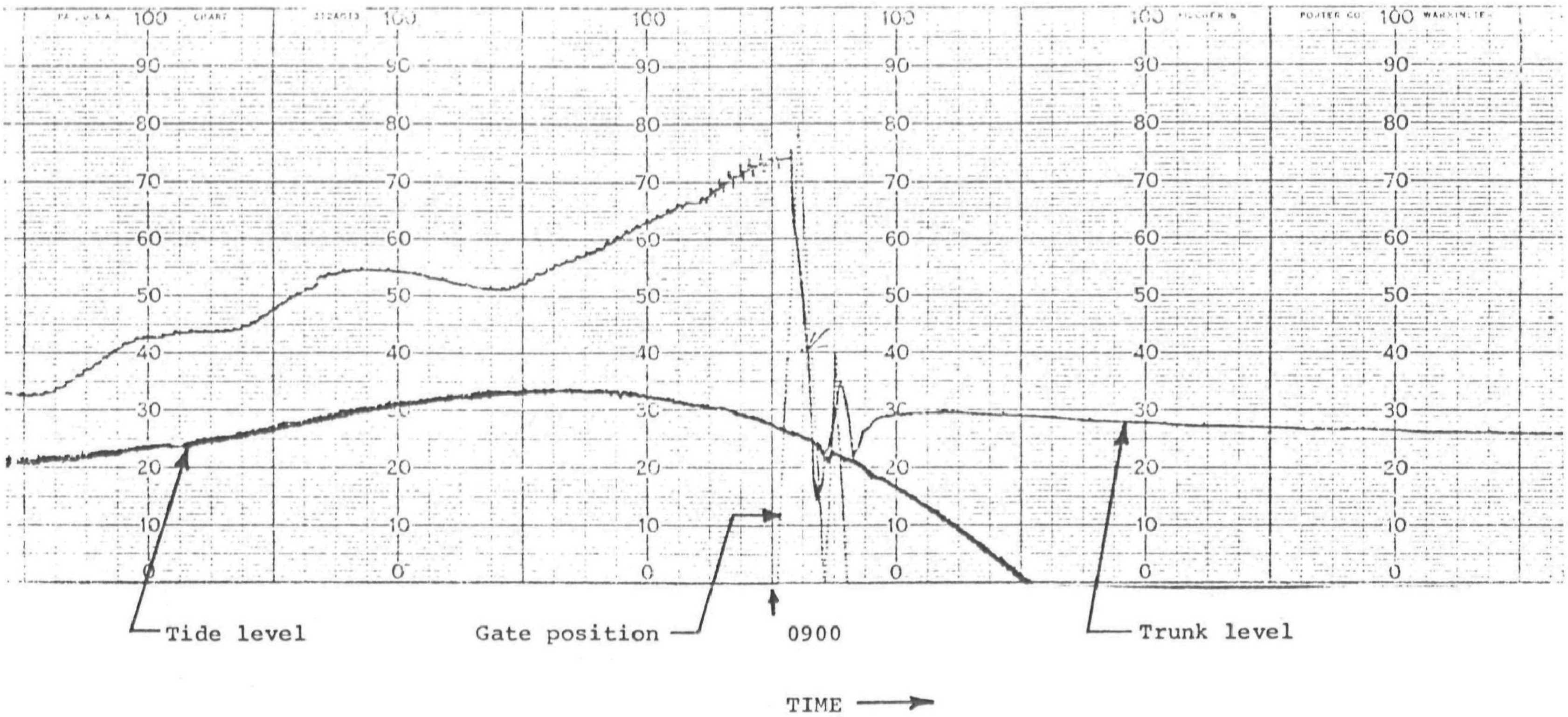


Figure H-5
Michigan Regulator

Date: 12/16/70

Comment: (continued from previous page)

Appendix I

<u>Overflow Water Quality Data</u>

Table I-1

Regulator Station Overflow Data
1970

Station 34 Brandon Street

Date	Rain Total Inches	Rain Max. Rate in./hr.	Sample Volume Liters	Overflow Volume gal. x 1000	Solids Sett. ml/l	Solids Susp. mg/l	Solids Vol. mg/l	BOD mg/l	COD mg/l	NH_3 mg N/l	NO_2 +NO_3 mg N/l	PO_4 mg P/l
1-13	1.59	.26	12	-	1.8	200	100	54	119	4.00	-	1.63
1-18	.63	.11	12	-	.7	162	52	-	100	1.00	.12	1.10
1-26	1.34	.17	12	-	.3	172	54	-	-	.60	.19	.50
2-15	1.08	.12	12	-	40.0	380	292	80	424	3.20	.05	2.30
3-6	1.75	.46	12	-	1.5	368	92	32	144	2.60	.15	1.60
3-12	.36	.13	8	-	1.0	32	8	21	120	2.90	.10	1.00
4-9	.84	.12	12	-	.8	148	76	21	184	3.00	.06	1.00
4-24	.23	.09	9	-	2.5	840	156	38	816	1.40	.01	1.90
4-27	.35	.21	12	-	1.5	144	36	49	104	1.60	.35	.70
4-29	.19	.07	3	-	.1	14	8	10	32	1.20	.25	.60
6-29	.14	.10	12	-	2.0	144	132	46	200	5.40	.07	2.90
9-3	.29	.10	9	-	1.0	76	34	39	-	2.70	.25	1.50
11-8	.78	.12	12	-	.3	50	-	24	51	2.30	.14	.45
12-30	.91	.24	3	-	.3	178	50	7	34	.60	.07	.45

Station 36 Michigan Street

Date	Rain Total Inches	Rain Max. Rate in./hr.	Sample Volume Liters	Overflow Volume gal. x 1000	Solids Sett. ml/l	Solids Susp. mg/l	Solids Vol. mg/l	BOD mg/l	COD mg/l	NH_3 mg N/l	NO_2 +NO_3 mg N/l	PO_4 mg P/l
1-13	1.59	.26	1	-	.1	3700	3520	600	-	2.80	-	5.63
1-18	.54	.09	15	-	.5	728	666	-	1215	1.60	.36	1.40
4-9	.84	.12	13	-	.7	367	308	78	758	1.80	.34	1.20
4-27	.35	.21	6	-	2.3	178	115	213	490	3.90	.20	2.60
4-29	.19	.07	1	-	.1	28	20	66	320	7.10	.25	1.30
9-17	.70	.15	4	1653.8	9.9	73	43	-	300	2.09	.22	.87
9-20	.44	.15	5	755.2	1.9	95	27	-	398	1.68	.13	.93
11-8	.78	.12	9	6748.4	1.7	73	23	41	333	4.61	.07	1.33
11-19	.57	.10	7	170.7	2.4	200	136	58	522	4.25	.27	1.56
12-5	1.64	.19	1	23558.2	1.2	45	-	6	69	1.55	1.77	.90
12-28	.67	.10	1	-	.2	55	30	22	68	5.60	.01	1.45

Table I-2

Regulator Station Overflow Data
1970

Station 37 West Michigan Street

Date	Rain Total Inches	Rain Max. Rate in./hr.	Sample Volume Liters	Overflow Volume gal. x 1000	Sett. ml/l	Solids Susp. mg/l	Solids Vol. mg/l	BOD mg/l	COD mg/l	NH_3 mg N/l	$NO_2 + NO_3$ mg N/l	PO_4 mg P/l
1-19	.70	.13	12	-	4.0	162	56	-	100	1.90	.10	2.00
3-6	1.52	.17	12	476.9	2.0	256	70	33	192	1.50	.15	1.70
3-12	.40	.14	8	90.0	1.8	206	40	42	128	2.20	.45	4.30
4-1	.23	.14	5	-	34.0	404	244	306	744	4.90	.30	2.40
4-9	.94	.16	12	-	.7	156	50	6	120	.80	.25	.06
9-6	.42	.13	9	6.4	1.5	129	40	180	300	3.20	.28	1.60
9-16	.13	.10	12	4.6	5.0	345	200	84	-	4.52	.39	2.20
9-17	.84	.17	12	86.5	1.0	-	-	-	140	5.20	.03	2.60
9-20	.47	.22	12	118.9	.3	112	68	-	130	.75	.30	.25
10-17	.31	.21	8	62.9	1.3	116	-	31	64	3.35	.42	.70
11-8	.96	.15	12	125.2	1.6	-	-	-	-	1.80	.22	.50
11-30	.28	.08	12	232.6	1.5	268	86	24	144	2.15	.34	1.64
12-3	.26	.07	12	.7	.8	510	105	30	126	2.05	.32	.82
12-6	1.69	.15	12	2483.8	.5	20	20	6	142	1.15	3.03	1.85
12-28	.60	.09	12	143.2	1.1	334	58	16	154	1.60	.42	1.30

Station 38 8th Avenue South

Date	Rain Total Inches	Rain Max. Rate in./hr.	Sample Volume Liters	Overflow Volume gal. x 1000	Sett. ml/l	Solids Susp. mg/l	Solids Vol. mg/l	BOD mg/l	COD mg/l	NH_3 mg N/l	$NO_2 + NO_3$ mg N/l	PO_4 mg P/l
1-19	.70	.13	2	-	1.8	120	58	-	8	.80	.05	.80
1-26	.41	.22	8	-	.3	252	52	-	-	1.00	.14	.86
3-6	1.52	.17	2	-	1.8	228	52	20	200	1.50	.05	1.30
3-12	.40	.14	1	-	1.8	293	66	18	200	3.90	.05	2.70

Table I-3

Regulator Station Overflow Data
1970

Station 40 Norfolk Street

Date	Rain Total Inches	Rain Max. Rate in./hr.	Sample Volume Liters	Overflow Volume gal. x 1000	Solids Sett. ml/l	Solids Susp. mg/l	Solids Vol. mg/l	BOD mg/l	COD mg/l	NH_3 mg N/l	NO_2+NO_3 mg N/l	PO_4 mg P/l
1-9	.22	.10	3	-	11.8	366	215	146	833	9.00	.19	6.80
1-13	1.50	.24	8	-	6.8	317	228	86	206	7.60	-	4.00
1-19	.66	.11	14	-	4.0	50	36	-	241	7.20	.61	3.80
1-26	1.18	.15	3	-	1.7	149	69	-	-	1.90	.60	.76
2-5	.14	.04	9	-	8.4	228	98	74	296	8.50	.29	5.50
2-17	.20	.07	7	-	6.1	189	81	26	249	7.00	.24	2.20
3-3	.10	.04	3	-	7.3	269	173	114	808	16.20	.30	6.30
3-6	1.53	.19	6	-	8.9	421	139	74	254	7.30	.27	4.00
3-12	.32	.11	7	-	9.4	151	46	33	257	4.70	.39	3.80
4-1	.31	.11	1	-	3.5	288	128	60	400	8.70	.30	3.30
4-6	.23	.07	-	-	4.2	132	110	-	160	8.60	.24	8.30
4-9	.85	.12	10	-	4.9	136	55	55	366	3.30	.49	1.10
4-24	.28	.09	8	-	2.3	198	41	28	188	3.20	.54	1.60
4-27	.20	.16	4	-	4.2	173	87	202	205	12.80	.29	5.00
4-29	.19	.04	3	-	3.2	95	55	70	347	8.80	.31	3.10
5-8	.21	.07	2	-	8.1	208	190	-	400	8.60	.18	8.60
6-29	.13	.06	6	-	5.2	317	222	54	243	11.90	.19	3.80
9-3	.27	.09	3	-	8.3	340	122	130	-	13.73	.22	5.00
9-17	.84	.18	15	-	8.5	134	67	-	576	4.81	.30	2.87
9-20	.39	.13	12	-	3.4	90	83	-	492	3.80	.25	1.63
10-4	.20	.09	10	-	11.7	338	245	35	182	6.25	.22	3.25
10-11	.11	.04	19	-	6.1	446	254	29	97	7.12	.05	3.79
10-17	.23	.15	7	-	14.5	309	25	39	214	4.72	.07	1.32
10-19	.19	.04	22	-	5.0	261	10	20	140	4.94	.42	1.23
11-30	.18	.05	23	-	5.1	159	96	78	207	7.23	.58	4.10
12-1	.19	.06	20	-	5.2	101	40	61	388	9.50	.60	3.58
12-10	.75	.15	24	-	6.0	111	93	68	224	6.14	1.34	3.66
12-15	.50	.08	23	-	5.5	138	72	68	122	4.36	.81	2.81
12-28	.51	.10	22	-	6.9	312	91	14	239	3.64	.59	2.34

Appendix J

Stepwise Regression Analyses

Table J-1

Station 4901

Nutrient Parameter	Independent Variable	Multiple R	F Value
Ammonia Nitrogen as mg N/l	Volume antecedent stormflow	.4899	9.4750
	Time since last stormflow	.6209	6.8686
	Intensity of Rain	.7288	8.6947
	Air temperature	.7475	1.6848
	Wind Direction	.7770	2.9517
	Volume of Rain	.7881	1.1449
	*Intensity of antecedent stormflow	.8004	1.3049
Nitrate Nitrogen as mg N/l	Air temperature	.4407	7.2326
	Intensity of stormflow	.4615	.6910
	*Volume of rain	.5099	1.7763
Total Phosphate as mg P/l	Volume of antecedent stormflow	.4736	8.6757
	Time since last rain	.5951	5.8277
	Volume of stormflow	.6484	3.2063
	Intensity of rain	.6949	3.2593
	Duration of antecedent rain	.7179	1.7415
	Duration of antecedent stormflow	.7400	1.7839
	Intensity of stormflow	.7646	2.1325
	Duration of stormflow	.8013	3.6984
	Time since last overflow	.8178	1.7777
	*Air Temperature	.8274	1.0521

*Although more variables correlated increase the "R" low "F" values beneath this point lead the statistician to ignore lower variables.

Table J-2

Station 4902

Nutrient Parameter	Independent Variable	Multiple R	F Value
Ammonia Nitrogen as mg N/l	Volume of Overflow	.6377	8.9122
	Duration antecedent rain	.7211	2.8327
	Intensity antecedent overflow	.8341	6.3530
	Air Temperature	.8741	2.8973
	Intensity of rain	.8898	1.1980
	*Intensity of overflow	.9080	1.4903
Nitrate Nitrogen as mg N/l	Intensity of rain	.4845	3.9874
	Air temperature	.6025	2.4158
	Volume of overflow	.6543	1.2532
	*Volume of antecedent overflow	.6763	.5402
Total Phosphate as mg P/l	Volume of overflow	.4233	2.8383
	Time since last overflow	.5193	1.4856
	*Duration of rain	.5493	.5062

*Although more variables correlated increase the "R", low "F" values beneath this point lead the statistician to ignore lower variables

Table J-3

Station 4903

Nutrient Parameter	Independent Variable	Multiple R	F Value
Ammonia Nitrogen as mg N/l	Time since last overflow	.3781	1.8352
	Intensity of rain	.7457	9.3721
	Duration antecedent Rain	.8572	6.0085
	Air Temperature	.9170	5.3338
	Duration of rain	.9439	3.2239
	Duration of overflow	.9554	1.4909
	Intensity antecedent rain	.9668	1.6935
	Volume antecedent overflow	.9763	1.5707
	*Volume overflow	.9834	1.2696
Nitrate Nitrogen as mg N/l	Wind Direction	.4513	2.8136
	Duration of overflow	.5389	1.2226
	Duration of antecedent rain	.6534	2.1435
	Air temperature	.7339	1.9377
	*Intensity rain	.7673	.8530
Total Phosphate as mg P/l	Time since last overflow	.5065	3.7966
	Intensity of rain	.8034	10.9700
	Volume of antecedent rain	.8270	1.0946
	Volume of antecedent overflow	.8788	3.1055
	Wind Direction	.9242	3.9302
	Duration antecedent rain	.9528	3.4903
	*Volume of overflow	.9594	.8004

* Although more variables correlated, increase the "R". low "F" values beneath this point lead the statistician to ignore lower variables

Table J-4

Station 4904

Nutrient Parameter	Independent Variable	Multiple R	F Value
Ammonia nitrogen as mg N/l	Duration antecedent overflow	.5160	7.2564
	Intensity antecedent rain	.6725	6.4536
	Wind Direction	.7768	6.8644
	Intensity rain	.7997	1.7019
	*Intensity of overflow	.8546	5.3817
Nitrate Nitrogen as mg N/l	Time since last overflow	.4672	5.5838
	Wind direction	.5853	3.5925
	Volume of rain	.6135	.9757
	Volume of antecedent overflow	.6476	1.2594
	Intensity of overflow	.6817	1.3532
	Duration of overflow	.7215	1.7505
	Intensity antecedent overflow	.7611	1.9532
	Intensity antecedent rain	.8135	3.1719
	*Duration of antecedent overflow	.8385	1.6709
Total Phosphate as mg P/l	Wind Direction	.4712	5.7089
	Intensity Antecedent Rain	.6194	4.9801
	Volume Antecedent overflow	.7073	4.2013
	Intensity antecedent overflow	.7653	3.5026
	Intensity rain	.8596	9.3880
	*Time since last rain	.8709	1.2191

*Although more variables correlated, increase the "R", low "F" Values beneath this point lead the statistician to ignore lower variables

Appendix K

Area Rainfall Distribution

Table K-1

1969 Monthly Rainfall Distribution

Station *(See Fig K-1 for Map Location)

	3	6	14	15	17	18	19
Jan.		5.81	4.12	6.65	6.02		
Feb.		3.43	3.28	4.04	3.91		
Mar.		2.22	1.67	1.83	1.17		
Apr.		3.99	2.95	3.51	3.78		
May		2.34	2.27	2.44	3.05		
June		1.85	1.06	.92	1.40		
July		.20	.21	.18	.45		
Aug.		.24	.19	.38	.30		
Sept.		6.57	4.94	5.49	5.83		
Oct.		1.89	1.33	1.26	1.67		
Nov.		3.70	1.83	.81	2.16		
Dec.		8.00	5.97	7.07	6.94		
Year Total (Inches)		40.24	29.82	34.58	37.38		

Table K-2

1970 Monthly Rainfall Distribution

Jan.	7.36		7.78	6.51	9.35	8.92	8.46
Feb.	1.77		1.86	2.21	2.34	2.11	2.33
Mar.	3.06		2.99	3.78	3.81	3.54	3.64
Apr.	2.89		2.40	3.15	3.55	3.73	3.25
May	1.22		.85	1.04	1.25	1.04	1.21
June	.40		1.00	.26	.66	.67	.94
July	.61		.45	.53	.63	.62	.67
Aug.	-		.07	.04	.24	.06	-
Sept.	1.81		1.77	2.32	2.96	2.49	2.40
Oct.	1.83		3.12	3.25	3.49	2.94	3.63
Nov.	4.14		4.45	5.46	5.59	5.15	5.01
Dec.	7.68		7.65	9.21	9.13	8.37	9.02
Year Total (Inches)	34.09		34.40	37.76	43.00	39.64	40.56

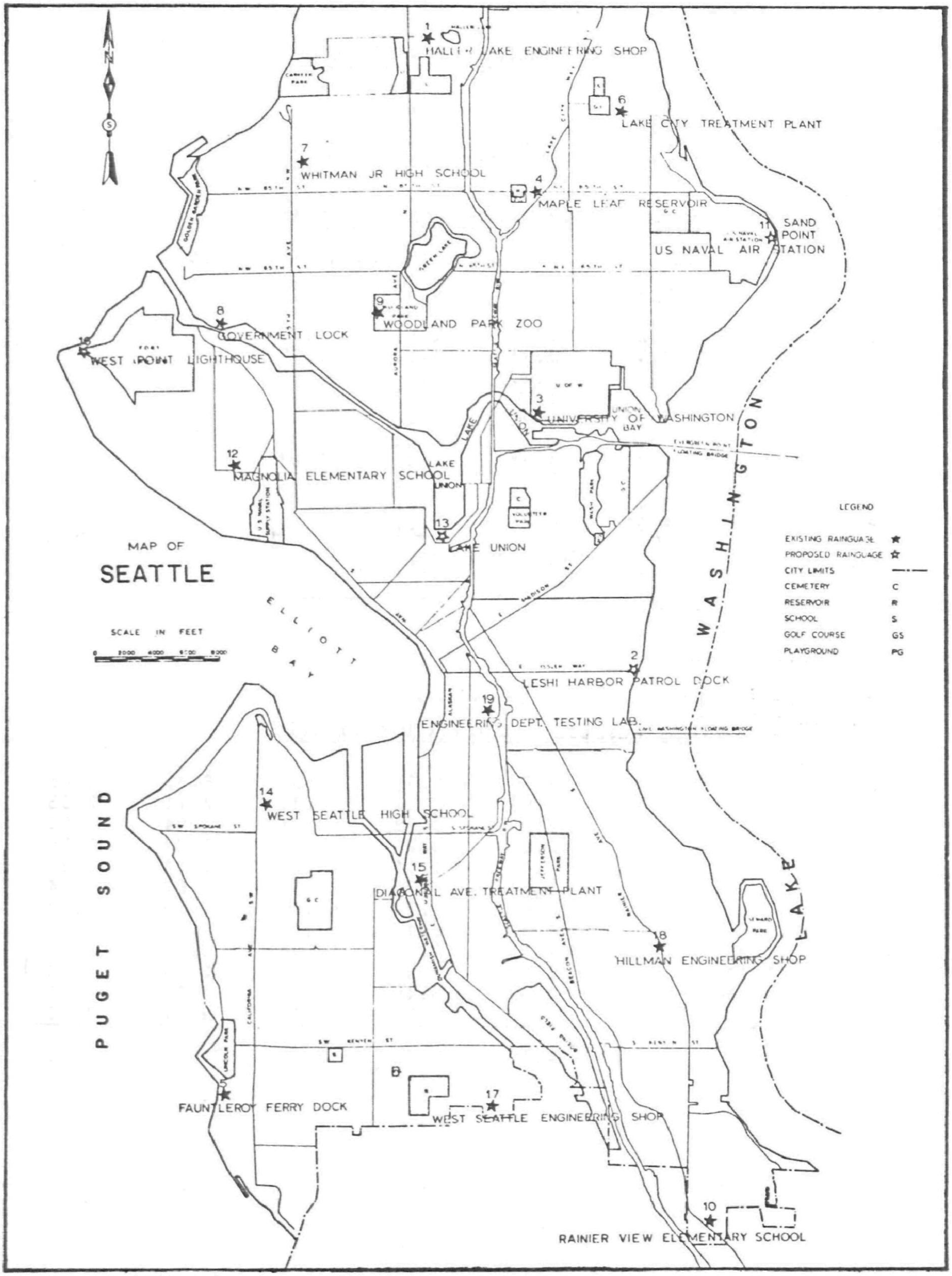


Figure K-1. City Engineering Dept. Rain Gage Locations

Appendix L

Condensed Computer System Specifications

1. Computer Main Frame (XDS Sigma 2)

Core Memory words installed:	45,056	
Core Memory words maximum:	65,536	
Access Time:	920	nanoseconds
I/O Transfer Rate:	400,000	bytes/sec.
I/O Channels, peripherals	12	ea.
direct	1	ea.
Word Size	16	bits
Byte Size:	8	bits
Hardware Registers, General Purpose:	8	ea.
I/O channel:	16	ea.
Memory Protect:	16	ea.
Arith. & Control:	3	ea.

2. Fixed-Head, Rapid-Access Magnetic Disk Bulk Memory

Capacity, words:	1,474,560	
Transfer rate:	180,000	bytes/sec.
Average Access Time:	17	milliseconds
Rotational speed:	1780	rpm

3. Peripheral Devices

a. Card Reader	400	cards/min.
b. Card Punch	300	cards/min.
c. Tape Reader	300	characters/sec.
d. Tape Punch	120	characters/sec.
e. Buffered Line Printer	800	line/min.
f. Drum Plotter	300	increment/sec.
g. Magnetic Tape Drive	30,000	byte/sec.
h. Keyboard-Printer	10	characters/sec.

1 Accession Number	2 Subject Field & Group	
	05F	**SELECTED WATER RESOURCES ABSTRACTS** INPUT TRANSACTION FORM

5 Organization

Seattle, Municipality of Metropolitan

6 Title

MAXIMIZING STORAGE IN COMBINED SEWER SYSTEMS

10 Author(s)

Leiser, Curtis P.

16 Project Designation

EPA-WQO Contract No. 13-WASH-1
Project No. 11022-ELK

21 Note

22 Citation

23 Descriptors (Starred First)

*Wastewater storage, *Water pollution control, *Regulation, *Computer programs, overflow, infiltration, flow separation, sampling, computer models, storm runoff, storage tanks, construction, telemetry, monitoring, calibrations, rainfall intensity, water pollution sources, water pollution effects, operations, maintenance, wastewater treatment

25 Identifiers (Starred First)

*Combined sewers, *Seattle, Washington, *Computer control, system control, control consoles

27 Abstract

A major portion of the Seattle Metro area's comprehensive sewage collection and treatment plan launched in 1958, included improvements to an existing combined sewer system within Seattle's city limits. Initial plans included: (1) interception and treatment of raw sewage flowing to saltwater points, (2) regulation of combined flows to utilize all available trunk storage and (3) construction of temporary storage tanks at freshwater overflow points. In 1968, a $70 million sewer separation project was approved and will enlarge system storage by reducing storm inflow. All construction has been completed in an effort to demonstrate the feasibility of applying computer-control concepts to theoretically make maximum use of all available storage within a collection system.

Automatic and manual sampling programs are monitoring overflows and adjacent waters. Accumulated and analyzed data shows dramatic improvements in receiving water quality resulting from interception and treatment phases of construction. Analysis of separation monitoring data, projects a 50-70% reduction in pollutant loading to fresh water from combined sewer overflows. Overflow volume, frequency and quality factors are established to serve as a basis for measuring the performance of the control system as it leaves the instrumented local control phase and begins the totally computer-managed phase.

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