METROPOLITAN WATER INTELLIGENCE SYSTEMS

COMPLETION REPORT - PHASE 1

George L. Smith

Neil S. Grigg

L. Scott Tucker

Duane W. Hill

prepared for
U. S. DEPARTMENT OF THE INTERIOR
OFFICE OF WATER RESOURCES RESEARCH

under grant agreement
No. 14—31—0001—3410

Department of Civil Engineering
Colorado State University
Fort Collins, Colorado

June, 1972

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FOREWORD

Colorado State University was awarded a grant by the Office of Water Resources Research (OWRR) to study "Metropolitan Water Intelligence Systems." The purpose of the study was to develop criteria and a rationale for the establishment of centralized metropolitan water intelligence systems in urbanized and urbanizing areas.

The project consists of three phases each lasting approximately one year; this report was prepared during Phase I. During Phase I primary attention was focused on real-time automation and control facilities for combined sewers. Basic objectives of Phase I were to:

1. Investigate and describe modern intelligence systems for the operation of urban water facilities with emphasis on combined sewer systems.

2. Develop criteria for managers, planners, and designers for use in the consideration and development of centralized intelligence systems for the operation of combined sewer systems.

3. Study the feasibility, both technical and social, of intelligence systems for urban water facilities with emphasis on combined sewer systems.

The method of achieving the above objectives was through the division of the work into the following tasks:

1. Integrate information on current systems.

2. Study relationships between urban growth and requirements for automation and control systems.

3. Evaluate automation and control schemes for combined sewer systems.

4. Develop a model for a real-time automation and control system (RTACS).

5. Evaluate computer and control equipment needs.

6. Formulate a design strategy for automation and control of combined sewer systems.

7. Study nontechnical aspects of automation.

8. Describe research and development needs.

9. Establish a project advisory committee.

On the basis of the recommendations and guidance of the advisory committee representing national expertise in the field of combined sewer catchment and distribution systems for metropolitan regions, the research effort for Phase I was divided into two major categories: technical and nontechnical. The work performed under each category was published as Technical Reports which are listed herein and available separately.

Technical Criteria

The technical effort was initiated with Task 1, which was divided into two tasks, Task 1a and Task 1b. In Task 1a (See TR 3), the Combined Sewer Control Demonstration Project of Minneapolis - St. Paul was carefully reviewed to ascertain its strong points and weak points. In Task 1b (See TR 1) water agencies and/or jurisdictions in the United States were identified that implemented or have plans to implement systems for either automatic or remote control of urban water systems. The purpose of Tasks 1a and 1b was to provide decision-makers with information regarding existing projects that might assist them in evaluating their own situation.

The need for a method to evaluate the possible and actual effectiveness of an automation and control project was evident from previous studies[1,2,3] on urban drainage systems. It is very important to the implementation of a combined sewer control system that the manager have

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[1]Tucker, L. S., "Northwood Gaging Installation, Baltimore - Instrumentation and Data," ASCE Urban Water Resources Research Program, Technical Memorandum No. 1, April, 1969.

[2]Schaake, Jr., J. C., "Response Characteristics of Urban Water Resources Data Systems," ASCE Urban Water Resources Research Program, Technical Memorandum No. 3, August, 1968.

[3]Tucker, L. S., "Sewered Drainage Catchments in Major Cities," ASCE Urban Water Resources Research Program, Technical Memorandum No. 10, March, 1969.

the technical capability of evaluating both the effectiveness of the system and the data requirements for an adequate evaluation. Determination of the methods needed for evaluating automation and control projects for combined sewer systems was undertaken in Task 3 (TR 4).

In the consideration of a combined sewer control system, a manager is also interested in the relative importance of and degree of sophistication required from the various elements of the control system which is being considered. A model of a real-time automation and control system was formulated using a hypothetical combined sewer system in Task 4 (TR 7). Achievement of control logic mastery and advanced development of this model in Phases II and III is intended to assist a manager to make such evaluations.

The computer control center is the center or core of an intelligence system. The report of Task 5 (TR 2) describes the essential computation and control facilities needed to establish the control center. The relationship of size of computer facility required to the number of control parameters and to certain noncontrol activities such as maintenance formed the major effort of this task. Computer requirements have a profound bearing on cost and is an important aspect for the manager to consider.

Nontechnical Criteria

A study of urban size and its need for automation and control was identified in Task 2 (TR 6). The purpose of this task was to examine the urban parameters of some 60 cities and their relationship to the need or desire for urban water intelligence systems. A careful review of the economics and feasibility of an automated system as well as alternative systems is required for each situation. The report on this task identifies some of the incentives for automation, alternatives to an intelligence system and factors which affect the choice of alternatives.

If a manager decides that a control system might be utilized to accomplish his subobjectives regarding combined sewers, it will be necessary for him to recognize elements of the social system which might constrain the political acceptance of the project. These elements are defined in Task 7 (TR 5 and TR 8) along with the development of administration and management criteria that might be essential to effective implementation and operation of an intelligence system.

The formulation of strategy for planning, design and implementation of computer based systems for controlling combined sewers is set forth in the report of Task 6 (TR 8). The report argues that computer based control is a viable alternative solution to overflow reduction that should be considered. It tells why one should consider "automation," defines a computer based control system discusses relevant political implications, discusses evaluation of control systems, and describes several examples of computerized control systems that have been or will be implemented.

Lastly, a survey was made of existing and planned applications of instrumentation in water and wastewater systems of selected urban and metropolitan areas of the United States. This survey constituted the effort of Task 8 (TR 6).

Neil S. Grigg, who is replacing L. Scott Tucker, and George L. Smith had principal responsibility for preparation of this final report. Duane W. Hill of the Department of Political Science, Colorado State University, and L. Scott Tucker, Executive Director of the Urban Drainage and Flood Control District of Metropolitan Denver assisted in its preparation.

The material in this report has drawn heavily from the nine Technical Reports prepared during the course of the research. Authors of the reports other than those of this report include H. G. Poertner, Engineering and Research Consultant, Bolingbrook, Illinois; J. J. Anderson, President of Watermation, Inc. of St. Paul, Minnesota; R. L. Callery and D. J. Anderson, Research Engineers of Watermation, Inc. of St. Paul, Minnesota; Bruce Bradford and Warren Bell, Ph.D. students at Colorado State University, Fort Collins, Colorado; C. B. Winn, Associate Professor of Mechanical Engineering, Colorado State University, Fort Collins, Colorado; and, Kenneth Medearis, Computer-Engineer-Research Consultant, Fort Collins, Colorado. In particular, TR 8, "Guidelines for the Consideration of Automation and Control Systems" has been extensively used.

* * * * *

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* * * * *

Maurice L. Albertson and George L. Smith were Phase I co-principal investigators and L. Scott Tucker was project manager until March 1, 1972. Dr. Edward G. Altouney was Project Monitor for the Office of Water Resources Research during Phase I. His assistance is gratefully acknowledged.

A project Advisory Committee was formed to provide overall guidance on the research efforts of this project. The Committee met twice during Phase I, and their input into the research results has been invaluable in preparation of this final report. In particular, M. B. McPherson, Director, ASCE Urban Water Resources Research Program has provided helpful criticisms, suggestions and guidance in the research program and in the preparation of this report. The Advisory Committee represents a cross-section of nation-wide expertise on urban-drainage systems and related problems and includes the following members:

LOUIS J. BARTSCHER - Representing the Metropolitan Sewer Board of the Twin Cities, St. Paul, Minnesota

WILLIAM GIESSNER - Representing Mr. A. O. Friedland, from the Department of Public Works, San Francisco, California

STIFEL W. JENS - Senior Vice President, Reitz and Jens Consulting Engineers, St. Louis, Missouri

MURRAY B. McPHERSON - Program Director, American Society of Civil Engineers Urban Water Resources Research Program, Marblehead, Massachusetts

ROBERT C. McWHINNIE - Director of Planning and Water Resources, Board of Water Commissioners, Denver, Colorado

FORREST C. NEIL - Chief Engineer, Metropolitan Sanitary District of Greater Chicago

DARWIN R. WRIGHT - Representing the Environmental Protection Agency, Water Quality Office, Washington, D. C.

KENNETH R. WRIGHT - President, Wright Water Engineers, Denver, Colorado

* * * * *

The following technical reports were prepared during Phase I of the CSU-OWRR project, Metropolitan Water Intelligence Systems. Copies may be obtained for $3.00 each from the National Technical Information Service, U. S. Department of Commerce, Springfield, VA 22151. (When ordering, use the report title and the identifying number noted for each report.)

Technical Report No. 1 - "Existing Automation, Control and Intelligence Systems of Metropolitan Water Facilities" by H. G. Poertner. (Identifying number to be obtained.)

Technical Report No. 2 - "Computer and Control Equipment" by Ken Medearis. (Identifying number to be obtained.)

Technical Report No. 3 - "Control of Combined Sewer Overflows in Minneapolis - St. Paul" by L. S. Tucker. (Identifying number to be obtained.)

Technical Report No. 4 - "Task 3 - Investigation of the Evaluation of Automation and Control Schemes for Combined Sewer Systems" by J. J. Anderson, R. L. Callery, and D. J. Anderson. (Identifying number to be obtained.)

Technical Report No. 5 - "Social and Political Feasibility of Automated Urban Sewer Systems" by D. W. Hill and L. S. Tucker. (Identifying number to be obtained.)

Technical Report No. 6 - "Urban Size and Its Relation to Need for Automation and Control" by Bruce Bradford and D. C. Taylor. (Identifying number to be obtained.)

Technical Report No. 7 - "Model of Real-Time Automation and Control Systems for Combined Sewers" by Warren Bell, C. B. Winn, and G. L. Smith. (Identifying number to be obtained.)

Technical Report No. 8 - "Guidelines for the Consideration of Automation and Control Systems" by L. S. Tucker and D. W. Hill. (Identifying number to be obtained.)

Technical Report No. 9 - "Research and Development Needs in Automation and Control of Urban Water Systems" by H. G. Poertner. (Identifying number to be obtained.)

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The Metropolitan Water Intelligence System (MWIS) Concept is being developed with the objective of providing automatic operational control for metropolitan water systems. In full development, MWIS might link together all urban water functions to be operated as a single, unified system. This report presents an analysis of an investigation into the specific problem of controlling overflows from combined sewer systems in order to reduce this source of receiving water pollution. The technical and nontechnical aspects of the problem discussed include: the initiation of a Real-Time Automation and Control System (RTACS) by means of a simulation model for use in the design of the components of the RTACS, the initial criteria for use in the development and operation of an RTACS, and the technical and nontechnical feasibility of an RTACS for combined sewer systems and possible further application to overall urban water systems. The report is based on a series of technical reports which are available separately. They include: an inventory of existing automation, control and intelligence systems; a report on computer and control equipment; a field report on an actual control system located in Minneapolis - St. Paul; an evaluation report of control schemes; a social and political feasibility report; a technical report on the RTACS model; a guidelines report for managers; and additional analysis on the effect of urban size and on research and development needs.

GLOSSARY

In this study and in many current publications, systems terminology is used extensively. Often this results in communication gaps but, if properly used, this terminology can be very useful.

One of the primary advantages of systems terminology is that it provides a common basis for communication for professionals from various disciplines. Regardless of the problem being discussed, systems terms give precision to descriptions which could otherwise be confusing.

Although the advantages to the use of systems terminology are apparent, it is also apparent that communications problems will occur if terms are not precisely defined. For this reason, some of the terms used in this report will be defined in this section.

Metropolitan Water Intelligence Systems (MWIS) - A system which provides for automatic operational control of metropolitan water systems. In its ultimate form, the intelligence system, according to McPherson[4], would be in the closed-loop mode and would be computer centered. Using field intelligence -- precipitation, water and wastewater treatment facilities, water demands and distribution system rates and pressures, settings of regulating structures -- as inputs, the computer decision program would resolve best service - least operating cost options, taking into account estimated reliability and risks, and would actuate field regulating and control facilities to approach elected option states. Feedback features would be such as to permit manual supervisory intervention at any time.

Real-Time Automation and Control System (RTACS) - A system which provides for control in real-time of some physical system (such

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[4] American Society of Civil Engineers, "Basic Information Needs in Urban Hydrology," A Study for the Geological Survey, U. S. Department of the Interior, New York, April, 1969, p. 81.

as a combined sewer drainage basin) through use of at least the following components: sensing elements (rain gauges, flow meters, etc.), a centralized data processing unit, a mathematical model and/or rule curves which govern all or part of the physical system, a control program, a data bank and control elements which operate within the physical system. The objective of the RTACS is to achieve the objective established for the water resources system upon which it operates. The functions of the various components of the RTACS will be explained later.

Model of Real-Time Automation and Control System (RTACS Model) - A mathematical model of the physical system and the major RTACS components which allows for simulation of RTACS operating under different external and internal conditions. The purpose of the RTACS model is to aid in the design of the different components of RTACS.

Control Criteria - The control criteria establish the objectives of control and define all the constraints under which they must be accomplished. Some of the factors bearing on control criteria are: local political conditions; regional or state pollution control regulations and objectives; economic, sociological and legal considerations; local wastewater control agency objectives; public relations; and technical feasibility.

Control Logic - After control criteria have been established, development of a set of rules or logic operations is necessary in order to meet the specified criteria where certain field conditions occur. The control logic is this set of rules or logic operations. Control logic is part of the RTACS and constitutes the core of a real-time operational control system.

SECTION I. INTRODUCTION AND SUMMARY

There are many and varied sources of pollutants contributing to the pollution of the nation's waterways. From urban areas, four sources are particularly significant: residual pollutants in treatment plant effluents, sewage plant bypass flow, overflows from combined sewers, and storm drainage discharges. The Federal and state governments are working at present to bring the first two under better control. The sanitary wastes arriving at a treatment plant are convenient to work with in the sense that the volume is relatively small compared with stormwater, and the rate of flow does not vary significantly with time. The control of pollution from combined sewer overflows and storm drainage discharges is complicated by the large volume of water to be handled and by random occurrences both in time and in space. In combined sewers, the large volume of storm water generated during most rainstorms overloads the downstream treatment plant and must be by-passed directly to the river. There have been a number of federally supported Demonstration Projects completed with the objective of improving and demonstrating solutions to this problem.

One obvious solution to the combined sewer pollution problem is to separate combined systems into storm and sanitary systems. This solution, although technically feasible, usually is prohibitively expensive and is not a complete solution to the problem because of storm drainage pollution. With regard to the expense of such projects, the scale of expenditures required is equal to that which would be required to rebuild completely either a storm or a sanitary sewer system. Often quoted figures are those of the U. S. Public Health Service which estimated the cost of total separation at $20-$30 billion (1964 dollars)[5] and the APWA whose estimate was $48 billion (1967 dollars).[6] At the municipal level funds are normally not available for expenditures of the magnitude required.

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[5]"Pollutional Effects of Stormwater and Overflows from Combined Sewer Systems," U. S. Department of H.E.W., P.H.S., November, 1964, p.v.

[6]American Public Works Association, "Problems of Combined Sewer Facilities and Overflows, 1967," for the FWPCA, USDI, December 1, 1967, p.xii.

The pollution caused by combined sewer overflows and by storm drainage will become an increasingly severe problem due to population growth. The environmental consequences of growth are well-known.[7] The nation is embarked upon a comprehensive program of environmental protection, and separation of sewers is a piecemeal approach to the problem. A better, more comprehensive solution may be to control combined sewer flow in time or space in such a manner as to reduce greatly or minimize pollution resulting from rainstorms and the resultant overflows.

This control of combined sewer flows can be viewed either as an interim or as a final solution to the problem of reducing overflow pollution. As an interim solution, it may be highly cost effective in terms of dollars per unit reduction of pollution. Also, it avoids the vast expenditures for new sewer construction which is necessary for separation. As a final solution, if sufficient storage can be incorporated into the sewer system, near total control could be achieved which would practically eliminate overflows.

The storage in the sewer system can be classified as either "ambient" or "auxiliary." These types of storage are similar to in-line and off-line storage. Existing systems have a great variation in the amount of ambient storage available. A system with large, flat sewers would obviously have a great deal more storage than one with small, steep sewers. Similarly, a region with frequent, heavy rainstorms might not find it feasible to rely entirely on auxiliary storage as a solution to the overflow problem whereas a region with a drier climate might find storage to be an excellent solution.

Some computer augmented control systems for the reduction of combined sewer overflows are presently in existence. They incorporate different concepts of control and are in different stages of development. The term "control system" regarding combined sewers used herein means a system for the

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[7] McPherson, M. B., "Prospects for Metropolitan Water Management," a report for the Office of Water Resources Research, USDI, ASCE, New York December, 1970, p. 3-14.

> "...manipulation of stormwater flows by in-system storage, off-line storage or basin transfer to accomplish treatment of potential overflows by regulated release to existing treatment plants or in specially built treatment facilities."[8]

The ultimate objective of a control system is to minimize overflows of combined sewage to a body of receiving water. It can do this by maximizing the use (in time and space) of available in-line and off-line storage. Specific objectives of the control or management of combined sewage were identified by APWA as follows:

> "1. Make maximum utilization of interceptor sewer capacity to carry combined sewage to the wastewater treatment plant;
>
> 2. Make maximum utilization of in-system storage;
>
> 3. Give priority in the interceptor sewer to those flows which have a higher pollutional load and which, if they overflow, would result in adverse conditions in receiving waters; and
>
> 4. Integrated use of combined sewer overflow storage or treatment facilities."[9]

In order to accomplish the needed control, various devices and techniques are available. A comprehensive discussion of these is given elsewhere and need not be repeated here.[10] However, it is important to understand that the development of the art and science of the automatic real-time control of combined sewage overflow is in its embryonic stage and a great deal of work will be necessary before the concept can reach generally fruitful application.

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[8]Tucker, L. S. and Hill, D. W., "Guidelines for the Consideration of Automation and Control Systems," Metropolitan Water Intelligence Systems, TR No. 8, Colorado State University, Department of Civil Engineering, March, 1972, p. 13.

[9]American Public Works Association, "Combined Sewer Regulator Overflow Facilities Report," (for the FWQA, USDI, and 25 Local Jurisdictions.) July, 1970, p. 109.

[10]Field, Richard, "Management and Control of Combined Sewer Overflows, Program Overview," USEPA Report presented at 44th Annual Meeting of the New York Water Pollution Control Association, New York, January 26-28, 1972.

Existing combined sewer systems operate under gravity and opportunities for their manipulation are minimal, such as at interceptor regulators. Once a commitment to real-time manipulation of the combined sewer system is made as a method to reduce overflow pollution, it becomes obvious that sophisticated control techniques must be developed. The ratio of incremental benefits, measured in pollution reduction, to incremental costs may be high for a given degree of proposed automatic control sophistication. The general nature of the actual relationship of benefits, measured as reduction of pollution, to the degree of sophistication of the system is probably of the shape shown on Figure I-1.

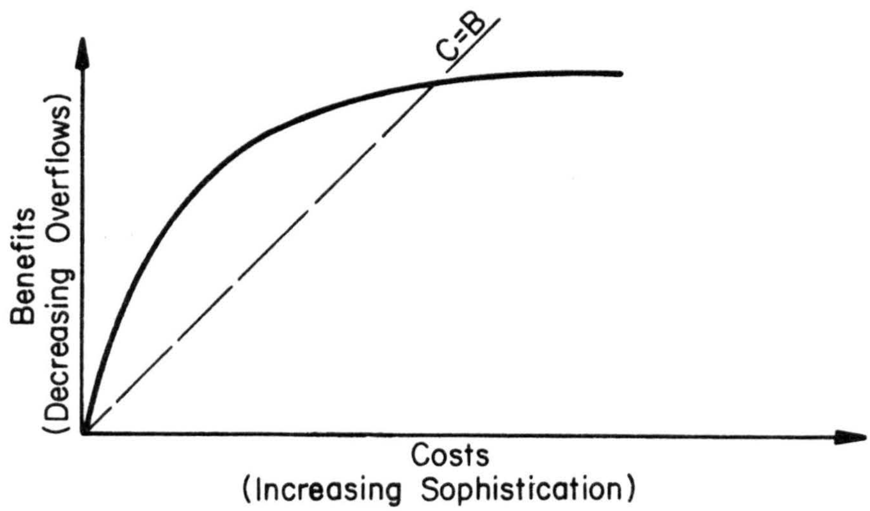

FIGURE I-1

Hypothetical Cost Curve for Control Systems

The general shape of the curve shown is substantiated in a study done for the City of San Francisco by their engineering staff to determine the best methodology to reduce overflow pollution.[11] In their study they determined that costs ranging from $333 million to $665 million would be incurred to reduce the current average of 82 overflows per year to acceptable levels. The cost to reduce to 8 overflows per year is $333 million while the cost to reduce to one overflow in five years is $665 million.

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[11] City and County of San Francisco, Department of Public Works, "San Francisco Master Plan for Wastewater Management - Preliminary Comprehensive Report," September 15, 1971.

The most important and basic reasons why real-time automatic control is necessary may be summarized as follows:

1. Storm flows in combined sewer systems occur randomly with respect to both time and space. It is extremely difficult to forecast flows and overflows without an adequate data gathering system and without high speed data processing and prediction methods.

2. The serious nature of pollution resulting from overflows requires a high degree of reliability. Automatic control most likely can provide the required reliability.

3. It is necessary for the control system to be sufficiently flexible to adapt to changing land-use conditions, changing water quality standards, changing policy and to be able to accomodate increasingly sophisticated mathematical models.

In this report the writers have attempted to present information on the technical and nontechnical aspects of automated control systems as solutions to the pollution problems associated with combined sewer overflows. In addition, a discussion of an ongoing research project is presented for the purpose of dissemination of information to potential users. The research project has passed from the problem definition, initial research stage into the stage where actual problems and real solutions are being grasped. The results presented herein can provide an overview of the problem for technical and managerial personnel and lend some assistance to them in their consideration of control systems for adoption.

Throughout the report the difficulty of the technical and nontechnical factors involved is emphasized. This will aid all personnel in attaining a realistic focus on the problem. The high level of potential benefits should also be stressed as control systems may yield large reductions in pollution at low to moderate costs (compared to the costs for separating combined sewer systems).

An automatic computer based control system has a number of physical elements ranging from field intelligence or control elements to a sophisticated computer control center. All of these elements must be selected and designed so that they will work efficiently together in an overall system.

The term "Real-Time Automation and Control System (RTACS)" has been assigned to the system which controls a physical sewer system. In order to design or study the system a simulation model, called an "RTACS Model" is being developed. The model, using optimal control theory, can assist in the planning, design or calibration of the RTACS itself. At the present time the RTACS model is in an early stage of development, but its potential effectiveness has been demonstrated on a hypothetical basis.

When a control system is being considered, two basic questions arise. First, is a project feasible in terms of the five basic kinds of feasibility?

1. Technical
2. Political
3. Economic
4. Social
5. Environmental

Second, after the system is adopted, what will be the effects on the organization? This is related to social feasibility.

There are a number of actual examples of control systems in the planning or implementation phases in the United States. Some of these are described in detail in the report. Noteworthy are the systems in Seattle, Minneapolis - St. Paul, Detroit, and San Francisco. In addition, a large number of American cities have developed control capabilities for other urban water functions.

The research described has two more planned phases. In these phases it is intended that the development of control criteria and control logic can be greatly facilitated on an actual system. Also, it is intended that the RTACS model can be improved to the point where it can be used as a design tool for RTAC systems. As the ultimate objective, generalized guidelines for the development of control criteria and logic and for the utilization of the RTACS model will be developed.

SECTION II. THE ELEMENTS OF A COMPUTER BASED CONTROL SYSTEM

A computer based control system for combined sewers would incorporate remote operational control of the system. Combined sewers and how they might be "operated" and the components of control system are discussed in this section.

Manipulation of a Combined Sewer System

Portions of several sewer systems have been or are currently being placed under central computer control. These include systems in San Francisco, Minneapolis-St. Paul, Detroit, Seattle, Cleveland, and Grand Rapids, Michigan. The control projects in all but Cleveland and San Francisco were partly funded by the EPA Storm and Combined Sewer Demonstration program.[12] Summaries of the control systems in Minneapolis-St. Paul, Detroit, Seattle, and San Francisco are given in Section III.

The Minneapolis-St. Paul concept involves controlled storage of potential stormwater overflow in an interceptor system. Flows at various locations along the interceptor are anticipated by relating measured rainfall to runoff on a real time basis. Since many storms, particularly those of the summer thunderstorm type, have significant spatial variability, operating decisions can be made on a basis of maximum utilization of available storage space. Operating options occur at the points where trunk lines intersect the interceptors. A gate located in the overflow line between the overflow discharge point to the river and the diversion to the interceptor can be raised ("operated") to prevent overflows from entering the river or lowered if the interceptor is full. Also, the regulator gates can be opened or closed to control the rate of flow into the interceptor.

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[12] "Storm and Combined Sewer Demonstration Projects," U. S. Department of the Interior, Federal Water Pollution Control Administration, January 1970, p. 3.

San Francisco, on the other hand, has no available storage capacity in its existing combined sewer system; hence, they are considering upstream detention of storm flows at several locations in addition to low lying peripheral basins coupled with regulated release to a central treatment plant. The operation of their system requires that rainfall patterns be anticipated and related to runoff at various points. Again rainfall information is a key input and must be obtained on a real-time basis.

Seattle is more fortunate than San Francisco in having a substantial excess capacity in their trunk sewers except under conditions of maximum storm runoff from tributary drainage areas.[13] Flow can be stored in the trunk sewer and then released to the interceptor after the storm flows have receded. Again, rainfall information on a real-time basis followed by storm flow predictions are key elements of the control system.

Detroit illustrates another similar but somewhat different concept of combined sewage storage and treatment. The combined sewer system in Detroit is characterized by very flat slopes and interconnected conduits that resemble a water distribution system. The Detroit system takes advantage of these characteristics and incorporates in-system storage, interceptor storage, and flow routing to reduce combined sewage overflows. Just as elsewhere an important aspect of the Detroit scheme is rainfall anticipation. Storms are detected long before they affect the combined sewer drainage basins, and potential storage locations are emptied to accept and store the expected storm flows.

The above examples (Minneapolis-St. Paul, San Francisco, Seattle, and Detroit) are each unique in their application of storage combinations, but have one thing in common: the real-time operational control of portions of the combined sewer system based on rainfall information. To be most effective, real-time operational control must be part of an overall management scheme included in what is sometimes called a "systems approach." The following quotation sums up nicely what a systems approach means to combined sewer management:

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[13]"A Computer-Directed System for Regulation of Combined Sewage Flows," by Charles V. Gibbs, Stuart M. Alexander and Curtis P. Leiser, ASCE National Water Resources Engineering Meeting, Atlanta, Georgia, January 1972.

"The systems concept in its simplest form envisions the management or control of all elements or facilities which are parts of the sewer system to:

1. Make maximum utilization of interceptor sewer capacity to carry combined sewage to the wastewater treatment plant;

2. Make maximum utilization of in-system storage;

3. Give priority in the interceptor sewer to those flows which have a higher pollutional load and which, if they overflow, would result in adverse conditions in receiving waters; and

4. Integrated use of combined sewer overflow storage and treatment facilities.[14]

Thus, systems control or management converts the combined sewer system from a static system where all components have preset functions which are not easily changed, to a dynamic system where the elements can be manipulated or operated as changing conditions dictate.

Elements of a Combined Sewer Control System

The ability to control or manage a combined sewer system on a real-time basis is dependent on a computer based control system. Information from the field such as rainfall, water levels in sewers and receiving waters, quality conditions, gate positions, and pump settings must be used to assess the situation and make decisions as to alternative courses of action. The decisions must be made in a matter of minutes, and instructions for operating gates, valves and pumps must be issued and acted upon without delay. Facilities and techniques are required that will efficiently route and store (control) combined sewer flows within or without the sewer system according to a planned scheme of action. The hydrology and hydraulics of combined sewers are extremely complicated, giving rise to the need for computer assistance.

The components comprising a combined sewer control system, as shown in Figure II-1, consist of the following:

1. Sensing elements: Instruments to measure rainfall, water level, flow rate, quality, etc.

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[14] Combined Sewer Overflow Regulator Facilities, American Public Works Association, Chicago, Illinois, June 1970, p. 109.

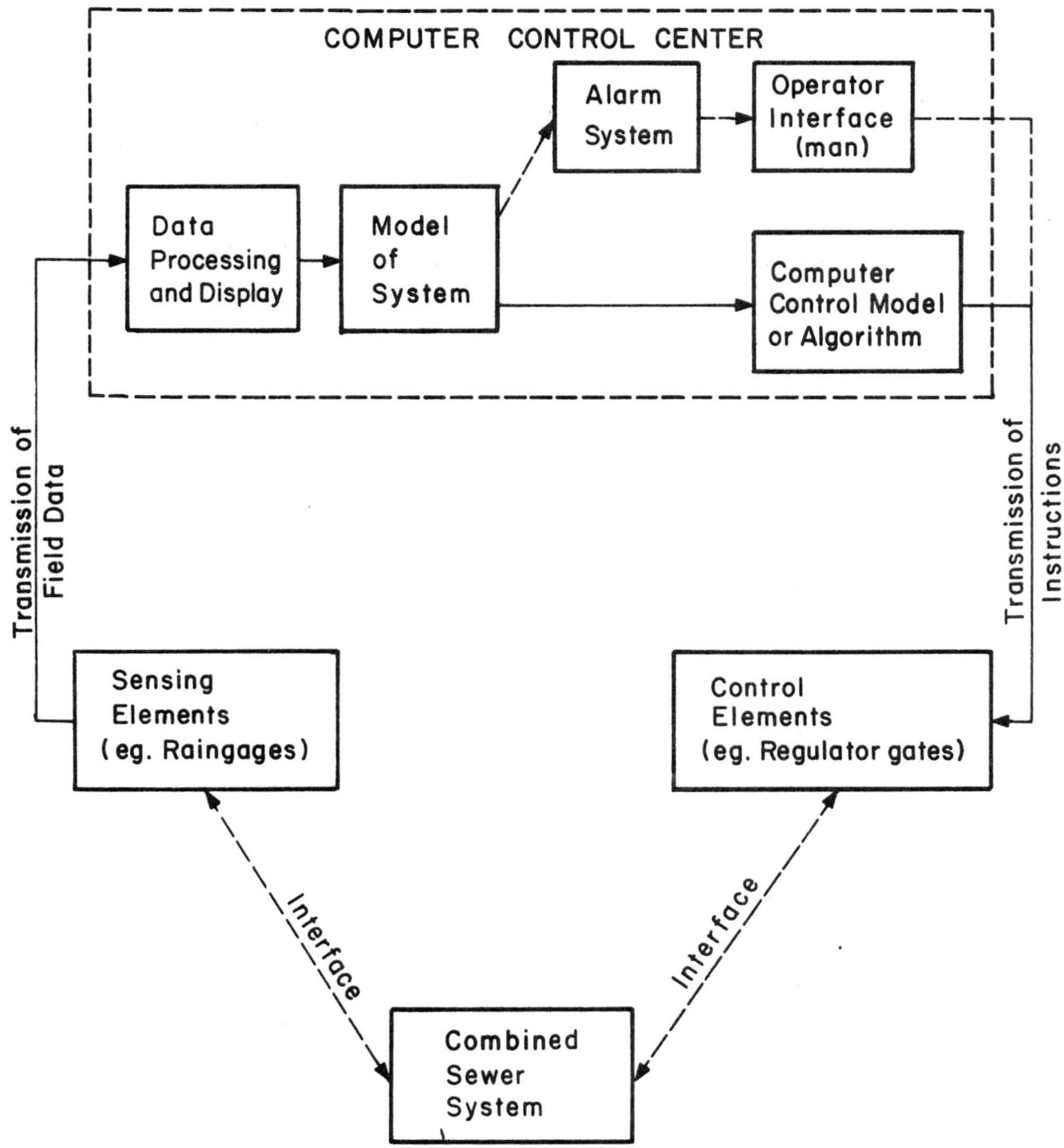

FIGURE II-1 COMPONENTS OF A COMBINED SEWER CONTROL SYSTEM (Control Cycle in Automatic Mode)

2. Computer control center: Computer based facility to receive, process, display incoming data, and determine course of action if in automatic mode.

3. Field control elements: Gates, valves and pumps which can be remotely actuated to control flow.

4. Information transmission: Facilities such as telephone lines, microwave and radio that transmit data from the field to the control center and directives from the control center to the field control elements.

The system illustrated in Figure 3 is closed loop or automatic. The sensing elements such as rain gauges, quality parameter probes and level sensing devices, measure basic data which define the field conditions. The field data is transmitted to a control center where expected flow conditions at various points in the combined sewer system are estimated with assistance of computers and associated software programs.

Using predicted flows, decisions are made according to predetermined operating rules that will reduce sewer overflows to a minimum. Signals are (indeed, must be) sent to the field control elements (gates, inflatable dams, pumps, valves) that will accomplish the operational objectives (storage of storm flow in interceptor or trunk sewers, diversion of storm flow to treatment facility or off-line storage, etc.).

Data transmission capabilities are required to transmit field data to the control center, instructions from the control center to the field control elements, and feedback or monitoring data from the physical system. Feedback capabilities are necessary to insure that predictions are occurring within reasonable accuracies and that the decisions made are having the desired effects.

In reality there is no truly <u>automatic</u> real-time control system in operation today (1972) for combined sewer systems. As previously discussed several projects are underway that incorporate some degree of control. There are other degrees or stages of computer assistance that can be exploited prior to complete real-time automatic control. Five such stages of development are:

1. Data logging and analysis
2. Data processing and reduction

3. Remote supervisory control

4. Automation of parts of system

5. Total "hands off" automatic operational control

The use of field data sensing devices, data transmission facilities and a computer or control center to accomplish one of the above objectives is sometimes called an "intelligence system." The status of most of the current intelligence systems is of the a and b type, with very few of the c type. Stage e will most likely be accomplished in programmable phases so that operating experience can be gained prior to full automation.

Excellent references are available[15,16,17] which describe the equipment that can be used, but a detailed description will not be included here. However, some terminology and equipment is discussed in a general way to provide a working knowledge of the field.

Computer and Control Equipment[18] The selection of computer and associated peripheral equipment for any stage of intelligence system is of great importance. The requirements of a computer center generally are:

- The acquisition of data
- The displaying of data
- The evaluation of data
- The logging of data
- Issuance of control commands

The selection of computers, peripheral equipment, and software (computer system programs if a digital system) is a difficult and very complex task. Computer hardware and software terminology is hard to understand except for the people who work routinely with computers. The development of well conceived specifications can spell the difference between a successful computerized operation and an unsuccessful one.

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[15] Combined Sewer Overflow Regulator Facilities, Ibid.

[16] Public Works Computer Applications, Special Report No. 38, American Public Works Association, Chicago, Illinois, August 1970.

[17] "Computer and Control Equipment," by Kenneth Medearis and Associates, Technical Report No. 2, CSU Metropolitan Water Intelligence Systems Project, Ft. Collins, Colorado, December 1971.

[18] Ibid. (This section based primarily on this reference which was prepared in connection with this project.)

Significant factors related to the selection of computer hardware are:

- Number and type of remote locations for which data are to be obtained.
- Time required to scan all locations.
- Degree of sophistication of the methods utilized for evaluating scan data.
- Time required for a complete cycle, beginning with data acquisition and ending with the accomplishment of an appropriate control command.
- Possible requirements for other than control functions such as statistical analysis and utility billing.

All computers basically have similar hardware components, but there may be significant differences in their speed, make up, and operating characteristics. These components include, but are not necessarily restricted to the following:

- An input unit
- A memory or storage unit
- A central processing unit
- An output unit

There exists an almost infinite variety of types and makes of the above components.

A computer and/or control automation effort presents a difficult analysis, design, and procurement problem. The specifications for the equipment and associated software must be carefully written, being explicit with regard to details. Competitive bidding may not be desirable because specifications can be interpreted quite differently by the compiling firms providing detailed designs. The writing of good specifications is very important and also very difficult.

One of the greatest pitfalls is the failure to gear specifications to final performance. One control system manager stated the problem tersely:

> Accomplishment of set goals or objectives should be the purchaser's main concern; a minimum amount of stress to be placed upon the type of hardware utilized. Too often specifications become so clouded with specific hardware demands, circuit cycle time and color coded module wiring that no one recalls what the original task was supposed to be. The seller of hardware or skills can innocently or purposely lead management into a forest of jargon

> and catch-phrases that cause the best managers to lose sight of the real goal. To expect that one vendor and one purchaser, or a number of vendors or a number of consultants would all mean exactly the same thing by the same computer catch-phrase, e.g. "program background," "time sharing," and "core swapping," would be presumptuous. The differences in each computer-oriented field (the different disciplines) are unbelievable.
>
> I would emphasize the need for gearing specifications in computer systems never lose sight of the true goals - elimination of overflow, improving the urban pollution problem, etc.[19]

Another problem is the enforcement of the responsibility for the specifications and their fulfillment. If responsibility is limited to proper installation and proper functioning of a particular part or segment of the system rather than functioning in terms of the total system to achieve the required production, the manager may find himself with a white elephant. To enforce sufficient responsibility managers would be well-advised to do the following:

- Make certain that contractual arrangements outline objectives of the system or performance requirements and obligations to achieve that performance.
- Include in the contract some approximations for criteria to be employed in judging performance.
- Make certain that judging criteria include requirements for such things as response time, continuous reading time, and percentage of acceptable error.

Transmission of Field Data and Other Information.[20] The various means of communication include leased telephone line, microwave, radio, or private lines; the most common of which is leased telephone line. Microwave is a form of point-to-point communications utilizing high frequency equipment. It provides a large communications capacity and there is usually not enough traffic to justify microwave for one utility service alone. Microwave operates on a line of sight basis. Microwave is very reliable, but is an expensive approach to a communications problem.

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[19] L. J. Bartscher, Memorandum to Duane W. Hill on "Hindsight Planning," August 31, 1971.

[20] Much of the information in this section is based on "Report on Operations Control Center for the Water Utility Department of the City of Dallas, Texas," *op. cit.*

Radio is rarely used where considerable information is being processed. Frequencies available are in most cases limited and are controlled and assigned by the Federal Communications Commission usually for use for only about five minutes out of an hour. Another serious disadvantage of radio is the possibility of required silence during periods of national emergency.

Private lines are rarely installed external to on-site or in-house locations. Easement problems, security, and the cost of installation make the external use of private lines impractical.

Leased telephone lines normally furnished by a telephone company are the most commonly used form of communications. Leased telephone lines fall into principal classifications which may vary in quality and performance from one company to another. These classifications are:

- Class 1, or Class C - A direct current slow speed telegraph circuit. Such circuits are suitable for individual control circuits.

- Class 2, or Class B - A direct current or low frequency teletypewriter or teleprinter circuit. Frequently Class 1 and Class 2 circuits are not available in residential areas of a city.

- Class 3, or Class A - A voice grade circuit. Generally this class circuit may pass audio frequency signals from 0 to 3,000 cycles per second on short distance lines. Longer lines requiring repeaters usually pass audio tones from 300 - 3,000 cycles per second.

- Other special classes which deal with high speed data transmission are available and can usually be furnished under special arrangements with the telephone company.

The flexibility in leasing arrangements for telemetry via leased lines is considerable and thus communications is not considered a serious constraint.

Telephone companies offer an invaluable source of information and assistance. The local company should be contacted prior to design for advice. This will reduce to a minimum future problems with communication and will result in the best service for least possible cost. The complexity of the telephone business including items like lines in use, billing, line quality and capability, trouble repair, security and records keeping make close liaison with the local telephone company a must.

Problems Regarding Automation and/or Control of Combined Sewers

Real-time control, particularly automatic control, of combined sewers or separate storm sewers offer some difficulties peculiar to these systems. Stormflow and resulting overflows occur over a small part of a year and at unpredictable times or frequency. Facilities for storage and/or treatment of overflows must be provided instantly and at any time of the day or night including Sundays and holidays. These requirements necessitate in many cases some form of automatic operational control. A major difficulty lies with the development of "control logic" which is the software that would make it possible for the control system to substitute for a human supervisor. Control logic will be even more difficult to develop for the operational control of separate storm sewers because all stormwater will have to be passed through specially constructed treatment facilities because of the lack of interceptor sewers leading to perennially operated wastewater treatment plants.[21]

> "Another liability is the scale of the control objective, even when restricted to the bounds of a city. The extent of underground stormwater conveyance conduits is indicated by the total lengths in the 95 square miles of the City of Milwaukee: storm sewers, 820 miles; and combined sewers 550 miles. Milwaukee has 465 combined and storm water drainage catchments, the largest being 1,820 acres and the median size being 25 acres..."[22]

Most urban drainage catchments have their own outfalls which is both an advantage and disadvantage. Their large number make it difficult to employ automatic control because there would be a large number of control elements.[23] On the other hand catchments can be controlled on a selective basis. The larger catchments and the catchments contributing the greatest pollutants would be controlled first. Total system control is very difficult, but selective control offers an alternative.

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[21] "Feasibility of the Metropolitan Water Intelligence System Concept," by M. B. McPherson, ASCE Urban Water Resources Research Program, Technical Memorandum No. 15, ASCE, New York, December 1971, p. 19.

[22] Ibid, p. 82.

[23] Ibid, p. 83.

It has been said that the

> "...ratio of art to science required for the automatic operational control of urban water services will probably be highest for storm sewer systems. Intimate knowledge of a sewer system's idrosyncrasies may well prove more important than exotic mathematical formulations. It appears, therefore, that the prospects for transferring control logic developed by one sewer department to a department in another metropolis are not particularly favorable on the whole. Well-formulated control criteria, on the other hand, should be eminently transferable, ...[24]

Storm and combined sewers offer probably the greatest challenge to automatic operational control of any of the water services. Storm and combined sewer systems are dynamic and would require many feedback features. Added to infrequent and undeterminable start-up requirements due to the unpredicable nature of storms, solutions are not easy.

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[24] Ibid, p. 87.

SECTION III. EXAMPLES OF COMBINED SEWER SYSTEM CONTROL PROJECTS

Perhaps the best way to illustrate what can be done with computer based control systems applied to the operation of combined sewer systems is to discuss some examples. Three systems have been installed and are either in operation or in start-up phases in Minneapolis - St. Paul, Seattle, and Detroit. One other city, San Francisco, is in the planning phases and is discussed also.

The Municipality of Metropolitan Seattle, Washington[25]

A total systems concept plan has been described in reports and technical papers prepared by Metropolitan Engineers, Consulting Engineers. The information following on feasibility studies of such a system for Metropolitan Seattle is excerpted from these documents.

The Municipality of Metropolitan Seattle ("Metro") has awarded a contract to the Philco-Ford Company for over $1,200,000 for furnishing and installing a Computer Augmented Treatment and Disposal System ("CATAD System").

The primary objective of the CATAD System is to permit optimum utilization of available storage within existing combined sewers in regulating storm water flows to minimize the frequency and magnitude of sewage overflows into Puget Sound. Successful implementation of the CATAD System will serve the immediate and urgent need for abatement of the pollution of Puget Sound by sewage overflows and postpone the multi-million dollar separation of combined sewers which can thereby be accomplished by an orderly construction program as funds become available. Further, it is expected that the degree of separation required will be substantially lessened by the CATAD System, thus saving many millions of dollars.

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[25] The entire description of the Seattle project is quoted from "Combined Sewer Regulator Overflow Facilities," *op. cit.*, pp. 110-114. Permission obtained from APWA.

To minimize the volume and duration of these overflows, motor-operated gate regulator stations are being built wherever major trunk sewers cross the main interceptor sewer. FWQA demonstration grant funds have partially contributed to construction of some of the regulator stations and all of the CATAD System controls. Ten regulator stations are now in operation and nine more are planned or are under construction.

The primary function of the Metro system is the interception of sewage from the collector sewers of the various cities and sewer districts in the Metro service area and the conveyance of the sewage to a treatment plant.

A significant portion of the Seattle Metropolitan area, including the downtown area and the major industrial area along the lower Duwamish River, is presently served by combined sanitary and storm sewers. All of these combined sewers are tributary to the West Point System. Economic considerations dictated that neither the interception system nor the treatment plant be designed to handle storm flows in addition to ultimate sanitary flows. Thus, during some storms, it may be necessary to overflow untreated combined sewage into the Duwamish River and into Puget Sound.

Existing Local Station Controls. Each regulator-outfall station has been provided with local automatic controls which use operating conditions at the station as control references. Diversion of flows from trunk lines into the interceptor sewer is controlled by a regulator gate which is modulated to maintain a preset maximum level in the interceptor sewer. When the interceptor level is above the control set point, sewage is stored in the trunk sewer up to a preset maximum level. When this level is exceeded, the outfall gate is opened in steps to maintain the level at the overflow set point. The maximum tidal range in Puget Sound is about 16 feet and many of the outfalls are below high tide levels. Therefore, outfall gate controls have been provided with tidal override features which automatically maintain the trunk level control set point 6 inches above the tide level. The existing controls are of the pneumatic type, water levels being sensed through bubbler devices.

Objectives of Controls

The principal objectives of the CATAD System controls are as follows:

1. To provide optimum trunk sewer lines;

2. To permit utilization of potential storage capability of collector and interceptor sewers in separated areas under storm conditions and to make available the maximum capacity of the interceptor for combined storm and sanitary flows in unseparated areas; and

3. When overflows are necessary, to control such discharges at selected locations so as to obtain minimum harmful effects on marine life or public beaches.

Control Procedures. The regulation of storage in the sewage collection system will be accomplished by controlling the operation of regulator stations and of sewage pumping stations.

Since the primary objective of the CATAD System control is to reduce the number of occurrences of sewage overflows, it was considered essential that a high degree of reliability be built into the design. Therefore, an overflow occurrence directly attributable to any failure of the remote control equipment including the communications channel could not be tolerated and the criterion was established that upon failure of the remote control equipment, the station would be restored to local automatic controls in an orderly procedure.

Storage control at regulator stations is accomplished through direct control of the position of the regulator gates which control the volume of sewage being discharged into the interceptor sewers and consequently the volume of sewage being stored in the trunk sewers. The regulator gate will be returned to local control only on loss of the remote signal.

The storage of sewage in the trunk lines with overflow provisions is limited to a preset maximum level by a local outfall gate controller. If sewage is stored above the set point level the outfall gate will open, resulting in an overflow. In establishing the set point level for the outfall gate controller, the most unfavorable tidal condition has been considered since the local station controller does not include logic for determining either the direction of tidal movement of the maximum level of the next high tide. Consequently, the trunk level set point has been set low enough so that peak flows can be stored for the maximum duration of the high tide condition, which imposes a severe limitation on the use of potential storage in trunk lines.

In order to overcome this limitation when operating under remote control, it is necessary for the CATAD System to include remote controls for the outfall gates. Two procedures were investigated for these controls, as follows:

1. Direct control through the gate motor controller, and
2. Indirect control by varying the outfall gate controller set point.

Direct control of the outfall gate position from the central terminal would result in potential backup of sewage in the trunk if telemetry to the station failed while a storage operation was in progress. This problem cannot be resolved by restoring the station to local controls since this procedure would result in an unnecessary overflow if the level of sewage in the trunk was above the local set point.

Indirect control of the outfall gate through control of the set point provided a more satisfactory solution.

As in the first alternative, loss of the telemetry signal could result in a potential sewage backup if the set point had been moved above the normal level for local control or in a potential overflow if the set point was abruptly lowered from the abnormal high level on the loss of signal. To prevent either occurrence, electronic circuitry was installed at each outfall gate controller which will cause the outfall gate set point to be restored to the normal level for local control over a selected period of time. The time interval will be sufficient to allow sewage stored in the trunk sewer to be discharged into the interceptor through the regulator gate.

Remote control of the set point is accomplished by transmission of a contact command signal to the remote terminal which opens or closes 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 potentiometer signal is converted to a digital quantity through an analog to digital converter and transmitted back to the central terminal. When the desired set point has been reached a contact command signal is transmitted to the remote terminal which opens the contact.

A loss of signal from the remote control equipment will initiate a local control restoring sequence. The restoring circuit equalizes the remote controlled set point with a constant signal from a manual set point device at a prescribed rate through a closed-loop balancing circuit.

Pumping Station Control. Sewage pumping stations in Metro's system contain from three to six variable speed pumps. Existing pneumatic controls at these stations use a pressure signal which senses the influent sump level as a control reference. In response to changes in the influent level, the controller varies the pump operating speed and at designated levels changes the pump operating mode. The operating mode determines the number of operating pumps or, where the station contains pumps of more than one size, determines the specific combination of pumps.

The alternative for remote control of the pump stations were similar in principle to those investigated for control of the outfall gates. These alternatives were as follows:

1. Direct control, overriding local controls, and

2. Indirect control, overriding the pressure signal from the influent level sensor with a computer directed control signal. The direct control procedure would have required substantial modifications and extensions to the existing local controls which, in the case of the larger stations, were already quite complex. Direct control also introduced major problems of designing and installing the necessary circuitry for effecting an orderly transfer from remote to local control upon failure of the remote equipment.

As in the case of the regulator stations, indirect control provided the most satisfactory procedure. No modifications to existing local controls were necessary and relatively simple methods were available for controlling the set point and for restoring the station-to-local control. These methods and the control circuitry used for implementation are similar to those used for restoration of the outfall gate set point. The computer-directed control reference is varied by positioning a stepping motor connected to a potentiometer which provides a proportional current signal. The current signal is converted to a pneumatic signal through a current to a pressure transducer as the input to the local control equipment.

Loss of remote signal will initiate a sequence for restoring control to the influent level pneumatic signal which is equalized with the influent level signal through an electronic balancing circuit. Equalization takes place over a sufficiently long time interval to permit the local controller to settle into the control mode which is appropriate to the inflow rate without overshooting.

CATAD Equipment. The CATAD System includes the following principal items of equipment:

1. A computer central processor with input and output terminal equipment;

2. Peripheral input and output devices;

3. A digital transmission system; and

4. An operator's console.

The computer central processor is a Xerox Data Systems XD5 Sigma 2 Computer which is a high-speed unit with an access time of 920 nanoseconds to each 16-bit word of core memory and a maximum channel input-output transfer rate of 400,000 8-bit bytes per second. The initial system will provide 32,768 words of core memory expandable to 65,536 words which will be supplemented by a fixed head disk memory with a capacity of 1,474,560 16-bit words and an average access time of 17 milliseconds.

In addition to its data gathering and control functions, the computer will be time-shared by background data processing operations. For this purpose the system includes such peripheral input and output devices as a line printer, card punch and reader, and a paper tape punch and reader, in addition to the customary programmer's console.

Operator's Console. An operator's console and wall map display at the central terminal will serve as the interface between the operator and the control system. The console will incorporate light panels for displaying and operating status and alarm conditions at any remote terminal, and push-button arrays for selecting point locations for the execution of control functions and for data entry. A major feature of the console will be a bank of seven cathode ray tubes for display of quantitative operating data from selected groupings of pump and regulator stations which are located within a common area and are related from an operating standpoint. The operating data to be displayed will include both observed data, such as water levels, and computed data, such as sewage flow rates and storage volumes.

The wall map will supplement the operator's console by associating each cathode ray tube display and each alarm with its geographic location. Four lights will be situated adjacent to the location of each station to indicate one or all of the following conditions:

1. The station is one of the group being displayed on the cathode ray tubes, or a supervisory control command is being executed at the station.

2. The station is operating under remote control from the central terminal or is under local control.

3. An overflow is taking place at a regulator station or a high influent level is occurring at a pump station.

4. Alarm condition is present at the station (light blinks until the situation is corrected).

Telemetering. All data from regulator-outfall and sewage pumping stations will be telemetered to a central location in Metro's offices over leased telephone lines. At the central terminal these data will be entered in a process control computer which will also direct the data gathering. Control signals from the central terminal will be transmitted as contact operate commands.

Monitoring. A two-phase monitoring program has been implemented to evaluate the effect and eventually to provide input data for control of the CATAD System. Half of the monitoring program examines the receiving water quality; the other half checks on overflow strength and volumes.

The Duwamish River is monitored automatically by five robot instruments that telemeter dissolved oxygen, temperature, pH, conductivity, turbidity and solar radiation information hourly to a central recording station. This information is supplemented by manually collected receiving water samples at some 55 locations in the immediate study area (nearly 300 points in the entire Seattle area). Bacteriological and additional chemical tests are run on the manually-collected samples.

A second study centers on the overflow outfalls themselves. Refrigerated automatic samplers have been installed at nine overflow sites and will be installed at four more when the adjacent gate control structures are completed in 1970. These automatic samplers also are supplemented by a manual sampling program which adds bacteriological analyses to the chemical tests run on automatically collected overflow samplers.

The monitoring program: (1) provides information on amounts and variation of loading to receiving water caused by combined sewage overflows, (2) establishes relationships between overflows and rainfall characteristics, (3) provides information to determine the benefits of converting from locally controlled regulators to total system control, (4) locates critical overflow sites or other pollutants-should be programmed to be the last overflow point under total system management, (5) assists in locating sources of undesirable industrial wastes within the city, and (6) allows evaluation of the effects of Seattle's combined sewer separation program and other sewer construction activities within the collection system.

System Operation. It is planned that the central terminal initially will be attended by an operator only during the normal 40-hour work week. While this operator is on duty, the system initially will be operated in a supervisory control mode. During the remaining hours, control will be returned to the local stations, but data gathering and alarm monitoring from the central terminal will be continued.

When a mathematical model of the system has been developed and adequately reconciled with observed operating characteristics, the system will be put under program control by the computer.

Minneapolis-Saint Paul Sanitary District[26,27]

A system of computer control of its combined sewers has been developed for this important District, to "maximize capture of urban runoff by the

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[26] The Sanitary District is now the Sewer Board which is part of the Twin Cities Metropolitan Council.

[27] The entire description of the Minneapolis-St. Paul project is quoted from "Combined Sewer Regulator Overflow Facilities," ibid., pp. 114-117. Certain figures are omitted.

combined sewer system." Its purpose is to eliminate "past methodologies (which) assume the 'worst case', establishing the limiting threshold at the peak design conditions, necessarily requiring a low threshold limit to avoid damage due to flooding during extreme runoff. This method allowed overflows to occur during light, frequent runoff even though the system was not being used to fullest capacity or advantage."

It is evident from this statement by a representative of the Sanitary District that the new computer-controlled system will make fuller use of the in-sewer system capacity and markedly reduce the pollutional overflow wastewaters discharged into the upper Mississippi River.

The following excerpts have been taken from reports covering the new system.

Project Objectives. The project objectives, as outlined in the Minneapolis-St. Paul Sanitary District (MSSD) grant application to the Federal Water Quality Administration, were as follows:

> "The proposed project will demonstrate a new technique of instantaneous observation and control of interceptor system performance, based on adequate information, to drastically reduce losses of combined wastes. Information gathered will provide a basis for further reduction of losses by using trunk sewers for storage and the facilities constructed will allow such a measure to be attempted. Post-construction evaluation will provide information which will allow the method to be adapted to other large combined sewer systems of differing configuration and climatology.
>
> Since the majority of losses of wastes occurs during the recreational season, considerable benefit to the Mississippi River, where it passes through the populated area, will accrue."

Regulator Modifications. Modification of regulators and installation of the data acquisition and control system (DACS) were the largest of the tasks required for the physical installation. Regulators were typically modified to meet the needs. Existing floats on gates were removed and replaced by hydraulic cylinder operators. Inflatable dams were installed in the trunk sewer outlet to the river. Level sensing bubbler tubes with transducers and gate position slidewires were installed to provide sewer level and regulator status information. The control and telemetry equipment was installed in underground vaults.

Leased Telephone Lines. The leased line communications system utilized eight pairs, each connected in party-line fashion to a number of individual remote stations. Connection in this fashion minimizes line rental costs and substantially reduces equipment costs and maintenance problems. A slight sacrifice in access time and system redundancy and reliability occurs. Access time for any data point is less than two seconds. The system uses random access and by proper selection of sampling frequency, adequate system response is obtained.

Data Acquisition and Control System. The data acquisition and control system provides both manual remote, as well as automatic, control of the system by the central computer. The interface equipment uses multiplexed parallel tones to connect the manual controls and the computer to the leased communications lines. Table No. III-1 shows the number of measurements and control functions provided by the system. In addition to the out-plant functions shown, equipment was provided and interfaced to the treatment plant process to log approximately 250 points of plant process data.

Table III-1

NUMBER OF MEASUREMENT AND CONTROL FUNCTIONS

MINNEAPOLIS-ST. PAUL SANITARY DISTRICT

FUNCTION	NUMBER OF LOCATIONS	NUMBER OF POINTS
Level Measurement - Interceptor Sewers	12	12
Level Measurement - Trunk Sewers	15	16
Level Measurement - Outlets to Interceptors	14	14
Gate Positions and Controls	17	34
Rain Gauges	8	8
River Quality Monitors	5	30
Alarms	19	19
	(a)	133

(a) Total number of locations of telemetry equipment is 37 due to overlapping functions at certain stations.

River Quality Monitors. Five river quality monitor stations were installed, one in a permanent location and four in semi-portable trailers. The units measure chlorides, conductivity, dissolved oxygen, oxidation reduction potential, pH, and temperature. The units are installed in the 21-mile stretch of river in the urban area. They are intended to be used to measure the effect of combined sewer overflows on the river.

Sampling and Analytical Program. An extensive sampling and analytical program was undertaken and operated for various periods during two years of the project. Approximately 25,000 hourly grab samples of wastewater were obtained and analyzed, using automated sampling and automated chemistry techniques. Determinations of chemical oxygen demand, kjeldahl nitrogen, ammonia nitrogen, dissolved phosphate, and chloride ion concentration were made.

Data Reduction and Analysis. These data, and data obtained by manual sampling of the river, and from automatic composited plant influent samples have all been stored using electronic data processing techniques. The purpose of the sampling and analytical program and the placing of these data in ADP from were:

1. To facilitate an attempt to produce approximate chemical mass balances across the entire system;
2. To evaluate the pollutional losses from the combined sewer system to the river before and after modifications;
3. To possibly define the character and quantity of urban runoff in comparison with wastewater; and
4. To provide a basis for priorities of point of discharges at regulators, based on pollutional load at controlled locations.

Mathematical Model. The original purpose of preparing a mathematical model of storm runoff, regulator performance and interceptor routing was to provide a guide to the operator and assist him in making changes in gate settings during runoff events. In addition, as secondary objectives, the model preparation also was intended to be useful as a research tool and as a planning and design tool.

The mathematical model, using rain gauge data as input, generates a runoff hydrograph at each regulator, calculates the quantity of flow diverted by the regulators, and routes the diverted flow through the interceptor sewer system. The entire operation requires about 10 minutes to do all calculations and to communicate output information to the operator.

Detroit Metropolitan Water Services[28]

Faced with the problem of preventing pollution in the Detroit and Rouge Rivers and in Lake Erie, Detroit has evaluated what it characterizes as a "dubiously effective sewer separation program" at a cost of $2 billion, in comparison with a sewer monitoring and remote control system for controlling the pollution from overflows during numerous small storms at a cost of $2 million.

The total system would involve rain gauges which will be telemeter-connected to a control center; sewer level sensor systems; overflow detection facilities; a central computer; master data logging equipment; and a central control console for remote activation of pumping stations and selected regulating gates. The instrumentation system will enable the operators to anticipate storm flows; intercept "first-flush" flows; selectively retain storm flows; and selectively regulate overflows.

The following excerpts have been taken from a report on the Detroit system made by personnel of the Detroit Metropolitan Water Services.

The Detroit Metropolitan Water Services has been monitoring water pressures and remotely operating water pumping stations and valves throughout the metropolitan area for eight years. Utilizing this experience, DMWS studied the possibilities of installing a sewer monitoring system with remote control of sanitary sewage and storm water pumping stations and regulating gages. The following factors relate to the installation of a monitoring and remote control system.

1. There are large areas served by pumping stations whose tributary lines could be used as storage areas during small storms.

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[28]The entire description of the Detroit project is quoted from "Combined Sewer Regulator Overflow Facilities," ibid., pp. 117-119. Permission obtained from APWA.

2. The grades of the sewers, either rectangular or cylindrical types, are relatively flat, which would permit substantial storage under level conditions near the outfalls.

3. Interceptors along the Detroit and Rouge Rivers are fed through float-controlled regulators equipped with sluice gates which appear to be adaptable to conversion to remote-controlled, power actuated regulators.

4. Most of the 71 outfall points are equipped with backwater gates and/or dams which serve as automatic retention devices.

5. Interconnections exist throughout the system which could be used for flow routing if remote controlled gates are added.

6. From knowledge of the particular industrial plants connected to certain sewers, there apparently would be a wide variation in the quality of dry-weather effluent.

7. In order to utilize the potential of the system, it is necessary to have instantaneous synchronized information about the behavior of the system, including rainfall, sewer and interceptor levels, and the status of pumps, valves and backwater gates, as well as the ability to remotely operate the pumps and valves.

8. To later determine the improvements achieved through monitoring and remote control, it is first necessary to establish a base by monitoring the system as it would naturally behave.

Potential Benefits. With central system monitoring and remote control, the following benefits appeared possible:

1. The sewer system could be operated to contain completely a small spot storm.

2. Runoff could be anticipated, sewers could be emptied and in readiness, and grossly contaminated "first flushes" in areas adjacent to the interceptor selectively could be captured, especially during large storms.

3. All flow near the end of a large storm could be held in the system for subsequent treatment.

4. Regulators could be adjusted to get the most efficient use of the interceptor and to favor the most grossly contaminated inlets.

5. Backwater from floods in the Rouge River Valley could be selectively controlled.

6. Pumps could be operated to minimize basement flooding in the east side areas which have no gravity relief outlets.

7. The flow to the wastewater plant from various segments of the city could be better balanced.

Special Equipment. The recent Detroit installation includes the following equipment:

1. 14 telemetering rain gauges;

2. 89 telemetering sewer level sensors, 41 telemetering interceptor level sensors and 4 telemetering river level sensors;

3. 30 telemetering proximity sensors on backwater gates;

4. 38 telemetering probe-type dam overflow sensors;

5. 3 event recorders for storm water pumping stations discharging direct to river;

6. 1 central digital computer with drum and disc memory;

7. 3 data loggers with 30-inch platens;

8. 1 teletypewriter for input, output and alarm;

9. 1 central operator console;

10. 8 sets of equipment for the remote control and monitoring of pumping stations; and

11. 5 sets of equipment for the remote control and monitoring of sluice and flushing gates.

Anticipating Small Storms. In order to safely practice storm water storage in the sewer barrels, it is necessary to determine the correlation between the various storm intensities and the recorded downstream storm flow. From precipitation and flow data, the sewer hydrographs of the maximum amount of storm water that can be stored in the various combined system are being developed for each area.

The present level sensors on 25 of the larger outfalls in Detroit permit calculating the runoff from 86 percent of the area of the city. Measurement of the flow from the remainder of the smaller outfalls has been deferred because of the capital cost for equipment. However, some very reasonable estimates of the overflow can be secured since elapsed time of spilling is known, plus average runoff per square mile from other comparable areas. Figure III-1, Typical Level Cell Installation in Sewer Manhole-Detroit.

Small Storm Water Storage. The storage of flows from small storms within the barrels of sewers is dependent upon the following factors:

1. Size of box or parallel,
2. Slope of the conduit,
3. Imperviousness of tributary area,
4. Time elapsed since previous rain,
5. Available height in sewer before gates open,
6. Intensity of length of storm,
7. The level of the receiving water, and
8. Available capacity in the interceptor.

Available storage at the various outfalls either upstream of pumps or backwater gates, must be calculated and tabulated for use by the system control operators.

Any storage of runoff in larger trunk line sewers results in reduced velocity. Velocities below 2 feet per second usually cause graded sedimentation, with coarse deposits occurring upstream where the velocities are still relatively high and finer deposits downstream where the velocities approach zero. This is another problem which must be considered in the operation of a system with in-system storage.

Figure III-2, Flushing Arrangement, Detroit, indicates the physical location of a system of gates which has been installed in a three-barreled interceptor sewer. Dry-weather flow will be passed through only one barrel at a time in order to flush deposited solids to the treatment facility.

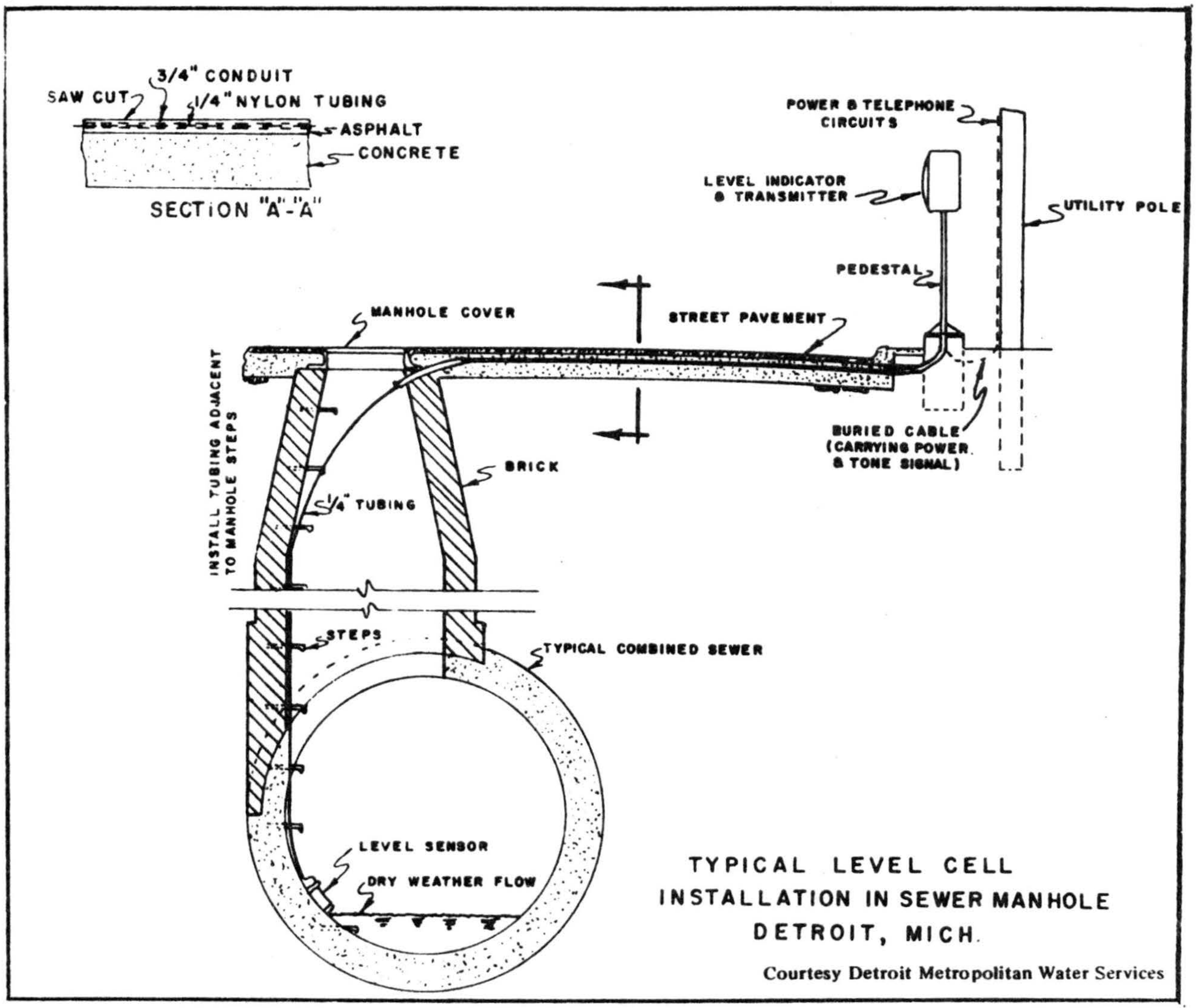

FIGURE III-1

Typical Level Cell Installation in Sewer Manhole Detroit, Michigan

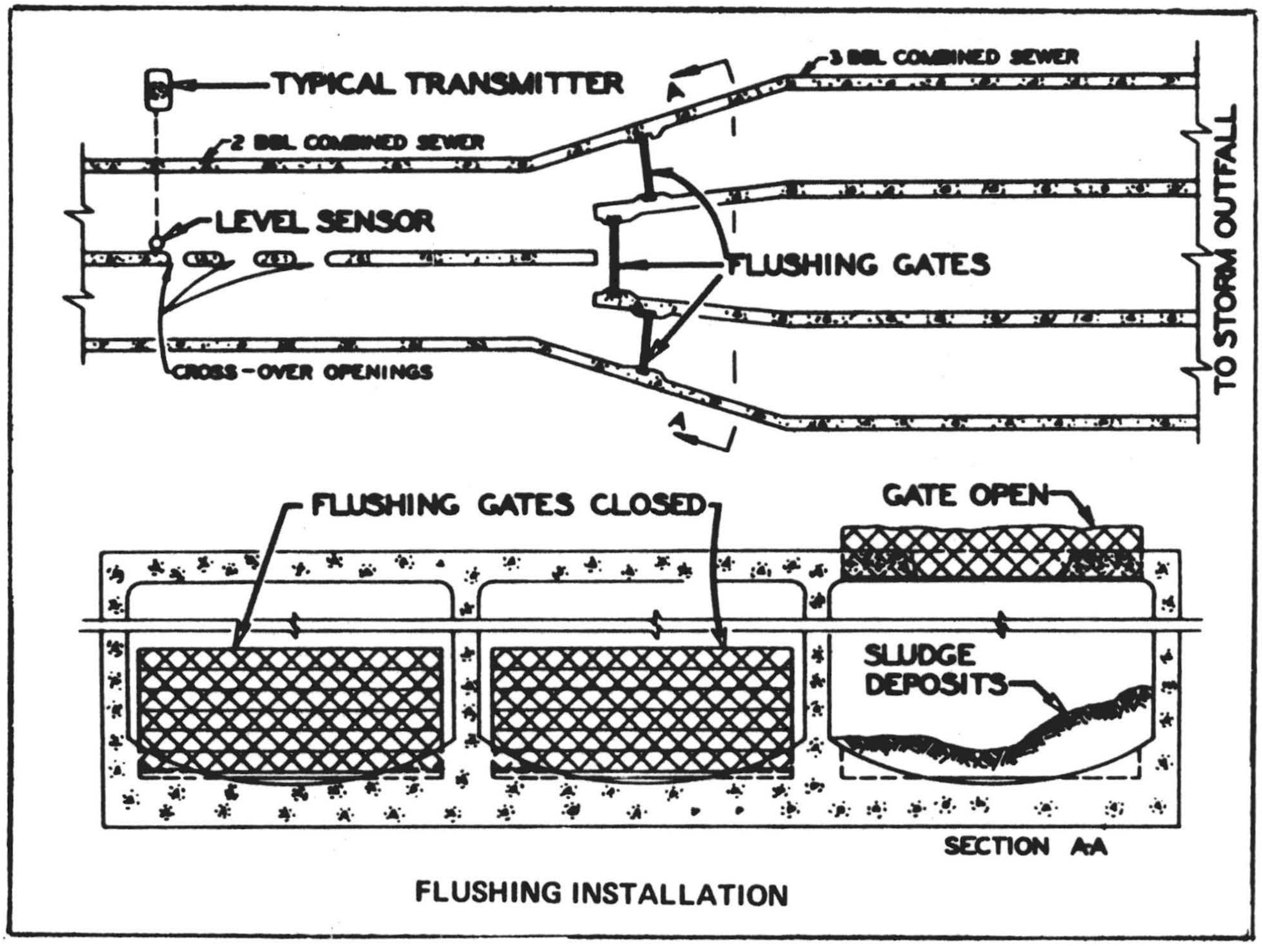

FIGURE III-2

Flushing Installation

San Francisco[29]

San Francisco provides an excellent example of total system planning. They very methodically and carefully prepared a master plan which identified alternatives for the facilities, costs, and construction schedules necessary for the control of pollutants going into San Francisco Bay and the Pacific Ocean from the City's combined sewer system. The alternatives will be presented to the decision-makers for selection of a preferred plan. The traditional approach to solving sewer problems had been to devise immediate and separate solutions to localized problems of flooding and water pollution control. San Francisco engineers recognized, however, that to properly assess the problem a systems approach was required that encompassed the mass balance relationships between system inputs and outputs.

The San Francisco sewer system is practically 100 per cent combined and serves an area of about 24,000 acres. The annual volume of wastewater flow from San Francisco is 36.5 billion gallons and the annual volume of stormwater runoff is 8.8 billion gallons. These volumes represent the annual water mass to be controlled prior to discharge. All of the wastewater and 2.8 billion gallons of combined sewage now receive treatment, leaving 6 billion gallons of combined sewage which enters the receiving waters without treatment.

All possible alternatives to solving the overflow problem were identified including the following:

- Separation
- Total treatment with no storage
- All storage using existing treatment
- Upstream and peripherial storage to selectively retain storm flow for controlled release to an intermediate sized treatment facility.

The economic and technical feasibility of each of the above alternatives was examined and the first three alternatives were eliminated from detailed consideration. The fourth alternative, which consists of several sub-alternatives, was studied in detail.

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[29] The description of the San Francisco project is based entirely on "San Francisco Master Plan for Waste Water Management," op. cit.

A report was prepared based on the fourth alternative including the several subalternatives which formed a City-Wide Sewerage Master Plan for the control of overflows. The plan was developed in three general stages which can be expanded in terms of total storage volume to allow overflow frequencies of eight times per year, four per year, one per year, and one every five years. Ninety per cent of the combined overflow can be controlled using a storage-treatment volume of less than 2% the annual overflow volume.

For the alternatives addressed in detail the master plan considered:

- Control requirements
- Required treatment
- Operational feasibility
- Acceptable discharge locations
- Costs

None of the above four alternatives was specifically recommended because the selection of which alternative to implement is another policy question involving large public expenditures. The alternatives will be presented to decision-makers and the alternative chosen to implement will be selected in the political arena.

The general plan developed includes consolidation of 43 existing overflow outfalls to 15. The storage of the storm flows incorporates a maximum of upstream storage in conjunction with peripheral detention basins used in catchments with elevations too low for the flow to be stored at higher locations. Upstream detention basins, if located above an inadequate portion of the system would not only reduce the overflows, but would also reduce the flow in the downstream sewers thus increasing their capacity. Upstream detention basins can also be located to relieve pooling of water on street surfaces during high intensity storms.

Included in the systems being recommended are tunnels to transport flow from one area to another. Flexibility is added to the system with inter-zone flow transport because many different sites for a treatment plant or plants may be considered. The tunnels, up to 34 feet in diameter, can also be used for storage; the tunnel bottoms will contain a separate transport section. Flow will be dropped into the tunnels from the surface system in such a manner that settleable and floatable materials will be directed into the transport tunnel. Flow can be discharged at a selected rate from the storage portions of the tunnels to the transport section. The control logic will include the capability of isolating each or any combination of tunnel storage sections from the tunnel transport sections in order that high releases can be made in those portions of the city experiencing high rates of rainfall.

In the upstream retention basins, the floatables and settleables will be diverted around the storage chambers to minimize the amounts of these materials retained in the basins. All storage facilities will contain an expansion chamber to slow the main sewer flow; a dropout will permit the normal dry weather flow to bypass storage and re-enter the sewer downstream. During storms, the settleables will drop out in the expansion chamber, and the floatables will collect in a scum chamber. The flow to be detained or stored will proceed through the expansion chamber below a curtain wall and over a weir type structure into storage. The flow will exit each upstream basin by gravity flow at an assigned rate to the downstream sewer. When the basin is full, overflowing occurs at the end of the tank through an overflow-discharge conduit into the downstream sewer. A spray system is incorporated in the storage compartment to wash the interior surfaces during the drawdown phase and a forced air ventilation system is provided. Control will be unattended automatic control via a master control system.

Shoreline retention basins will operate in much the same manner. As noted before in the upstream case, dry weather flow, and the floatable and settleable materials are routed around storage to the downstream sewer. In the downstream situation this flow is diverted to the interceptor ahead of the storage facility. Additionally, the flow exiting the storage basin is pumped into the interceptor, at assigned rates, for transport to the treatment plant for processing. The internal features of the shoreline retention basins are much the same as the upstream basins.

All storage will be interconnected in a system which will allow higher releases to treatment for those areas with greatest need during periods of non-uniform rainfall over the city. The interconnection of the drainage and storage system will allow the alleviation of multiple overflows at different locations and times caused by cellular high intensity rainfall patterns. Interconnection will also permit some judgment to be exercised in allowing <u>controlled</u> overflows in those areas of higher dilution potential or lower priority receiving water usage.

An important advantage of the controlled system is the ability to utilize full treatment capacity over an extended period of time. Preliminary determinations indicate that a treatment system should have a minimum running time of two to three hours. This must be coupled with an initialization period of about one hour.

Without central control and interconnection of drainage and storage systems the same facilities that would limit overflows to eight per year would permit 24 to 120 discrete overflows to occur per year. The automatic control system is therefore a vital element of each of the alternatives suggested.

Several treatment possibilities were investigated ranging from maintenance of the existing three plants and providing one wet weather plant for intermittent use in each treatment plant zone to combining all treatment facilities into one plant. Three treatment schemes each with three levels of treatment for the four overflow frequencies were identified. Scheme one was the most economical and consists of one treatment plant for wet and dry weather flow. This scheme would provide for only the absolute minimum of improvements necessary at the three existing plants until they are abandoned. The second scheme would provide only for one wet weather facility and an upgrading of the three existing, dry weather flow plants. Effluent from two of the dry weather plants would be diverted to the wet weather facility outfall for ocean disposal. The third scheme would be identical to the second with the addition of effluent from the third dry weather plant being diverted to the wet weather facility outfall for ocean disposal.

The storage-transport-treatment systems are interrelated in determining the amount of time the control system has to respond to each individual storm. A light rainfall of relatively short duration may be diverted to storage and released at a low rate for best treatment removal efficiencies. Conversely, a storm of high intensity rainfall and of long duration will require that the treatment plant respond as quickly as possible to the full operational mode.

The storage system capacity plus the transportation time to deliver the flow to the plant represents the maximum time period available for the plant to respond to wet weather conditions. The response time and commitment of facilities is a dynamic operation which must respond differently for each storm to produce the most efficient removals. To optimize the system a computer program must be in command of the whole system to consider the following input variables:

- Rainfall intensity
  - a. Temporal variations
  - b. Spatial variations
- Rainfall direction
- Storage volume available
- Sewer transportation time
- Storage volume available at the treatment plant
- Treatment plant rates
- Selection of controlled discharge location

Considering all the control variables available during wet weather operation the best results will be dependent on adequate data input. A system of rain gauges within the city is approaching the operating stage (Early 1972) and an advanced warning rain gauge system is being investigated. This aspect of the plan is critical to operational viability and must not be neglected in implementing any of the suggested alternatives.

Preliminary investigations of the alternative solutions of separation, increasing only treatment plant capacity, and maximum storage resulted in their abandonment as viable alternatives. The recommended solution of an automatic computer controlled storage-transport-treatment system thus was selected for the Master Plan. The next steps are selection of an alternative and then implementation.

SECTION IV. METHODS OF EVALUATING THE NEED FOR A CONTROL SYSTEM

A primary requisite for evaluating various alternative solutions to a problem is to examine all alternatives in a systematic manner. Another prime requisite is to look at the whole system as opposed to concentrating on any one portion. These requisites may seem obvious, but it is surprising how often they get sidetracked or ignored.

Identification of the Problem

The first step is to identify the problem. What is it you are trying to accomplish? Do you need to eliminate all overflows or reduce them by a specified amount? Is storm water storage available in your present system or is it already unable to handle storm flows? How soon do you have to show results? How much money is the taxpayer willing to spend?

Answers to these questions depend upon a thorough understanding of the combined sewer system. One needs to identify all drainage basins, and corresponding outfalls; conduit location, slopes and sizes; direction of flows; where sewer system is over or under capacity; what happens in terms of flow quantity and quality when it rains; and existing quality of receiving waters. It is also very important to determine the effect of overflows on receiving water quality and what effect the reduction or elimination of overflows will have on receiving water quality. This is important from the standpoint of justifying corrective measures and in terms of establishing a reference for post-project evaluations of receiving water quality to see what improvements were made.

Adequate hydrologic data is an important input to problem identification. Basic hydrologic information needs include rainfall, runoff and quality data. If this data does not exist then a data collection network must be established far enough in advance of planning and design to be of benefit. Concept feasibility can be studied with gross data (e.g., with data from one or two rain gauges in a city plus one or two outfall gaging stations.) The importance of adequate data is brought out in the San Francisco master plan experience. It was emphasized that

> "...the complexity of the rainfall-runoff process, the scarcity of base line data from which to measure process effectiveness, particularly in the areas of constituent levels in the receiving waters, characteristics of watershed runoff, and dynamics of pollutant buildup and flushing in catch basins and sewers, were all studied in a gross scale by use of typical samples.
>
> ...However, it is a basic recommendation that five years of hydrologic data acquisition and analysis be continued prior to the detailed design of the bulk of the Master Plan elements."[30]

Taking their own recommendations seriously, San Francisco is installing a hydrologic and hydraulic data acquisition system. This system is one of the most advanced in the world and will consist of 30 rain gauges and about 120 flow level monitors. All of the data will be telemetered to a central computer facility for processing and storage. The total area of San Francisco is 44 square miles; the rain gauge density is therefore about 1 per 1 1/2 square miles. A block diagram of the San Francisco data collection program is shown in Figure IV-1.

Identification of Alternatives and Determination of Feasibility

All alternative solutions to the problem should be identified. Many alternatives can be eliminated from detailed consideration by cursory examination and there will be a few that must be examined in detail. The feasibility of each serious alternative must be determined; in some cases an alternative might be dropped because of political constraints and other times technical problems. It is desirable to look at all types of feasibility somewhat simultaneously. The determination of technical and economic feasibility without political feasibility is useless. The various types of feasibility are summarized later in this section.

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[30]"San Francisco Master Plan for Waste Water Management," op. cit., p. VIII-1.

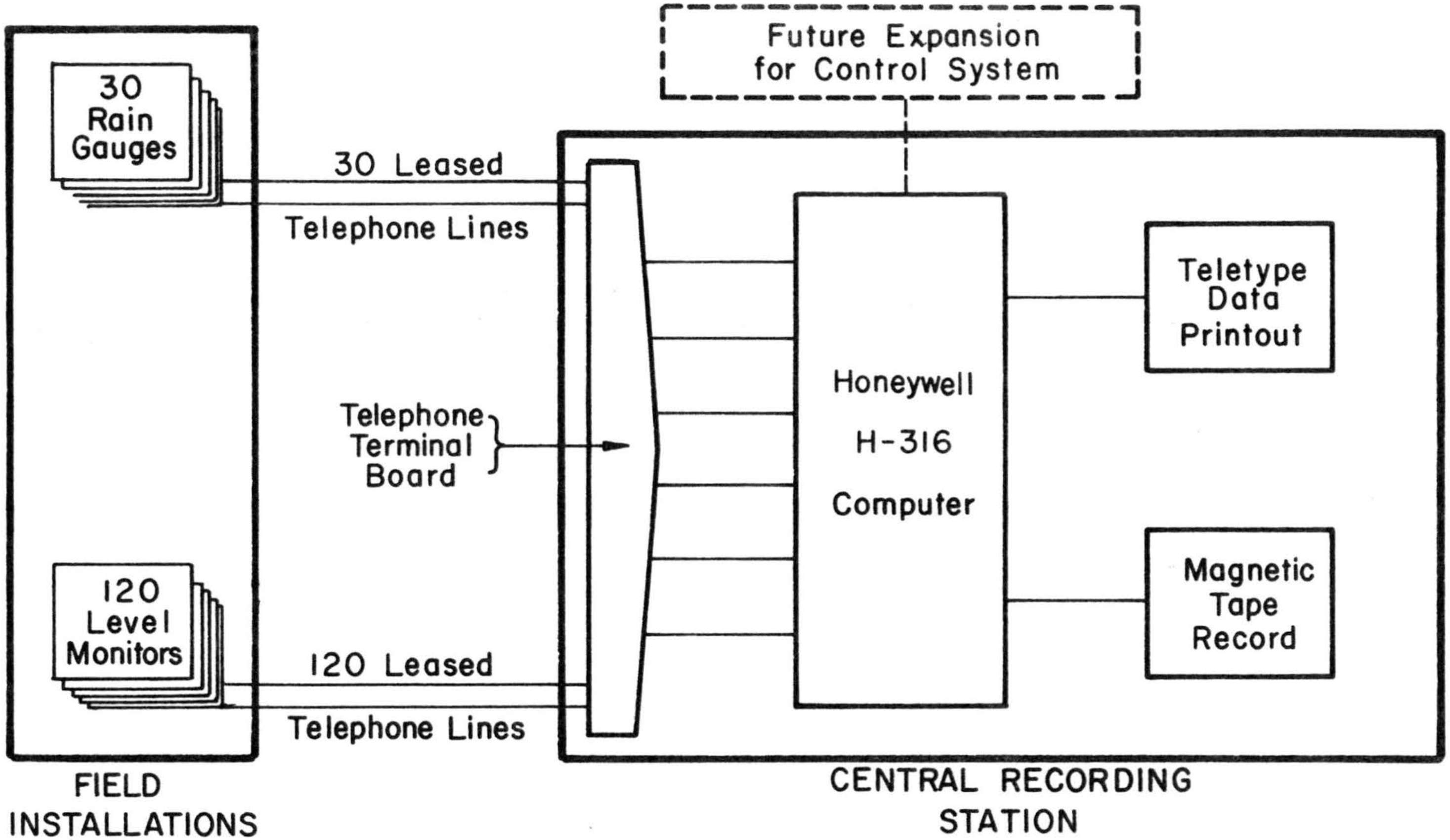

FIGURE IV - 1
San Francisco Hydrologic and
Hydraulic Data Acquisition System
BLOCK DIAGRAM

32 "San Francisco Master Plan for Waste Water Management," Preliminary Book of Plates, prepared by the Department of Public Works, September 15, 1971, Plate VIII - 1.

Technical and Economic Feasibility

Once the problem and the various alternatives are defined the next step is to determine the technical and economic feasibility of each alternative. Many alternatives can be eliminated rather quickly because of technical or cost constraints and a few alternatives will have to be examined very thoroughly.

The technical and economic evaluation process for each alternative will be different, but the objectives will be the same; a conceptual design will have to be developed to establish technical feasibility and to determine the approximate cost. A systematic process for identifying alternative solutions involving automation and control is shown in Figure IV-2. This process leads one through a series of questions with "yes" or "no" answers which bring out a total of 26 alternatives that must be evaluated for technical and economic feasibility.

For each alternative there are five basic classes of information which can be identified that make up an evaluation. These classes are categorized as follows:

- design
- costs and consequences
- operation
- maintenance
- performance

Various needs within each of these categories are listed in Table IV-1. This list is intended to be only exemplary in nature.

One of the tools available for evaluating a control scheme for a combined sewer system could be a simulation model of an entire control system. Such a model would probably be more useful in the design phase or in evaluations made subsequent to initial feasibility studies because it would involve a substantial commitment in time and funds to adapt it to any particular situation.

One cost that should be attributed to separation is many times overlooked; the cost of not being able to separate completely. There will always be either illicit sanitary connections to a separate storm sewer,

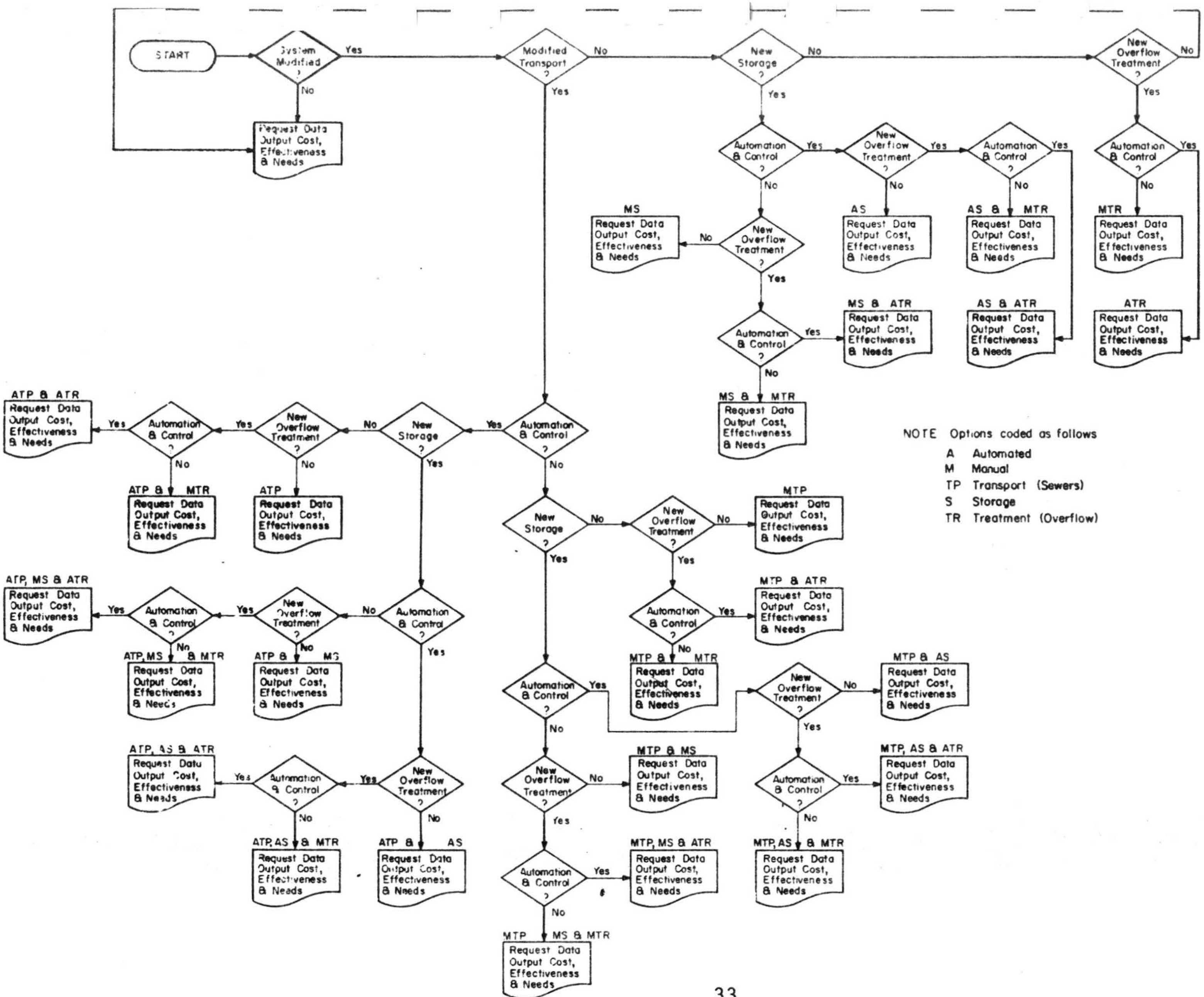

FIGURE IV-2[33]

Evaluation Process for Identifying Alternative Solutions

[33]"Task 3 - An Investigation of the Evaluation of Automation and Control Schemes for Combined Sewer Systems," by J. J. Anderson, R. L. Callery and D. J. Anderson, Technical Report No. 3, CSU Metropolitan Water Intelligence Systems Project, January 1971.

BASIC NEEDS IN EVALUATION METHODS BY CATEGORY[34]

DESIGN

Process Knowledge and Incremental Cost of Same
Central versus Multi-Point Control
Manpower versus Hardware
Potential Control Strategies
Real-Time Operating Response Required
Implementation Time
Reliability
Equivalence in terms of "Standard" Transport, Storage, and Treatment
Sensitivity Analysis
Develop Priorities

COST

Capital Costs
Operating Costs

OPERATION

Potential Control Strategies
Real-Time Operating Response Required
Reliability
Staffing Requirements
Operational Hazards
Emergency Requirements
Sensitivity Analysis

MAINTENANCE

Real-Time Operating Response Required
Reliability
Staffing Requirements
Maintenance Requirements
Sensitivity Analysis

PERFORMANCE

Effect on Treatment Plant
Pollution Reduction and Discharge (Quantity and Quality)
Damage Potential
Equivalent Rational Design Frequency
Sensitivity Analysis
Rangeability

TABLE IV-1

[34] "Technical Report No. 4 - An Investigation of the Evaluation of Automation and Control Schemes for Combined Sewer Systems," Ibid.

or sanitary connections made by mistake. Oil, soaps, and other wastes will also be dumped into the storm sewer either inadvertantly or on purpose. Wastes which normally found their way to treatment facilities in the combined system except during periods of overflow would be flushed into receiving waters during storms.

Storm sewers are being recognized as significant sources of pollution in some areas and if the public's demand for cleaner water continues it may be necessary to treat storm water. This is a probable future cost.

For people in the public works field there is nothing new about making technical and economic feasibility studies. It is important, however, to reemphasize that all alternatives should be considered in terms of how they effect the whole system; in other words, the systems approach.

A review of potential methods for evaluating the applicability and potential effectiveness of implementation of urban water resource systems and particularly combined sewer control systems are described in a report by Watermation, Inc. of St. Paul, Minnesota.[35]

Social Feasibility

Social feasibility addresses the question of whether a change should be accomplished even if it is technically and economically feasible. This is a question of how the action will affect people and the ultimate consequences of those effects. There is no fixed and proven method for determining what these effects might be, but the manager must be aware of potential effects on people.

For example, will people be put out of jobs? Will people have to be retrained for new and uncomfortable job settings? Will people be unduly inconvenienced because of construction in streets and on private property? Will people be relieved of tedious and boring tasks by computer assistance? Some of these potential social consequences are "costs" and some of them are "benefits." Although dollar figures cannot be attached to them in many cases, they should be considered in the evaluation process.

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[35]"Technical Report 4 - An Investigation of the Evaluation of Automation and Control Schemes for Combined Sewer Systems," Ibid.

Environmental Feasibility

Environmental feasibility has taken on greater importance from the public's point of view in recent years. It addresses the question of the effect the proposed activity will have on the environment. Regarding the control of combined sewer overflows, the concern for the environment is usually the principal motivating factor for action in the first place. If the alternative under consideration does not meet the environmental objectives of pollution control then it is not a feasible alternative.

Political Feasibility

Even though the technical, economical, social and environmental feasibility may be established, a project may not be politically feasible. Will the alternative selected win adoption in the decision making process? This is political feasibility and is a question of whether or not it can be done; this is the pay off. If it can be determined early in the evaluation process that an alternative is politically unacceptable, then the evaluation procedure can be terminated for that alternative.

Historically in the U. S. political feasibility was frequently decided largely in terms of economic feasibility. If the benefits in dollars exceeded the cost in dollars, then the riddle or question of political feasibllity was solved. More recently, however, questions involving social and environmental issues have been increasing in importance.

Many nontechnical constraints that may preclude project adoption are discussed in Section V. It is important that these nontechnical constraints be addressed in the evaluation process because it is at this stage of the game where "an ounce of prevention is worth a pound of cure."

SECTION V. SOCIAL AND POLITICAL CONSIDERATIONS[36]

Although now widely accepted by industry, automated process control has not been adopted extensively by public agencies. It is just beginning to be applied to the operation of urban water facilities. A major reason for slow acceptance in the public realm is the character of public agencies and enterprises, especially the character of their functions and behavior. This means that acceptance of automated process control will not only be somewhat more difficult to obtain in public than in private realms, but the technique and manner of obtaining acceptance will differ. Briefly, if management finds that automation is one of the most feasible alternatives for solution of a problem, the management must tailor their efforts, their programs, and the alternative itself to fit the characteristics of decision-making processes where acceptance has to be won.

Management also must tailor the alternative to the characteristics and requirements of its own system. The technical skills required to implement, operate, and maintain computer based control systems produce changes in administrative structure, personnel relationships and policy, group goals and loyalties, as well as methods for administering urban water resources. Automated control systems, moreover, can have broad environmental and social consequences which feed back to effect the character, operations and effectiveness of the control system itself.

Political acceptance, however, is of primary importance. Unless a major option can pass muster before the political decision-makers, it stands little chance of being implemented. An option may be technically possible and economically feasible yet the political decision-maker may turn it down on some other grounds. In fact, social and political considerations tend to dominate the policy making process despite the

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[36]This section is based on the following report: "Social and Political Feasibility of Automated Urban Sewer Systems," by Duane W. Hill and L. Scott Tucker, Technical Report No. 5, CSU Metropolitan Water Intelligence Systems Project, Fort Collins, Colorado, January 1972.

frequent tendency for them to play a relatively minor role in project planning and development stage. Besides, the credibility of the technical and economic evaluations may be questioned on different grounds in the decision-making arena than in the planning and design phases. Possibly of greater significance, however, is the higher priorities that decision-makers may give social and political costs and benefits, advantages and disadvantages.

The Value of a Project

Probably the most crucial question that management faces with respect to a major alternative is its economic, political, and social value or worth. Is a project worth it? The answer to this question determines a project's feasibility. The answer is not easy unless management chooses to resolve the question by using a simple formula which usually ignores important benefits, advantages, and disadvantages which do not fit the formula (e.g., measuring only those elements to which dollars can be assigned and ignoring the ones that are difficult to measure in terms of dollars such as the quality of life, water quality, or man hours lost).

Actually, a manager who is trying to solve a problem or win the adoption of some alternative in the decision-making process would be well advised to determine the feasibility of all possible alternatives and lay his findings before the policymakers for their selection. To the extent he is able, the manager should determine the feasibility for each alternative. There are five basic types of feasibility that he must address. These are:

- technical
- political
- economic
- social
- environmental

The first asks whether the alternative under consideration can be technically or physically achieved. If not, the idea is usually dropped.

If it is technically feasible then one must ask if it will be adopted in the decision-making arena. This is a question of political feasibility. In short whether a project is worth it or not is heavily dependent on whether the project, plan, or alternative will win approval in the decision-making system. No matter how worthwhile a technological solution to a problem may be, its worth is a direct function of its political feasibility or the barriers to getting it adopted in the decision-making arena. If the changes for acceptance are slim, then feasibility is certainly lowered.

In the past political feasibility has frequently been assumed if the benefits in dollars could be shown to exceed the dollar costs. However, it has gradually become more apparent that all benefits and costs cannot be measured in dollar terms; that is, economic feasibility is still exceedingly necessary to determine, but it must now be supplemented by other feasibility measures.

This points up the importance of a fourth class of feasibility -- social feasibility -- which is based on the effects and consequences for people. Will the introduction of a control system disrupt human relationships, lead to firings, make it necessary for employees to requalify for new jobs, or alter life styles in an undesirable way? There are also questions of social feasibility such as effects on human recreation, or the elimination of noxious odors, disease and inconveniences.

In recent years a fifth type of feasibility has emerged, that of environmental feasibility. This goes beyond the question of the consequences of changes to society and man, and asks about consequences to the environment.

Some Constraints to Project Adoption

The type of project being addressed in this report is one involving computer based control of combined sewer systems. The following discussion, however, is somewhat basic and can be applied to potential solutions to other problems of a technical nature.

Two major classes of constraints are discussed:

- those that constrain adoption of control systems
- those that constrain or impede continued successful operations of such systems.

First, a manager must be careful how he views a constraint. In some cases what is seemingly a constraint can be turned to an advantage. For example, some managers might view state water quality standards as impediments to their operation when the standards might provide justification for making desirable changes that might otherwise not have been attainable. Constraints should be inspected closely to determine whether they could be turned into advantages.

Social Choice Constraints

How the social system acts and reacts is extremely complex, especially in the U. S. where so many people can influence the direction of various activities. A manager has to be very careful how and where he tries to effect the social system. It is apparent in many cases that common sense approaches to solving a problem may in fact aggravate it. The tendency is to treat symptoms rather than causes and then to be surprised by an unexpected reaction. The following example illustrates this point:

> "...the symtoms of excess population are beginning to overshadow the country. These symptoms appear as urban crowding and social pressure. Rather than face the population problem squarely, we try to relieve the immediate pressure by planning industry in rural areas and by discussing new towns. If additional urban area is provided it will temporarily reduce the pressures and defer the need to face the underlying population question. The consequence, as it will be seen 25 years hence, will have been to contribute to increasing the population so much that even today's quality of life will be impossible."[37]

Another important characteristic of social and behavioral systems is the scarcity of points at which a system can be affected. As a result planners, managers, analysts, legislators, and other decision-makers are led into selecting the wrong places at which to affect the system. This is especially true for those who are "flying by seat the seat of their pants," so to speak.[38]

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[37] "Counterintuitive Behavior of Social Systems," by J. W. Forrester, Technology Review, January 1971, p. 7.

[38] Ibid.

A third characteristic of social systems is their tendency to produce short-term rather than long-term solutions. Many times a short-term solution to a problem will have adverse effects in the long run. Men live in the short-run so it is difficult to think otherwise. As John Maynard Keynes so aptly put it, "In the long run we are all dead."

These characteristics are presented to make the manager more cautious about seemingly obvious solutions and about taking the common sense or intuitive approach to problem solutions without careful evaluation. What can the manager do? He can first make a simple analysis of the urban system in which he is involved. He can try to determine how his decision will affect the various components of that system and their relationships. Second, he can also give more emphasis to long-run solutions. There are potential long term benefits that can be derived from the use of computer based control systems that are not always made a part of the evaluation such as the future flexibility that "operating" a sewer system can afford. For example, control systems should be scrutinized more closely to determine costs and savings from flexibility in treatment processes, storage optimization and effects on flooding, serving future re-use needs in water short areas, etc.

Suggested solutions to the social choice constraint are:

1. Obtain information about the urban system and its functions from simple urban system as well as economic analysis.

2. Commit a larger portion of funds, resources and time to defining long-run problems and secondary effects.

3. Upgrade agency political information levels and political skills.

Feasibility as a Constraint

The demands for certain forms of justification are in themselves sometimes severe constraints. As previously mentioned, project justification traditionally has been in terms of dollars. With such a strong commitment to dollar justification it is very difficult to develop feasibility in non-dollar terms. Consequently, some important benefits go unmeasured and may not affect the decision. Not included, for example, are benefits gained by doing something with a computer against doing it with a pencil in a frustrating manner. With regard to computer based sewer control systems, few if any dollar values can be placed on the flexibility that automation puts into the system. Nor can values be placed on the increased number of alternatives given management once a control system is in place. Moreover, despite all the furor over pollution, it still remains for someone to accurately and realistically estimate the costs of water pollution.

Equally serious, however, is the inability and failure to include several types of costs. Physical separation of sewers will result in losses in work time and the inconvenience to businesses and residences caused by street and building construction. Imagine the inconvenience of tearing up every street and building in downtown San Francisco to install a separate sewer system. Another example is the cost of the effort it takes to overcome political constraints or the amount of expensive personnel time and energy that may be involved in getting a decision through the political and social processes. In regard to control systems, no one yet has devised an adequate measure of the potential costs for labor disruptions that may occur (e.g., jurisdictional conflicts between electricians and pipe fitters).

Overcoming feasibility constraints will continue to plague the manager in the future. Technical and economic justification will not be discarded for social, political or environmental. The first two will always be essential. They must be supplemented; that is the key.

Like other alternatives, feasibility for the computer based control alternatives must be based on analysis of advantages and disadvantages, some of which have not previously been measured in terms of dollars. Some of these advantages and disadvantages are listed below:

- Improved quality of effluent to the receiving water.
- Increased system options;
- Secondary benefits from data collection and analysis;
- Use of computer in data processing activities, accounting functions and design;
- Increased safety;
- Reliability and maintainability (may be a disadvantage to computer based control systems).

Another measure that has been recommended by a water manager to overcome feasibility constraints is for management to encourage lay and professional decision-makers and politicians to attend regional and national meetings which address problems that managers face. There is evidence that such a policy pays off, especially with regard to implementation.

Suggested solutions to the feasibility constraint are:

1. Do the necessary homework on all types of feasibility - technical, economic, political, social and environmental.

2. Keep pace with the changing demand regarding feasibility.

3. Make certain that the following feasibility measures are included in any study:

   a. net improvements in water quality (both overflows and recurring water)

   b. benefits from increased flexibility and increase in system options

   c. secondary benefits from data collection and analysis

   d. secondary benefits from data processing activities

   e. increased safety

   f. reliability and maintainability

4. Encourage lay and professional decision-makers and politicians to attend more regional and national meetings.

Other Factors

Many technical managers have perhaps achieved their positions by pure competence alone. Many times these same managers have inadequate political and social skills for project implementation. One unnamed manager who was a technical innovator was quoted as saying:

> "Quote me if you want. I deserve to be a whipping boy in many ways, although my mistakes were human and resulted from a dedication to get something done. Like most people I believed I knew what was necessary politically, and in many ways I did. But too many of we experts think politics is easy to grasp or that our experience tells us all about it, because we could not have gotten to where we are if we didn't know about it. Believe me, I found out a lot I did not know, and unfortunately for the system, I found out some of these things too late."

In many cases one must be as politically adroit as he is technically or managerially competent.

Effects on the Organization

With the establishment of a control system come changes in organizational structure, personnel roles, and relationships between the two. The location of the computer control center, for example, can have an effect, sometimes adverse, on personnel. If a computer is located in a treatment plant the attitude of "that thing is spying on me" has been observed. On the other hand it is sometimes argued that proximity of a computer center to plant employees would encourage familiarity, allay fears and hostility, build pride in a modern image, and get support for the system at the operational level. In one system studied, a few of these goals had been fulfilled to some extent, but little evidence existed of such effects overall. Whether location of the computer center is in the plant achieves these goals or whether locating it elsewhere generates other problems is a question that should be carefully considered.

Introduction of a computer based control system means the introduction to the existing system of a new group ("computer types") of people with their own loyalities, goals, styles, and methods and procedures. It is important to note that using in-system personnel to form a new group or a part of it does not necessarily provide insurance against certain adverse consequences. Doubtlessly, many consequences are unavoidable, but managers might find it useful to remember that the introduction of a control system is more than the introduction of new technology and shiny machinery; it is equally the introduction of a new human process.

Low visibility of control system requirements and potentials can have adverse effects on both implementation and operation. One reason for low visibility can be that people in upper management and in political positions lack time, incentive, or resources to discharge their functions and obligations adequately. Still others do not have a sufficient overall understanding of control system needs and potentials.

Visibility and understanding among members of the upper echelons of organization are high priority needs for management. If only one or a few people in high places have a comprehensive understanding of system needs and potentials, probabilities increase that the unappreciative will constrain effectiveness and productivity.

An organization's internal and external people-to-people communications system requires identification and examination. Management should examine itself at all levels. Inevitably the engineering and human aspects must be adapted to each other if control system performance is to be achieved. The manager will probably require expertise either from within or without his organization both in the engineering and human domains to achieve his objectives. Failure to employ sufficient expertise in a proper manner measurably increases the chances for production failures.

Suggested solutions to the constraints of deficient political skills, organizational factors and low visibility are:

1. Recognition of adjustment for the social fact that introduction of a computer based control system involves a new group with its own group goals, job roles, work patterns, life styles, etc.

2. A close examination of the organization's communications systems and adjustment and improvement to its parameters.

3. Balanced use of engineering, psychological, and social science expertise.

4. Development of agency communications skills.

Communications

Communications can be compared to blood in the human circulatory system. It is in many ways the most vital aspect of an organization. Too many communications stoppages and an organization may be threatened with death. The most formidable communications constraint on management arises from stoppages and reductions in flow. Four factors are identified as contributors to communications failures in sewer systems.

1. Organizational status distance. In the great majority of instances there is far more contact between persons of similar status than between vertical layers of an organization. It is also true that the volume of communications flow is greater and easier from superior to subordinate than it is upward. Strong support should be developed in high places to maximize the tendency for high downward flow of communications. Also, managers of automated systems should be given as high a status as feasible to facilitate their power to communicate.

2. Specialization, functions, skills and expertise. Differences in specialization and interests tend to reduce the flow of communications in approximate proportion to the degree of the differences; like tends to talk to like to a greater degree than to unlike. This factor is particularly important in computer based control systems because of the requirement for engineering systems and computer experts whose specialization is not understood by many engineers, laymen or politicians. The difficulties are compounded by the tendency for computer and systems specialists to insist on a high degree of precision and quality control in a sewer system where more art than science is usually required. Systems engineers who believe that a sewer system should be run like a factor may find difficulty in communicating.

3. Language barrier. Each profession has a "screen of terms" that are not always understood by persons outside that profession. The manager should consider ways of getting the various professions (computer experts, systems analysts, hydraulic engineers, hydrologists, sanitary engineers and managers) to understand one another.

4. Attitudinal formations. Attitudes are orientations or tendencies to act that develop over a lifetime and shift slowly. Attitudes need to be identified and their potential effects defined; social and psychological research tools do exist for this purpose.

Suggested solutions. Suggested solutions to the constraints due to communications failures are:

1. Characterize the agency's communication system and flows.

2. Maximize use of downward communications flow.

3. Identify attitude sets and their primary and secondary effects upon the agency's communication system.

4. Without sacrificing requirements for technical competence, adjust recruitment criteria to insure acquisition of more skills in communications and the art of persuasion.

Planning and Implementation

Perhaps the inability and failure to develop and implement adequate plans is the biggest constraint on the development and implementation of successful and productive control systems. It has been previously inferred that in order to "operate" a sewer system that a "systems approach" must be taken. In other words, storms and subsequent runoff and overflows do not necessarily recognize jurisdictional boundaries, particularly where interconnections exist between jurisdictions. Comprehensive regional management is a necessary prerequisite to successful operational control of a regional sewer system.

If the impacts of sewage collection and treatment are regional and if regional solutions are required, then alternative solutions need to be compared in terms of their regional impacts as well as their more localized ones. The following alternatives, at least, need to be compared for their regional impacts:

- Increased interceptor and treatment capacity.
- In-system and off-system storage of combined sewer overflows.
- Treatment of combined sewer overflows.
- Total separation.
- Partial separation.
- Regulation and operational control of the combined sewer system.
- Combinations of the above.

Technical, economic, social and environmental impacts should be defined and compared in terms of both regional and localized effects. When such comparisons are not made, the probability of arriving at a less desirable alternative increases. Once selected and implemented, the less desirable alternatives become constraints on consideration and implementation of other alternatives later and on fulfillment of regional needs.

Constraints on adequate regional management include:

- Availability of Federal funding dollars for particular alternatives
- Limited and parochial perspective of selected types of local jurisdictions such as special districts.
- Use of a particular alternative on the part of its promoters to obtain status or to extract income.
- Temptation to get by cheaply or at low cost.

- Intergovernmental conflicts in jurisdiction and intra-governmental as well as intergovernmental jealousy.

- Lack of any regional agency with adequate capabilities to plan and implement plans which have a regional perspective.

- Internal governmental resistance to change.

- Fear of the implication of a new technology.

- Lack of financial resources.

Institutions will seldom if ever be ideal for fulfillment of objectives. To expect to change them in time to have any effect on a particular object is usually not practical. But by understanding them, the relations between them, and the behavior patterns within them the manager trying to effect a change will have much better chance of success.

Suggested solutions for the constraints due to planning and implementation failures include:

1. Close examination of the institutional frameworks.

2. Encouraging the development of regional approaches and organizations wherever and whenever they show signs of emerging.

3. Allocate more resources and manpower to long-range rather than short-range planning.

4. Insist that planning guidelines be followed and support efforts to enforce professional standards.

Crisis and Crash Programming as a Constraint

Often when a decision is reached, there is every reason to believe that speed in realizing the objective is primary. That may or may not be the case. In the case of sewer regulation and control, undue haste may sabotage ultimate productivity. Moving too slowly can be just as much a problem. Timing becomes a key factor.

One constraint on timing is the way in which consulting firms operate. Consultants, and clients tend to support them, like to move in, do their job, collect their fee, and move out. Once a system is installed, outside experts may be replaced by in-house personnel, or the consultant may be placed on reduced retainer to provide selected types of follow-up support. This tendency limits the opportunity to test a control system's effect and then modify it. It could take several years before a sewer system is fully understood and to modify a control system to respond adequately to it.

Suggested solutions to constraints brought about by crisis and crash programming are:

1. Avoid them.

2. Place more emphasis on the importance of timing.

3. Dedicate more funds to insuring follow-up responsibility of consulting expertise.

4. Key development to ultimate performance.

5. Develop and follow a plan of implementation by stages over a reasonable time frame that permits testing of the various stages.

Low Skill Levels and Financial Support as Constraints

Computer based control systems certainly require a high and solid base of high level skills. This means that personnel recruitment and administration become very important to the manager. Control systems require at least one or two highly skilled (and also highly priced) systems engineers and computer experts. Computer based control systems should also have the following skills represented among their core personnel:

- electrician
- instrumentation specialist
- computer programmer
- computer operator

Certain skills can often be combined in one or more persons, but such skills must be available at all times, must be of high quality, and must not be in short supply. Moreover, staffing requirements should insure that operating staff be adequately trained in the complete scope of how the sewer system functions. If manned control is needed or desired (even after automation has been reached) any of the control center operating staff should know how to "operate" the system during event times.

Adequate financial support is without question one of the most important considerations for successfully implementating a control system. Without adequate financial support the proper skill level cannot be obtained and the importance of that is noted above. Inadequate financial commitment also forces managers to plan and implement on a "shoestring" or in too short a time frame, both of which adversely effect successful implementation.

Suggested solutions to the low skill and financial constraints are:

1. Gear up the recruitment criteria to insure adequate expertise especially in:

    a. systems engineering

    b. electrical skills

    c. systems analysis

    d. programming skills

    e. computer operation

    f. instrumentation skills

2. Develop a training program in insure competence of central station personnel in all phases of the system's control functions.

3. Make certain that financial resources are adequate.

4. Plan development stages to permit reasonable amortization of available financial resources overtime.

SECTION VI. THE ROLE OF MODELS IN AUTOMATIC CONTROL SYSTEMS

The control logic required to "operate" a combined sewer system in the remote control mode is extremely complicated. It is beyond the capacity of the human mind to receive, process and reach decisions based on the hyriad of information pieces that must be made a part of routine decisions. The capabilities of computers, however, extend man's capability to cope with the information and decisions required in such a complex system. The computer is an extension of man and not the other way around; the computer by itself is helpless. The three categories of remote operational control which require substantial computer aid are:

1. Operator interface and system control (man directed)
2. Automatic closed loop control (computer directed)
3. Combination of above two

Man-Directed Mode (Operator Interface Mode)

In the Man-Directed mode it may or may not be necessary to incorporate the use of a computer software model of the sewer system. Based on incoming rainfall data, water level data, and other information an operator may through experience know which action to take. The control cycle for this mode is illustrated in Figure VI-1. It may be necessary, however, to process all the incoming data through a computer software model to determine alternative courses of action available to the operator. A model may also be used to determine the effect of various courses of action available to an operator before one is chosen. It is more difficult to make complex decisions without computer assistance.

One of the difficulties with modelling a sewer system is that the rainfall-runoff process is not understood in a precise manner. Urban hydrologic modelling is far from being an exact science. In most cases, a model has to be developed for each particular combined sewer system. That model must be "calibrated" for various rainfall events based on actual field data. In other words it is difficult to use a model in a truly predictive sense until operating experience is gained. Therefore, it is

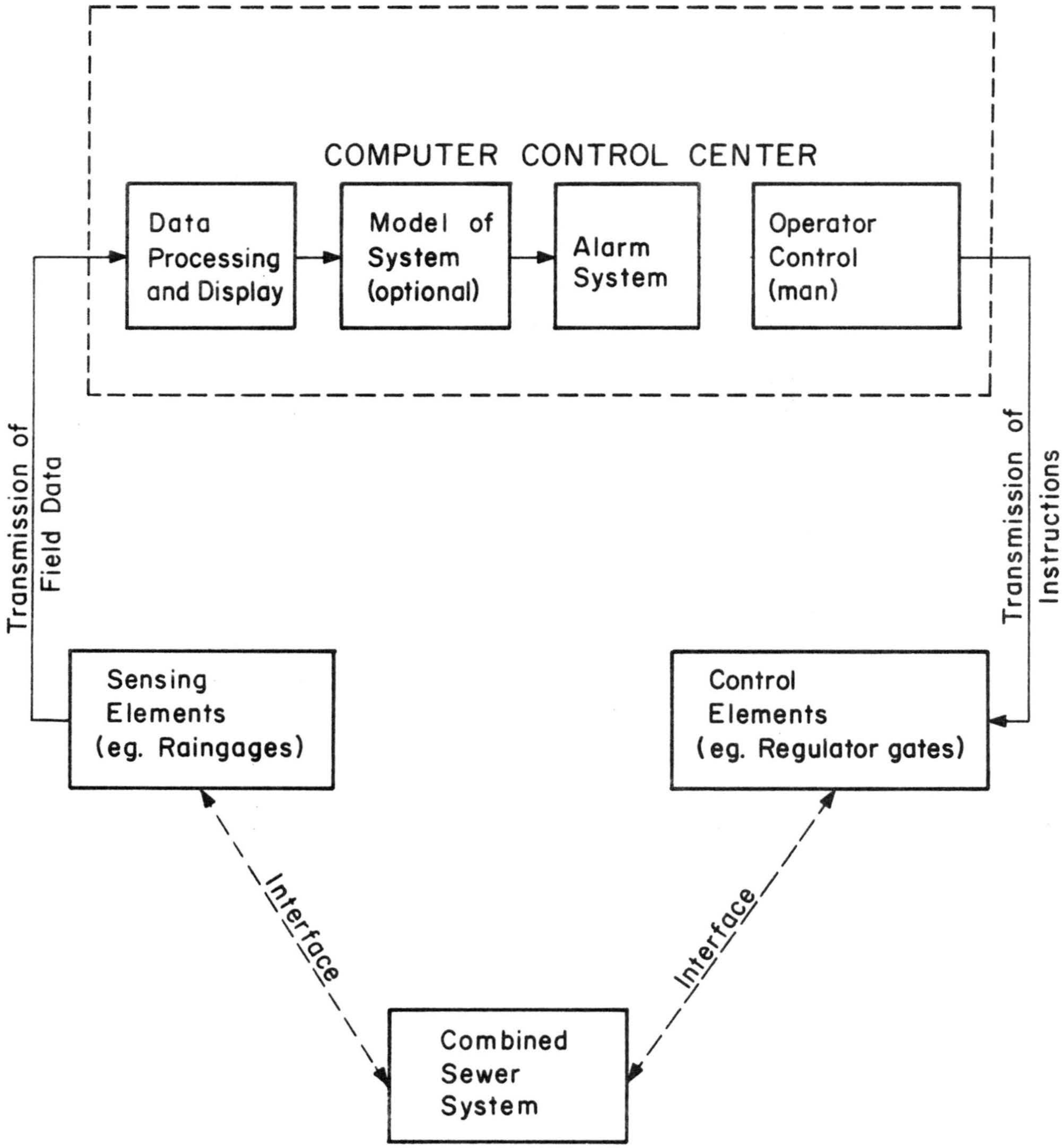

FIGURE VI - 1

CONTROL CYCLE FOR OPERATOR INTERFACE MODE necessary to approach the automatic mode in phases, with the first phase being the operator interface or man-directed mode. As experience is gained and models developed then the control can be phased into an automatic mode.

Automatic or Closed Loop Control Mode

In Figure VI-1 for the operator interface mode, the automatic decision chain is not continuous; the chain is broken when the human operator intervenes and makes decisions. In order to convert the system to the automatic mode the human operator must be replaced by a computer control model (or an algorithm). The control cycle for the automatic mode was illustrated in Figure II-1. In the automatic mode it is necessary to have a model of the combined sewer system that will predict future flow occurrences at various points in the system based on present rainfall data. Operating decisions can then be made by the computer based on operating rule curves which constitute the control logic. Again, it should be emphasized that the control logic can be very complex and it usually has to be developed over a period of time taking advantage of operating experience.

Although easily conceived, the jump from the man-directed mode to the automatic mode may be very difficult in reality. The lack of ability to model the rainfall-runoff-quality process of a combined sewer system and the complexity of the control logic lead to this difficulty. This does not say the automatic mode is impossible, but it is saying that project development must be approached on a highly professional level and without the naive assumption that "all we have to do is plug in a computer model to get things working."

Model Requirements

In either the operator interface mode or automatic mode it is necessary that the computer model of the system be relatively simple. Every 5, 10 or 15 minutes the model will be used to update predictions. If it requires a large amount of computer time to operate then operating expenses may become prohibitive. Also, if a large computer is required to process the computer model program its usefulness will be severely limited.

A comprehensive mathematical storm water management model was recently developed for the Environmental Protection Agency (EPA).[39] This model is capable of simulating the rainfall-runoff-quality process for an urban drainage basin. Based on rainfall data and antecedent conditions which include rainfall history, street sweeping data, land use and related data, flow can be routed through the system and the effects on receiving water quality can be determined. The effects of storage and treatment can be evaluated. However, for the operational control of combined sewer systems this model may be too comprehensive. The computer hardware system required to operate the model should be equivalent to an IBM 360/65 with peripheral storage devices and a usable core capacity of not less than 350 K bytes. For a combined sewer drainage basin, on the order of 500 punched cards are required for input and there are over 10,000 card operations in the completed model routine; this is for but one drainage catchment. The estimated capital cost for an IBM 360/65 or equivalent is generally in excess of $2 million depending on peripheral equipment.

The EPA model is very useful in the evaluation of pollution potential of existing systems and for comparing alternative courses of action in both the planning and design phases. The hardware and software facilities required to operate the model are what limits its usefulness in the operation control mode.

Mathematical Model Developed for Use in Design of Computer Based Control Systems[40]

During the Metropolitan Water Intelligence Systems (MWIS) Project, a software model for use on a computer has been developed to aid in sewers. The particular areas in which such a model should be useful are to:

- Determine the adequacy of the proposed control system to achieve the desired results.

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[39] "Stormwater Management Model," by Metcalf & Eddy (Consultants), University of Florida, and Water Resource Engineers (Consultants) for the Environmental Protection Agency; Washington, D. C., July 1971. (4 Volumes)

[40] This section is based primarily on the following report: "Model of Real-Time Automation and Control Systems for Combined Sewers," by Warren Bell and Byron Winn, Technical Report No. 7, CSU Metropolitan Water Intelligence Systems Project, Ft. Collins, Colorado, February 1972. (The reader is referred to this report for detail information and a listing of this computer program.)

- Determine the best location of control devices (gates, valves and pumps).
- Determine the best location and number of data sensors (rain gauges, water level gages, and quality probes).
- Determine the required accuracy of sensors and control devices.
- Determine the time interval in which to obtain field data.
- Determine accuracy requirements of the prediction model component of the computer control center (see Figure 3).
- Determine the control logic for the system.

The model is intended to simulate a real-time automation and control system (RTACS), and the components of the RTACS model are essentially the same as in the components shown in Figure II-1.

As with the EPA model the RTACS model is rather complicated and requires considerable machine capacity to operate. It is not intended to be used in the real-time operation of a system, but it should be useful in the planning and design phase. The RTACS model can within reasonable limits determine the maximum capabilities of the in-system storage capacities of the combined sewer system for any given storm and a specified objective. This will help determine whether or not the system can be "operated" to meet the desired objectives.

In the automatic mode of a control system the prediction model (usually a mathematical model) plays an essential role. As previously pointed out, it is important that this model be of such a size to keep computer requirements within reasonable limits. The effects of model size, sophistication or degree of accuracy with which the model can simulate reality on the accuracy of the desired results can be evaluated with the aid of RTACS. Several different prediction models can be tried and the effects of each evaluated.

The RTACS model is also designed to aid in the development of the control logic to arrive at an "optimal control strategy." These uses of RTACS appear to be independent processes. In fact, the optimization of the use of control system components to achieve a desired objective (Note: This is the objective of using RTACS) requires several iterations of varying component specifications. Only in this way will the most economical system be found that will satisfy stated objectives.

The RTACS model was developed using information and data from a hypothetical combined sewer system. The use of RTACS in other cities would require the development of models of that city's combined sewer system, prediction model and control logic. Generalized guidelines for accomplishing this are currently being developed in the MWIS project.

SECTION VII. THE COLORADO STATE UNIVERSITY RESEARCH PROJECT

A. Description of the Project

Project Concept

The combined sewer performs more than one function. Its usefulness as a storm drain must not be forgotten when control of overflows is being emphasized. Also, a combined sewer in serving its drainage function is only one element in the flood control plan of a metropolitan region. Combined sewers work in conjunction with flood control measures such as detention and retention works and the different techniques of flood plain management.

With regard to the objective of pollution control, there are many ways in which the overflows from combined sewers can be controlled while still accomplishing the drainage objective. Alternatives include complete separation of combined sewer systems into sanitary and storm sewer systems and control with partial separation and partial treatment. For additional control there are methods such as detention storage with or without disinfection, increasing storage in sewers and accompanying structures, increasing treatment capacity and providing operational control measures within the sewer systems.

Operational control requires some degree of real-time control of the combined sewer system. This might include:

1. Manipulation of regulator gates within the sewer system to maximize in-sewer storage,
2. Use of gates and/or pumps to transfer flows from one urban basin to another,
3. Diversion of flows to temporary storage,
4. Injection of disinfectants for in-sewer treatment, and
5. Injection of polymers for increasing the flow capacity of the sewer.
6. Operation of auxiliary wet weather flow treatment facilities.

Operational control infers that decisions will be made on a real-time basis as an instantaneous function of field information received such as rainfall data. A set of components comprising a combined sewer control system is shown in Figure VII-1. (Similar to Figure II-1). The components shown identify the elements of a Real-Time Automation and Control System (RTACS) in a schematic form. The interaction and field application of such a system is complicated. As defined in Figure VII-1, the sensing elements receive basic data from the physical system, such as rainfall data or the positions of gates within the system. The prediction model estimates the resultant expected flow conditions at selected points in the combined sewer, such as at overflow regulator gate locations. Based on predicted flow conditions, the control program will calculate the initiate signals for the required changes in control element positions that will accomplish the operational objective satisfying the control criteria.

A control system is one of several alternatives which can help control overflow pollution from combined sewers. The justification for an operational control system is that it may be the most cost-effective option available. In all cases the use of a control system must be superior in comparison with other alternatives in terms of performance, reliability and cost-effectiveness.

Project Scope

With the support of OWRR grant number 14-31-0001-3410, Title II, Project No. C-2207, the Civil Engineering Department of Colorado State University is conducting a research study of the possible effectiveness of and requirements for an "intelligence system" related to the operational control of a combined sewer system.[41] The principal project concerns in this Phase I study were:

1. Evaluation of the technical aspects of a metropolitan water intelligence system as related to control of combined sewer overflows; and

2. Investigation of the nontechnical constraints on metropolitan water intelligence systems.

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[41]This work complements and builds on an investigation by M. McPherson, "Feasibility of the Metropolitan Water Intelligence Concept," op. cit.

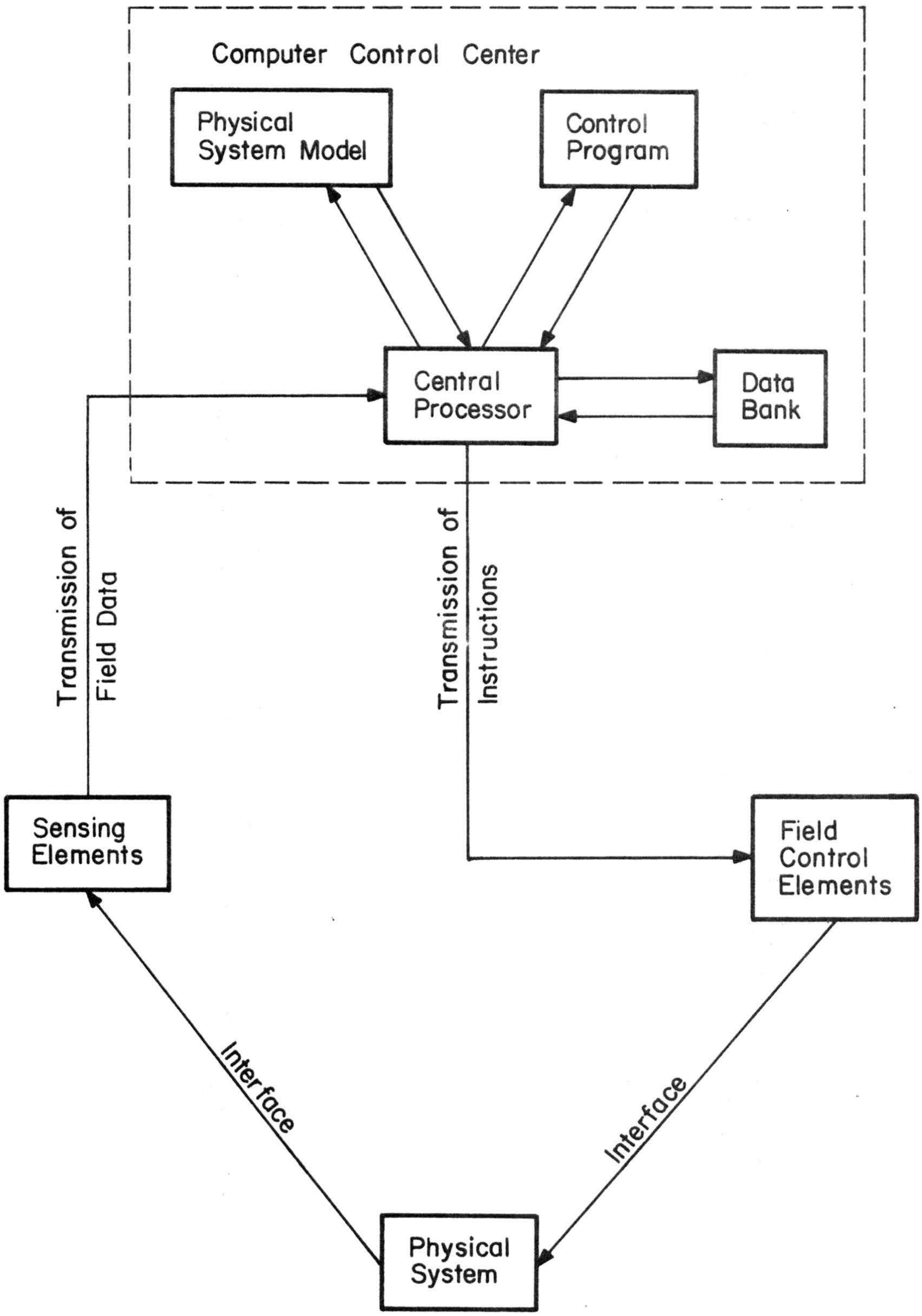

Figure VII-1

COMPONENTS OF REAL-TIME AUTOMATED CONTROL SYSTEM

The method of achieving the specific project objectives was through the division of these objectives into tasks under technical and nontechnical categories:

The technical tasks included:

1. Providing municipal managers with information such as objectives, problems, costs, and effectiveness regarding planned or existing projects to assist in evaluating the situation. This task was subdivided into two parts:

   a. An in-depth study of the intelligence system installed for the Minneapolis - St. Paul combined sewer system. The objective was to ascertain both strong and weak points of an actual project.

   b. Identification and summary of water agencies or jurisdictions in the United States that have implemented or have plans to implement systems for either automatic or remote control of urban water systems.

2. Evaluating the possible and actual effectiveness of an automation and control project for a combined sewer system. Establishing a method of evaluating automation and control projects for combined sewer systems was undertaken as a technical task.

3. Developing a model of a real-time automation and control system was a task assignment with the objective of providing a tool for evaluating an automation and control for a combined sewer system. The technique in its final form would provide the simulation of a system over a range of actual field conditions.

4. Describing computation and control facilities that might make up the control center. Computer requirements comprise the central core of the control system. A determination of the relationship of size of computer facility required in terms of number of control parameters was a major part of this effort. Computer requirements have a profound bearing on cost and is an important aspect for the manager, city planners and others to consider.

The nontechnical tasks included:

1. Studying the characteristics of a metropolitan region that seem to indicate that a city is "ready" for a control system for combined sewer systems or other urban water facilities. These characteristics should be useful in determining whether or not a metropolitan region might lend itself to the development of an automatic real-time combined sewer control system.

2. Defining the elements of the social system which might constrain the political acceptance of the intelligence system (i.e., political feasibility of control systems).

3. Developing guidelines for managers which would emphasize the following:

    a. Potential application of an intelligence system for achieving control of combined sewer overflows related to broader water quality objectives,

    b. Formulation of a model of a real-time automation and control system that can be used as a research tool to determine the effect and importance of various components of an intelligence system,

    c. Computer facility requirements for various sized systems,

    d. Identification of characteristics of the social system that might constrain political acceptance of an intelligence system, and

    e. Identification of physical and social characteristics of a metropolitan environment that might lend themselves to or detract from the installation and operation of an intelligence system.

Because there was a need for expertise in several areas outside the academic scope of the project, assistance was sought from consultants that were uniquely qualified in the following specific areas:

1. Computer hardware and software.

2. Evaluation of the effectiveness of automated control systems.

3. Provision of an inventory of existing automation systems.

In addition to the assistance in the specialty areas mentioned above, assistance was also sought from an advisory committee representative of various agencies and organizations involved in metropolitan water system problems. Individuals were selected on the basis of their background and experience in dealing with a wide range of urban water problems. Those who comprise the committee represent government agencies, consulting firms, a national engineering society and large metropolitan areas located in markedly different geographic regions.

The Advisory Committee emphasized the principle that research findings should be applicable both within and beyond the immediate project concept and that, to this end, the project studies should be applicable to actual problems as well as understandable and acceptable to managers involved in these problems. The studies or tasks accomplished in this spirit are documented in detail in a series of eight technical reports bound separately.

B. Technological Aspects of the Problem: Description and Significance

To accomplish the general objective of minimizing overflow pollution all available ambient and auxiliary storage in a combined sewer system must be utilized efficiently. When this is done the magnitude and frequency of untreatable overflow volumes will be at a minimum. The RTAC system is designed to achieve this.

The most significant part of the RTACS is the physical system. A schematic view of a physical system without auxiliary storage is shown in Figure VII-2. This consists of a catchment with sewers which serve both sanitary and storm drainage service. These sewers empty into an interceptor sewer running parallel to a receiving water stream. The interceptor discharges into a conventional treatment plant. The point of interest is at the overflow structure, located downstream of the basin of interest.

Figure VII-3 shows a typical storm hydrograph at the overflow point. Since the capacity of the interceptor is limited, a significant portion of the storm volume (combined, untreated sewage) must be spilled to the river. The effect of RTACS is to attenuate the peak by using ambient storage available in the interceptor and in other portions of the sewer system (and auxiliary storage when available). This is shown by the hydrograph labeled "with RTACS" on Figure VII-3. This hydrograph shows all of the potential overflow eliminated, although in many storms it might not be possible to eliminate 100% of the overflow.

Development of the RTACS Concept

The RTACS concept is basically that control of urban water systems in general and of combined sewer systems specifically, should be achieved automatically, in real time.

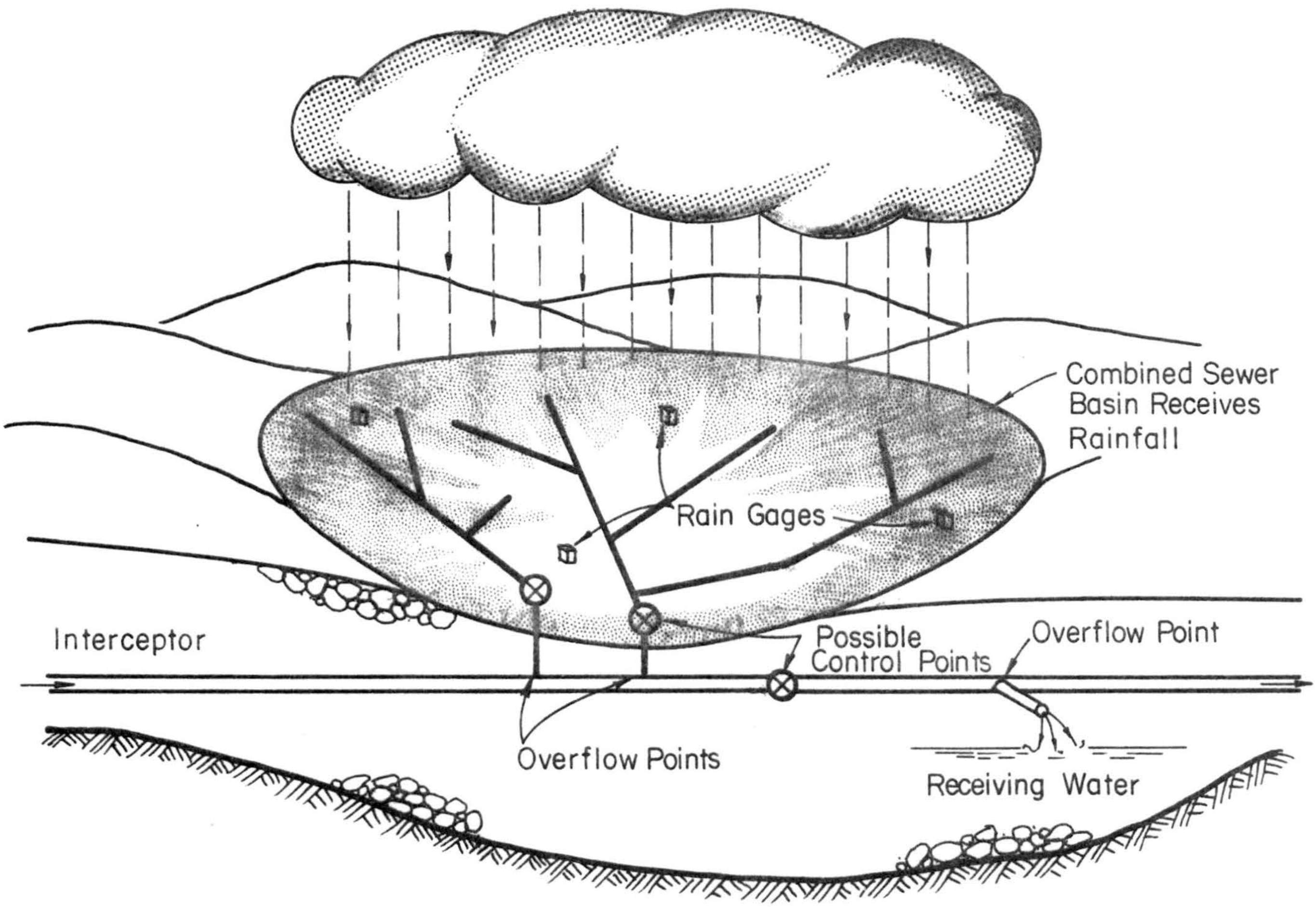

Figure VII - 2 Hypothetical Physical System

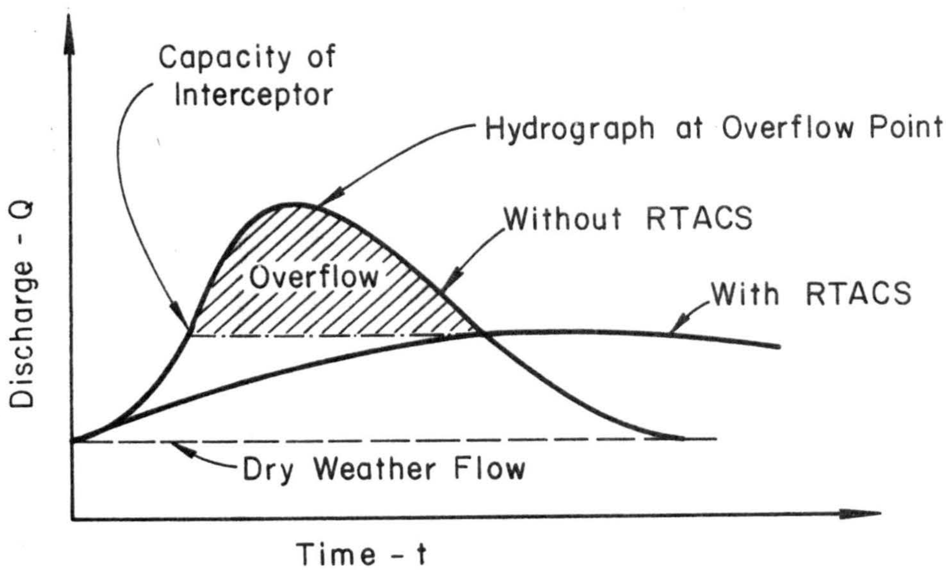

Figure VII-3 Hydrographs in Sewer System (for adequate control conditions only)

The components of the RTACS, along with their specific functions are listed below (See Figure VII-1).

1. The physical system. This component has been previously described. It consists basically of the sewered catchment as a drainage basin.

2. The field control elements. To achieve control of the physical system certain control elements are necessary. These may consist of gates, pumps, dams, pipes, orifices or other mechanical devices. A number of such control devices are listed elsewhere.[42]

3. Sensing elements. Field sensing elements such as rain gauges, flow meters and quality sensors are needed in order to provide intelligence from which decisions can be made and the RTACS can operate.

4. Prediction model. In order for the control criteria to be met certain predictions must be made based on intelligence received from the sensing elements. These predictions are made using a mathematical model that can simulate performance of the physical system.

5. Control program. In order to implement control criteria, certain control logic, mostly unique to a given system, must be developed. This is incorporated into a control program which allows the control to be implemented by actuating the field control elements.

6. Central processor. This is the computer control center of the system.

7. Data bank. Certain data must be stored for use in the prediction model and control program. This is retained in a separate location rather than being part of the prediction model and control program themselves.

Operation of RTACS

Consider a hypothetical example of the operation of RTACS under real conditions. A given catchment such as the one in Figure VII-2 is initially in a given state of dry-weather flow. The sensing elements are continually reporting intelligence such as the position of the control elements, the occurrence or absence of any rainfall and the conditions of the receiving water.

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[42] American Public Works Association, "Combined Sewer Regulator Overflow Facilities Report," (A report for the FWQA), July, 1970.

Suddenly an intense rainstorm occurs in parts of the total system administered. The rain gauges report the occurrence of rainfall to the central processor which actuates the prediction model. On the basis of initial rainfall rates, the prediction model predicts probable future flows at various control locations revealing that excess storage is available in parts of the system and that at other points, significant overflows may occur. The control program then instructs the control elements to adjust so that the available storage will be utilized and that overflows will be consequentially reduced. This completes one time sweep of RTACS. After a designated time interval the process would be repeated and updated commands sent to the control elements. This procedure would be followed throughout the storm until the cessation of storm flow.

The above is a rather simple explanation of how a RTACS works. The reader can visualize how more flexibility could be introduced into the system with even more sophisticated methods.

The Model of RTACS

The principal uses of the RTACS model are: to determine maximum system control capability; to aid in optimizing the number of sensors and control points and in determining their best location; to aid in the determination of the optimum interval between control recursions; to aid in the development of regeneration routines and runoff models; and to aid the development of the field control logic.

To accomplish the above, the basic requirements of an RTACS model are: first, that the physical system model be a reasonable approximation of the actual physical system (the better the approximation the more faith that can be placed in the final results); and second, that an optimal control logic be developed as an absolute standard of comparison. The optimal control logic, besides serving as a standard of comparison should indicate the more important criteria to be included in any less than optimal control logic (which may be more economical to use, for example, because of smaller computer requirements).

The significant components of the present RTACS model include:

1. The Physical System Model - The major portion of the physical system model is the RUNOFF and TRANSPORT sections of the FWQA Storm Water Management Model developed for the FWQA (now EPA) by a triumvirate of Metcalf & Eddy of Palo Alto, California, Water

Resources Engineers, Inc., and the University of Florida. This model computes the runoff resulting from a given rainfall space-time pattern over an urban area and then routes the resulting controlled flow through the interceptor sewer system. To make this model a satisfactory representation of the physical system for an RTACS model it was necessary to modify the routing section of the program so that control device positions could be varied with time. It was also necessary to add to this model a program which would take a given rainfall pattern over the drainage area and determine the point rainfall at any desired location and integrate the rainfall over each of the subcatchments of the physical system model to determine the average rainfall at each point in time. This information is then used as input to the FWQA model.

2. The Control Algorithm - The major portion of the control algorithm is the control logic. Given the present state of the system and the expected inflow, the control logic determines what the control device positions should be.

3. The interface routine - Data generated by the physical system for processing through a control algorithm (or vice versa) would normally be subject to errors in sensing, transmitting, receiving and in some cases using the signal. Simulation of these errors in the RTACS model is accomplished by a routine that takes the true data value and modifies it according to the type of errors and the order in which they occur in the relevant part of the physical system.

It is noted in the report that it is not necessary to use the physical system model adapted for this project. Any model that will give a reasonable representation of the physical system and that has the capability of variable control at backwater storage locations may be used.

For the RTACS model, the control logic was determined from optimal control theory (based on the calculus of variations) in order to have an absolute standard of comparison for the effect of errors at less than optimal control. Optimal control theory will determine the theoretical control-time history to maximize (or minimize) a specified objective function. For this study the chosen objective was to minimize overflows to the receiving waters that escape the interceptor system. The report outlines salient points of optimal control theory and develops in full the equations for an elementary three-reservoir analogy to a sewer system having three back-water storage locations, each having orifice and weir controls. The analogy includes flow, storage depth, and control device constraints in the analysis, but does not include the time lag that normally exists in flow going from one control point to another. This latter aspect is presently being investigated.

Solution of optimal control problems is nearly always approached by means of numerical methods. A flow chart of the solution procedure is included in the task report (TR 7), but as yet there are still convergence problems to be overcome.

For the runoff model portion of the control algorithm this study used the RUNOFF section of the FWQA model (the same as used in the physical system model.) No rainfall regeneration model was developed as a part of this study; however, two simple models were used in an example included as part of the report.

Example of the Operation of the RTACS Model

The purpose of the test example was to demonstrate how an RTACS model could be used to optimize the selection rain gauge locations and to determine the optimal time between control recursion intervals. The physical system was assumed to be a small drainage basin feeding a two-branch sewer system containing three backwater storage locations. (See Figure VII-4). An assumed rainstorm was passed over the hypothetical drainage basin and point rainfall determined for three rain gauge locations. Control strategies were determined on the basis of information from each of the rain gauges (separately) and for the known "true" runoff to the sewer system.

In this example the control used was nonoptimal due to the fact that accounting for the time lag in flow moving through a sewer system was not included. Also the computer program developed for the three reservoir problem did not converge to the correct answer. The control logic did, however, produce reasonable results.

All parts of the RTACS model were used except the interface routines. It was felt that their use in the example would not add significantly to the demonstration at that time. This example successfully demonstrated the effect of using information from different rain gauge locations on the diversions to the receiving water and showed how a designer could improve on the selection of the rain gauge locations, the rainfall regeneration model, and determine a reasonable first guess for a control interval.

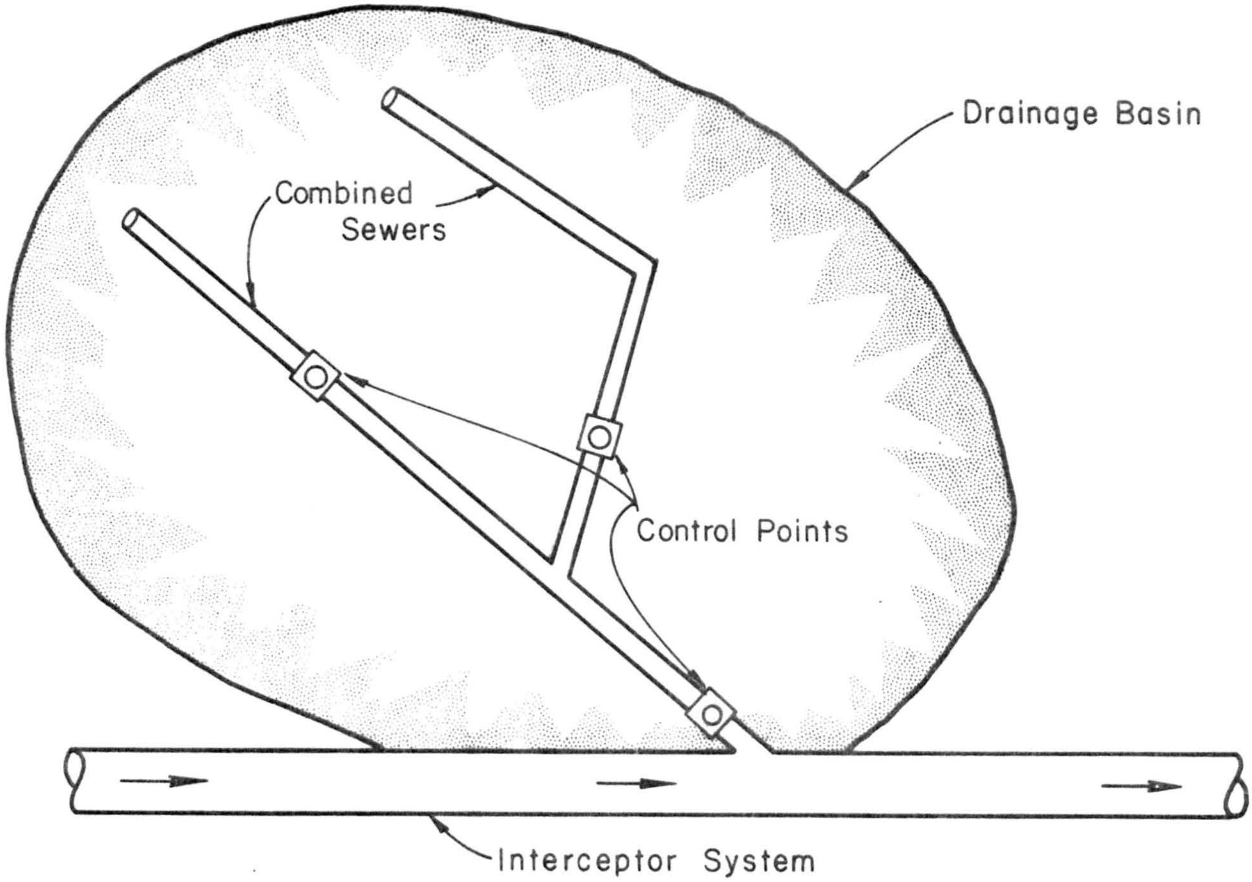

Figure VII - 4 Schematic View of Combined Sewer Drainage Subsystem
(Three Reservoir Problem)

C. Social, Political, and Economic Aspects of the Problem

The social and political aspects of combined sewer pollution control are really questions of how social systems (including political and economic systems) function to facilitate or impede the consideration, adoption, implementation, and productivity of a given combined sewer control alternative. A second set of questions involves how the control system affects or impacts upon the social systems.

Activities concerning these questions during Phase I have been devoted primarily to the first question, more specifically to a definition of actual and potential constraints on the consideration, development, and implementation of control systems. This focused the research effort primarily upon questions of political feasibility, the question of whether or not it can or will win acceptance in the social decision-making process.

Special, although not exclusive effort was directed at those elements in social decision-making and managerial systems which constrain or facilitate:

1. adequate consideration of the combined sewer control alternative with other alternatives (e.g., sewer separation);

2. productivity of combined sewer control systems.

This constituted the research problem for Phase I. The Minneapolis - St. Paul Combined Sewer and Treatment System was selected as a case study of the problem. This case was used as a basis for generating a hypothesis of relationships among system characteristics and functions which could then be used for developing a model during Phase II that could be tested during Phase III of the research.

The Social Research Problem

The problem in Phase I was to define constraints and facilitating elements for:

1. Adequate consideration and implementation of combined sewer system controls, and
2. Successful operation of combined sewer control systems.

Research Findings

Research findings are primarily those from the on-site case study, literature searches, and a study of San Francisco's plan for developing a system, and from cursory examinations of several other systems. Two critical observations emerge. First, as is somewhat the case in many public systems, it is difficult to get combined sewer control systems to approach performance potentials; second, control alternatives are generally not as apparent to management and political decision-makers as are some of the more familiar alternatives. The control alternative, as could be expected, appears to be highly visible in some urban domains and less in others, and it could be hypothesized that visibility is generally higher among managers than political decision-makers. Variance in visibility could be expected to constitute a rather severe constraint on political feasibility in some areas, on the possibilities for winning adoption.

Further constraints identified through the case study and companion efforts were:

1. Peculiarities of the parameters of the social choice system and its decision-making sub-systems.

2. The need and demand for specific justifications, especially monetary justifications.

3. The possible failure of control systems to produce what is prophesied by the technical and environmental feasibility measures. (This results partially from a lack of support by management in the first place -- an interactive effect.)

4. The possible failure of lay and even professional management and political decision-makers, as well as the public, to perceive many of the benefits when they accrue, which is a partial function of 5, below.

5. The communications barrier between the technological expert and the rest of society.

6. The inherent regional character of water problems despite the existence of few viable regional concepts and little or no means for implementing and institutionalizing regional plans.

7. Inadequate skill levels and financial resources.[43]

Social systems, as do all systems, contain intricate and complex congeries of interrelated characteristics and functions, many of which have never been adequately defined or understood. Among their more crucially important characteristics are:

- their insensitivity and resistance to change.
- the paucity of points at which they can be affected and changed.
- the tendency for them to generate short-term solutions at the expense of long-term consequences.
- the consequent tendency to turn managers into short-term "hole-pluggers" and "firefighters."

All comprise constraints on the development and the eventual productivity of control systems.

Definition of these and corollary constraints provide the basis for generation of a model of expected relationships bearing on sewer systems which can be employed to determine how constraints influence the decision

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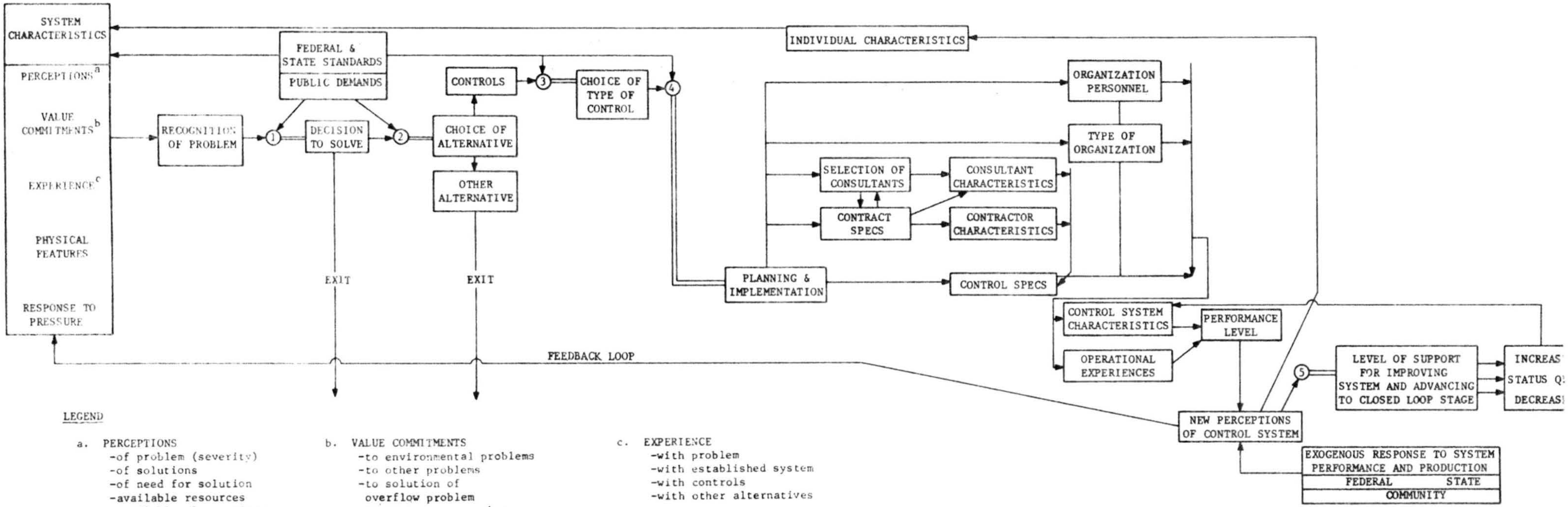
[43] For a fuller elaboration, see Duane W. Hill and L. Scott Tucker, "Social and Political Feasibility of Automated Urban Water Systems," (Fort Collins, Colorado: Colorado State University, 1972) Metropolitan Water Intelligence Systems Project, Technical Report No. 5.

processes from the standpoint of the amount and character of consideration given control alternatives as well as the levels of production sought and the amount of support provided for upgrading the system. Figure VII-5 provides a decision flow model of expected relationships among system elements and externalities. Five decision stages are hypothesized as critical points at which elements within the system and external factors can be anticipated to affect choices at each of the stages. According to the decision model, recognition of the problem results from sewer system characteristics and the personality, socialization and other characteristics of relevant decision-makers. As such, a choice is made to solve or not to solve in stage 1. This choice will be dependent upon individual personnel and sewer system characteristics, the intensity of recognition of the problem, and the pressures of external factors, especially federal, state and public demands. If the choice is to solve rather than exit, stage 2 is reached were the type of alternative is selected. It is expected that choices at this stage will be decidedly affected, or determined to a considerable extent, by the same set of characteristics or elements as in stage 1.

Stage 3 involves the choice of general characteristics of the type of controls to be implemented (e.g., a demonstration project, or development by stages of a total system). It is anticipated that choices of general characteristics will also be influenced by decision-makers and external factors as in stages 1 and 2. This stage will also be affected by an increased level of commitment to controls resulting from the choice of the control alternative, and the amount of information fed into the system by advisors, consultants and outsiders.

Stage 4 involves again a series of many technical and planning choices which determine the final character of the control system and its performance potential and level. The character and productivity of the control system and its operational experience are determined by individual decision-makers and system characteristics, as well as consultant, contractor and control personnel characteristics.

As implementation proceeds, new perceptions will form at an accelerating rate, and they, together with the influences of externalities and control system characteristics, will function to determine levels of support for the system and changes to it (stage 5).



LEGEND

a. PERCEPTIONS
- -of problem (severity)
- -of solutions
- -of need for solution
- -available resources
- -available alternatives
- -physical features

b. VALUE COMMITMENTS
- -to environmental problems
- -to other problems
- -to solution of overflow problem
- -to systems approaches
- -receptivity to change
- -to feasibility measures
- -to being instrumental or expressive about problems

c. EXPERIENCE
- -with problem
- -with established system
- -with controls
- -with other alternatives

FIG. VII-5 Automated Control System Developmental Model

It will be noted that feedback loops indicate that a control system's output or performance level at one stage of development may feed back to initiate a later step or stage of development. In this respect, the model is capable of providing information concerning in-system variance over an extended period of time as a system may develop. Further, varying types of systems can be compared with each other for a single stage of development common to all of them. Finally, personal and behavioral characteristics of relevant human actors and other system characteristics can be tested for their effects at each decision point.

In development of the decision model during Phase II, varying types of systems will be compared through the model using as a norm, one or two traditional types of metropolitan sewer systems which have not moved appreciably toward solution. Elements of the model will be given operational definitions to assist in exercising its components. Data will be retrieved and ordered in a manner that permits coding in metric terms.

Individual perceptions and value commitments will be retrieved from responses to interviews. Responses to tested and validated scale items which can be scaled metrically will be obtained.

Extent and intensity of experience can also be retrieved from interview data as well as from other sources. Similarly, federal and state standards, as well as public demands, can also be rated and scaled separately. Likewise, metric scales will be developed for other variables such as contractor and consultant characteristics, control specifications, types of operational experience, etc. In this sense, the traditional feasibility measures for justifying projects will be expanded beyond their traditional economic base which asked primarily whether a project would yield benefits which exceeded costs. The question will be asked not only whether a project is worth it economically, but also if it is possible to accomplish the objective technically (technical feasibility) and whether the objective can win acceptance among those who do the deciding for the social system (political feasibility).