THESIS

APPLICATION OF AUTOMATIC MONITORS FOR STATE WATER QUALITY SURVEILLANCE

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY MARC SYLVESTER ENTITLED APPLICATION OF AUTOMATIC MONITORS FOR STATE WATER QUALITY SURVEILLANCE BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

APPLICATION OF AUTOMATIC MONITORS FOR STATE WATER QUALITY SURVEILLANCE

Field use of automatic water quality monitors began during the mid 1950's. Experience gained since that time has revealed that the best application of automatic monitors is to supplement grab sampling surveillance systems. When employed on a real-time basis using telemetry and computer processing of collected data, automatic monitors are capable of satisfying the abatement objectives of state water quality management agencies.

Presently, only five reliable sensors (DO, T, pH, Cond, and Turb) are available. With this limitation, automatic monitors are not presently able to provide 100 percent pollution event detection effectiveness. However, the present state-of-the-art on sensor detection ability indicates that a detection effectiveness of greater than 50 percent is possible using DO, T, pH, Cond, and Turb sensors. With this detection capability the abatement objectives of a state water quality management agency can be fulfilled by designing an automatic monitoring system which will optimize traceability (the accuracy and expediency with which a pollution event can be traced).

The network of automatic monitoring stations which optimizes traceability is called the effective primary network. The design procedure developed in this study provides: (1) A quantitative basis for determining the location of effective primary stations and (2) A method of relating abatement effectiveness to the number of effective primary stations.

The relationship between cost and number of effective primary stations is developed by computing the cost of automatic monitoring networks (1-30 stations in size) using average costs for purchase price, installation, and first year operation and maintenance expenditures.

The cost effectiveness relationship is generated by comparing cost and abatement effectiveness while summing over the number of stations comprising the effective primary network. The cost-effectiveness relationship reveals the benefits gained in abatement effectiveness per increment of cost for the acquisition of each effective primary station. A schedule for effective primary station acquisition is also indicated.

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CHAPTER I

INTRODUCTION

"According to John Esposito, one of Ralph Nader's Raiders, 'monitoring is not very sophisticated --- at one enforcement conference, officials had to go out in a row boat and scoop up water samples.'" The above quote appears in the June-July 1971 issue of National Wildlife. Perhaps the wording is a bit harsh, yet at the National Symposium on Data and Instrumentation for Water Quality Management held at Madison, Wisconsin July 21-23, 1970, similar views were aired by water quality managers. At this symposium "few if any regulatory agencies were prepared to offer answers to the frequently asked question of whether our waterways are in better or worse condition today than they were at various periods in the past" (E. J. Cleary, 1970).

Answers were not available because water quality surveillance systems had failed to provide the necessary data. In part, this is due to the inability of state agencies to determine data needs to meet their objectives. Also, surveillance techniques had not been evaluated as to their ability to supply the type of data necessary to match state water quality control objectives.

The purpose of this study is to elucidate the role automatic monitors can play in satisfying the data needs of state water quality management agencies. This role will be determined on the basis of a cost-effectiveness analysis.

In developing the cost-effectiveness analysis, the subsequent steps are followed:

1. A review of literature pertaining to the explanation, application, capabilities, and limitations of automatic monitoring;
2. Determination of spill detection ability based on sampling frequency and parameter limitation;
3. Development of a relationship between abatement effectiveness and number of monitoring stations;
4. Development of a relationship between cost and number of stations; and
5. Generation of the cost vs effectiveness relationship.

CHAPTER II

REVIEW OF LITERATURE

Definition and Explanation of Automatic Monitoring Systems

To begin, a concise definition of automatic monitoring is, "Continuous multiparameter measurement of water quality characteristics" (Ballinger, 1968a). The design specifications of systems fulfilling the above requirements are described by Mentink (1968). In general, such a system requires three functional modules as shown in Figure 1. (1) flow chamber; (2) analyzer; and (3) output component.

Support equipment is necessary unless an immersion monitor is employed. Usually a shelter is needed to house the monitor and provide weather protection. Also, a positive displacement submersible pump is required (United States Department of Interior, 1966).

Immersion monitors do not require a flow chamber since the analyzer and output components are submerged in the water body being sampled (Figure 2). For the same reason, support equipment such as shelter and pump is not necessary (Palmer, 1969).

Operation of an automatic monitoring system entails sample collection by submersible pump and intake line, analysis by parametric sensors located in the flow chamber, signal conditioning

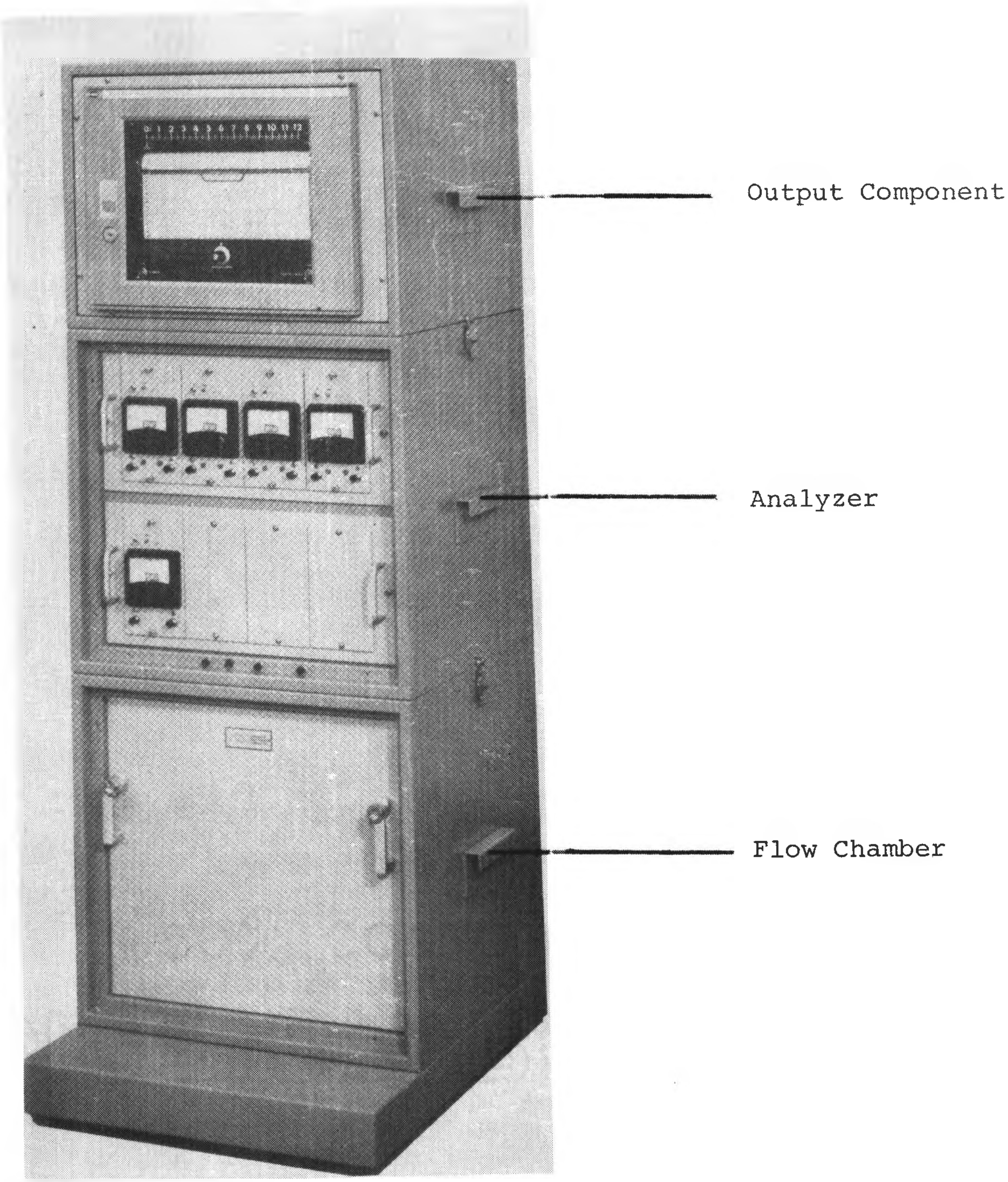

Figure 1. Automatic monitor showing functional modules. (Courtesy of Automated Environmental Systems, Inc., AES)

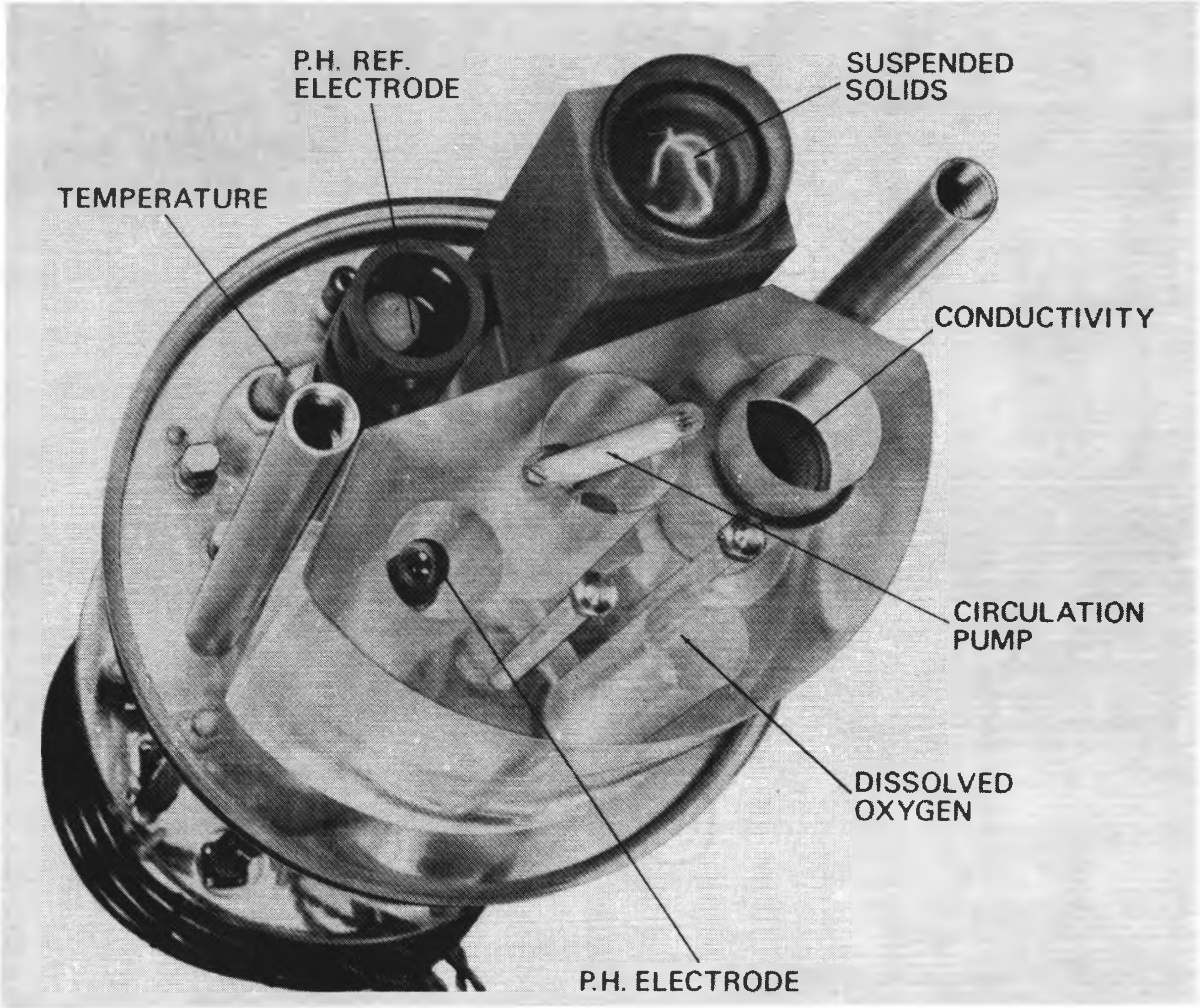

Figure 2. Immersion monitor showing sensor assembly. (Courtesy of Plessey Electronics)

in the analyzer phase, and data recording and/ or transmission in the output module (Cleary, 1967).

A fair amount of flexibility is allowed in the choice of recording mode. The methods available include on site strip chart recording (Figure 3), punched paper tape (Figure 4), or magnetic tape (Mentink, 1968 and Anderson, James J., 1970b). Recording format can be either analog or digital (Mentink, 1968). When telemetry is employed, output devices are located at a central receiving station containing the computer. The same choice of recording mode is available except that here it is advisable to perform teletype log sheet display in addition to other data logging. Thus, rapid detection of water quality changes as well as data storage for later statistical analyses are provided (United States Department of Interior, 1966).

Telemetry requires transmitter components, communications link, interface, computer, and output devices as illustrated in Figure 5 (Anderson, James J., 1970b and Mentink, 1966). The transmitter module is composed of a programmer which sequences sensor recording, an input addressor which assigns sensor signals to the appropriate memory storage module, and an output addressor which calls for transmission of values contained in the memory storage modules (Figure 6). The communications link may be telegraph, telephone, radio, microwave or a combination of these (Smoot, 1970). The interface shown in Figure 6 contains the receiver which accepts

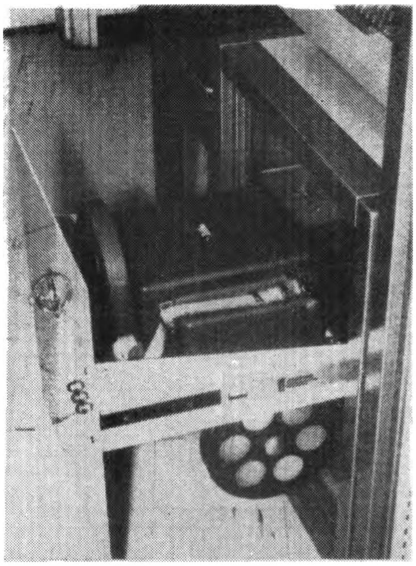

Figure 4. Punched paper tape recorder.
(From Ballinger, 1968)

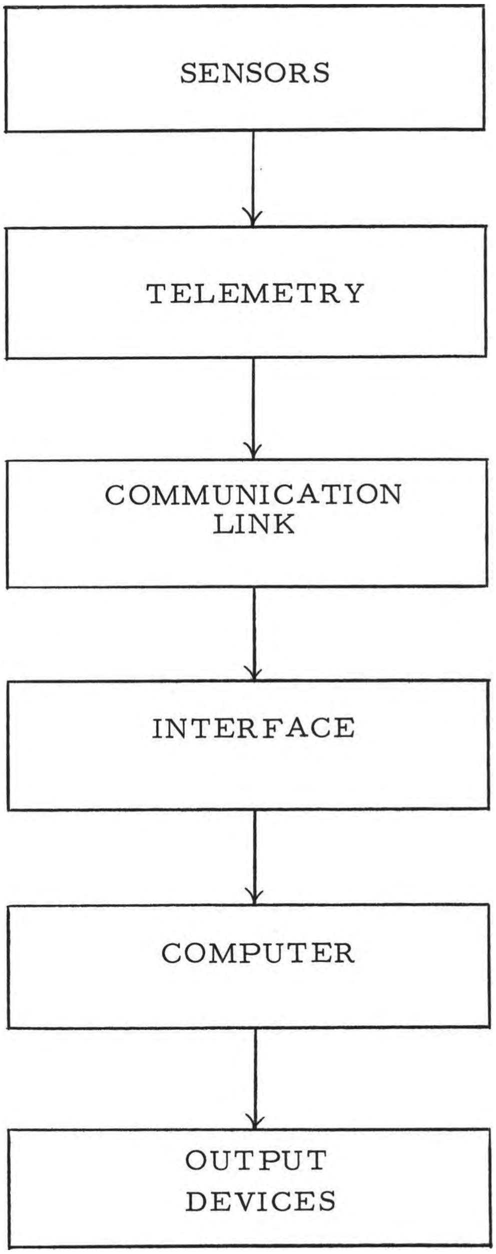

Figure 5. Computer-based data acquisition system. (From Anderson, James J., 1970b).

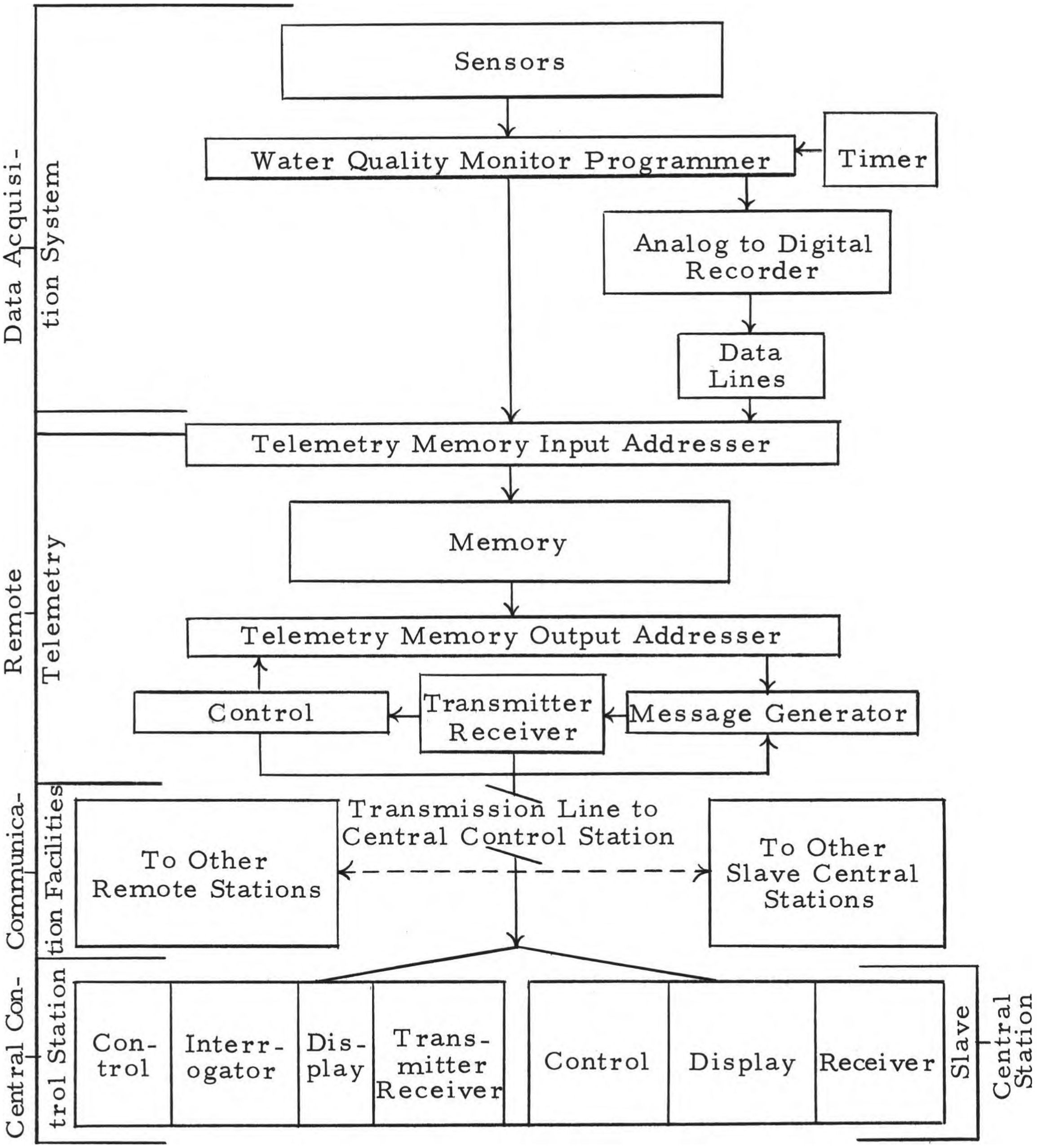

Figure 6. Telemetry system functional block diagram. (Modified from Smoot, 1970).

signals from the monitors and converts these for display or recording (Anderson, James J., 1970 and Mentink, 1966). For a discussion of the computer facilities available, see Anderson, James J., 1970).

Telemetry may employ either analog or digital formats for data transmission (Shubrooks, 1968). Also, a telemetry ststem may be adapted for simultaneous two-way communication, duplexing (Smoot, 1970). Two-way communications allow functional commands (pump and automatic sampler-activation, A. C. power control, etc.) to be sent to the monitor from a central receiving station. Thus, computer control over the operation of the entire telemetry and monitoring network is possible as shown in Figure 7 (Anderson, James J., 1970b).

There are two approaches to continuous measurement of water quality characteristics. One employs electro-chemical probe type sensors, while the other utilizes automated wet-chemical analyses (Ballinger, 1968a and Jones and Joyce, 1961). A discussion on the basic operation of electro-chemical probes is given by Ficken (1970).

Most of the following discussion on the application of automatic monitoring systems will be restricted to electro-chemical probe-type monitors, because present wet-chemical monitors are not suitable for field use requiring unattended operation (O'Brien and Olsen, 1970 and Ballinger, 1971b and Maylath, 1970a).

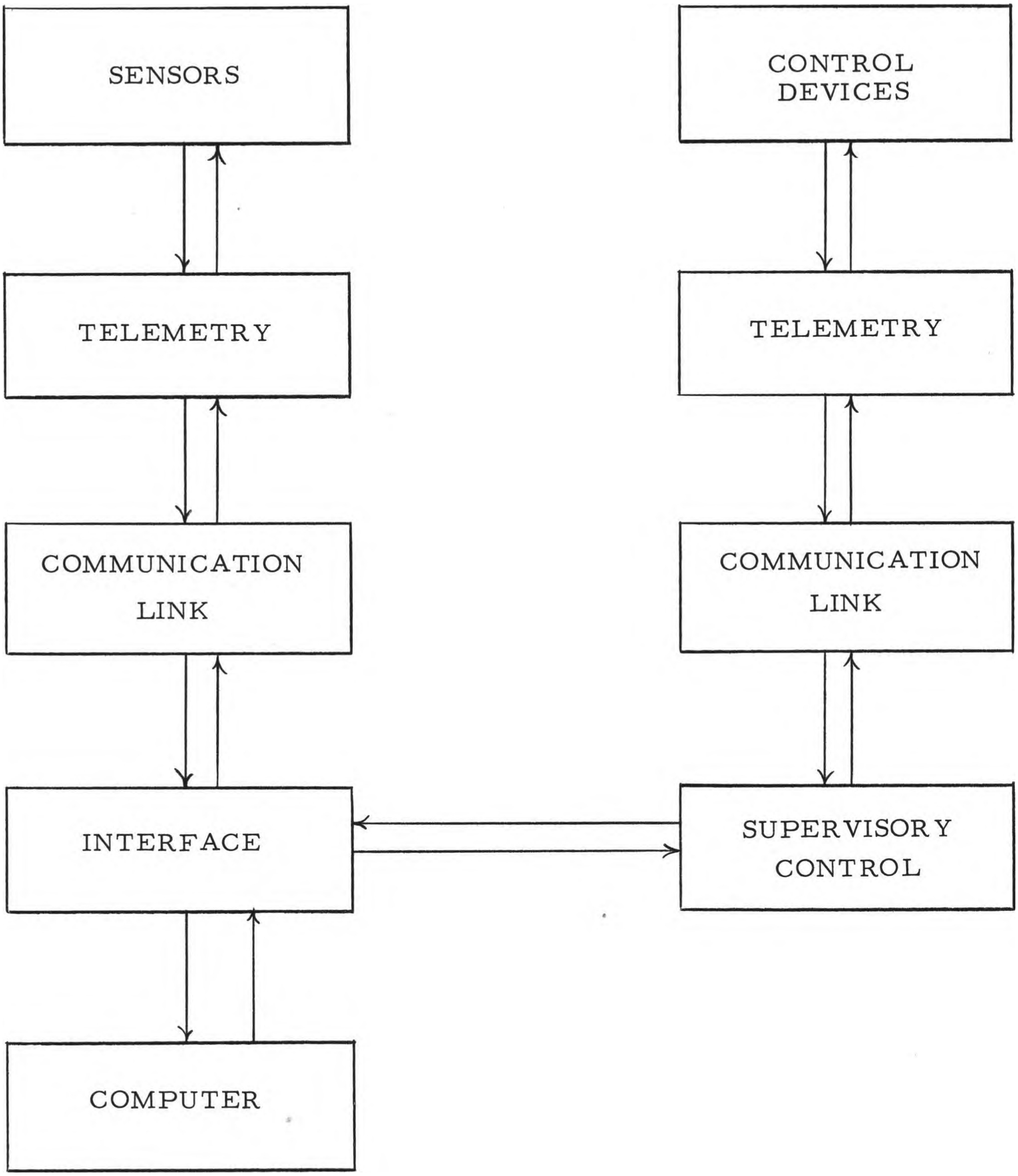

Figure 7. Computer-based data acquisition and control system. (Modified from Anderson, James J., 1970b).

Application of Automatic Monitors

To avoid a lengthy discussion on the use of automatic monitors for both freshwater and effluent monitoring, applications are summarized in Table 1. The table is intended to be useful as an index whereby the reader may locate those applications which most closely parallel his interest. Once determining the application(s) of interest, the reader may locate literature on the application(s) by referring to the reference source given in the far right column of the table.

Initial Development of Instrumentation

Initial development of automatic monitoring instrumentation was undertaken by various industries to provide a means of process control (Marks, 1966). Beginning in the mid-1940's with the introduction of the laboratory pH meter for on line use, many laboratory instruments have been adapted for process stream monitoring (Considine, 1965). A list of available process stream monitors and their application in various industries is given by Kehoe (1965).

Laboratory instruments are used in a controlled environment with frequent standardization (Babcock, 1970). This is not the case in a natural water body where the monitor operates unattended and may be subject to wide and rapid variations in environmental conditions (Feltz and Smoot, 1969). The significance of this

TABLE 1. Application of Automatic Monitors

System Name and/or Agency Involved	Where Employed	When Employed	Type of Water Sampled	Number of Stations	Type of System	Parameters Measured	Recording Technique	Purpose	Data Use	Reference Source(s)
USGS	Delaware Estuary	1955--	Estuarine	8	In situ	DO, pH, Cond, T, Turb, S Rad, Cl, Stage, ORP	Strip chart w/o telemetry & ppt.	Suppl. grab sa. program. Detect rapid flucuations in w. q.	Regulation: Water & Waste Treatment control	McCartney and Beamer, 1962 Keyser, 1964
USGS	Patuxent River Estuary	1963--	Estuarine	1	In situ	T, DO, Cond, Turb, Stage	Strip chart w/o telemetry	Suppl. grab sa. program. Rapid flucuations & Diurnal variations	Research: Effects of thermalpollution on biological life of estuary	Cory and Davis. 1965. Nauman and Cory, 1970
EPA/WQO	Potomac River & Estuary	--	Freshwater & Estuarine	4	In situ	DO, T, Cl	Telemetry	Provide real time continuous records of w. q.	Planning: mathematical models	McDermott, Ballinger and Sayers, 1968
EPA/WQO	New York Harbor	1963--	Freshwater & Estuarine	5	In situ	pH, Cond, T DO, Turb, ORP, S Rad	ppt at the site & telemetry/twls & ppt	Historical, continuous records of water quality	Planning: mathematical models	Bromberg and Carames, 1970
EPA/WQO	Hudson-Delaware Basin	--	Freshwater & Estuarine	--	Mobile Van	--	--	Collect w. q. data in remote areas	--	Dewling, 1969
EPA/WQO	Oregan	1968--	Freshwater	3	Mobile Trailer	pH, Cond, DO, T	Strip chart w/o telemetry	--	--	O'neal, 1971
EPA/WQO & Metro. St. Louis Sanitation District	Mississippi River in Missouri	--	Freshwater	--	Mobile Boat	DO, T, Cond, pH	--	Determine extent of pollution in 100 mi. stretch of Mississippi R.	Regulation: Water & Waste treatment control	Anon., 1969
Bureau of Reclamation	Calif. Cen. Valley Project	1965--	Freshwater & Estuarine	--	Mobile Trailer	Cond, T, Turb, DO, pH, S Rad	Strip chart w/o telemetry	Collect w. q. data in remote areas. Determine flucuations in salinity	Regulation: Water quality to control quality. Planning: New reservoir(s)	Anon., 1967 Marks, 1966
Ohio River Valley Water Sanitation Commission (ORSANCO)	Ohio River Valley	1960--	Freshwater	27	In situ & 1 Mobile	pH, T, Cond, DO, Cl, ORP, S Rad	Tele/ppt & Computer control & processing	Suppl. grab sa. program with realtime system	Regulation: Evaluate pollution control efforts	Cleary, 1962 Klein et al., 1968

TABLE 1. Continued

System Name and/or Agency Involved	Where Employed	When Employed	Type of Water Sampled	Number of Stations	Type of System	Parameters Measured	Recording Technique	Purpose	Data Use	Reference Source(s)
Interstate Commission for the Delaware River Basin (INCODEL)	Delaware River Basin	1959--	Freshwater & Estuarine	12	*In situ*	T, pH, Cond, DO, Turb	Strip chart w/o telemetry	Suppl. grab sa. program	Planning: Mathematical models	Parker, 1961 Smith and Morris, 1969
Empire State System	New York State	1966--	Freshwater	12	*In situ*	pH, Cond, DO, T, Turb, Stage Cl, F, S Rad.	Telemetry/ Computer Control & Processing	Suppl. grab sa. program & provide rapid intelligence system to protect state waters	Regulation: Water & Waste treatment control Planning: Mathematical Models	Maylath, 1970a Maylath, 1970b
New Jersey State Dept. of Environ Protection & USGS	New Jersey	1968--	Freshwater	10	*In situ*	Cond, T, pH, Turb, DO	ppt w/o telemetry	Suppl. grab sa. program	Planning: Trends in w.q.	Anderson et. al., 1970
Pennsylvania Dept. of Health	Pennsylvania	1965--	Freshwater	2	*In situ*	pH, Cond, T	ppt & printer w/o telemetry	Supply data on Acid mine drainage	--	Mentink, 1970
Wisconsin Dept. of Natural Resources	Wisconsin	1968--	Freshwater	--	Mobile Trailer	T, DO, pH, Cl, ORP, Cond, S Rad	Strip chart w/o telemetry	Suppl. grab sa. program. Special surveys, diurnal variations	Regulation: Formulate stds. Locate pollution source Research:	Anon., 1968 Schaufnagel, 1971
Wisconsin Dept. of Natural Resources	Wisconsin	1970--	Freshwater	11	*In situ*	DO, T, pH, Turb	Telemetry/ Computer Processing & control	--	--	Anon., 1968 Schaufnagel, 1971
Dept. of Ecology State of Washington	Washington State	1969--	Freshwater	--	Mobile Trailer	DO, T, Cond, Turb, pH, Cl	--	Collect Historical data	--	Palko, 1971
Texas Water Pollution Control Board	Galveston Bay	1963--	Estuarine	--	Mobile Boat	DO, Cond, pH, T	--	Determine affects of Indus. & Munic. pollution of w.q. & fish	Planning: Water pollution management	Davis, 1966

TABLE 1. Continued

System Name and/or Agency Involved	Where Employed	When Employed	Type of Water Sampled	Number of Stations	Type of System	Parameters Measured	Recording Technique	Purpose	Data Use	Reference Source(s)
Greater Chicago's Metropolitan Sanitation District	Chicago, Ill.	1968--	Effuent & Freshwater	11	*In situ*	DO, T, Cond, pH, ORP, Cl, Turb, S Rad	Strip chart ppt & twls	Obtain a better appraisal of w.q. conditions	Regulation: Water & Waste treatment control	Lanyonand Kurland, 1971
Detroit Sewer Monitoring & Remote Control System	Detroit, Mich.	--	Collection system	--	*In situ*	--	--	Better understand behavior of sewer & drainage systems	Regulation: water & waste treatment control	Sahre, 1970
University of North Carolina	Chapel Hill, N.C.	1960--	Freshwater Reservoir	1	Submersible	T, DO,	Telemetry/ strip chart & ppt	Study material transfer through metalimnion in impoundment reservoirs	Regulation: Water Impoundments	Weiss and Oglesby, 1963
Georgia Institute of Technology	Georgia	--	Freshwater	--	Mobile Van	DO, T, Cond, Turb, Stage, Depth, S Rad	Strip chart w/o telemetry	Study the affects of storms on w.q.	Research: Relation between water flow & quality	Ingols, 1970
Ontario Water Resources Commission	Lake Erie	1969--	Freshwater	2	Immersion	pH, T, Cond, Turb, Depth, Current (velocity & direction)	Magnetic tape	Determine the dispersion characteristics for near shore areas of Great Lakes	Planning: Mathematical Models	Palmer and Izatt, 1970 Palmer, 1970

Abbreviations

N.C. = North Carolina
Ill. = Illinois
Mich. = Michigan
EPA/WQO = Environmental Protection Agency/Water Quality Office
USGS = United States Geological Survey
Metro = Metropolitan
# = number
ppt = punched papertape
w.q. = water quality

twls = typewritten log sheet
stds = standards
Suppl. = Supplement
sa. = sampling
R = rivers
mi = miles
w/o = without
indus = industial
munic = municipal
Calif. = California

Cen = Central
pH = negative log of hydrogen ion activity
DO = dissolved oxygen
T = temperature
Cond = Conductivity
ORP = Oxidation reduction potential
Cl = Chlorine (Dissolved Chloride)
Turb = turbidity
S Rad = Solar Radiation
F = Fluoride

reliance on laboratory sensors for incorporation into automatic monitors will be examined later under the section: Needed Improvements in Automatic Instrumentation.

General Comments on Automatic Monitoring Applications

Examination of Table 1 reveals that the application of automatic monitors can be divided into the following categories:

1. Federal;
2. Interstate;
3. State;
4. Municipal; and
5. University Research.

This is the order in which they appear in Table 1. Also, note that actual field use of automatic instrumentation did not take place until the mid 1950's (USGS - Delaware Estuary). In fact, much of the initial work on the application of automatic monitors to measure water quality characteristics was performed by the U. S. Geological Survey. These initial systems were only capable of measuring one or two water quality characteristics (i.e., electrical conductivity and/or water temperature). Also, strip chart recording was standard, which required manual extraction of the data. Because this process was very time consuming and costly, conversion to punch paper tape and/or telemetry was commenced in 1965. Both methods have the advantage that recorded data is computer compatible; that is, data recorded are ready for computer processing without prior manual manipulation. Most of the some 300 automatic monitoring stations now operated by the USGS employ this preferred type of data recording (Blakey, 1970).

Similarly, USGS installations have progressed to systems measuring more parameters: Dissolved oxygen (DO), Turbidity (Turb), Solar Radiation (S. Rad), Chlorine (Cl), Oxidation Reduction Potential (ORP), pH, and Stage. All sensors are packaged in one cabinet (See Table 1 - USGS applications and reference sources).

Without reviewing all applications, perhaps other important advancements and achievements in automatic monitoring can be displayed by examining two very notable systems: (1) ORSANCO's Robot Monitoring Network, and (2) New York's Empire State System.

The early 1960's saw the beginning of the application of automatic instrumentation to monitor water quality on a regional, drainage basin basis. First developments of this kind were undertaken by the Ohio River Valley Sanitation Commission, ORSANCO (Anon., 1963). Much preliminary thought and investigation was given to an automatic water quality data acquisition before a formal program was initiated in 1958. The first phase of this project was to investigate instrument availability, capability and reliability. This was followed by the selection of instrument type and the installation of a prototype system. Electro-chemical probe type analyzers were found preferable to automatic wet-chemical units because of the signal requirements of the telemetry component and the remote location of the monitors made reagent replenishment difficult. The probe type unit chosen was designed by Schneider Instrument Company and termed "Robot Monitor." These analyzers were capable of measuring pH, temperature (T) conductivity, (Cond.), DO, chlorides, ORP, and solar radiation. The prototype unit was an integrated system consisting of the three basic modules mentioned earlier.

Operational as of September 1960, the prototype unit employed telemetry with data being transmitted to ORSANCO headquarters in Cincinnati, Ohio. There, a data logging facility was provided. Successful operation of the prototype unit allowed for expansion of the system. The resulting network consisted of six telemetry units on the upper Ohio River and five on-site strip chart recording units stationed on the lower Ohio (Cleary, 1962).

The ORSANCO system now comprises 27 automatic monitoring stations (17 on the Ohio and 10 on tributaries) (Ohio River Valley Sanitation Commission, 1969). In addition, a mobile version of the robot analyzer has been used in special studies which employs on-site strip chart recording (Anon., 1963).

The in situ system is fully integrated with data telemetered to a central receiving station where an IBM 1130, 2B computer processes the data (Klein et. al., 1968). Data are not just compiled and stored; statistical analyses are performed resulting in monthly and annual reports. Reports contain tables, graphs, charts and qualigrams showing maximum, minimum, and average values for each parameter in relation to station, time of year, and water quality criteria. Naturally, these reports are excellent for public relations and aid state and ORSANCO officials in evaluating the effectiveness of their pollution control efforts (Ohio River Valley Sanitation Commission, 1970 and Ohio River Valley Sanitation Commission, 1969).

Many states have entered the field of automatic water quality surveillance (Table 1). Most noteworthy is New York's Empire State System. The main purpose of this automatic network is to "provide a rapid intelligence system" to protect the waters and water users of the state. Emphasis is placed on rapid retrieval and analysis of data to yield instantaneous reports on the prevailing water quality conditions (Maylath, 1970b).

Like ORSANCO's Robot Network mentioned previously, much preliminary research which began in 1960 was necessary before any installations could be made. A prototype network was installed in 1966 with the purchase of two electro-chemical probe-type monitors (Maylath, 1970a). An exhaustive study of wet-chemical monitors revealed that they were really not satisfactory for unattended field use (O'Brien and Olsen, 1970).

Field experience using the prototype probe system yielded the following conclusions: (Maylath, 1970a).

1. Automatic monitors, if applied in a true real-time computer approach, are necessary to supplement a grab sampling program;
2. A well trained team of engineers and technicians is necessary to maintain the system; and
3. The monitoring system should be expanded.

Thus, steps were taken in 1969 to produce a small-scale monitoring network consisting of 12 monitors, with telemetry and central computer processing of data. A Burroughs B3500 computer was the heart of the system. Every attempt was made to incorporate the latest design features into the monitoring system. Monitors were equipped with sensors measuring pH, dissolved oxygen, conductivity, water temperature, turbidity, stage, dissolved chlorides, dissolved flourides, solar radiation and air temperature. In addition, environmental parameter alarm sensors, automatic samplers, equipment status sensors, and functional command equipment were included for better control of analyzer operation. Monitors were housed in trailers equipped with a lab plus air conditioning and heating. Leased telephone lines were employed to transmit data to the central computer station (Maylath, 1970a).

Monitoring stations were polled every hour with data traveling to the computer and remote terminals. Remote terminals are an integral part of the overall system since they are installed at water and waste treatment plants. Data received here are instantaneously available for altering plant processes in relation to prevailing water quality and quantity. Data received at the computer center is also displayed for rapid control of the water resource. However, statistical analyses are also performed which are the basis for daily, monthly and annual reports (Maylath, 1970b).

Future plans are to enlarge the small scale system into a basin network, with data telemetered to the central computer processing station. Mathematical models of each basin are being prepared. Data from the basin networks will then be fed into the mathematical models to ascertain (Maylath, 1970b):

1. The water quality at all points in a stream (not just at the monitoring station);
2. Prediction times for pollutant spills to travel downstream;
3. The source of a pollutant; and
4. The best location, design, and operation of water and waste treatment plants.

The above discussion will hopefully serve to inform the reader of the capabilities of fully integrated, real-time automatic monitoring systems. Note that some states utilize mobile monitors (Table 1).

The advantages and shortcomings of these mobile units, in comparison with *in situ* monitors mentioned above, will be described later under the section: Needed Improvements in Automatic Instrumentation. For a complete review of other applications, the reader may either refer to the literature cited in Table 1 or consult Section 7 of "Data Acquisition Systems in Water Quality Management" (Ward, 1971).

The Ability of Automatic Monitoring to Satisfy the Data Needs of State Water Pollution Control Agencies

The previous discussion has shown *how* automatic monitors are applied in water quality surveillance programs. However, two very basic and important questions remain unanswered: (1) *why are automatic water quality data collected*, and (2) *what are the data used for once they have been collected*. Answering these questions will help to define the ability of automatic monitors to satisfy the data needs of state water pollution control agencies.

The foundation for understanding the need for and the utility of automatic monitoring data are based on two facts: (1) grab sampling has many shortcomings when applied to situations where water quality fluctuates rapidly, and (2) water quality management is becoming more complex, requiring real-time data.

To begin, Klein, et. al. (1968) states that there are three deficiencies in grab sampling programs:

(1) cost

(2) limitations on the frequency with which analyses can be made

(3) time lag between collection of samples and receipt of analytical results for stream evaluation purposes.

Cost and limitations on frequency must be considered together. Frequency limitations are mainly related to manpower limitations. As applied to grab sampling, increased sampling rate means increased field and laboratory personnel to collect and analyze samples with a concurrent increase in operational expenses (Anon., 1970).

In comparison, the major advantage of automatic monitoring is the increased capability for high frequency sampling (Ballinger, 1971a). Nevertheless, automatic instrumentation does not eliminate field and laboratory personnel because of the necessity of periodic maintenance on automatic equipment (Sayers, 1971). Indeed, personnel requirements are such that higher salaries are required to obtain people with the necessary qualifications (Sayers, 1971).

While automatic monitoring has some advantages with respect to manpower limitations, the wealth of data produced increases operational costs due to the necessity of expensive data handling procedures (Sayers, 1971). Effective data interpretation and analysis require digital computers (Ballinger, 1971a). ORSANCO's robot monitor system collects so much data that it would take 150 man-years to process all the data collected during only one year (Klein, et. al., 1968).

Taking the above factors into consideration, as well as installation and maintenance costs associated with automatic monitoring, automatic instrumentation is favored on a least cost basis when a sampling frequency greater than daily is desired (Ballinger, 1971a).

However, the trade-off between automatic and manual sampling involves other considerations also. According to Klein, et. al. (1968), the third deficiency of grab sampling is the time lag between collection and receipt of analytical results. This topic will also be discussed later in relation to the need for real time data for water quality management. For the purposes here, it will be sufficient to note that grab sampling programs entail time consuming collection and analysis procedures (Cleary, 1962). Grab sampling programs applied to situations involving rapid fluctuations in water quality may be very inefficient and expensive due to the large proportion of time spent in collection of samples and travel between stations and to the laboratory (Mentink, 1970).

Another problem in grab sampling associated with time consuming collection and transportation is the retrieval of a representative sample. "In general, the sooner the samples are analyzed after the collection, the more reliable the data" (Ball, 1970). This is true because after sample collection, changes in composition may occur rapidly (Glenn, 1970). Parameters such as temperature, dissolved gases, and pH are subject to rapid alteration upon collection and "must be measured in the field" (Ball, 1970). Other parameters which are not now reliably measured by automatic monitors such as biochemical oxygen demand, (BOD), nitrates, (NO_3), and phosphates, (PO_4) can change significantly with time requiring precautions such as refrigeration in order to assure minimum sample degradation between field collection and laboratory analysis (Ball, 1970).

Another important consideration in comparing manual and automatic monitoring is the relative compatibility of a particular water to either method of evaluation. To explain, some waters exhibit rapid fluctuations in water quality while others show relatively slow changes (Thomann, 1970). "In any sampling, the frequency of sampling is directly related to the rate of change of a given parameter" (Ballinger, 1971a). Thus, some waters are naturally more conducive to automatic monitoring than others (Thomann, 1970; Ballinger, 1971a; Ballinger, 1968). The proper sampling frequency for any water can be determined by spectral analyses. Ironically, this requires a "relatively large amount of data" (Ballinger, 1971a).

The above discussion has described some of the deficiencies of grab sampling. Most of these limitations are related to monitoring programs requiring detection of rapid fluctuations in water quality. As pointed out, herein lies the major value of automatic monitoring, the capability for high frequency sampling. The question now is: Why is it necessary to detect rapid fluctuations in water quality? Smoot (1970) gives the explanation:

> Today many complex water-quality problems associated with protecting and improving our environment frequently require immediate evaluation and prompt action. More and more, real time data networks are being recognized as essential in providing the current information necessary for good water-quality management.

For some time, water resource managers have desired to keep a continuous watch on upstream conditions so that good water quality could be maintained for downstream users (Jones, 1961). The need for continuous surveillance of water quality is a direct result of the increased quantity and variety of waste matter entering our nation's waters (Jones and Joyce, 1961) (Cross, 1968). True, some waters are still blessed with good quality due to sparse population and large stream flows in relation to pollution loads. In these areas, only modest sampling programs may be sufficient (McDermott, Ballinger and Sayers, 1968). However, Elving (1967) states that any flowing water constitutes a constantly changing and dynamic system which must be monitored continuously. Moreover, in some areas of dense population, complex waste sources, intensive water use, and rapidly fluctuating water quantity, day to day water quality management requiring continuous automatic monitoring is needed (McDermott, Ballinger and Sayers, 1968).

Now that the general need for and utility of automatic data has been described, the merits of automatic monitoring in relation to its ability to satisfy the data needs of state water pollution control agencies can be discussed. The data requirements of a state water pollution control agency are a function of its program objectives. In general, these objectives are:

(1) planning;
(2) research;
(3) aid;
(4) technical assistance;
(5) regulation;
(6) legal enforcement; and
(7) data collection and dissemination.

The data requirements for each objective need not be considered in detail because data essential for planning and regulation are also the data needed for the other objectives (Ward, 1971).

Ability to Satisfy Planning Data Needs

Long range planning frequently connotes the use of mathematical models. Data needed for mathematical models "must be perfect continuous records with no sags or bad readings" (Palmer, 1970). This basic requirement is satisfied by automatic monitoring which supplies large quantities of continuous inexpensive data (Palmer, 1970). Ballinger (1971a) agrees in that automatic monitors provide large amounts of data in short time intervals which are valuable as input into predictive river basin models. Also, automatic data are very suitable to certain statistical analyses often used in water quality models: time series and Markov chain analyses (Palmer, 1970) (McCartney and Beamer, 1962).

River basin models based on automatic data have much planning utility. They are useful as an aid in locating municipal and industrial intakes and outfalls (Palmer, 1970; Glenn, 1970). In New York, the Empire system provides pertinent data to "improve the precision of math models predictions" (Maylath, 1970a). These predictions are the basis for formulating design and operational criteria guiding the construction and operation of water and waste treatment plants. New York also plans to use monitor data in the preparation of stream models useful for water quality forecasting (Maylath, 1970a). Using deterministic and probabilistic BOD-DO models based on continuous DO measurements and BOD waste load determinations, downstream DO predictions can be made knowing upstream conditions and events (Boes, 1970). Automatic data plugged into predictive models can also yield information on water quality conditions at non sampled sites and at any time of day (Glenn, 1970; Maylath, 1970a).

Ability to Satisfy the Data Needs for Regulation

A state water pollution control agency concerned with regulating water quality is interested in detecting pollution, determining its source, and seeing that the pollution is abated. One of the principal assets of automatic monitoring lies in its ability to detect abnormal water qualities (Klein, et. al., 1968). In this respect, automatic monitoring surpasses manual monitoring as "grab sampling, even at frequent intervals, may not detect undesirable levels in time to permit effective counter measures" (Ballinger, 1971a). Automatic instrumentation, however, has the capability of sounding an alarm and/or collecting a sample for further analysis once an abnormal variation in water quality has been detected (Keyser, 1965; Parker, 1961). Also, as mentioned earlier, one of the deficiencies of grab sampling lies in the difficulty of maintaining a representative sample. Sample degradation can occur due to the time lag between collection and analysis (Ball, 1970). Surveillance by automatic monitors does not reduce the problem of sample degradation since the parameters reliably measured by automatic monitors are presently measured in the field when grab sampling.

The capability of monitors to detect abnormal changes in water quality and collect a sample at these times has significance for determining pollution sources. Analysis of the collected sample may indicate the particular waste causing the abnormal water quality. Knowing the nature of the pollutant may be valuable for locating its source (Ballinger, 1971a). A good example is the tracing of two fish kills to a common cause by the ORSANCO Robot Monitoring System (Klein, et. al., 1968). The advantage of the large spacial distribution of the ORSANCO network was brought out in tracing the source of widespread low DO readings to natural causes (Klein, et. al., 1968). A similar situation existed on the USGS Delaware system in April, 1963 when DO values were depressed below 3 parts per million (ppm). Again, the monitoring network traced the source to natural causes (Anon., 1963a).

Electronic monitors are also amenable for detecting diurnal fluctuations in water quality characteristics; especially for documenting DO sags (Ballinger, 1968a; Kleinert, 1971).

Making data readily available to water quality agencies is an important part of pollution abatement. "Those who are active in water resources management agree that any pollution abatement program must be preceded with the acquisition of a continuing intelligence on the quality of all our rivers and streams." Merely collecting data is not enough, data must also be made readily accessible to those concerned with controlling water quality (Shubrooks, 1968).

Once the data are made available, they must also be used. A rapid intelligence system of automatic monitors, telemetry, remote terminals and central data logging and analysis facilities provides a highly effective means of water quality regulation (Maylath, 1970a). As mentioned earlier, instantaneous relay of water quality conditions allows for alteration of treatment plant processes to conform to the quality of receiving waters (Maylath, 1970a; Lanyon and Kurland, 1971). Monitored data is also useful for determining low flows and the amount of water necessary to supplement stream flows so that standards are not violated. Using automatic data,discharges of pollutants can be traced and their effect on the entire water system evaluated (Ballinger, 1971a).

Monitored data coupled with mathematical models can be useful for establishing effluent concentrations for industries and waste treatment plants. In this way, the assimilative capacity of receiving waters is not exceeded and compliance with water quality standards is assured (Palmer, 1970).

Processing of telemetered data allows for rapid report generation. Such reports on an hourly, daily, weekly, monthly, or annual basis are extremely valuable as aid in regulation, since graphs, charts, and tables can be devised to show the percent of time water quality parameters are in violation of standards. In addition, computer analysis can determine the extent of daily pollution loading, including: dissolved oxygen deficits, suspended solids loads, salt water intrusion, acid loads from mines, caloric loading from thermal pollution and waste treatment plant effluents (Ballinger, 1971a; Elving, 1967).

Needed Improvements in Automatic Instrumentation

The previous section has cited the advantages of using automatic instrumentation for water surveillance. Nevertheless, even with sophisticated telemetry systems, present day water quality surveillance leaves much to be desired. The fact is that most state and federal agencies are still not able to determine whether our nation's waters are getting better or worse (Cleary, 1970).

Disadvantages of Present Instrumentation

Agencies are handicapped because monitoring systems still fail to supply the right sort of data (Cleary, 1970). Automatic monitoring has many shortcomings in this respect. In 1960, at a "Conference on Water Quality Management and Instrumentation" held in Cincinnati, Ohio, it was pointed out that data processing technology was sufficient for water quality monitoring, but that much research on sensing devices was needed. Ten years later at a similar conference held in Madison, Wisconsin, the same conclusions were reached (Lyon, 1970). Data recording and processing represents the strongest link in the automatic water quality data acquisition system because it is fully developed and relatively trouble free (Smith, 1970). Similar words cannot be spoken for sensing devices. Most experts agree that in the last ten years, little progress has been made in developing new automatic sensors (Lyon, 1970).

The reason for this lag in the development of new sensors is twofold. One, as mentioned earlier, initial emphasis on developing automatic water monitoring instrumentation was focused on supplying monitors for industrial process control (see section on application of automatic monitors). Two, instruments devised for this purpose were merely adaptations of existing laboratory instruments (Considine, 1965). Thus, development of automatic field equipment paralleled and was dependent on the development of laboratory and process control instrumentation, thereby resulting in the deplorable situation described by Ballinger (1968a) where field sensors "represent parameters for which electrode systems are readily available--and do not include many measurements vital to the adequate characterization of water quality" (Tables 2 and 3).

The past ten years have not been completely fruitless. Development of specific ion electrodes and wet chemistry monitors have had some impact on alleviating the sensor limitation

TABLE 2. Water quality criteria in state standards. (From Ballinger, 1971a...Underlined criteria represent parameters for which sensors are already available).

Water Quality Criteria

Acidity
Alkalinity
Ammonia
Arsenic
Barium
BOD
Boron
Bottom Deposits
Cadmium
CCE
Coliform

Iron
Lead
Manganese
MBAS
Nitrate
Pesticides
pH
Phenols
Phosphates
Plankton
Radioactivity
Selenium

Chloride
Chromium
Color
Copper
Cyanide
Dissolved Oxygen
Electrical Conductance
Floating Solids
Flouride
Hardness
Hydrogen Sulfide

Setteable Solids
Silver
Sodium
Sulfate
Suspended Solids
Taste & Odor
Temperature
Total Dissolved Solids
Toxic Substances
Turbidity
Zinc

TABLE 3. Parameters for which sensors are not available but are needed. (From Green, 1966).

Parameter	Ranges of Concentration Desired mg/l			Ranges of Concentration Desired mg/l		
	L	M	H	L	M	H
Organic nitrogen	0-1	-	0-10	0.01	-	0.5
Ammonia nitrogen	0-1	-	0-10	0.01	-	0.5
Nitrate nitrogen	0-1	-	0-10	0.01	-	0.5
Nitrite nitrogen	0-0.1	-	0-2	0.01	-	0.1
Inorganic phosphorus	0-2	-	0.20	0.01	-	0.5
Organic phosphorus	0-2	-	0-20	0.01	-	0.5
COD	0-50	-	0-500	1	-	10
MBAS*	0-1	-	1-10	0.01	-	0.1
Acidity or alkalinity	0-250	-	0-1000	5	-	50
Hardness	0-250	-	0-1000	5	-	50
Sulfate	0-100	-	0-1000	2	-	20
Phenols	0-0.5	0-5	0-50	0.01	-	0.1
Calcium	0-100	-	0-1000	2	-	20
Cyanide	0-0.1	0-1.0	0-10	0.005	0.05	0.5
Manganese	0-0.5	-	0-5	0.01	-	0.1
Zinc	0-2	-	0-10	0.01	-	0.5
Sodium	0-100	0-500	0-5000	2	10	100
Potassium	0-10	0-100	0-1000	0.5	5	50
Copper	0-0.5	-	0-5.0	0.01	-	0.1

* Methylene blue active substances

problem (Table 4). Specific ion electrodes can broaden the spectrum of sensor detection to include some specific water quality parameters. In general, ion selective electrodes detect ions in solution, thereby developing an electrical potential in proportion to the activity of the ion (Riseman, 1970; Kaminski, 1969). The chloride ion is an example of such an electrode presently used in automatic water quality monitoring. However, other specific ion electrodes available for laboratory use are "not satisfactory for monitoring purposes" (Ballinger, 1971b). This includes electrodes for measuring important nutrient parameters (e.g., nitrates and phosphorus). Electrodes for these paramenters do not possess adequate sensitivity and fail to truly measure the desired constituents (Ballinger, 1971b).

Another serious problem is interference from like ions. Pretreatment of a water sample can be performed in the laboratory to minimize these effects, but this is difficult under field conditions (Riseman, 1970).

Wet chemistry monitors can also broaden the scope of sensor detection. However, severe handicaps must be overcome before these monitors are suitable for field application (Ballinger, 1971b). Some of the disadvantages are interference from color and turbidity, biological fouling of sampling lines, failure of solenoid valves, reagent supply and disposal, buildup of color complexes on the

TABLE 4. Currently available specific ion electrodes (From Riseman, 1970).

Ion	Membrane	Lower limit of detection*
Bromide	crystal	0.4 mg /l
Cadmium	crystal	0.01 mg /l
Calcuim	ion exchanger	0.4 mg /l
Chloride	crystal	1.8 mg /l
	ion exchanger	0.4 mg /l
Cupric	crystal	0.006 mg /l
Cyanide	crystal	0.03 mg /l
Fluoride	crystal	0.02 mg /l
Fluoroborate	ion exchanger	0.1 mg /l as B
Iodide	crystal	0.007 mg /l
Lead	crystal	0.02 mg /l
Nitrate	ion exchanger	0.6 mg /l
Perchlorate	ion exchanger	1 mg /l
pH	glass	pH 14 (10^{-14} MH^{+})
Potassium	ion exchanger	0.4 mg /l
Silver	crystal	0.01 mg /l
Sodium	glass	0.02 mg /l
Sulfide	crystal	0.003 mg /l
Water Hardness	ion exchanger	0.001 mg /l as CaCO3

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* Assuming no electrode or method interference.

measurement cell, and slow response of the system (typical time is two hours from sampling to recording) (O'Brien and Olsen, 1970; Feltz and Smoot, 1969; Ballinger, 1968). Sample filtration has generally been employed to minimize some of these problems. However, this "renders the sample not entirely representative of the source" (O'Brien and Olsen, 1970).

Besides not supplying entirely the right kind of data, automatic monitors are still plagued with maintenance problems. Characteristically "automatic monitoring equipment is delicate and unstable" (Blakey, 1970). This is evident from operational experiences in which typical monitoring systems require weekly maintenance. Sensors require cleaning and calibration due to biological and sediment fouling, thereby causing electronic drift (Blakey, 1970). Self-cleaning with automatic wipers, water jets or ultrasonics may eliminate this problem (Ficken, 1970).

Pump failure remains the number one maintenance problem. Semi-positive displacement submersible pumps are advantageous since they do not aerate or deaerate the water sample. However, they are disadvantageous because of frequent breakdown due to electric motors burning up and metal fatigue producing pump strator breakage (Maylath, 1970a). The problem arises from placing pumps in the harsh stream environment where they are naturally subject to strain, abrasion, and clogging from sediment, organic debris and biological growths on the pump itself (Feltz and Smoot, 1969).

Another significant limitation is aging and depreciation of equipment. Solid state circuitry, amplification of sensor signals, maintenance of proper velocity of sample through the flow cells, and large electrolyte reservoirs are helping to extend instrument life and provide long term stability for automatic sensors (Bromberg and Carames, 1970; Klein, et. al., 1968). Nevertheless, sensors and other monitor components do wear out and require replacement as shown in Table 5 (Bromberg and Carames, 1970).

Rising costs of automatic monitors are another drawback. The trend of instrument manufacturers is to produce more complicated, costly systems, which is in direct opposition to the needs of the users who desire simpler, more reliable and less expensive instrumentation (Klein, et. al., 1968).

Other considerations and limitations include freezing of pump and sampling lines during winter operation, salt bridging and corrosion of mechanical parts during operation in saline waters, vandalism, and high initial costs for land acquisition and installation (Maylath, 1970a; Bromberg & Carames, 1970; Ballinger, 1971a).

Future Needs

The above discussion has already pointed out many of the improvements needed by explaining the disadvantages of present systems. Some specific suggestions for improvement are (Maylath, 1970a):

TABLE 5. Replacement interval and tolerance for some automatic sensors. (From Bromberg & Carames, 1970).

Parameter	Replacement Interval	Tolerance
Dissolved Oxygen	12 weeks	± 0.25 mg/l
pH	4-5 months	± 0.1 units
Temperature	6-12 months	± 1 °F
Oxidation-reduction Potential	6-12 months	12 mv

1. Lessen frequency of cleaning by changing the configuration of the flow chamber so that it has the same internal shape as the water supply lines (possibly have the sensor surround the sample instead of the converse); and
2. Develop a standard calibration procedure for sensors.

Other modifications are needed to make automatic monitors more reliable and versatile. The trend in sensor technology is toward developing microcircuit, digital sensors. These sensors would eliminate analog to digital conversion before signal transmission. This not only simplifies data transmission and logging but also provides sensors of greater reliability through the use of microcircuits (Tajima, 1969).

Monitor versatility can be increased by developing satellite and mobile monitors for supplementing major stations and for use in intensive surveys (Maylath, 1970a; Ballinger, 1971a). Some progress has already been made in supplying monitors suitable for both of these uses. One such system is the immersion or submersible water quality recording monitor (Maylath, 1970b). Portability is an important feature of this unit. The monitor is small, compact and battery operated. In addition, advantage is gained by using submersible sensing and recording instrumentation. The necessity of pumps, intake and outlet lines, and a shelter to house the monitor is eliminated. Also, a representative sample is assured because measurements are taken and recorded in-stream. Data logging and telemetry is also possible via external terminals attached to the submerged monitor (Palmer, 1969).

One disadvantage is the difficulty in maintenance due to in-stream placement of the monitor. Such a location is awkward for servicing since removal from the stream is required. During times of cold weather or high water, this can be come quite a chore. Also, in-stream placement may result in the monitor being damaged because of floating debris, change in water flow, biological and sediment fouling, and vandalism (Ballinger, 1971a; Ballinger, 1968a).

Mobile adaptations of *in situ* monitors can also be employed as satellite monitors and for intensive surveys. Most *in situ* systems can be modified for mobile operation without significant change in design (Ballinger, 1971b; Ballinger, 1968a). Mobile operation has some distinct advantages. Most obvious is the fact that such units "provide maximum flexibility in sampling location" (Ballinger, 1971a). This asset makes mobile monitors valuable for intensive surveys because of their capability to sample for short periods at a number of critical points. Other advantages are: (1) ease in maintenance, and (2) reduction in the initial expenditures for land acquisition and installation (Ballinger, 1971a).

One disadvantage of mobile adaptations of in situ systems cited by (Ballinger, 1968a) is the problem of inadequate operation of support facilities (i. e., propane storage tank and generator).

The benefits derived from mobile operation could be increased if mobile monitoring were expanded to include buoy-type or float systems (Anon., 1970). Two applications are listed in Table 1 District Sanitation (St. Louis Sanitation District and Texas Water Pollution Control Board). In addition, research on a floating system housed in a small boat has been conducted by Raible and Testerman (1969) at the University of Arkansas Graduate Institute of Technology.

The last point to be made, but an important one, is that automatic monitoring data must be used to be effective (Ballinger, 1971a; Cleary, 1970). Automatic monitoring produces a wealth of data which require computer storage and analysis (Klein, et. al., 1968). Moreover, report generation is extremely important and all water users should be informed of water quality conditions on a real time, daily, weekly, monthly, annual and long term basis (Maylath, 1970a).

Cost Analysis

The cost of automatic water quality data acquisition systems will vary according to the type of system (in situ, mobile, immersion), the recording technique (strip chart, punched paper tape, magnetic tape), and whether telemetry is performed. The cost of telemetry systems varies according to the type of transmission, communications link and whether merely data logging or a computer facility is employed. To obtain a feeling for the kinds of expenditures involved, an analysis of three principal cost categories will be examined:

1. purchase price of instrumentation;
2. installation; and
3. operation and maintenance.

Purchase Price of Instrumentation

The initial cost of developing an automatic monitoring system is purchasing the equipment. Monitors conforming to EPA/WQO specifications (Mentink, 1968) "cost from $6,000 to $12,000 depending upon the sensors required and the data acquisition employed" (Ballinger, 1971a). The five parameter system employed by the USGS on the Patuxent River costs approximately $8,000 (Nauman and Cory, 1971). For his case study on the design of urban water data acquisition systems, Anderson, James J., 1970b) estimated a cost of $8,000 for a six parameter "Robot Monitor." Mentink (1970) estimates a cost of $7,000 for a four parameter monitor. Purchase price estimates developed from company quotations are given in Table 6.

The cost of the monitor usually includes the price of a strip chart recorder, which runs approximately $2,200. If another recording technique is desired, a slightly higher expenditure is

TABLE 6. Purchase price estimates for automatic monitors.*

Monitoring System	Companies							
Number of Parameters Measured	Honeywell	AES	KDI	Delta Sci	Schneider	Plessey	Martek	Average Figure
4 (DO, T, Cond, and pH)	5,005.00	7,895.00	7,705.00	6,628.00	6,200.00		3,250.00 to 4,000.00	6,687.00
5 (DO, T, Cond, pH, and Turb.)	6,851.00	9,595.00	8,700.00	8,175.00	7,150.00	8,000.00	1,850.00 to 2,500.00	8,078.00
6 (DO, T, Cond, pH, Turb, and Cl)	7,766.00	10,720.00	9,495.00		8,010.00		5th/parameter is depth	8,998,00
6 (DO, T, Cond, pH, ORP, Cl)	7,500.00	7,980.00			7,770.00			7,750.00
6 (DO, T, Cond, pH, Turb, S Rad)	7,691.00				8,075.00			7,883.00
Mobile Package 4 (DO, Cond, T, pH)		3,430.00		4,125.00	6,200.00 + Trailer = 2,200.00			5,728.00

* Price estimates are for total systems (sensors, flow chambers, signal conditioners, cabinet and recorder).
All meet EPA/ WQO specifications.
Prices will vary with quantity ordered.

necessary. For eight channel punched paper tape, a cost of $6, 000 can be expected (Mentink, 1970). Although less expensive in itself ($4, 000), sixteen channel tape does not record data in computer compatible format. If data processing is desired, an additional $7, 500 for a translator is required, along with $1, 600 for a digital clock plus analog to digital converter. Also, a spare reading head for the translator is advisable from a maintenance standpoint. The price of this part is $2, 000 (Mentink, 1964 and Mentink, 1970). Recording on magnetic tape is also possible. Incremental magnetic tapes cost approximately $5, 000 (Mentink, 1970).

In addition to the price of the monitor and recording, the expense of accessories and support equipment must be considered. The sum cost of submersible pumps, intake and outlet lines, sample takers and sensor cleaning devices can be significant. Sensor cleaning by high velocity water jet costs $970, while ultrasonic cleaning runs $2, 200 (Mentink, 1970). Component price estimates developed from company quotations are compared with literature values in Table 7.

If telemetry is not desired, the previously mentioned expenditures constitute the initial capital investment on equipment. With telemetry a higher initial capitalization is necessary. Initial telemetry expenses can be divided into three areas: (1) transmission; (2) interface; and (3) data logging and processing.

TABLE 7. Component price estimates for automatic monitors. (and other expenses).

Component	Source of Information								
	Companies					Literature Source			
	Honeywell	AES	KDI	Delta Sci	Schneider Instrument Company, Inc.	Mentink	Ballinger	Nauman and Cory	Average
Submersible Pump	245.00	350.00							298.00
Sample Taker	450.00				940.00				695.00
Analog Strip Chart Recorder	2,000.00	2,150.00	2,315.00			2,000.00			2,116.00
Digital 8-Channel Punched Paper Tape			5,000.00		4,500.00	6,000.00			5,167.00
Digital Magnetic Tape						5,000.00			5,000.00
Automatic Cleaning: Ultrasonics			2,465.00			2,200.00			2,332.00
Water Jet					950.00	970.00			960.00
Installation				1,000.00			1,000.00 to 3,000.00	4,000.00	2,300.00
Central Receiving Station					10,000.00	9,500.00			9,750.00
Telemeter Transmitter					1,800.00				1,800.00
Trailer for Mobile Operation					2,200.00				2,200.00

Telemetry may be by either analog or digital transmission. For analog transmission, there are two modes: (1) pulse duration, and (2) millivolt to frequency (Smoot, 1970). Both modes require a transmitter at the monitor. For either mode, analog transmitters cost $2, 250 (Mentink, 1964). However, a lower figure of $600/ location is given by James J. Anderson (1970b).

Digital transmission requires higher cost transmitter packages. Mentink (1964) gives a figure of $4, 500. Again, Anderson James, J. (1970b) gives a lower cost of $4, 000.

Telemetry also entails expense at the receiving end of the communications system. This phase of the system is referred to as the interface since it receives the transmitted signal from the monitoring stations and converts them into a form suitable for display, recording, data logging, and/or computer processing (Anderson, James J., 1970b).

If pulse duration analog transmission is employed, a cost of $11, 500 is possible at the interface phase (receiver and analog to digital converter plus packaging and engineering). For millivolt to frequency analog transmission, the expense is reduced to $7, 500 (receiver plus analog to digital converter) (Mentink, 1964). Anderson, James J. (1970b) gives a cost of $10, 000 for this phase, using analog transmission.

Since digital transmission does not require analog to digital conversion at the interface, the cost here is nominal. (Anderson, James J., 1970b).

The interface is located at the central receiving station which can be either a data logging unit or a computer processing and control facility. Data logging units may display and record data on typewritten log sheets and record data for future analysis on punched paper tape or magnetic tape. (Smoot, 1970). If analog transmission is employed, the cost of the data logging unit is $20,000. With digital transmission, data logging units cost $22,000 (Mentink, 1964).

Computer processing facilities are employed when more than data logging is desired. Anderson James J. (June, 1970b) gives a rundown on the cost of a computer facility with data processing, monitor control, and math modelling capabilities. The cost of a minicomputer with 4K core memory is given as $15,000. Additional core is available at a cost of $6,000 per 4K words. The disk file costs $40,000 and is necessary if foreground/background programming is desired. Other peripheral equipment needed includes:

1. paper tape punch-reader, $6,500;
2. magnetic tape, $28,000 first unit;
3. magnetic tape, $18,000 added units;
4. fine printer, $30,000;

5. cathode ray tube display, $4,000 each; and
6. logging typers, $5,200.

In addition, special software systems are important and cost 10% of hardware costs, plus $100/remote point. Applications software cost is $5,000/program.

Installation

After purchasing monitoring equipment, the next expense is installation. The literature with respect to this topic is sparse. The only figures available appear in a recent article by Ballinger (1971a). He indicates that an expenditure of from $1,000-$3,000 in construction costs is necessary for installation.

Operation and Maintenance

Automatic monitors are intended for unattended operation in the harsh stream environment. Yet, the present state-of-the-art indicates that they are unstable and delicate instruments subject to deterioration due to biological fouling, etc., and depreciation because of aging (See discussion on Needed Improvements in Automatic Instrumentation). Given these limitations, it is no wonder that maintenance constitutes a large portion of the expense of operating an automatic monitoring system.

Considering only maintenance on the monitors, a cost of $1,250/station/year was determined for the ORSANCO system of fourteen monitors. This is a total of $17,500 for all the stations combined. When maintenance costs at the central receiving station are added, the total cost is only increased to $18,600. Thus, only a small portion of the total maintenance cost was attributed to the central receiving station. A breakdown of the maintenance costs on the monitors shows approximately 35% for travel, 30% labor, 20% servicing, and 15% parts and supplies (Donnelly, 1971). Maintenance costs are based on a two week service schedule (Klein, et. al., 1968).

Donnelly (1971) points out that the maintenance cost per station per year ($1,250) has not changed despite inflation and holds for ORSANCO's present system of 27 stations.

An analysis of costs for a single monitor system on the Patuxent River shows an annual maintenance expense of $2,700. This figure is comparable to ORSANCO's results, since servicing on the Patuxent River monitor was on a weekly basis. The $2,700 annual maintenance cost includes servicing, recalibration, transportation, and salaries (Nauman and Cory, 1970). Wages paid ranged from $7.50-$8.00 per hour (Nauman, 1971).

Besides the maintenance expenses, operational costs include expenditures for telemetry and data processing. Operational telemetry costs are mainly attributable to the communications link.

Charges vary according to the type of leased line employed. For telegraph grade (schedule 1001) lines a charge of $.75-$1.00/month/mile can be expected (Shubrooks, 1968).

ORSANCO's system utilizes telegraph grade lines and has experienced a yearly cost of $11,300 (611 miles at $1.00/month/mile plus a monthly terminal service charge per location) (Klein, et. al., 1968).

EPA/WQO experience with the New York Harbor monitoring network showed a cost of $1,980/year for leased telegraph lines for a five station network and $3,170 for an eight station system (Bromberg and Carames, 1970).

For voice grade lines, the charge is $3-$4/month/mile (Shubrooks, 1968). A comparable figure of $3 for the first one-fourth mile plus one dollar for each additional one-fourth mile is given by Anderson, James J. (1970b). In addition, he indicates that an installation charge of $10 per termination is necessary.

If tone multiplexing is desired with voice grade lines, an additional charge can be expected. For the central receiving station, a charge of $10,000 per eight remote sites per party line is made. For remote sites, a $1,500 charge per site per eight points is assessed (Anderson, James J., 1970b).

When data processing equipment is leased, it should be considered as an operational expense. ORSANCO leases its data processing equipment at a charge of $23, 600 per year. The computer facility contains "an IBM 1130, 2B computing system, with 8K and disk pack, 1134 paper tape reader and 1055 punch, 1442 card-read punch unit, 1132 medium speed printer, and 029 interpreting key punch (Klein, et. al., 1968).

Other operational expenses include electric service and salaries. Electric service for the New York Harbor system of five stations was $2, 400 per year. Charges figured for an eight station network were $3, 840/year. Salaries for both the five and eight station systems were $25, 250/year (Bromberg and Carames, 1970).

An appreciation of the constituent operation and maintenance expenses mentioned above is important. However, a discussion of the total operation and maintenance expenditures is probably more valuable. For the New York Harbor monitoring system of five stations (6-8 parameters per station), the total operation and maintenance cost was $31,684 per year (includes salaries, servicing, replacement equipment, leased lines, electric service, and transportation). On a per station basis, this is $6, 340/station/year. Total operation and maintenance costs for the New York Harbor system of eight stations was $35, 189/year, or $4, 400/station/year (Bromberg and Carames, 1970).

Anderson, James J. (1970a) estimates a total operation and maintenance cost for an eight station system (7 parameters per station) at $33,000/year, or $4,125 per station/year.

A total annual operation and maintenance cost for the somewhat larger ORSANCO system (14 monitors - 7 parameters per station) is lower, at $53,500 or $3,821/station. This cost includes servicing, telegraph line charges, and leased data processing equipment (Klein, et. al., 1968).

Life Expectancy of Instrumentation

Another important consideration which has significant impact on the cost of an automatic monitoring system is depreciation of equipment. Due to aging (increase in maintenance necessary) and obsolescence, replacement of equipment may be necessary every seven years (Klein, et. al., 1968).

Total Annual Cost

Given the seven year life expectancy, operation and maintenance costs, initial capital investment for equipment, installation, and amortization, the total annual cost of an automatic monitoring system can be determined. For the ORSANCO system (14 monitors), a cost of $74,000 or $5,300/ station was computed (Klein, et. al., 1968).

Anderson, James J. (1970a) estimates a cost of $60,000 or $7,500/station for an eight station telemetry network over a one hundred mile stretch of river. Included in this cost is an amortization rate of 10% for a ten year period.

Without telemetry the cost is only slightly lower for a one station system. Total annual costs for the Patuxent River system averaged $5,000 (Nauman and Cory, 1970).

Mobile Monitors

Actually, the cost analysis for a mobile system will be very similar to that for the *in situ* systems mentioned above. The same monitors can be employed since no significant design change is needed (Ballinger, 1971b). The only real difference is the increased cost for installation since mobile packaging is necessary. Wisconsin's mobile unit initially cost $20,000, including monitor and trailer packaging. Assuming that the price of the monitor alone was $8,000, the cost of the trailer and installation must have been about $12,000. Total operation and maintenance expenses for this trailer monitor have been $5,000 per year which includes assumed cost of $2,000/year for depreciation of the mobile laboratory (Kleinert, 1971).

Immersion Monitor

Since immersion monitors are a fairly recent addition to monitoring technology, little information is available on the cost of such units. However, Palmer, (1971) has provided the following figures:

Purchase price		$10,000/unit
Remooring electronic check out and calibration	approx	$ 2.000
Grab and sample check on calibration	approx	$20-travel 30-labor 12-analysis (each time)
Postmooring electronic check out and calibration		$80
Data processing		$65-computer time 10-labor
Further data analysis (highly variable cost)	approx	$400-computer time 400-labor (interpretation and report writing)
Support system		<$700

Palmer also commented that immersion units due to their portability and compactness, allow easy handling in the field and electronic servicing in the laboratory. This may have a beneficial and significant impact on the maintenance costs associated with these monitors.

CHAPTER III

ANALYSIS OF THE DETECTION EFFECTIVENESS OF AUTOMATIC MONITORS

Ability to Detect Pollution Events

For grab sampling, Vanderholm (1972) has developed a relationship between percent spill detection (effectiveness) and sampling frequency (Figure 8). This same relationship can be employed to analyze the ability of automatic monitors to detect spills. Automatic monitors have the capability to acquire and analyze samples on a continuous, instantaneous basis. Nevertheless, nearly all systems sample at hourly intervals. This is a compromise between obtaining statistically valid data and cost. According to Klein, et. al. (1968), investigations of interrelationships between water quality parameters require at least twenty pairs of observations in order to obtain statistically meaningful results on a daily basis. Now, however, hourly sampling intervals can be justified on a spill detection (effectiveness) basis. From Vanderholm's relationship (Figure 8), it can be seen that sampling frequencies in excess of once per day will approach 100% spill detection. Thus, the assumption will be made that sampling at hourly intervals using automatic monitors will give 100% spill detection effectiveness.

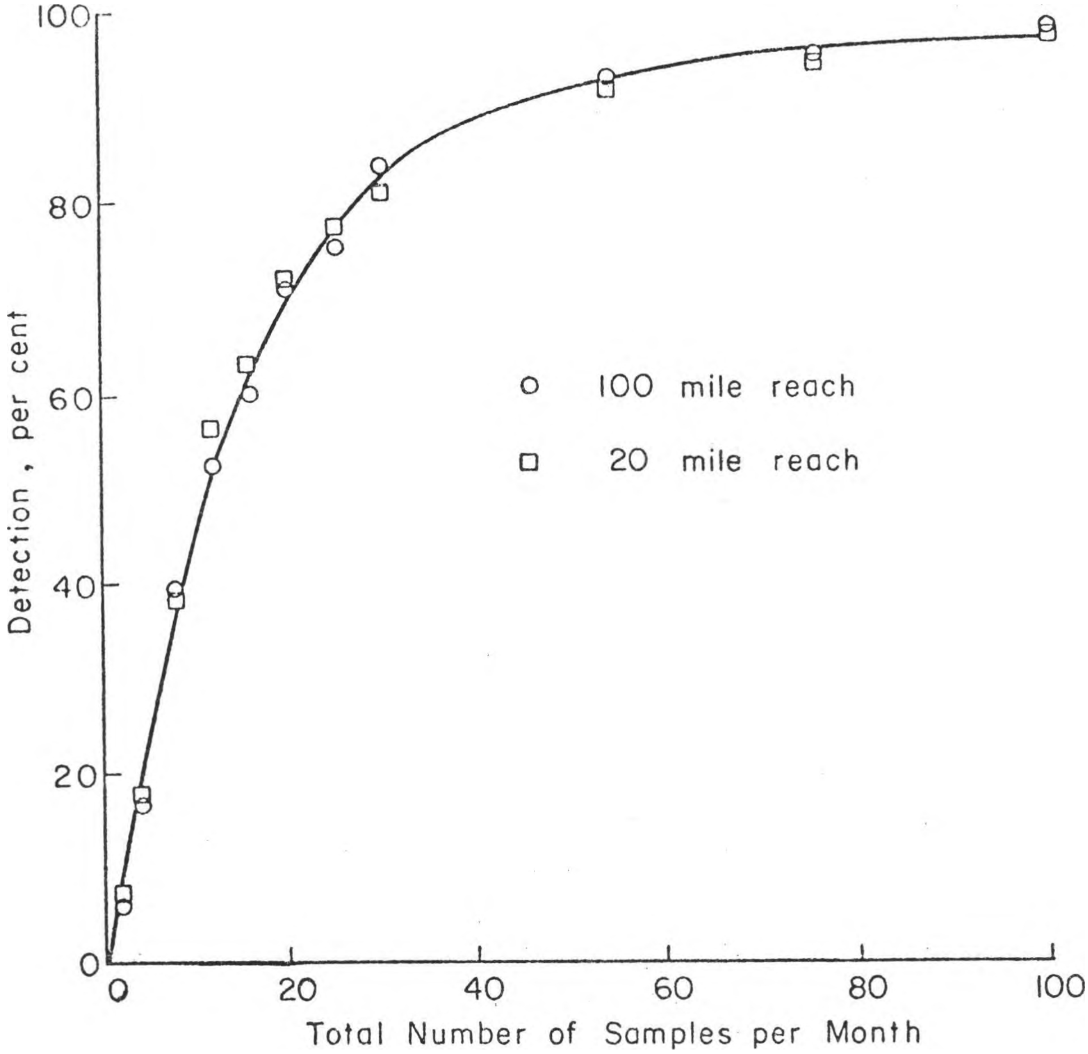

Figure 8. Relationship between sampling frequency and detection probability for one station at lower end of reach with 0-3 day random spill duration (From Vanderholm, 1972).

Parameter Limitations

In the literature review mention was made of the inadequate progress in developing new sensors. Really, only five sensors can be considered sufficiently dependable for unattended field use. These five sensors are: temperature, dissolved oxygen, pH, conductivity, and turbidity. The question now arises as to the ability of these parameters to detect pollution events.

One approach towards solving the problem would be to look at the water quality criteria mentioned in state standards. Few of the parameters listed are actually measurable by automatic monitors (Table 2). If only the five parameters (DO,* T, pH, Cond, and Turb) mentioned above are considered, 5 out of 45, or about 11% of the criteria are measurable with automatic monitors.

Another approach might be to consult Table 3 of the literature review. Here, Green (1966) has made a determination of the parameters needed for automatic monitoring. The number of parameters listed in Table 3 is nineteen. Thus, only 5 out of 24, or approximately 21% of the important parameters (needed plus those already reliably measured) are now being monitored.

The research which has been accomplished with respect to relative parameter importance can be utilized as another approach to answering the question: What proportion of pollution events can be detected by measuring only temperature, dissolved oxygen, pH, conductivity, and turbidity? First, by observing Table 8, the relative frequency of occurrence of criteria listed in state water quality criteria is revealed. Note that out of the eight parameters occurring more than 50% of the time, three are capable of being dependably measured by automatic monitors. Thus, nearly 40% of the most frequently used criteria are measurable by currently available sensors. The assumption is made that the more frequent criteria are also those considered to be the most significant for water and waste water characterization.

Secondly, a determination of the opinions of water quality experts may be performed. The results of a poll of 142 experts conducted by Brown, et. al. (1970) are given in Table 9. Out of this list of 11 parameters, 4 are measured by automatic monitors, Thus, approximately 36% of the parameters identified as the most significant are those available by automatic monitoring.

Both approaches reveal which parameters are most significant. However, does high parameter significance correspond to high detection ability? This question is presently unanswerable since the state-of-art of individual parameter waste detection ability is minimal. There is some indication of an interrelationship among parameters. For instance, it is generally accepted that dissolved oxygen (mg/l) is negatively correlated with temperature. Similarly, there is some indication that BOD is correlated with dissolved oxygen,

TABLE 8. Frequency of parameter usage for water quality criteria based on 43 states and District of Columbia (387 basins) (From Ballinger, 1968b). Parameters reliably measured by automatic monitors are indicated by an asterisk.

Uniform 100%	Frequent 99-50%	Infrequent 49-20%	Rare 19-0%
*DO	*pH	Arsenic	Bottom deposits
	Coliform	Barium	Chromium
	Taste-Odor	Cadmium	*Conductivity
	Radioactivity	Chromium (HEX)	Ammonia
	*Temperature	Cyanide	Acidity
	Toxic Substance	Fluoride	Alkalinity
	Oil-Grease	Lead	Carbon (Extractable)
		Selenium	Hydrogen Sulfide
		Silver	Pesticides
		Suspended Solids	Sodium
		*Turbidity	Iron
		Chloride	Plankton
		Copper	Foaming Substances
		Nitrate	Boron
		Phenols	Manganese
		Phosphate	Hardness
		Sulfate	BOD
		Color	MBAS
			Zinc

TABLE 9. List of eleven most significant parameters (From Brown et. al., 1970). Parameters reliably measured by automatic monitors are indicated by an asterisk.

Parameters
* Dissolved oxygen
Biochemical oxygen demand (5 day)
* Turbidity
Total Solids
Nitrates
Phosphates
* pH
* Temperature
Fecal coliforms
Pesticides
Toxic elements

and conductivity with alkalinity and total dissolved solids. If definite relationships exist for the above parameters, perhaps by measuring one the other can be computed. Or, more importantly, measurement of one of the parameters may indicate pollution events as well as the measurement of both. Thus, measurement of dissolved oxygen may indicate the presence of BOD wastes. Similarly, conductivity measurements should be capable of detecting total dissolved solids violations. If this is the case, then the five measurements (DO, T, pH, Cond, and Turb) may account for 6 out of 11, or about 54%, of the parameters listed in Table 9. In other words, it is probable that only a few parameters need to be measured in order to detect the majority of pollution events.

The foregoing discussion on automatic monitor parameter limitations is predicated on many assumptions which have no firm support. However, it is not the purpose of this paper to fill these gaps in the state-of-the-art of relative parameter importance. The objective here is to determine the effectiveness of automatic monitors. Using what is presently known on relative parameter significance, a range of 11-54% of the important water quality parameters may be measurable by the automatic monitoring sensors that are presently reliable.

The primary assumption of 100% detection effectiveness appears to be invalid. For automatic monitors with the present state-of-the-art, parameter limitations will reduce detection effectiveness to a percentage lower than 100%. Without specific information on individual parameter detection ability, an exact percentage can not be generated. However, is it necessary to have 100% detection ability in order for automatic monitors to be an effective abatement tool? This is perhaps a subjective evaluation to be made by each water quality manager when he is designing a surveillance network. Nevertheless, the fact that automatic monitors can presently measure a large share of the most important water quality parameters is significant. With this capability, few pollution events should escape detection. Thus, automatic monitors may not provide perfect detection effectiveness but the detection afforded should be sufficient to assure a high level of abatement effectiveness. For example, if a polluter knows that there is a greater than 50% chance of being detected he may not be willing to take the risk of being caught. Thus, anything over 50% detection may be sufficient to assure that pollution is abated.

CHAPTER IV

ABATEMENT EFFECTIVENESS OF MONITORING STATIONS

Design Procedure

For enforcement activity, the primary consideration is abatement of pollution sources. Abatement involves detection of pollution, tracing the pollution to its source, and enforcement proceedings with the guilty party in order to reduce the pollution to a level that will not cause a violation of stream standards. The relationship between abatement effectiveness and detection effectiveness was discussed in the previous chapter. The other factor influencing abatement effectiveness is the location of water quality surveillance stations. For the water quality manager, the choice of station location is presently a subjective evaluation. The first two steps of the design procedure provides a quantitative method for determining station location. Steps 3-5 are employed to obtain the relationship between abatement effectiveness and number of effective stations. The design procedure is;

1. Enumerate primary stations using stream characterization data;
2. Enumerate effective primary stations using waste outfall information;

3. Rank effective stations;
4. Assign effective stations to an importance category; and
5. Calculate numerical importance values for the effective stations.

Enumeration of Primary Stations

Deciding on the number of stations needed to fulfill the abatement objectives of a station water quality control agency first requires characterization of the water bodies in the state. Stream characterization involves determining variability in water quality and identification of waste outfalls. Variability can be determined using data from various sources: (1) the state's routine surveillance system, (2) county and city health department records, and (3) special surveys. Some sort of waste outfall inventory is needed for the identification of pollution sources. Special surveys and possibly county and city records can also be used for this purpose. In addition, a permit system would be extremely useful in providing information on the location of waste outfalls. The permit system would also make available information on the type of waste discharged at each outfall. The necessity of a permit program for the determination of station location cannot be overemphasized.

Once collected, information on variability and waste outfall identification can be very effectively displayed on river mile graphs. Visual observation can then reveal points of high variability and/or high pollution potential (areas of numerous waste outfalls). Using the design procedure devised by Ward (1971), the state agency can then determine the location of stations for its primary and secondary network. Primary stations will correspond to areas of high variability and/or high pollution potential. Existing surveillance stations in areas of little variability or low pollution potential will be designated as secondary stations. Thus, the surveillance system reflects the two main objectives of state water quality control agencies: abatement and prevention. Primary stations will demand high sampling frequencies and will supply regulatory data, while secondary stations will be sampled less frequently and will supply information on water quality trends for use in planning and prevention.

Enumeration of Effective Primary Stations

Naturally, primary stations are of major concern in this study since automatic monitors are geared towards supplying abatement data. Once the number of primary stations has been enumerated, the second step in determining the number of stations necessary to fulfill abatement objectives involves an analysis of waste types and numbers of waste outfalls. This analysis will reveal the effective stations. Effective stations are those primary stations that are essential to accurately and expeditously trace pollution events.

Important in this analysis is the idea that tracing pollution events constitutes the surveillance phase of abatement and that accuracy and expediency are critical factors in traceability. Mere detection of stream standard violations is not abatement until the violator has been discovered. Location of sources of detected pollution will require grab sampling of the upstream water course and of waste outfalls in order to trace the pollution to the violator(s). The performance efficiency of this task will depend on the time delay in detection, the number of outfalls upstream, and the types of wastes discharged. The latter two factors will determine traceability (i. e., accuracy and expediency in tracing). The former criterion is met by utilizing automatic monitors which are capable of instantaneous (real time) data accumulation and analyses. Hence, in the enumeration of effective primary stations, accuracy and expediency of tracing pollution events will be the essential considerations.

The foregoing discussion indicates that the number of primary stations can be reduced by the proper choice of stations so as to eliminate those stations not significantly contributing to traceability (i. e., surveillance abatement efficiency). The proper choice of effective stations will require an analysis of the stream to determine points most suitable for accurately and expediently tracing pollution events. In this analysis, accuracy and expediency can be translated into waste type and number of outfalls, respectively. Hence, as the number of waste outfalls between stations increases, the less expedient it is to trace the pollution event to any individual outfall. For accuracy, there is a different relationship. If the waste types are different, the easier it is to trace the pollution event to one source. For example, in a city such as Fort Collins, Colorado, where most of the wastes are of municipal origin, a pollution event causing high acidity (low pH readings) would be relatively easy to trace because there are few sources apt to discharge this kind of waste. Thus, under such conditions a local pickle factory may be suspect.

When industrial and municipal wastes are combined and treated in a municipal treatment plant, the process of locating the waste source may be complicated. The collection system of the municipal facility must also then be monitored. This, however, is rightfully the responsibility of the municipality in charge of the plant and not the state agency. The state agency can only trace the pollution event to the outfall of the municipal treatment plant. In the determination of effective primary stations, such combined treatment plants will be treated as multiple waste source outfalls. These outfalls must be sampled any time the pollution event is indicative of any of the waste types treated by the plant.

Ranking of Effective Stations

Once the number of effective primary stations has been enumerated, the least number of stations necessary to fulfill state abatement objectives will have been established. In other words, the number of effective primary stations decided upon using the above procedure should yield the best possible abatement based on the identification of the polluter and the abatement objectives of the state agency. Any further reduction in stations will then result in a decreased ability in meeting abatement objectives and therefore a reduction in the effectiveness of the agency's regulatory function. The purpose of this section is to determine the increment decrease in abatement effectiveness due to the loss of each effective primary station. To accomplish this, effective primary stations will be ranked according to their importance. Importance will be determined on the basis of four criteria: (1) traceability, (2) pollution potential, (3) variability in stream characteristics, and (4) mean values of stream characteristics. Here, pollution potential refers to the magnitude of the industrial or municipal operation as well as its likelihood of polluting. Thus, areas having large industries and/or municipal treatment plants with records of polluting will be assigned a higher importance ranking than areas of small operations without pollution records. Since effective primary stations are determined on the basis of retaining traceability, accuracy and expediency are the primary criteria used in station ranking. In the previous section, surveillance abatement effectiveness was equated to traceability. A reduction in abatement effectiveness resulting from a decrease in the number of effective primary stations can be directly related to the loss in the ability to trace a pollution event. The last two factors of variability and means in stream characteristics are the same criteria which were used by Ward (1971) to determine the location of primary stations. They are important now since some effective primary stations may exhibit more variability or parameter means nearer stream standard violations than others. All other factors being equal, stations showing these characteristics should receive higher ranking.

Assigning Effective Stations to an Importance Category

Employing the above criteria, stations will be grouped into the following categories:

1. High importance
2. Medium importance
3. Low importance

Each station grouped into the first category will then be assigned a value (V) representing the numerical importance of the first category. Stations in the second category (medium importance) will be assigned values equalling V/2. Similarly, stations in the last category will be assigned values equal to $V/4(\frac{1}{2}V/2)$. Hence, the following table can be constructed:

1.	High importance	$V \cdot (\# \text{ of stations}) = W$
2.	Medium importance	$V/2 \cdot (\# \text{ of stations}) = X$
3.	Low importance	$V/4 \cdot (\# \text{ of stations}) = Y$
		Total = Z

Calculation of Numerical Importance Values

The letters (W, X, Y) equal the relative numerical importance of their corresponding category. Thus, if V is large but there are few stations grouped into the first category, category two may have a larger numerical value than number one (given two has many more stations). The value Z is the summation of the numerical values of all categories (i. e., W+X+Y). To put all values in the table on a percentage basis, the following calculations are carried out:

(1) $Z' = \frac{Z}{a} = 100$

(2) $W' = \frac{W}{a} = \%$ figure

(3) $X' = \frac{X}{a} = \%$ figure

(4) $Y' = \frac{Y}{a} = \%$ figure where $\underline{a}$ equals any number when divided into Z yields 100.

then:

(5) $V' = W'/\#$ of high importance stations = numerical importance value for each high importance station
$\frac{V'}{2}$ = numerical importance value of medium importance stations.
$\frac{V'}{4}$ = numerical importance value of low importance stations.

The value (V) is assigned arbitrarily. Once V is chosen the importance table completed, and the necessary calculations performed the relationship between abatement effectiveness and number of stations is readily available. Loss of a low importance station will result in a reduction of effectiveness equal to $\frac{V'}{4}$. For medium and high importance stations, the decrease in effectiveness due to loss of a station will be equal to $\frac{V'}{2}$ and V', respectively.

Application of Design Procedure to Colorado

Enumeration of Primary Stations

Ward (1971) has determined the primary stations for Colorado. His assessment is based on an analysis of the major river basins in Colorado. In his analysis, the Arkansas, Colorado, and South Platte River Basins are characterized using the means and variances of five parameters, BOD, DO, pH, TDS, and flow. Areas of high parameter variability, mean values close to or in violation of stream standards, and many waste outfalls are identified as primary stations (Figure 9).

Enumeration of Effective Primary Stations

For the Arkansas River Basin, four primary stations have been identified. The stations at Nepesta and La Junta were chosen because of high and greatly varying BOD readings. A similar determination was made for the Holly station using TDS values.

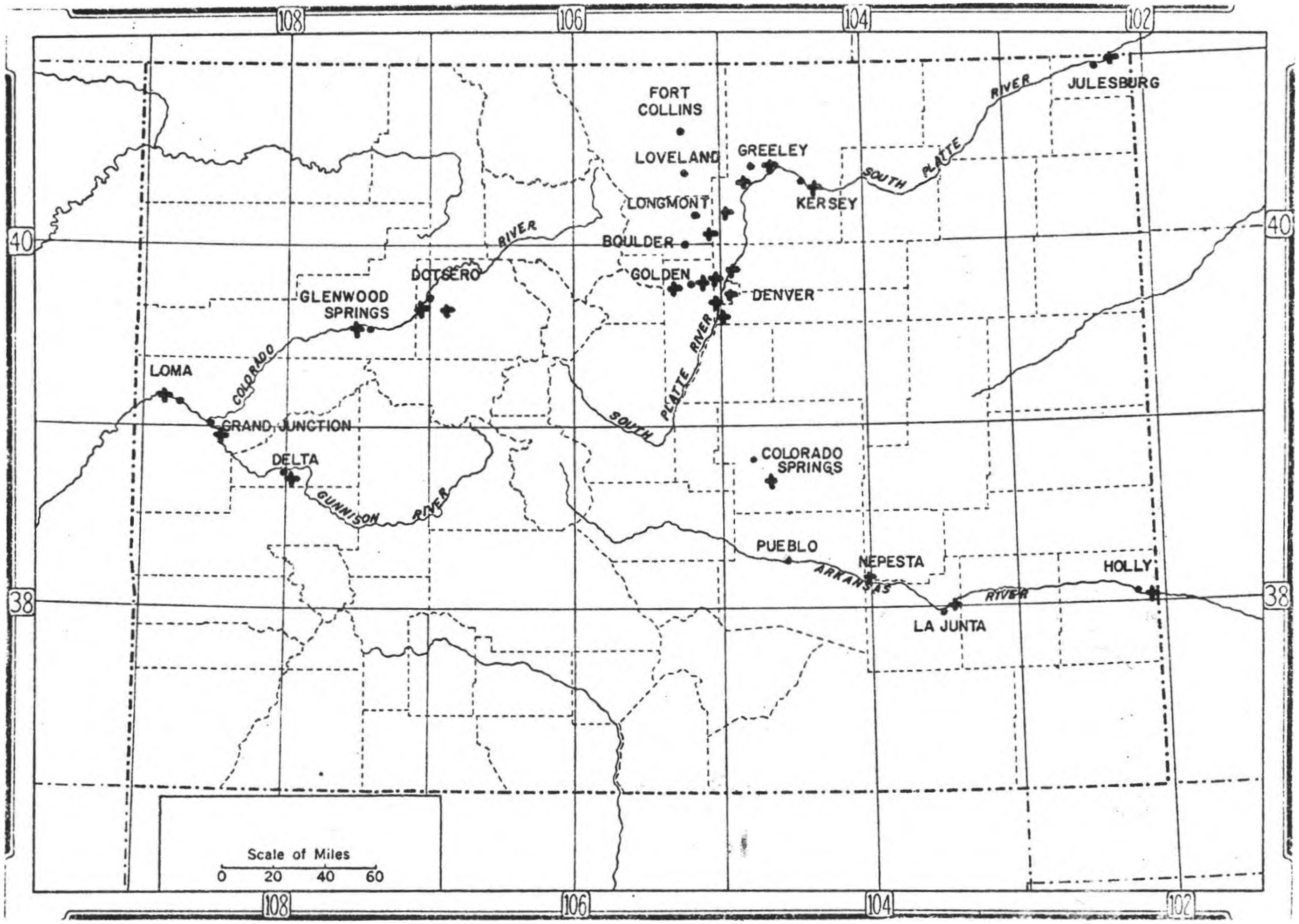

Figure 9. Colorado primary stations identified by Ward (1971).

The station on Fountain Creek near Colorado Springs was chosen on the basis of low flow and the high pollution potential of the location.

Since automatic monitors can reliably measure T, pH, DO, Cond, and Turb, the stations at Nepesta and La Junta would both be likely to detect violations in BOD and DO standards. Pueblo is the only likely, major source of BOD wastes in this stretch of the Arkansas River. Thus, only one of these stations would be sufficient to trace pollution originating from Pueblo. Since Nepesta is closer to Pueblo, it will be chosen as an effective primary station. This choice is based on the assumption that the Neqesta station will detect more violations due to less dispersion of the pollution event. Since TDS values do not increase significantly until downstream from La Junta, the station at Holly is necessary to detect TDS violations. Due to the high pollution potential between the Nepesta station and the one on Fountain Creek, expediency demands that both stations be retained. Also, the types of wastes found in Fountain Creek near Colorado Springs and those found in Arkansas downstream from Pueblo are apt to be very similar. Thus, to accurately pinpoint a pollution source, both stations are essential.

For the Colorado River Basin, six primary stations have been identified. On the basis of the five parameters used, TDS seems to be the major criterion affecting water quality in the Colorado River. Readings appear to be greater than stream standards, with large variability as the Colorado River leaves the state. Similar conditions exist at points where major tributaries enter the Colorado River and at Delta on the Uncompahgre River. Thus, primary stations at Grand Junction on the Gunnison River, at Delta on the Uncompahgre River, at Glenwood Springs on the Roaring Fork, and at Gypsum on the Eagle River were chosen. Since the TDS problem is due to leaching and erosion of geologic formations as well as irrigation return flows, the number of sources are likely to be large, dispersed, and not easily defineable. Hence, the criteria of expediency and accuracy in tracing the pollution to its source indicate that all these stations are essential.

The station at Dotsero on the Colorado River was chosen on the basis of high variability in DO values, with readings likely to be in violation of stream standards. Downstream from Dotsero, the variability and likelihood of stream standard violations decrease. In fact, violations in the section between Dotsero and Fruita appear unlikely. At the Loma station variability increases and DO values decrease. Hence, the source of low DO readings and high variability in the Colorado must be upstream from Dotsero and downstream from Grand Junction. Due to the large distance between these two stations, expediency demands that both stations be retained as a part of the effective primary network.

The analysis to follow on the South Platte River basin can be more precise due to the availability of data on waste sources. This information is available as a result of the South Platte River Basin Project which was conducted by the U.S. Department of Interior, Federal Water Pollution Control Administration, FWPCA in response to the 1963 through 1966 Conference in the Matter of Pollution of the South Platte River Basin in the State of Colorado. Information on the number of outfalls and types of industrial wastes present in the Basin is extremely valuable for determining effective primary stations. Remember that expediency is directly related to the number of waste outfalls and accuracy depends on the types of wastes present. Expediency and accuracy are the factors which determine traceability, the criterion used to enumerate effective primary stations.

Again, it must be emphasized that waste outfall inventories do not exist for other river basins in Colorado. A permit system would provide such data and therefore is considered valuable for any evaluation of station locations.

The number of waste outfalls and types of pollution expected in different regions of the South Platte River Basin are shown in Tables 10 and 11 as well as Figures 10, 11, and 12. Note particularly that the outfall study identified 74 outfalls considered of major importance on the basis of their waste discharges (Figures 10 and 11).

TABLE 10. Total number of waste outfalls in different regions of South Platte River Basin. (Based on data from South Platte River Basin Project, 1966c).

Littleton-Englewood	24
Bear Creek	29
S. Denver to Cherry Creek	128
Cherry Creek	197
Cherry Creek to N. Denver Co. Line	112
N. Denver to Henderson	Not Measured
Sand Creek	3
Clear Creek	34
Henderson to Greeley	Not Measured
Boulder Creek	58
Saint Vrain	3
Big Thompson	13
Cache La Poudre	28
Greeley to Kersey	Not Measured
Kersey to Fort Morgan	Not Measured
Fort Morgan to Sterling	3
Sterling to Stateline	8

TABLE 11. Types of wastes expected in different regions of the South Platte River Basin. (Based on data from South Platte River Basin Project, 1966a, b and 1967).

REGIONS	WASTE TYPES									
	Sewage	Oils	Thermal	Packing Plant	Feedlot	Detergents	Garbage*	T. D. S.	Heavy Metals	Acids
Littleton - Englewood	14	6	9	0	0	5	0	6	5	5
Bear Creek	--	--	--	--	--	--	--	--	--	--
S. Denver to Cherry Creek	5	8	4	0	0	4	1	4	2	4
Cherry Creek	--	--	--	--	--	--	--	--	--	--
Cherry Creek to N. Denver Co. Line	3	6	5	6	6	2	1	1	0	0
N. Denver to Henderson	12	12	7	5	4	4	1	6	0	1
Sand Creek	5	8	4	0	0	4	1	5	1	5
Clear Creek	8	9	5	1	1	2	1	3	2	2
Henderson to Greeley	2	2	2	3	1	2	1	1	0	1
Boulder Creek	6	0	1	0	0	1	1	0	2	0
Saint Vrain	4	2	1	1	0	0	1	1	0	0
Big Thompson	7	1	0	1	0	0	3	1	1	1
Cache La Poudre	10	2	2	4	1	4	1	2	0	1
Greeley to Kersey	--	--	--	--	--	--	--	--	--	--
Kersey to Fort Morgan	--	--	--	--	--	--	--	--	--	--
Fort Morgan to Sterling	--	--	--	1	--	--	--	--	--	--

* Culinary and food processing wastes.

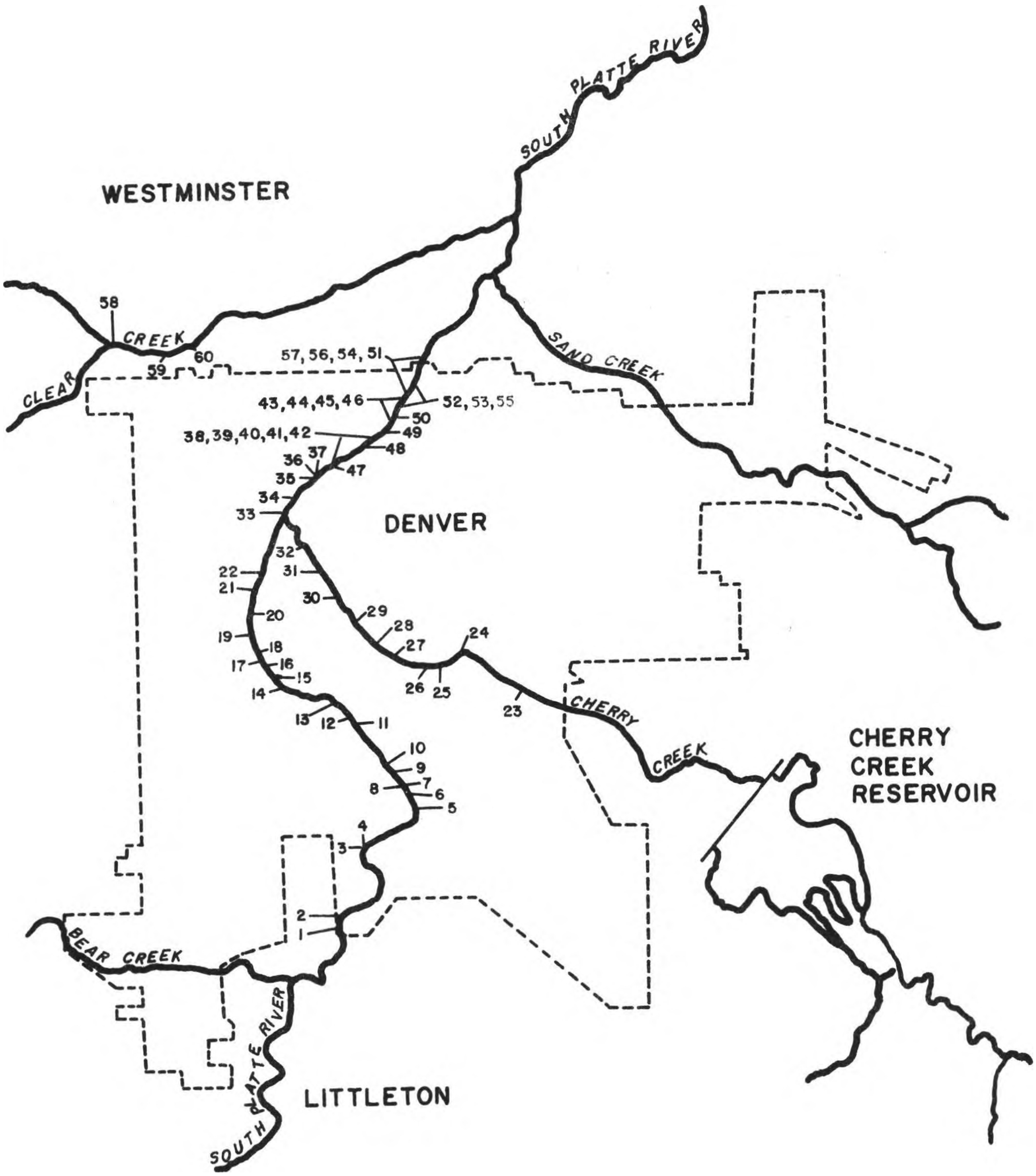

Figure 10. Waste outfalls identified as most important, Denver Metropolitan Area (Based on data from South Platte River Basin Project, 1966c).

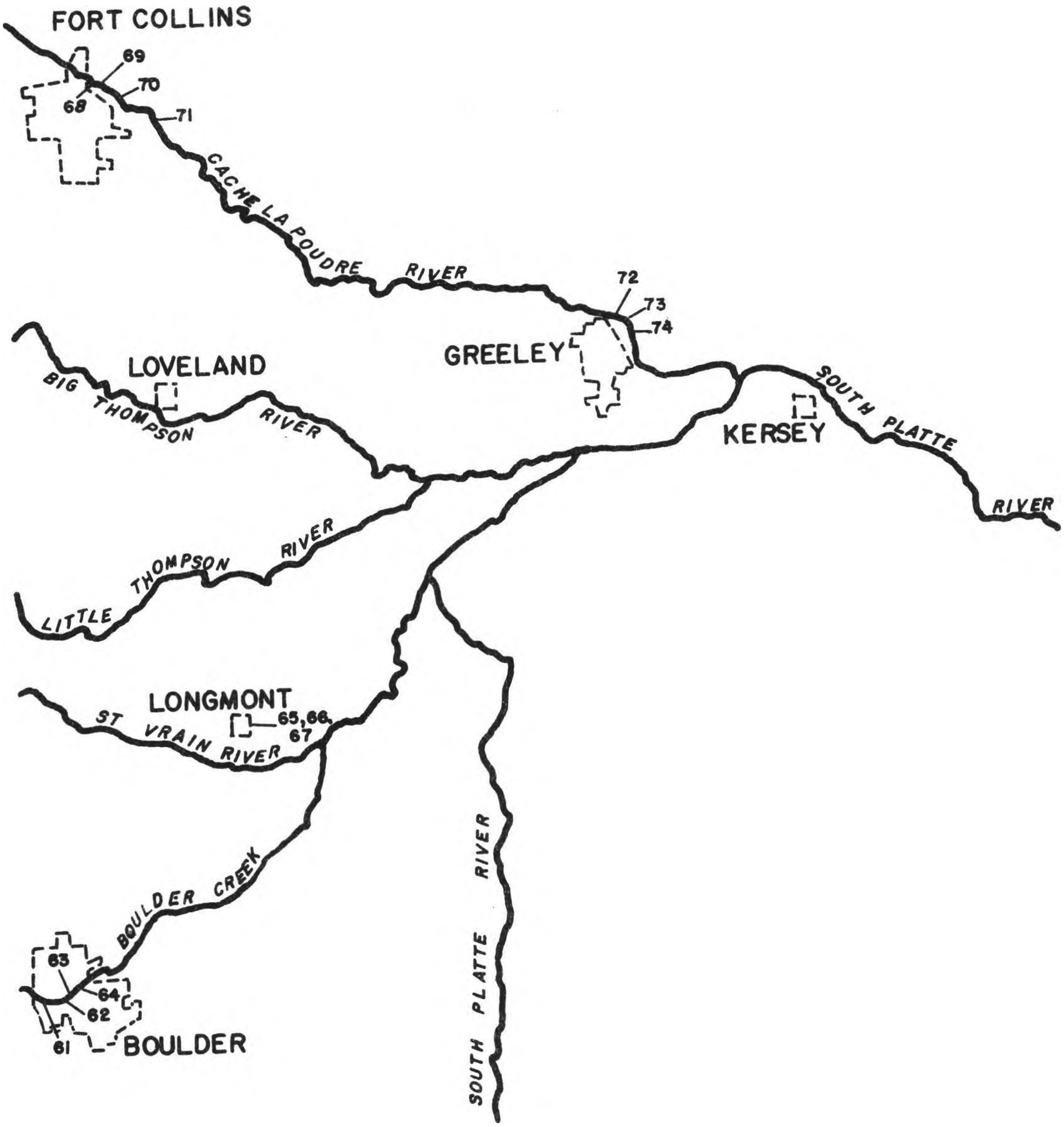

Figure 11. Waste outfalls identified as most important, remainder of South Platte River Basin (Based on data from South Platte River Basin, 1966c).

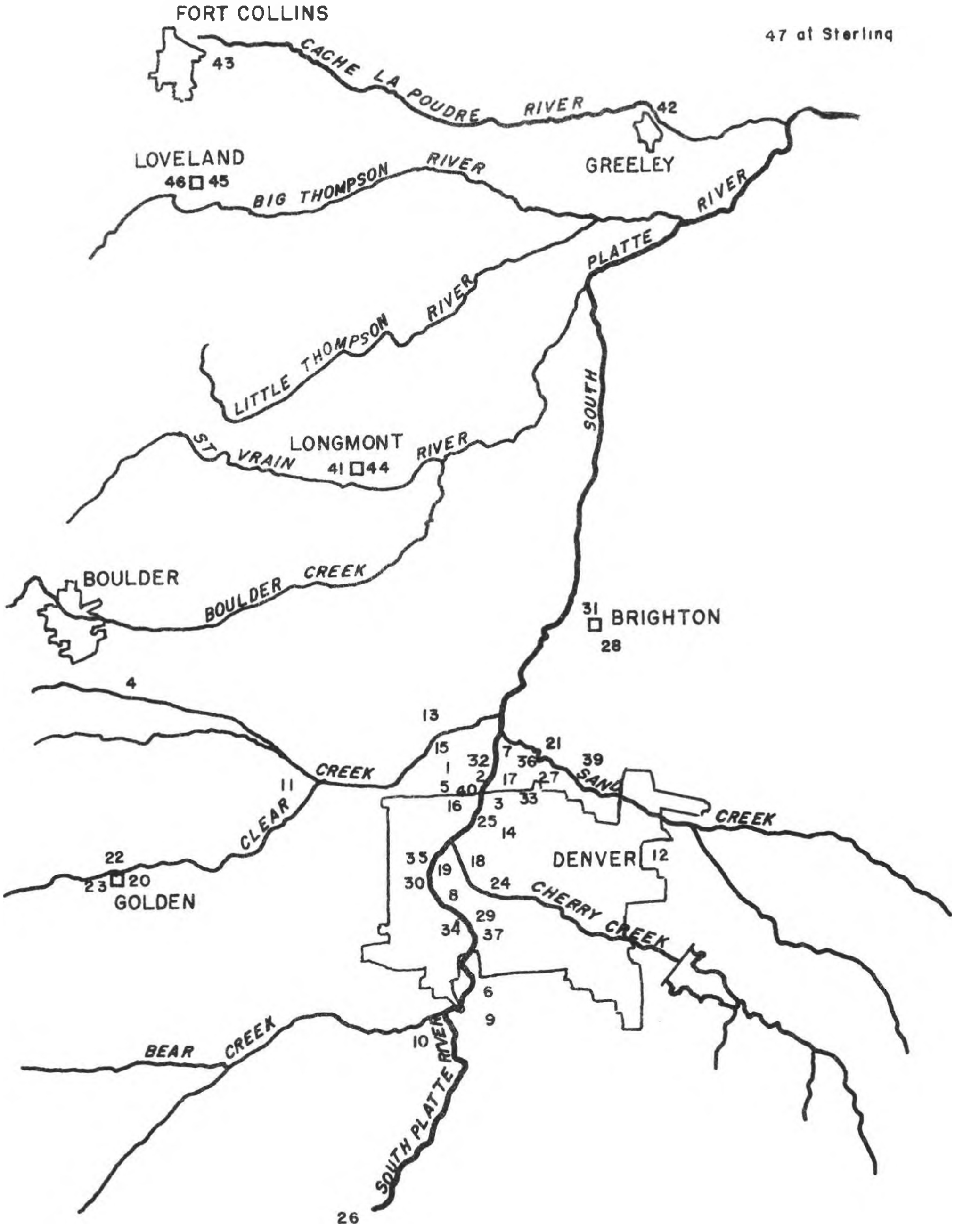

Figure 12. Location of industries with high pollution potential (Based on data from South Platte River Basin Project, 1966a, b, and 1967).

Sixty of these outfalls are in the Denver-Metro Area, with 47 on the main stem of the South Platte, 10 on Cherry Creek and 3 on Clear Creek. Also, observe the concentration of major outfalls in the Northwest section of Denver (outfall numbers 33-57). The total number of outfalls for the South Platte Basin is given by region in Table 10 while Table 11 lists the types of wastes discharged by industries along the South Platte or its tributaries. Figure 12 shows those industires which were mainly responsible for water quality degradation in the South Platte at the time of the FWPCA study.

The information in these tables and figures can now be used to delineate the effective primary stations in the South Platte River Basin. Later, these same tables and figures will be applied in ranking the delineated effective stations.

The major concentration of waste outfalls is in the Denver Metropolitan Area (Table 10, Figure 10 and 11). The region with the highest total number of outfalls is Cherry Creek (Table 10). Cherry Creek also has 10 of the 60 major outfalls. Thus, on the basis of expediency alone, the recommended primary station at the mouth of Cherry Creek should also be retained as an effective station. For Cherry Creek, information on waste types was not provided by the South Platte River Basin Project. Nevertheless, the large number of outfalls is sufficient to warrant an effective station at this location.

The station at Henderson will be responsible for detecting stream standard violations originating from the entire Denver Metropolitan Area. Argument for the retention of this station may be advanced on the basis of its strategic location alone. However, by observing Table 10, we see that 264 outfalls empty into the main stem of the South Platte between Littleton and the North Denver County line. Expedience demands that the Henderson station be retained. In addition, the types of wastes occurring in this area are very similar, being mainly organic, BOD wastes (Table 11). Similarity in waste type makes tracing a pollution event more difficult and affirms the need for the station at Henderson. Figures 10 and 11 supply more evidence supporting the classification of the Henderson location as an effective primary station.

Due to the large number of waste outfalls between Littleton and North Denver County line and the similarity in waste types, an additional primary station on the main stem of the South Platte just upstream from the junction with Cherry Creek is recommended. Since there are 152 outfalls between Littleton to Cherry Creek and the waste types are similar (BOD), the same argument applied to the Henderson station can be employed for the new station. Thus, the new station is also an effective station.

Retention of the station at the mouth of Bear Creek follows a similar line of reasoning. Since the station upstream from Cherry

Creek is responsible for 152 outfalls on the main stem of the South Platte (between Littleton to Cherry Creek), the addition of 29 outfalls on Bear Creek would significantly increase the difficulty of tracing a pollution event. This is especially true if the wastes entering Bear Creek are similar to those entering the South Platte between Littleton and Cherry Creek. The South Platte River Basin Project does not supply waste type information for Bear Creek. However, due to the large increase in residential development along Bear Creek in recent years, BOD wastes are likely to be present.

The foregoing considerations also apply to Clear Creek. There are 34 outfalls on Clear Creek, 3 of which are considered major. Also, the wastes are mainly BOD types. Hence, to reduce the burden on the Henderson station and to provide more expediency in traceability, the station at the mouth of Clear Creek will be retained. However, the station at Wheatridge on Clear Creek duplicates the efforts of the station at the mouth and provides little additional effectiveness in tracing a pollution event. For these reasons, it will be eliminated. There is some enforcement advantage to having a station upstream from a major population center to indicate the quality of water entering the city. This station can be used as a basis for determining how badly the city degrades the water. However, Golden is not a major population center. Thus, the advisability of the station on Clear Creek upstream from Golden would seem unsupportable. Also, the types of wastes entering Clear Creek up stream from Golden (TDS) are of a different nature than those in and downstream from Golden (BOD). Thus, the station upstream from Golden will not be retained.

The station at Littleton is, however, upstream from a major population center (Denver) and will be retained even though the waste sources above Denver are likely to be few and of a different nature than those occurring in Denver.

Besides the Denver-Metro Area, the region having the most outfalls is Boulder Creek. The waste types in this drainage are highly invariable, being mostly organic, BOD wastes. Thus, both expediency and accuracy demand that the station on Boulder Creek at the Weld-Boulder County line be retained.

The waste types are few on the Saint Vrain, and the number of outfalls is also small. Since there are only three outfalls on the Saint Vrain, an effective primary station is not warranted. Thus, the station downstream from Longmont will be eliminated.

The decision on the Big Thompson station is more difficult. The number of outfalls is relatively small, but the waste types are invariable, being almost entirely organic, BOD wastes. Expediency does not really demand designation as an effective station. However, accuracy does warrant the designation since the majority of wastes entering the South Platte are organic. To distinguish those coming from the Big Thompson may be quite difficult. Thus, the Big Thompson station located near the mouth of the river will be retained to improve accuracy in traceability.

Both accuracy and expediency warrant the retention of the Greeley station. A substantial number of outfalls enter the Cache La Poudre River and the wastes are clearly invariable. Again, wastes are mainly the organic BOD type.

The discussion pertaining to the Kersey station is unique. The Kersey station, like the Henderson station, is located very strategically. In terms of distance, the mileage between Henderson and Kersey is large and few primary stations are located on the main stem of the South Platte. Hence, the station at Kersey is critical since it is responsible for detecting stream standard violations in the South Platte, which may originate from a number of tributaries and over many river miles. Also, BOD and DO variability and mean values indicate that stream standard violations for these two parameters are likely to occur at this location. Thus, the Kersey station may be designated as an effective station by virtue of its strategic location. In addition, the Kersey station can be analyzed on the basis of traceability. Table 11 indicates that the majority of wastes in the Henderson to Greeley region are organic. However, the South Platte River Basin Project did not include irrigation return flow as a waste source. TDS values from Denver to Julesburg appear greater than state standards (584 at Henderson to 1438 at Julesburg) and show high variability (Ward, 1971). Stream standard violations can not be confirmed until flow measurements are made in accompaniment with TDS measurements. Most likely, irrigation return flow is responsible for the high TDS values observed. As mentioned, for the Colorado River Basin, the sources of increased salinity are apt to be many, variable, and dispersed. This is equivalent to saying that the number of waste outfalls is large. Thus, expediency warrants having a station at Kersey. Accuracy also demands retention of the Kersey station since the waste constitutents from irrigation return flow are apt to be very similar.

The Julesburg station is retained for the same reason. Although Table 10 shows only 11 waste outfalls between Fort Morgan and Julesburg, if the irrigation return flows had been considered, the number would likely be much larger. This is evident from the fact that TDS values increase about 400 ppm from Kersey to Julesburg (Ward, 1971). Thus, accuracy and expediency warrant designating the Julesburg station as an effective station. In addition, continuous monitoring at Julesbury provides protection against downstream states claiming that violations in their state originated in Colorado.

The selection of effective primary stations in now complete. Figure 13 shows the location of these stations in Colorado. This

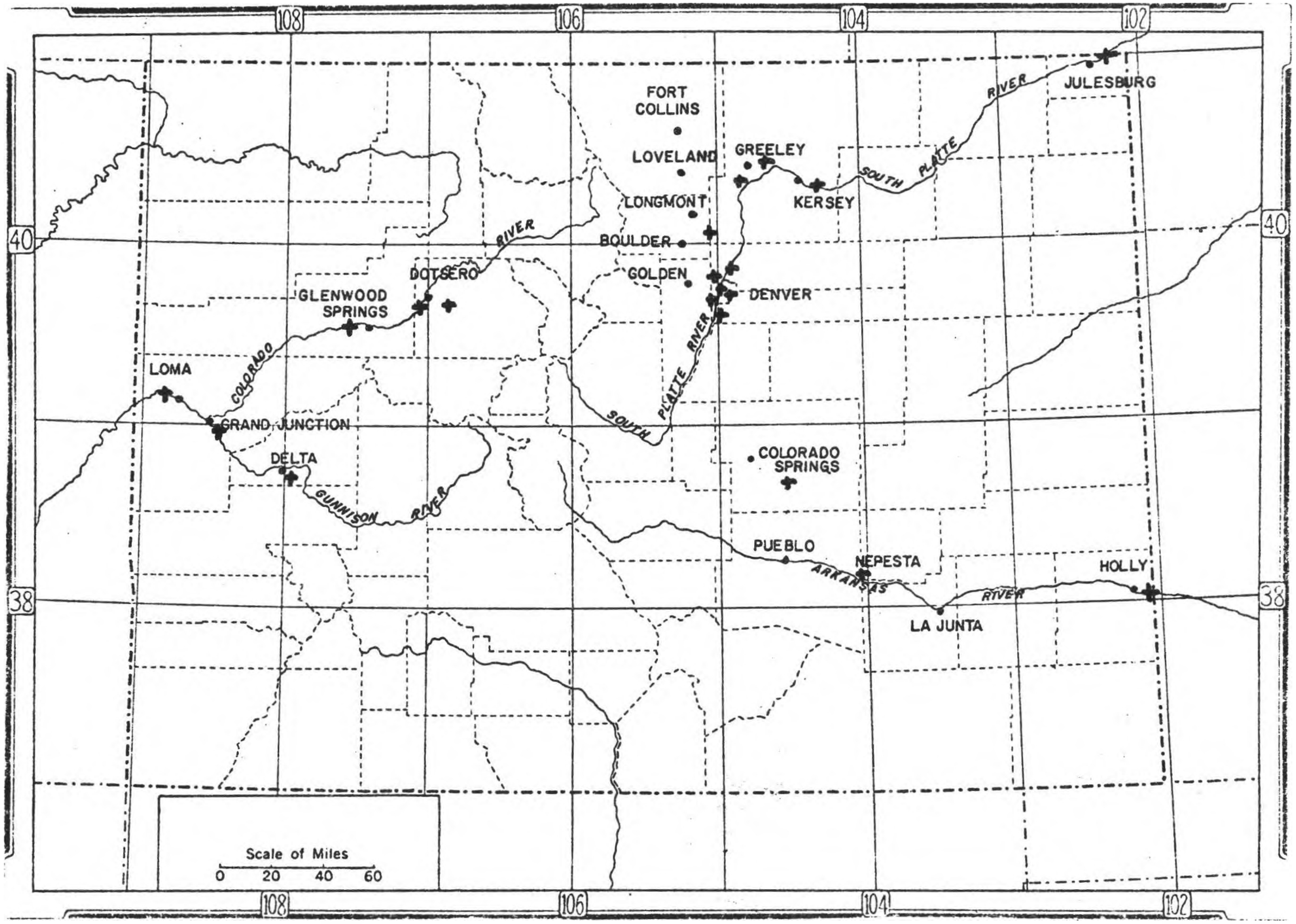

Figure 13. Colorado effective primary stations.

is the network which will yield the best possible abatement effectiveness with the least amount of stations.

Ranking of Effective Stations

The stations appearing in Figure 13 will now be ranked in order to generate the effectiveness vs number of stations relationship for Colorado. As mentioned under the Design Procedure section, this ranking is based on four criteria:

1. Traceability;
2. Pollution potential;
3. Variability in stream characteristics; and
4. Mean values of stream characteristics.

In performing the ranking, more weight will be given to the factors of traceability and pollution potential since abatement effectiveness is primarily related to these criteria. Variability and mean values of stream characteristics will be employed when information on traceability and pollution potential do not exist and in borderline situations.

Since more information is available on the South Platte River Basin, the discussion on station ranking will begin here. Tables 12-17 show how South Platte stations are ranked according to each of the four criteria mentioned above. Table 18 gives the overall or cumulative ranking of all stations in the state. The order of appearance of stations in the tables is the station ranking. Thus,

TABLE 12. South Platte stations ranked on the basis of expediency.

Station	Number of Outfalls
Cherry Creek	197
S. Platte upstream from Cherry Creek	152
Henderson	112
Boulder Creek	58
Clear Creek	34
Bear Creek	29
Greeley	28
Big Thompson	13
Julesburg	11
Kersey and Littleton	Not Measured

TABLE 13. South Platte stations ranked on the basis of accuracy.

Station	Similarity of Waste Types Proportion of Waste Type	 Percentage
Henderson	DO 80/115	69.6
	Cond 13/115	11.3
	Temp 16/115	13.9
	pH 6/115	5.2
	Turb 80/115	69.6
S Platte upstream from Cherry Creek	DO 43/82	52.4
	Cond 17/82	20.7
	Temp 13/82	15.8
	pH 9/82	11.0
	Turb 43/82	52.4
Clear Creek	DO 22/34	64.7
	Cond 5/34	14.7
	Temp 5/34	14.7
	pH 2/34	5.9
	Turb 22/34	64.7
Greeley	DO 22/27	81.5
	Cond 2/27	7.4
	Temp 2/27	7.4
	pH 1/27	3.7
	Turb 22/27	81.5

TABLE 13. Continued

Station	Similarity of Waste Types	
	Proportion of Waste Types	Percentage
Big Thompson	DO 12/15	80.0
	Cond 2/15	13.3
	Temp 0/15	0.0
	pH 1/15	6.7
	Turb 12/15	80.0
Boulder Creek	DO 8/11	72.7
	Cond 2/11	18.2
	Temp 1/11	9.1
	pH 0/11	0.0
	Turb 8/11	72.7
Julesburg, Cherry Creek Kersey, Bear Creek and Littleton	No Information Available	

TABLE 14. South Platte stations ranked on the basis of pollution potential - major waste outfalls.

Station	Number of Major Outfalls
Henderson	25
S. Platte upstream from Cherry Creek	22
Cherry Creek	10
Greeley	7
Boulder	4
Clear Creek	3
Littleton, Big Thompson	None
Julesburg, Kersey	None
Bear Creek	None

TABLE 15. South Platte stations ranked on the basis of pollution potential - industries likely to pollute.

Station	Number of Industries
Henderson	19
S. Platte upstream from Cherry Creek	9
Clear Creek	7
Cherry Creek, Kersey Big Thompson and Greeley	2
Bear Creek, Julesburg, and Littleton	1
Boulder Creek	0

TABLE 16. Effective stations ranked on the basis of variability in stream characteristics.

Stations	Parameter	Standard Deviation	Parameter Ranking
Big Thompson	BOD	21.18	3
	DO	2.43	3
	TDS	451.18	3
	pH	.46	9
			18
Uncompahgre River	BOD	0.97	12
	DO	2.02	9
	TDS	496.87	2
	pH	0.54	3
			26
Loma	BOD	2.1	10
	DO	2.4	4
	TDS	269	8
	pH	0.5	6
			28
Boulder Creek	BOD	2.79	8
	DO	2.30	5
	TDS	180.39	13
	pH	0.53	4
			30
Holly	BOD	0.8	13
	DO	1.9	11
	TDS	640	1
	pH	0.5	6
			31

TABLE 16. Continued

Stations	Parameter	Standard Deviation	Parameter Ranking
Dotsero	BOD	2.1	10
	DO	2.3	5
	TDS	57	17
	pH	0.6	1
			33
Fountain Creek	BOD	22.23	2
	DO	1.88	11
	TDS	304.01	5
	pH	0.39	16
			34
Greeley	BOD	22.38	1
	DO	1.73	14
	TDS	192.24	12
	pH	0.47	8
			35
Kersey	BOD	4.9	5
	DO	1.8	13
	TDS	290	6
	pH	0.4	12
			36
Roaring Fork	BOD	.59	16
	DO	2.48	2
	TDS	95.42	16
	pH	0.58	2
			36

TABLE 16. Continued

Stations	Parameter	Standard Deviation	Parameter Ranking
Clear Creek	BOD	3.89	6
	DO	2.05	8
	TDS	179.46	14
	pH	0.45	10
			38
Eagle River	BOD	.56	17
	DO	2.25	7
	TDS	209.14	11
	pH	0.53	4
			39
Julesburg	BOD	3.4	7
	DO	1.7	15
	TDS	282	7
	pH	0.4	12
			41
Henderson	BOD	9.4	4
	DO	1.6	17
	TDS	221	9
	pH	0.4	12
			42
Gunnison River	BOD	.43	18
	DO	1.91	10
	TDS	322.15	4
	pH	0.45	10
			42

TABLE 16. Continued

Station	Parameter	Standard Deviation	Parameter Ranking
Nepesta	BOD	2.4	9
	DO	1.7	15
	TDS	220	10
	pH	0.4	12
			46
Bear Creek	BOD	0.65	15
	DO	3.04	1
	TDS	119.27	15
	pH	0.32	17
			48
Littleton	BOD	0.7	14
	DO	0.3	18
	TDS	54	18
	pH	0.2	18
			68

TABLE 17. Effective stations ranked on the basis of mean values of stream characteristics.

Station	Parameter	Mean	Parameter Ranking
Big Thompson	BOD	17.21	3
	DO	6.38	4
	TDS	1673.89	2
	pH	8.00	9
	FLOW	71.9	3
			21
Greeley	BOD	26.99	2
	DO	6.22	3
	TDS	1421	5
	pH	7.93	12
	FLOW	96.0	6
			28
Fountain Creek	BOD	29.10	1
	DO	5.21	2
	TDS	491.89	12
	pH	7.85	15
	FLOW	11.8	1
			31
Kersey	BOD	9.6	6
	DO	6.6	6
	TDS	1045	6
	pH	7.9	13
	FLOW	130	7
			38
Holly	BOD	2.0	14
	DO	7.5	9
	TDS	3700	1
	pH	8.0	9
	FLOW	233	9
			42

TABLE 17. Continued

Station	Parameter	Mean	Parameter Ranking
Henderson	BOD	13.8	4
	DO	5.2	1
	TDS	584	10
	pH	7.7	17
	FLOW	328	11
			43
Boulder Creek	BOD	7.38	7
	DO	7.91	15
	TDS	358.07	15
	pH	8.23	2
	FLOW	90.6	4
			43
Julesburg	BOD	4.2	9
	DO	7.7	13
	TDS	1438	4
	pH	8.1	6
	FLOW	458	12
			44
Clear Creek	BOD	9.93	5
	DO	7.60	11
	TDS	412.83	13
	pH	7.99	11
	FLOW	90.9	5
			45
Uncompahgre River	BOD	1.97	15
	DO	7.78	14
	TDS	1451.86	3
	pH	8.20	4
	FLOW	274	10
			46

TABLE 17 Continued

Station	Parameter	Mean	Parameter Ranking
Loma	BOD	3.4	10
	DO	7.3	8
	TDS	773	7
	pH	8.1	6
	FLOW	5,692	18
			49
Nepesta	BOD	6.1	8
	DO	6.4	5
	TDS	650	9
	pH	7.9	13
	FLOW	683	14
			49
Dotsero	BOD	2.1	13
	DO	7.2	7
	TDS	261	16
	pH	8.2	4
	FLOW	2,082	16
			56
Bear Creek	BOD	2.15	12
	DO	7.52	10
	TDS	203.67	18
	pH	7.82	16
	FLOW	34.9	2
			58
Gunnison River	BOD	1.36	17
	DO	7.95	16
	TDS	721.41	8
	pH	8.28	1
	FLOW	2,558	17
			59

TABLE 17. Continued

Station	Parameter	Mean	Parameter Ranking
Eagle River	BOD	1.31	18
	DO	7.60	11
	TDS	501.26	11
	pH	8.09	8
	FLOW	561	13
			61
Roaring Fork	BOD	1.39	16
	DO	8.02	17
	TDS	366.71	14
	pH	8.23	2
	FLOW	1,367	15
			64
Littleton	BOD	2.2	11
	DO	9.2	18
	TDS	218	17
	pH	7.7	17
	FLOW	217	8
			71

TABLE 18. Overall ranking of effective stations.

Ranking	Station
High importance:	Henderson, South Platte upstream from Cherry Creek, Cherry Creek, Fountain Creek and Nepesta.
Medium importance:	Greeley, Clear Creek, Boulder Creek, Kersey, Big Thompson, Bear Creek, Holly, Loma and Uncompahgre River.
Low importance:	Julesburg, Dotsero, Gunnison River, Eagle River, Roaring Fork and Littleton.

for Table 12 the Cherry Creek station has the highest ranking and Julesburg the lowest. Stations for which information is not available are indicated, but are not included in the ranking (e. g. Littleton and Kersey in Table 12). Tables 12-15 were developed from information contained in Tables 10 and 11 and Figures 10, 11 and 12. Traceability has been divided into its components: expediency and accuracy, with stations ranked according to each of these factors. Table 12 is simply a ranking of stations on the basis of the number of outfalls entering the South Platte between consecutive stations.

In constructing Table 13, the waste types listed in Table 11 were translated into those capable of detection by automatic monitors. Thus, sewage, oils, packing plant, feedlot detergents and garbage are grouped together since discharges of these organic wastes may cause a reduction in dissolved oxygen and may be detectable by a DO sensor. Similarly, TDS and heavy metals are grouped together since they may be detected by a conductivity sensor. Acid wastes of course will be indicated by the pH sensor and thermal discharges by the temperature probe. Waste sources contributing to turbidity (suspended matter) are in general the same as those causing DO reductions, so the proportions indicated for turbidity and DO are the same. The proportions indicated in Table 13 were developed by summing the number of waste sources between consecutive effective stations. Hence, for the Henderson station the total number of waste sources for all waste types is equal to the sum of all the numbers in Table 11 corresponding to the rows labeled Cherry Creek to N. Denver Co. Line, N. Denver to Henderson, and Sand Creek. These are all the waste sources between the station on the South Platte upstream from Cherry Creek and the Henderson station. This value is 115. Summing over these same rows, but only for those columns representing organic, BOD wastes, yields a figure of 80. Thus, the proportion of wastes detectable by DO measurement at Henderson is 80/115 or 70%.

The most important factor in ranking stations for Table 13 is the number of waste sources associated with any particular waste type. Higher rankings are given to stations experiencing larger numbers of waste sources for each waste type. Thus, Henderson received the highest ranking because of the large number of DO detectable waste sources (80). Similarly, the South Platte station upstream from Cherry Creek is ranked above the Clear Creek station because of the larger number of DO, Cond, Temp, pH and Turb detectable waste sources. Stations are ranked in this manner since traceability decreases as the number of waste sources for any particular waste type increases. If a DO violation is indicated at the Henderson station, eighty waste sources may have to be sampled in order to locate the violator. The task is much easier at the Boulder station, since only eight waste sources need be sampled.

By counting the number of major waste outfalls occurring between stations (Figures 10 and 11) Table 14 can be constructed. Table 15 is based on data presented in Figure 12. Together Tables 14 and 15 represent the ranking of South Platte stations on the basis of pollution potential.

All effective primary stations in the state are included in Tables 16 and 17. Information to construct these tables was extracted from Ward (1971). The water quality at each station is characterized by the mean values of five water quality parameters (BOD, DO, TDS, pH and Flow) and standard deviations of four water quality parameters (BOD, DO, TDS and pH). Mean values and standard deviations are calculated from data collected at monthly intervals over a period of years, 1968-1971. Large standard deviations mean that the water quality of that location is unstable and stream standard violations are more likely. High mean values for BOD and TDS indicate areas of high pollution. Low walues for DO, and pH values deviating greatly from 7.0, also indicate polluted areas. Parameters displaying such values are given high rankings (lower numbers). Because there are eighteen effective stations for which information is available, parameters are ranked from 1 to 18. Stations accumulating a high ranking (low numerical sum of all four parameters) have higher importance then stations showing large numerical totals This is so, because stations with low totals of parameter rankings are located at places where stream quality is lower and/or fluctuates more rapidly. Such locations represent areas of high pollution, which should be sampled frequently. On this basis, they are determined to be of greater importance than areas of higher and more consistent water quality.

Assigning Effective Stations to an Importance Category

A cumulative ranking of effective stations is given in Table 18 which is derived from Tables 12-17. High importance rankings are given to Henderson, South Platte upstream from Cherry Creek and Cherry Creek because of their high rankings in Tables 12-15. Fountain Creek and Nepesta are included because of their strategic location. Information on waste sources is not available for the Colorado Springs-Pueblo region. Yet, according to the 1970 Census, this is the fastest growing area in Colorado with Colorado Springs now being the second largest city in the state. The accumulation of people and industry in this area will continue to increase the pollution load on Fountain Creek and the Arkansas River downstream from Pueblo. On the basis of this high pollution potential, the likelihood of numerous waste sources of similar type and the present evidence of pollution porblems downstream from both cities (Ward, 1971); the stations at Fountain Creek and Nepesta were selected as high importance locations.

Greeley, Clear Creek, and Boulder Creek stations received fairly high rankings in all the tables, but usually appear below Henderson, South Platte upstream from Cherry Creek and Cherry Creek. Thus, these three stations are placed in the next importance category. Kersey is included in this category because of its ranking in Tables 15, 16 and 17. Also, as indicated in the selection of effective stations, the Kersey station occupies a strategic position being the only station on the main stem of the South Platte between Henderson and Julesburg Bear Creek has been placed in the medium importance category because of its ranking in Table 11 and because of rapid residential and commercial development in the Bear Creek area. The Big Thompson station has few waste sources and is ranked relatively low in Tables 12 and 14. However, the waste sources present must be fairly significant since the water at the Big Thompson station is the most variable and the lowest quality of any in the state (Tables 16 and 17). The relatively high ranking of the Big Thompson station in Table 15 provides some insight into the cause of this low water quality. For this reason, the Big Thompson station is included in the medium importance category.

Holly, Loma and the Uncompahgre River stations are borderline stations between the medium and low importance categories. They are included in the medium importance category because of their high ranking in Table 16 and/or 17. Their high ranking in one or both of these tables indicates that they are situated at a location where stream standard violations are very likely. Such critical points are indicative of numerous and/or major waste sources entering upstream from the station. Hence, greater abatement effectiveness will be achieved if such points are continuously monitored.

The remainder of the effective stations were assigned to the low importance category (Table 18). The assignment was difficult since (with the exception of Littleton and Julesburg) specific information on waste sources does not exist. Considering this lack of information, the primary reason for assigning stations to the low importance category is that none of them are located in populated areas. Thus, the number of waste sources and pollution potential from organic wastes of municipal origin should be small. Also, stations placed in the low importance category only received low or medium rankings in Tables 16 and 17. Thus, compared to other effective stations, they are located in areas of less critical pollution. Having information on waste sources, the assignment of the Littleton and Julesburg stations to the low importance category, is obvious. In Tables 12-16, both stations are ranked low. Only in Table 17 does Julesburg rank in the top half of the stations.

Calculation of Numerical Importance Values

With effective stations categorized, the calculation of numerical importance values can now be performed (Table 19). The initial value V is chosen arbitrarily. It does not matter what value is picked since a change in V will cause a compensating change in a. The same values for Z', W', X', Y', V', $\frac{V'}{2}$ and $\frac{V'}{4}$ will be obtained. V' is the numerical importance value of each high importance station. Medium importance stations have a numerical importance value of $\frac{V'}{2}$ and low importance stations of $\frac{V'}{4}$.

To obtain the graph shown in Figure 14, increments of abatement effectiveness (percentages) are summed for each station added to the monitoring network. Thus, high importance stations being added first, the first five points on the graph are multiples of V' (i.e., 9.09, 18.18, 27.27, 36.36, and 45.45). For the next nine points, increments of 4.54 are added. The last six points reflect added increments of 2.27. Figure 14 is the abatement effectiveness against number of stations relationship which has been the objective of this chapter. With this relationship established a relationship between cost and number of stations can now be developed.

TABLE 19. Calculation of numerical importance values for effective stations.

Assign an initial value of 50 to V

1. High importance $(50)(5) = 250 = W$

2 Medium importance $(25)(9) = 225 = X$

3. Low importance $(12.5)(6) = \underline{75} = Y$

$550.0 = Z$

$$Z' = \frac{Z}{a} = 100 \qquad a = \frac{550}{100} = 5.5$$

$$W' = \frac{W}{a} = 45.45$$

$$X' = \frac{X}{a} = 40.91$$

$$Y' = \frac{Y}{a} = 13.64$$

$$V' = 9.09$$

$$\frac{V'}{2} = 4.54$$

$$\frac{V'}{4} = 2.27$$

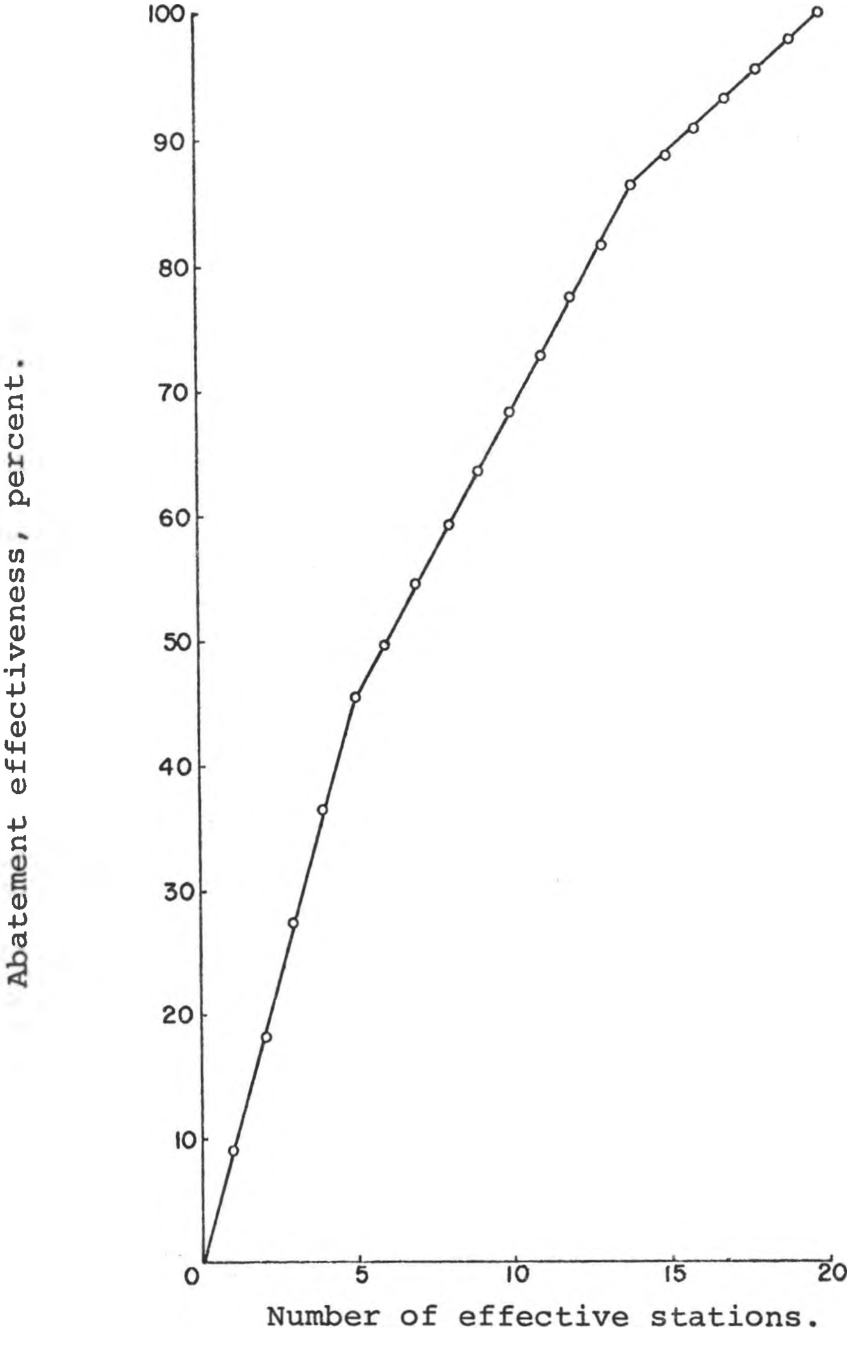

Figure 14. The relationship between abatement effectiveness and number of effective stations.

CHAPTER V

COST OF MONITORING NETWORK

Development of Total Cost Figures

Total cost figures for the first year of operation of various sized automatic monitoring networks are listed in Table 20. The total costs listed include purchase price, installation, and operation for one year. Tables 21-23 reveal how these totals were obtained. An average cost of $8, 000 for the purchase price of a five to six parameter monitor was selected on the basis of information presented in Table 6. Schneider Instrument Company has indicated that a central receiving station costs $10, 000. This company also lists a price of $1, 800 for a telemeter transmitter. From Table 7, the average price for a submersible pump is $300; a sample taker, $700; and automatic cleaning by water jets, $1, 000. These components plus the monitor and central receiving station constitute the initial capital outlay for purchasing a monitoring system.

An average cost of $2, 300 for installation is given in Table 7.

The $400 for parts and supplies is derived from ORSANCO's breakdown of operation and maintenance costs. Operating with a service schedule of once every two weeks, ORSANCO experienced operation and maintenance costs of $1, 250.00/ station/ year.

TABLE 20. Total Costs for the first year of operation of an automatic monitoring network.

	Cost ($)	
Size of Network (# of Stations)	W/O Computer Processing	W/ Computer Processing
1	$ 33,910	$ 162.610
2	54,820	172,120
3	71,560	200,260
4	86,480	215,180
5	101,400	230,100
6	124,720	253,420
7	139,640	268,340
8	154,740	283,440
9	177,880	306,580
10	192,800	321,500
11	216,120	344,820
12	231,070	359,770
13	255,960	384,660
14	269,280	397,980
15	284,200	412,900
16	298,360	427,060
17	322,440	451,140
18	337,320	466,020
19	360,680	489,380
20	375,600	504,300
21	390,520	519,220
22	413,840	542,540
23	428,665	557,365
24	443,680	572,380
25	467,000	595,700
26	490,520	619,220
27	514,740	643,440
28	529,660	658,360
29	544,580	673,280
30	569,100	697,800

TABLE 21. Example of total costs calculation for 1 station network (5-6 parameters).

	Item Purchased	Number	Cost/ Item	Total
Purchase Price	Monitor (flow chamber and analyzer modules)	1	$ 8,000	$ 8,000
	Central Receiving Station (data logger- 8 channel punch paper tape and telemeter receiver)	1	10,000	10,000
	Telemeter Transmitter	1	1,800	1,800
	Submersible Pump	1	300	300
	Sample Taker	1	700	700
	Automatic cleaning (water Jets)	1	1,000	1,000
				$ 21,800
	Service Purchased		Cost/Station/Year	Total
Operation and Maintenance Costs	Installation		$2,300	$ 2,300
	Parts and Supplies		400	400
	Communications Link		530	530
	Electricity		480	480
	Maintenance and Calibration		------	8,400
				$12,110
	Total Costs First Year of Operation			$33,910

TABLE 22. Example of total cost calculation for 5 station network (5-6 parameters).

	Item Purchased	Number	Cost/ Item	Total
Purchase Price	Monitor (flow-chamber and analyzer modules	5	$ 8,000	$40,000
	Central Receiving Station (data logger-8 channel punch paper tape and telemeter receiver)	1	10,000	10,000
	Telemeter Transmitter	5	1,800	9,000
	Submersible Pumps	5	300	1,500
	Sample Takers	5	700	3,500
	Automatic Cleaning	5	1,000	5,000
				$69,000
		5% quantity discount ---		2,950
				$66,050
	Service Purchased		Cost/Station/Year	Total
Operation and Maintenance Costs	Installation		$ 2,300	$11,500
	Parts and Supplies		400	2,000
	Communications Link		530	2,650
	Electricity		480	2,400
	Maintenance and Calibration (2 technicians)		------	16,800
				$ 35,350
	Total Costs First Year of Operation			$101,400

TABLE 23. Example of total cost calculation for 27 station network (5-6 parameters).

	Item Purchased	Number	Cost/ Item	Total
Purchase Price	Monitor (flow chamber and analyzer modules	27	$ 8,000	$216,000
	Central Receiving Station (data logger-8 channel punch paper tape and telemeter receiver)	2	10,000	20,000
	Telemeter transmitter	27	1,800	48,000
	Submersible Pumps	27	300	8,100
	Sample Takers	27	700	18,900
	Automatic Cleaning (water jets)	27	1,000	27,000
				$338,600
		5% quantity discount ---		16,430
				$322,170
Operation and Maintenance Costs	Service Purchased		Cost/Station/Year	Total
	Installation		$ 2,300	$ 62,100
	Parts and Supplies		400	10,800
	Communications Link		530	14,310
	Electricity		480	12,960
	Maintenance and Calibration (11 technicians)		-------	92,400
				$192,570
	Total Costs First Year of Operation			$514,740

However, as indicated in the Literature Review Section, a weekly service schedule is recommended. Thus, the ORSANCO cost should be doubled. Fifteen percent of ORSANCO's operation and maintence costs were for parts and supplies to replace damaged or worn-out equipment. Fifteen percent of $2,500 equals $400.

The cost of the communications link (schedule 1001 leased telegraph lines) is an average of costs given in the literature. ORSANCO's cost is $11,300 annually, or $800/station/year. The five station network operated by EPA/WQO experienced an annual cost of $1,980, or $396/station. When expanded to eight stations there was no change in cost. The mean of these costs is $530.

Electric service costs are only available for the New York Harbor System. This cost is $480/station/year.

Besides expenditures for parts and supplies maintenance costs are due to wages paid technicians to calibrate and service the monitors and the central receiving station. Wages paid by EPA/WQO on the New York Harbor System were $25,200 or $8,400 per technician. For this network, it was estimated that three technicians could adequately service eight monitors. Thus, each technician could handle 2-2/3 stations. This relationship was applied when calculating the total costs listed in Table 20.

Cost estimates listed in Tables 20-23 are given with, and without computer processing. Table 24 shows the costs which can be

TABLE 24. Purchase price of computer processing equipment. (From Anderson, James J., 1970b).

Equipment Purchased	Cost
Mini Computer	$ 15,000
Disk File	40,000
Paper Tape Punch Reader	6,500
Magnetic Tape Unit	28,000
Printer	30,000
Cathode Ray Tube Display	4,000
Logging Typers	5,200
	Total = $128,700

expected when purchasing a computer processing facility. The cost of $128,700 is added in Table 20 to the total costs for the first year of operation to obtain the cost with computer processing. In lieu of purchasing a computer processing facility, equipment may be leased, as ORSANCO prefers, at a cost of $23,600/year.

Note in Tables 21-23 total costs are obtained by multiplying a constant cost per item by the number of stations in the network and then summing these totals. The only exceptions to this procedure are the 5% discount on items purchased in quantities of three or more, the addition of a technician for every 2-2/3 increase in the number of stations, and the cost of an additional central receiving station for networks consisting of twenty-six stations or more.

The Relationship Between Cost and Number of Stations

The cost vs number of stations relationship shown in Figure 15 was constructed using the total costs with computer processing listed in Table 20. This relationship can be approximated by a straight line. However, for the region between 1 and 30 stations the straight line approximation is really not necessary, since the cost for each additional station has been calculated and appears in Table 20. Figure 15 merely emphasizes the relative advantage of acquiring another station when the addition of that station will not necessitate an increase in the number of technicians employed.

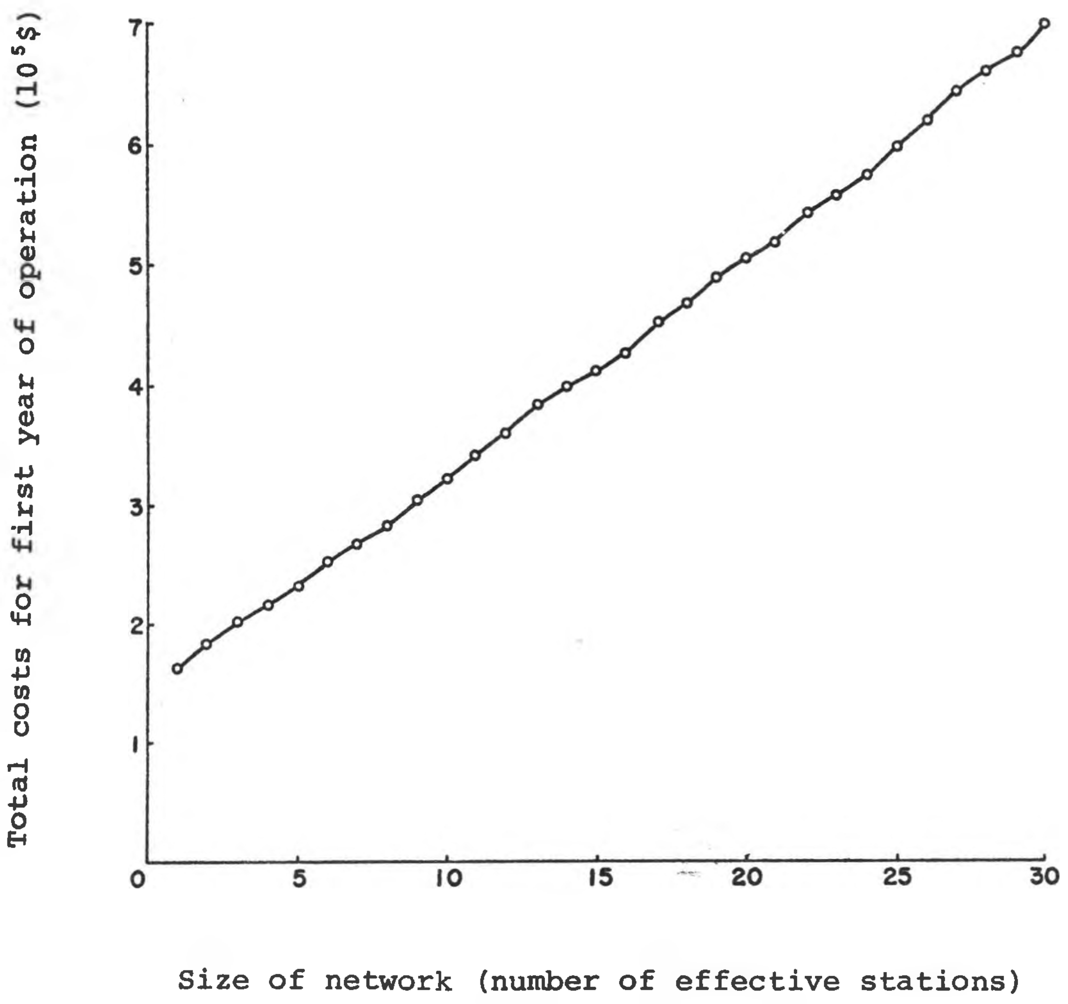

Figure 15. The relationship between cost and number of effective stations.

This is demonstrated on the graph by the more horizontal sections of the rippled curve. For example, the cost of adding a station once nine have already been established will not require an increase in staff since four technicians are necessary for 9 or 10 stations. This is indicated in Figure 15 by the decreased slope in going from nine to ten stations. For eleven stations, 5 technicians are required. Thus, the slope increases in going from ten to eleven stations. In response to these changes in slope with additional technicians, the cost vs number of stations relationships takes on a rippled appearance.

The Relationship Between Cost and Abatement Effectiveness

Once the abatement effectiveness vs number of stations relationship is developed, and the cost vs number of stations relationship established, generating the cost-abatement effectiveness relationship merely requires a comparison of cost and effectiveness associated with the various sized networks. For Colorado, Figures 14 and 15 plus Table 20 provide the needed comparison. Using this information Figure 16 is constructed. The total costs including computer processing are used because it is considered essential for water quality management agencies to not only collect data, but also to analyze the data they have collected.

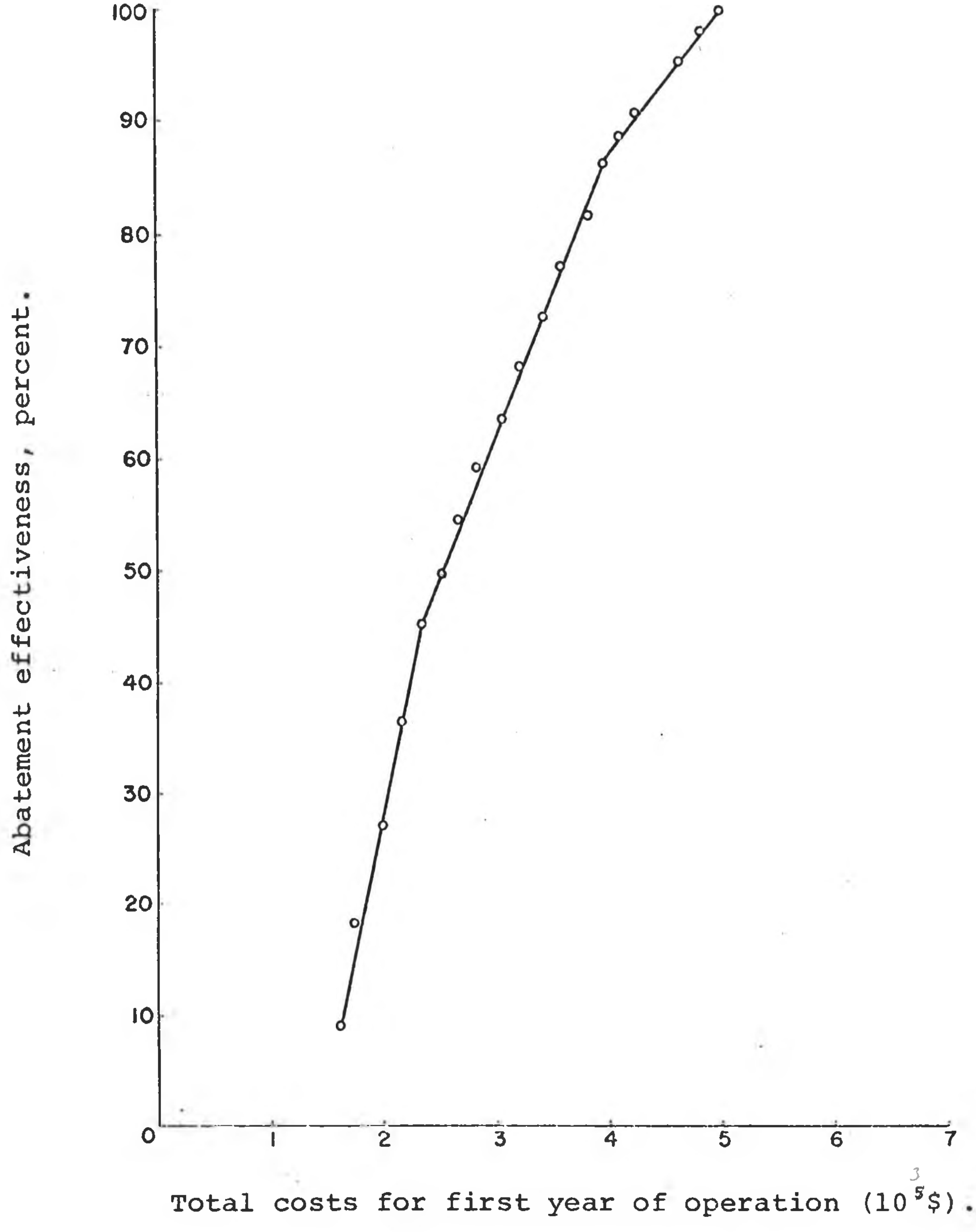

Figure 16. The relationship between cost and abatement effectiveness for Colorado.

Since the cost vs number of stations relationship is nearly a straight line, the cost vs effectiveness relationship will resemble the relationship found between abatement effectiveness and number of stations.

Under the design procedure developed for determining station importance, the graph relating abatement effectiveness to number of stations will always be composed of three straight line segments conditional on there being at least two stations per importance category. Also, the slope of the segment representing the acquisition of high importance stations will be greater than the slope for medium and low importance stations.

Thus, any state using the design procedure developed in this study will derive a cost-effectiveness relationship resembling the one developed for Colorado. The slopes of the line segments may of course be different.

CHAPTER VI

DISCUSSION

Interpretation of the Cost-Effectiveness Relationship

Application to Colorado

Following through with the Colorado example, a determination of station acquisition will now be made. The Colorado Water Pollution Control Division of the State Department of Health has requested $345, 136 for surveillance programs in 1973. If all of this request were employed towards developing an automatic monitoring system, an effectiveness level of about 73% could be obtained in one year. However, this is an unrealistic assumption, in that the agency of course has to supply data for other objectives besides abatement (i. e., planning, research, and aid programs). Furthermore, the Literature Review Section plainly points out that the best utilization of automatic monitors is to supplement a grab sampling network. The secondary surveillance stations enumerated by Ward (1971) must be retained to supply planning data needs.

On the basis of the self evaluation; strategy determination procedure developed by Ward (1971), the Colorado Water Pollution Control Division has assessed its data needs to be 45% for prevention and 55% for abatement. Prevention data needs are for planning, research, and aid programs and are provided by the secondary network (grab sampling stations). If $345, 136 is obtained in 1973 for surveillance activities, then $155, 311 should go into the grab sampling program. Assuming that the abatement objective can be best satisfied using automatic monitors, $189, 825 could be applied towards obtaining an automatic monitoring network. This would permit the acquisition of two stations and cover operational costs for one year (Figure 16). The importance ranking (Table 18) shows which stations should be acquired. Stations in Table 18 are not only grouped into categories, but also their sequence indicates relative importance in their respective category. Thus, the two most important stations are the Henderson station and the South Platte station upstream from Cherry Creek. These are the stations that should be acquired.

From the cost-effectiveness relationship, the total cost for a two station network for the first year of operation would be $178, 120. Hence, $11, 705 would remain after implementation of the two station network. To eliminate this unused portion, it is recommended that the budget request for surveillance activities be increased to $365, 136 which would allow the acquisition of a three station network. With three stations, two technicians are required (1 more than for two stations), but the purchase price of the monitoring equipment is reduced due to the 5% quantity discount.

Abatement effectiveness is increased 9.09 percent since another high importance station can be added. With two stations, only 18.18 percent effectiveness is obtained. With three stations an abatement effectiveness of 27.27 percent is realized. The third station added should be the one at the mouth of Cherry Creek (Table 18). The 9.09 increase in effectiveness makes the additional $20,000 investment advisable.

In subsequent years, the monitoring network could be expanded at much less cost. This is true since expenditures for the initial three station network includes the price of a central receiving station and computer processing center. An additional receiving station and enlargement of the computer facility will not be necessary until the network is much larger.

As a hypothetical situation, assume that $420,000 is requested for surveillance in 1974. Again, 45% should go for the secondary network or $189,000. This means that $231,000 will be available for enlarging the effective primary network of automatic monitors. For $231,000, 11 additional stations can be established. The number of stations is calculated as follows:

$231,000	Available
- $ 21,030	Operational costs for three station network (wages - 2 technicians, communications link, electric service, and parts and supplies) for one year.
$209,970	For the acquisition of additional stations and operation for one year.

From Table 20, the addition of eleven stations is shown to cost $216, 120 - $10, 000 for the central receiving station, or $206, 120. Twelve stations would cost $231, 070 - $10, 000, or $221, 070. Thus, eleven stations may be added to the three station network with the $231, 000 available. The resulting 14 station network will yield an abatement effectiveness of 86%. All the high and medium importance stations would be included, but none of the low importance stations (Table 18).

After the second acquisition of stations, expansion of the automatic monitoring system would preceed at a slower pace since a larger share of the money available for the acquisition of abatement data will go for operation and maintenance of the monitoring system. For example, assume that $231, 000 is again available for the effective primary network. As illustrated by the following calculations, only eight stations can now be acquired.

$231, 000	Available
- $ 70, 140	Operation cost for a 14 station network for one year.
$160, 860	For the acquisition of additional stations and operation for one year.

From Table 20, the addition of eight stations costs $154, 000 - $10, 000, or $144, 000. Addition of nine stations cost $177, 880 - $10, 000, or $167, 880.

However, only six stations need be added to complete the effective station network and obtain 100% abatement effectiveness

(Table 18). Hence, only $70,140 plus $114,720 or $184,860 is required for the acquisition of abatement data in 1975.

Once the monitoring network is complete, the main expenses are operation and maintenance. For a twenty station system, an operation and maintenance cost of $95,400 can be expected. The $95,400 cost is computed as follows:

$400 x 20 =	$ 8,000	For parts and supplies
$530 x 20 =	$10,000	For communications link
$480 x 20 =	$ 9,600	For electric service
	$67,200	For wages paid 8 technicians
	$95,400	

In addition, the cost of replacing monitors after the seven year life expectancy must be mentioned. However, this cost will not be calculated since the exact replacement pattern for the twenty station network is unpredictable.

Applications to Other States

Similar calculations can be performed for other states once their abatement effectiveness vs number of effective stations relationships have been determined. The cost vs number of stations relationship need not be performed for each state. This relationship was devised using average cost figures and is intended to represent the costs experienced by any state. Waste outfall information is required in order to formulate the abatement effectiveness vs number of stations relationship. States not having such information will not be able to evaluate the traceability factor.

These states must rely on stream characterization data and interferences on pollution potential. Thus, the station importance ranking will be less definitive and the abatement effectiveness vs number of stations relationship less meaningful.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

A few general observations have been brought out in the text of this investigation. They deserve emphasis. Automatic monitors have proven to be most valuable when used to supplement grab sampling networks and when operated on a real-time basis for the collection of data to be used for abatement purposes. With this in mind, the design procedure developed in this study is offered as a means of determining the appropriate automatic surveillance system to meet the abatement needs of any state water quality control agency. For any state, the cost-effectiveness relationship obtained by this procedure will take the form of a decreasing function composed of three line segments. Each line segment will have a slope corresponding to the numerical importance value (abatement effectiveness) of the category of stations it represents. Since high importance stations have greater importance values, greater increments of effectiveness are achieved per dollar expended for the acquisition of high importance stations than for medium or low importance stations.

Application of the design procedure to Colorado has elucidated the data requirements for implementing an automatic monitoring system. Also, the Colorado example has revealed that even though initial costs of acquiring an automatic monitoring system are high, a complete system affording one-hundred percent abatement effectiveness may be obtained in a short period of time. For Colorado, assuming reasonable increases in budget requests for surveillance in 1973 and 1974, the complete twenty effective station network may be acquired in three years. Costs in 1975 would decrease since only six stations need be obtained to complete the network. Thus, budget requests for surveillance activities may be reduced after 1974. Only $95,400 is required for the collection of abatement data after 1975.

Understanding the concept of traceability is critical. Surveillance abatement effectiveness is dependent on the expediency and accuracy with which a pollution event can be traced. Of course, detection of the pollution is required before it can be traced.

Recommendations

The Literature Review section has exposed many of the weaknesses of automatic monitors. Suggestions for improvement have also been given. The principal need is for more sensors which will operate reliably. Dependable nitrate and phosphate sensors would greatly increase the detection ability and usefulness of automatic monitors. More rugged construction of monitoring equipment to reduce maintenance problems is also recommended.

The lack of knowledge on sensor detection ability has been revealed in Chapter III. More research on the proportion of wastes detectable by reliable sensors is needed in order to determine an exact relationship between parameters monitored and detection effectiveness.

The importance of collecting waste outfall information has been mentioned several times in this study. This is not by accident. The collection of data on the location and effluent characteristics of waste sources is considered imperative not only for the implementation of the design procedure developed in this study, but also for the effective abatement of water pollution. A permit system would be very helpful in providing such information.

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