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TASK FINAL REPORT

on

TECHNOLOGY TRANSFER POTENTIAL OF AN AUTOMATED WATER MONITORING SYSTEM

(Report No. BCL-OA-TFR-76-6)

by

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

Page

LIST OF TABLES

LIST OF FIGURES

TECHNOLOGY TRANSFER POTENTIAL OF AN AUTOMATED WATER MONITORING SYSTEM

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SUMMARY - APPROACH, FINDINGS AND CONCLUSIONS

Approach

This study task addresses the nature and characteristics of the potential economic need (markets) for a highly integrated water quality monitoring system (WMS) as configured by NASA at the Johnson Space Center (JSC).

The proposed technical characteristics of the system and its approximate capital costs were developed through discussion with NASA and Boeing personnel at JSC. Battelle's Columbus Laboratories (BCL) was not obligated to make any judgement on the technical merits of the overall system concept nor any of its subsystems or components. We proceeded on the assumption that the system would perform to its design objectives.

Given those target performance objectives, BCL investigated the market potential of the system for application to public and private water supply, public and private wastewater treatment and environmental monitoring of rivers and lakes.

The study was accomplished through extensive literature review, discussions with potential users, design/engineering firms, regulatory officials, private and public testing laboratories and instrumentation suppliers. Throughout the study the potential for and the process for technological transfer were kept in mind. Finally an analysis was conducted on the technological, institutional and marketing factors that would influence the transfer and adoption of a "WMS-like" system.

While we tried to downplay the very specific configuration of WMS, its centralized characteristics for sample transport and instrumentation came through as a design philosophy - sometimes negatively and sometimes positively.

Findings

- The NASA Water Quality Monitoring System (WMS) is a multi-parameter high capacity system and is capital intensive. Therefore, the potential for transfer is dependent upon needs in the public or private sectors above and beyond conventional reporting or process control needs.
- Existing and expected future compliance reporting needs in the public and private sectors (potable water, wastewater effluent, and environmental monitoring) rarely indicate requirements for more than test results from 24-hour composite sampling.
- Process control needs in the conventional public water supply sector are not too demanding of on-line quality measuring systems. Industrial process control of water supply is even less demanding and is usually confined to one or a few critical parameters.
- Process control for the automation of public wastewater treatment appears very promising in the long run. The present art is crude with respect to understanding of the treatment processes, development of control strategies and effective utilization of on-line instrumentation, and the existence of reliable sensors. Reliable on-line sensors are perhaps <u>the</u> critical key to further development of the art. Federal

policies regarding the implementation of P.L. 92-500 will have major influence on the speed of development of automation of wastewater treatment.

A 1973 EPA estimate of wastewater treatment plant capital expenditures by localities required to meet the public law standards was $22.8 billion. A rule-of-thumb estimate of 3% to 5% of those expenditures for instrumentation suggests a market of about $1 billion for monitoring/process control instrumentation.

- Research/pilot plant/demonstration plant needs for monitoring equipment seems a viable area for NASA technology. This is particularly true for advanced wastewater treatment systems aimed at reuse. There are probably about 20 public organizations in the country that are dedicated to reuse research programs in one form or another. The technology of developing potable reuse systems will be particularly demanding. Massive data acquisition and analysis programs lasting at least 10 years will be needed. We would estimate that there could be a market for four to six approximate equivalents of WMS within the next five years for this use.
- Another potential application for WMS in the research mode would be for the test and evaluation of on-line sensors. Sensor performance represents such an overwhelming problem that within the next year, EPA may seek to institutionalize a protocol and an organization to qualify sensors. WMS

could be a valuable laboratory adjunct as an on-line simulator. This would represent a "new use" for WMS.

Conclusions

- In the short run (within 5 years) the greatest potential for WMS is its possible utilization in the research mode in connection with wastewater reuse pilots and demonstrations. Its high capacity for data acquisition and storage should make it desirable. NASA could work directly with the users and their engineering representatives.
- Also short run, WMS could find application as a simulator for testing and evaluating commercial on-line sensors. Again, transfer could probably be direct.
- In the longer term, WMS or some reasonable variations of it could find application in the automation of waste treatment plants. This represents by far the greatest potential for economic benefit. This would pose a much more difficult technical development program in that the monitoring function must be directly related to control functions and strategies. The transfer problem would also be more difficult in that the market is highly fragmented, and direct NASA transfer to the user would not seem feasible. It is also probable that a "commercializer" of the system would need to come from outside the present industry structure. Risks attendant to an outside

venturer would be such that clearly demonstrable superior technology would be a must, and protective features within that technology a probable additional requirement.

- To realize its potential, WMS must be rigorously demonstrated and proven. This should be NASA's first priority.
- When NASA is satisfied with its trials of WMS, it should seek feedback from user groups via informal seminar/demonstration programs. Such programs should also include documentation of performance, reliability, operating costs, maintenance costs, and capital costs of WMS.
- Based on the feedback obtained, future programs for technical development and demonstrations should be determined, and the desired technology transfer process should also be postulated.
- Technology transfer can occur in one or a combination of ways; (1) indirectly through demonstration, publication and dissemination, (2) working directly with public users in a few limited applications, and (3) working directly with one or more commercial venturers. The latter option would present the most problems to NASA from a policy point of view. A combination of Options (1) and (2) seems most practical in the short run.

INTRODUCTION

This study was initiated under NASA Contract NASw-2800, "NASA Applications Studies - New Initiatives". The objectives of the study were to:

(1) Determine the economic benefit and consequent market potential for the NASA water monitoring system

(2) Determine and evaluate those factors (technical, economic, market and institutional) that will assure the most beneficial transfer of this technology to the appropriate civil sectors.

The geographic scope of the study was limited to the United States. The water user communities to be considered included:

(1) Public water treatment (potable water)

(2) Industrial water treatment (process water)

(3) Wastewater treatment - public

(4) Wastewater treatment - industrial

(5) Environmental water-quality monitoring.

The study approach incorporated literature review and interviews among water user communities, designers, instrument producers, and institutional water quality regulators.

NASA SYSTEM CAPABILITIES

System Design and Current Status

NASA has undertaken several programs in pollution monitoring and water reuse technology. A laboratory at the Johnson Space Center in Houston, Texas, has undertaken the task of developing an automatic water quality monitoring system (WMS) that can assure high effluent quality standards for integrated municipal utility systems and result in an increase and acceleration in the practice of reclamation and reuse of water.

Objectives. The objectives of the NASA program are to:

(1) Develop an automated water monitor system for effluent monitoring of wastewater treatment systems

(2) Accelerate the development of "real-time" microorganism sensor technology within NASA

(3) Demonstrate feasibility and reliability by correlating data with standard laboratory techniques

(4) Develop the system to a field demonstration configuration, and demonstrate the system to municipalities

(5) Develop model specifications

(6) Publish results and distribute to federal, state, and local agencies.

Current Status. At this time, Objectives (1) and (2) have been largely met. The trailer has been delivered and final wiring and a checkout of all the components of the system are being carried out. The reliability of the system will be determined during May through July by testing out the system in a 24-hour-day operating mode.

In late summer it is planned that the unit will be delivered to the Ponderosa treatment facility where it will be tested by the Gulf Coast Waste Disposal Authority for the remainder of 1976.

System Design. The water monitor system is installed in a mobile trailer, which houses the data acquisition system (DAS), sensors, sample conditioning/distribution system, and the report generating system. The total system can include up to a maximum of 40 water quality sensors. The major elements of the WMS include the DAS, which consists of two separate data collection and display subsystems, a computer and a backup hardware fixed-format device (Phase I DAS), sample collection distribution and filtering system and the sensors. A more complete description of this system can be found in "Urban Systems Project Office Water Monitor System Description" by NASA/JSC, Houston, Texas, December 18, 1975.

System Capabilities

Wastewater monitoring can be accomplished by sampling the flow stream at various points or phases of the wastewater treatment process. The samples are routed into the sample collection and distribution system, where they are processed and distributed to the various sensors. It should be noted that the basic DAS is versatile and other sensors can be added as they are required or as they are developed.

The selection of the type of sensors by NASA personnel was based primarily on the needs of wastewater treatment authorities. The selection of specific sensors was based to some extent on chance since some sensors were "inherited" and some others were acquired without an opportunity to evaluate all of the available sensors of a particular type that were available commercially. The versatility of the WMS would allow the substitution of alternate sensors at a later date if preferred by a specific user or required for a specific purpose.

The sampling collection system was designed so that samples could be taken at various locations in a wastewater treatment facility. The system can provide sampling data from up to six different locations at predetermined intervals. The sampling/distribution system has a built-in capability to filter samples for some sensors (pH, chloride, ammonia, nitrate, conductivity, temperature, biosensors, sodium, residual chlorine, and hardness). The parameters of TOD, TOC, DO, and turbidity are considered to be affected by filtering the substrate so these sensors receive unfiltered water.

The sensors that are presently incorporated in the WMS are listed in Table 1. Also shown are the companies of manufacture and an indication of the type of chemistry involved. The three biosensors shown in Table 1 were developed by NASA. Although the coliform detector is not a "real-time" detection system (2-12 hours are required depending on concentration) it has the capability of detecting either fecal coliform or total coliform depending on the operating temperature (conventional analytical laboratory procedures take at least 2 to 7 days).

TABLE 1. NASA--WATER MONITOR SYSTEM CAPABILITIES

Analysis Of:	Sensor	Method	Developer (Model No.)	Range or Signal
TOC	CO_2/IR	Combustion	Astro Ecology Corporation	0-10 and 0-500 C
TC	CO_2/IR	No scrub	Astro Ecology Corporation	0-10 and 0-500 C
TOD	O_2/solid electro-lyte	Depleted O_2 in air	Astro Ecology Corporation -(?)	0-100 and 0-1000 ppm
pH	pH electrode	pH elect./stand-elect.	Great Lakes Inst. (70)	0-5 volt DC
Chloride$^-$	Cl^- electrode	iff. electrode	Great Lakes Inst. (Orion 94-17 elect.)	10° to 5×10^{-5} molar
Ammonium$^+$	Colorimeter	Reaction/Phenol + NaOCl	Delta Scientific (8119)	0-1 to no upper limit
Sodium$^+$	Na^+ electrode	Na^+ elect./stand elect.	Beckman 194204 (9415)	Trace?
Hardness (Ca^{++})	Cu^{++} & Br^- elec-trodes	Release Ca^{++} from chelate	Orion (1132)	0.1 to 1000 mg/l.
Dissolved O_2	DO probe	O_2 permeable Teflon mem-brane	Delta Scientific (8310)	0-2, 0-10, 0-20 ppm + mg/l.
Turbidity	Photocell	Dual beam optical bridge	Sigrist Photometer Turbidi-meter	2-100, 2000-15000 JTV
Nitrate (NO_3^-)	Colorimeter	Reduce to nitrite→Azo dye	Delta Scientific (8138-153105-002XX1) (52-TJ)	0.0-0.4 ppm (dil. for higher conc.
Specific Conduct-ance	Conduct. indicator	Electrical conductance	Beckman (R15) Solu bridge	0-2000 umhos/cm
Total Resid. Cl	Na^+ redox elec-trodes	Iodometric analysis	Orion (1125) Cl analyzer	0.1-1000 mg/l.
<u>Biosensors</u>				
Bacterial Cells (V & NV)	Chemiluminescent	Luminol-H_2O_2	NASA	(Bacterial Metal Porphy-rins)
Bacterial Cells (V)	Bioluminescence	Firefly extract/enzyme	NASA	(Adenosine triphosphate-ATP)
Coliform or fecal coliform	Pt/calomel elec-trode	Hydrogen Prod.& Detection	NASA	(Hydrogen)

<u>Others</u> - Being developed/evaluated

Phosphate
Cl-hydrocarbons
Virus

The data acquisition processing and display system has a NOVA 1200 CPU and a 9-track magnetic tape unit as a backbone. The computer can provide for automated monitoring and control of the system, real-time display of operational parameters and automated control of equipment by the use of preprogrammed instructions in the computer. The operational data can be sorted and stored within the memory for a period of 24 hours to five days. Capabilities of the system include: data reports and statistical analysis, minimum/maximum values with time of occurrence, sample selection and identification, instantaneous data values, out of limit alarm, provision for correcting sensor drift, sensor status, and selection of recording frequency.

Expected Capital Costs

The total capital costs for NASA's original water monitoring system including both the Phase I DAS and the computer amounted to $269,900 plus an estimated additional 25 to 50 percent for assembly and hookup man-hours. NASA personnel indicated that they estimated that a commercial version of the system would cost about $150,000. Some of the equipment that was included in the present NASA version was added to increase the versatility of the system as a research tool and would not be required for a commercial version. For example, all four heads of the Sigrist turbidimeter would not be required for a system designed for a specific end use, and some of the $12,000 total cost would be saved. Also, a commercial version would not necessarily require the Auto Analyzer, a potential saving of $26,000.

A more exact estimate for a commercial version cannot be made until specific end-use requirements are specified and the extensive testing and checking of the system is complete. For example, this testing program will probably indicate whether the Auto Analyzer will be required as a backup and calibration instrument in a commercial version.

Expected Operating and Maintenance Costs

The anticipated operating and maintenance costs cannot be made with any degree of precision until the reliability, stability, and accuracy of the system have been thoroughly checked out. It will probably be early in 1977 before these estimates can be made with any degree of confidence. However, analogies can be made to other existing analytical instrumentation systems and some indication of probable costs can be developed. The results of this exercise are illustrated in Table 2, where the estimated annual operating and mtaintenance costs for the WMS are tabulated. A number of assumptions had to be made to develop these costs including that a technician would be required for eight hours per day for seven days a week. Most of the other assumptions are indicated in Table 2 and in the footnotes.

The Ohio Health Laboratory informed Battelle that in a typical year (1974) 176,378 water quality analyses were carried out. Since a total of 13 junior chemists, technologists, and laboratory technicians performed these analyses, the work load per person can be calculated to be 13,568 analyses/year or about 56/day or 7/hour. The Ohio Health Department Laboratory is a modern, well equipped, well-run laboratory, so this work load probably approaches an optimum.

TABLE 2. ESTIMATED ANNUAL OPERATING AND MAINTENANCE COSTS FOR WMS

Capital	150,000	
Installation, startup, etc.	75,000	
Total fixed capital		$225,000
Operating costs		
Reagents		6,000
Operating technicians (including fringe benefits)[a]		36,753
Supervision (15% of direct labor)		5,513
Utilities		Negligible[b]
Maintenance labor (includes overhead)[c]		6,760
Incidental supplies (0.5 percent of fixed capital)		1,125
Depreciation (10 percent of fixed capital)		22,500
Taxes (property, 1 percent of fixed capital)		2,250[d]
Insurance (1 percent of fixed capital)		2,250
Plant overhead (50% of direct labor)		18,376
General headquarters overhead (10 percent of direct labor)		3,675
Amortization (8% interest on total fixed capital)		18,000
Total operating costs		$123,202

(a) Based on $24,150 per year for a technician-operator for 1,920 hours plus 1,002 hours make-up (Saturdays, Sundays, holidays, and vacation) for a total 365.25 days times 8 hours per day or at the hourly pay rate of $9.68 plus 30 percent payroll burden.

(b) This assumes installation in an available air conditioned space.

(c) Calculated as contract maintenance labor at four hours per week (average) at the rate of $32.50 per hour including overhead, or alternatively, includes in-house maintenance shop with its associated overhead.

(d) Would not apply for a community system.

If the assumption is made that a hypothetical plant requires the monitoring for laboratory analysis of 10 water quality parameters every hour, a total of 87,660 analyses would be required per year. At an estimated 13,500 analyses per technician per year, a laboratory would require 6.5 technicians to perform these analyses. A very preliminary estimate for the operating costs is given in Table 3. These costs amount to about $252,500 per year or about twice the cost of operating the WMS. Since most of these costs are labor related and since the operating and maintenance costs of the WMS are essentially insensitive to work load, reducing the work load by half would make the systems essentially equivalent. In other words, around-the-clock monitoring of 5 water quality parameters is the work load where both systems have essentially identical costs. Thus, it would appear on the surface that if requirements call for monitoring more than 5 parameters on an hourly basis, the WMS would be cost-effective. It should be stressed that it was assumed that the hypothetical analytical laboratory case involves collecting and transporting samples to the laboratory for analyses. Actually, in most situations, some of the required parameters, such as pH, can be monitored continuously with relatively inexpensive instruments. The minimum number of 5 hourly parameters should exclude those that can be monitored in this manner.

There are basically two types of analyses that can be performed on water. The first are instrumental in situ analyses where no reagents have to be added to effect the analysis. Some of these are pH, turbidity, DO, conductivity, redox potential (ORP) and specific ion electrode analyses. Many of these techniques are generally classified as potentiometric analyses.

TABLE 3. ESTIMATED ANNUAL OPERATING COSTS FOR A HYPOTHETICAL ANALYTICAL LABORATORY

Capital	$75,000	
Installation, building allowance, etc.	25,000	
		$100,000
Operating costs		
Reagents		6,000
Operating technicians[a]		136,500
Supervision (10% of direct labor)		13,650
Utilities		Negligible[b]
Incidental supplies (0.5% of fixed capital)		500
Depreciation (10% of fixed capital)		10,000
Taxes (property, 1% of fixed capital)		1,000[c]
Insurance (1% of fixed capital)		1,000
Plant overhead (50% of direct labor)		68,250
General headquarters overhead (10% of direct labor)		13,650
Amortization (8% interest on total fixed capital)		8,000
Total Operating Costs		$252,550

(a) Based on $21,000 per year for a technician (6.5 required) including fringe benefits.

(b) This assumes that an air conditioned space is available.

(c) Would not apply for a community system.

For this broad classification of analytical techniques, it is usually more expeditious and economically more sound to introduce a probe in situ in the tank or stream where the water is contained. This is certainly true for potable water supplies or most river monitoring, where there is no need for filtering. For waste water treatment plants, this would also be true if the probes did not malfunction as a result of the solids content of the water. In cases where solids sensitive probes are the only probes available and filtering is a must, then sample transport (either flow or grab) must be used. However, several industry contacts have indicated to Battelle that they might dispute the validity of some analyses that have been performed on filtered samples.

The second broad category of water analysis can be called wet chemical analysis. This includes all analyses where one or more chemical reagents have to be added to the sample to perform the analyses or the sample has to be combusted. Some examples of this category of analysis that are incorporated in the WMS are TOC, TC, TOD, ammonia, hardness (Ca^{++}), nitrate, residual chlorine, and the biochemical analyses. For this class of analysis, sample transport to a laboratory is required because of the need to accurately meter and mix the sample and reagents.

In determining the economic feasibility of using the WMS, only the wet chemical analytical requirements of the plant or process should realistically be considered. If economic feasibility of the WMS based on wet chemical analytical needs has been established for a particular requirement, then the equipment for the needed potentiometric continuous analysis could also be incorporated. It should be stressed that "potentiometric" type analyses can be monitored by existing commercial instruments that cost a small fraction of the proportional cost of the WMS.

COMPETING SYSTEMS

Present Testing Procedures

Most of the present testing that is carried out by plants for public and industrial water treatment, public and industrial wastewater treatment and environmental water-quality monitoring involves grab samples that are transported to a laboratory where they are tested by wet chemical methods, colorimetric methods, atomic absorption, or by other instrumental techniques. Some facilities have some continuous monitoring capabilities, for example, modern potable water plants often have equipment to monitor for pH, residual chlorine, fluoride and turbidity. One factor that has tended to sustain the laboratory analysis practice of using grab samples is the reporting requirement of the federal and many state EPA's. For example, for analyses that are required on a frequent basis, composite samples are usually permitted. Samples may be taken every one or two hours for 24 hours, the samples combined and the composite analyzed.

Analytical Testing Laboratories

The costs for having routine water quality parameters measured were determined from three local laboratories. The results of this investigation are listed in Table 4. The average cost for these analyses for the three laboratories investigated ranged from $2 to $5.86 per analysis. The lowest number ($3.00) was derived from costs obtained from the Ohio State Department of Health, which is a modern laboratory with good staff and equipment. This cost is probably a good lowest cost available.

TABLE 4. COST OF INDIVIDUAL WATER ANALYSES
(ANALYTICAL TESTING LABORATORIES)

Parameter	Laboratory Number 1[(a)]	2	3
Turbidity	$1.95	$1.70	$3.25
Color	1.63	1.70	3.90
Odor	1.63	--	3.25
Conductivity	0.98	1.70	1.95
Alkalinity - Total	0.98	--	3.90
Acidity	0.98	--	3.90
Hardness - Total	1.63	1.70	3.90
Residue - Total	1.63	1.70	2.60
Residue - Settleable solids	1.05	--	2.60
TSS	3.25	3.35	7.80
Ammonia	3.25	3.35	4.88
Nitrite	3.25	3.35	3.58
Nitrate	3.25	3.35	3.58
TKN	3.25	3.35	6.50
P-ortho	3.25	3.35	3.25
P-Total	3.25	3.35	6.50
Sulfate	3.25	3.35	3.90
Cl^-	3.25	1.70	3.90
F^-	1.95	1.70	3.90
Hardness (Ca)	1.63	1.70	3.90
Sodium	2.93	3.35	3.25
Calcium	2.93	3.35	3.25
Antimony	2.93	3.35	6.50
Lead	3.25	3.35	5.20
Mercury	3.58	10.00	7.80
Metals - other	2.93	3.35	3.25
BOD-5	8.13	10.00	13.00
TC	2.60	13.33	--
TOC	2.60	13.33	16.25
Cyanide	2.93	3.35	16.25
Oil & Grease	15.28	--	9.75
Phenols	2.93	--	16.25
Average Laboratories	$ 3.00	$ 4.12	$ 5.86

(1) Ohio State Department of Health (these prices have been increased by 30 percent to allow for space costs).

(2) Commercial laboratory A.

(3) Commercial laboratory B. (Prices for (2) and (3) are quantity estimates for 10 or more samples per day. Lower prices may be obtained on a contract basis.

(a) Additional prices are:

Total coliform	$7.80	Fecal coliform	$9.36
Fecal strep.	6.76		

The frequency of testing required to justify the WMS compared to laboratory analysis can be estimated by some simple arithmetic. If we divide the estimated annual operating cost of the WMS of $123,202 by $3.00, we find we need a minmum of 41,067 analyses per year, or 790 per week, or 113 per day or 4.7 per hour. _If_ analyses were required or desirable on an hourly basis, the WMS seemingly would pay for itself if 5 or more water quality measurements were performed by the WMS per hour. This number of 5 or more water quality parameters per hour agrees with the calculations made to determine operating and maintenance costs of laboratories with and without the WMS. As mentioned previously, however, the 5 hourly water quality parameters that are used to economically justify the WMS should be based on only those parameters that require sample transport to the laboratory. Of course, the above calculations are based on an average cost per analysis, and so should be adjusted for the costs of the specific analyses required. For example, if all of the analyses required were the least expensive analyses in Table 4 (Column 1) ranging from $0.98 to $1.95 per analysis, then up to 9 different water quality parameters would have to be monitored to economically justify the WMS.

It should be emphasized that the above comparison is not equivalent since the WMS gives real-time results, in most cases. The only important exception is the coliform results which are obtained within two to 12 hours. On the other hand, the analytical laboratory results usually require two to seven days for completion. The standard turnaround time required from a commercial testing laboratory is one week. If real-time results are required for process control, then obviously the commercial or in-house wet testing laboratory will not suffice and some type of monitoring equipment is required.

Analytical Monitoring Equipment

A number of multiparameter continuous monitoring analytical instruments are commercially available that are suitable for the monitoring of water supply effluent, waste treatment effluents, rivers, and tidal estuaries. Some of the better known systems are listed in Table 5. Although most of these systems do not come with built-in computers, most of them are computer compatible. For example, the Hydrolab Surveyor system can be connected to Metrodata data acquisition systems or process controllers.

One of the available multiparameter water monitoring systems that has some unique characteristics is the automatic water monitoring station that is sold by Philips Electronic Instruments, Inc., a Division of North American Philips Company. This system uses ultrasonic cleaning at predetermined regular intervals by remote automatic control. The pH, redox (ORP), pCl, T, and DO sensors are cleaned automatically by an ultrasonic transducer to prevent harmful interference from algae and sludge deposits. These sensors are specially designed to withstand ultrasonic oscillations. A second feature of the Philips system is automatic calibration. Every 12 or 24 hours, as desired, motor driven valves switch from the sample stream to two standard calibration liquids of different values, in sequence. This automatic calibration is performed for pH, redox, pCl, and DO.

The cost of most of the monitoring systems listed in Table 5 for perhaps 5 to 8 non-wet chemistry kinds of analysis ranges from about $10,000 to $20,000.

TABLE 5. WATER QUALITY PARAMETER PACKAGES AVAILABLE WITH COMMERCIAL MONITORS[a]

Monitor System #[b]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Physical Methods																			
Turbidity	x	x	x	x	x		x	x	x				x	x			x		x
Color		x	x	x			x	x							x		x		
Hardness	x		x					x				x					x		x
Total Dissolved Solids		x	x				x	x	x			x							
Conductivity	x	x	x		x			x	x	x		x	x	x			x	x	x
Redox Potential (ORP)	x	x	x							x	x	x	x	x					
Acidity	x							x				x					x		
Alkalinity	x	x		x		x		x				x					x		
Suspended Solids			x	x			x	x				x							
Chemical Methods, Anion																			
Bromide, Br^-										x				x					
Chloride, Cl^-	x	x			x					x		x	x	x			x	x	x
Cyanide, CN^-	x						x			x	x	x		x			x		
Fluoride, F^-	x	x	x			x	x	x		x		x		x			x		
Iodine, I^-										x				x					
Manganate, MnO_4^-							x	x											
Nitrate, NO_3	x		x														x		x
Nitrite, NO_2^-		x	x									x					x		
Phosphate (Ortho), PO_4^{-3}	x		x					x			x						x		
Sulfate, SO_4^{-2}			x														x		
Sulfide, S^{-2}	x									x				x					
Sulfite, SO_3^-																			
Chemical Methods, Cation																			
Cadmium, Cd^+			x			x	x			x				x			x		
Calcium, CA^{+2}	x		x			x						x							
Chromium, Cr^{+6}	x		x	x		x	x	x				x					x		
Copper, Cu^{+2}	x		x	x		x	x	x		x		x		x			x		
Divalent Maganese, Mg^{+2}	x		x														x		
Hydrogen (pH), H^+	x	x	x					x	x			x							
Iron, Fe^{+3}	x		x		x			x									x		
Lead, Pb			x		x					x			x						
Silver, Ag^+						x								x					
Sodium, Na^+		x					x					x					x		x
Zinc, An^{+2}			x		x														
Other																			
Ammonia, NH_3	x		x	x								x					x		x
BOD			x	x				x			x								
COD			x					x			x						x		
DO	x	x	x		x		x	x	x			x	x	x				x	x
Phenols				x													x		
Residual Chlorine, Cl_2	x		x				x	x	x								x		x
Silica								x									x		
TC	x	x	x								x							x	x
TOC	x	x	x								x								x
TOD				x															x

TABLE 5. (Continued)

Monitor System #[b]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Viable Organisms (ATP)				x															x
Total Organisms (Porphyrins)																			x
Coliform																			x

(a) Most systems can monitor for temperature and pH in addition to the parameters shown.

(b) See Table 6 for companies manufacturing each monitor system.

TABLE 6. MANUFACTURER LISTING FOR ON-LINE WATER QUALITY MONITORS

Listing Number	Company Name and Address
1	Automated Environmental Systems, Series 1500, Woodbury, NY
2	Beckman Instruments, DSA-560, Fullerton, CA
3	Delta Scientific Corporation, Series 8000, Lindenhurst, NY
4	DuPont Instrument Products Civ., Wilmington, DE
5	Enviro Control, Washington, DC
6	Ecologic Instruments Corporation, Hauppauge, NY
7	Fisher & Porter Company, Warminster, PA
8	Hach Chemical Company, Ames, IA
9	Honeywell, Inc., S550-6, Fort Washington, PA
10	Hydrolab, Surveyor 6D, Austin TX
11	Ionics, Inc., 1700 Series, Watertown, MA
12	Ohmart Corporation, Cincinnati, OH
13	Philips Electronic Instruments, Mt. Vernon, NY
14	Robertshaw Controls, Model 900, Anaheim, CA
15	Royco Instruments, Inc., Menlo Park, CA
16	Schneider Instruments/Robot (Orsanco), Cincinnati, OH
17	Technicon Corporation, Autoanalyzer II and Monitor IV, Tarrytown, NY
18	Union Carbide, Model 1600, White Plains, NY
19	NASA, Lyndon B. Johnson Space Center, Houston, TX

Anticipated New Equipment and Procedures

Although the trend in water quality measurement is definitely in the direction of more integrated monitoring, some industry sources indicate that the present practice of combining several individual instruments will continue in the foreseeable future. This is primarily due to the individual monitoring requirements of each individual customer. This is most pronounced for industrial effluents. An indication of this problem can be seen in Table 7 where the EPA effluent guidelines for 33 industrial segments are listed. This table lists all of the effluent parameters required for a given industry. All of these parameters are not required for each plan in the industry. For example, a plant manufacturing a specific inorganic chemical may be required to analyze for 6 to 10 of the specific parameters, not all 23 listed for the inorganic chemicals industry.

For all the multi-industry categories in Table 7 each sub-industry will probably require a different set of parameters from the other sub-industries. A monitoring system that will have wide appeal in the industrial effluent market will therefore have to be extremely versatile. The system will have to be truly modular so that the customer could select the parameters (from a total of 45) that he will want to monitor. One problem with this concept is that most of these parameters are heavy metals which are best analyzed by atomic absorption, which is not readily convertible to a real-time monitoring system.

TABLE 7. EPA EFFLUENT GUIDELINES AND STANDARDS (FEBRUARY, 1974)

Water Regulation Number	Industry	TSS	pH	BOD5	O&G	COD	Cr_t	Cr_{VI}	Phenols	F	NH_3	PCB	CN^-	P	Cu	Zn	Pb	S	Fe	Al	As	Mn	Ni	Others
409	Beet sugar	X	X	X								X												Temp.
413	Cane sugar	X	X	X																				
427	Fiberglass insulation	X	X	X		X			X															
431	Glass	X	X		X					X	X			X			X							
441	Feed lots			X								X												
461	Rubber	X	X	X	X	X																		
471	Ferroalloy	X	X				X	X	X													X		
481	Asbestos products	X	X			X																		
501	Meat products	X	X	X	X						X	X												
521	Phosphate	X	X							X				X							X			
541	Cement	X	X																					Temp.
551	Fruits and Vegetable canning	X	X	X								X												
561	Grain mills	X	X	X																				
571	Inorganic chemicals	X	X	X	X	X	X	X		X	X		X		X	X	X	X	X	X	X		X	TOC, Se, Ba, Ag, Hg
601	Electroplating	X	X				X	X		X			X	X	X	X	X		X				X	Cd, Sn
	Electroplating precious metals	X	X				X	X					X	X										Ag, Au, Ir, Os, Pd, Pt, Rh, Ru
611	Plastics and synthetics	X	X	X	X	X	X		X	X					X	X								
631	Nonferrous metals	X	X			X				X	X				X					X				
641	Fertilizers	X	X							X	X			X										Organic N, NO_3^-
661	Soap and detergent	X	X	X	X	X																		Surfactants
691	Timber products	X	X	X	X				X															
711	Organic chemicals	X	X	X		X			X															
721	Leather tanning	X	X	X	X		X					X						X						TKN
731	Petroleum refining	X	X	X	X	X	X	X	X		X							X						
751	Building paper and roofing	X	X	X																				Settleable solids
761	Seafood processing	X	X	X	X				X															
781	Iron and steel	X	X		X				X		X		X			X	X	X				X		NO_3^-
801	Textiles	X	X	X	X	X	X					X						X						Color
901	Steam electric power plants	X			X		X			X			X	X	X				X					Cl_2
931	Paving and roofing	X	X	X	X																			
991	Mineral mining and processing	X	X																X					
1011	Coal mining and preparations	X	X													X			X	X		X	X	
1021	Ore mining	X	X			X							X		X	X	X			X	X			Hg, Cd

Probably, the areas where new innovative procedures for water quality measurements will be forthcoming are those involving biological and specific-ion sensors. The biological detection systems being developed by NASA represent major contributions to water-quality monitoring capabilities. It should be noted that duPont has developed and is selling their 760 Luminescence Biometer which is based upon technology developed at the Goddard Space Flight Center and is essentially equivalent to the NASA ATP detector. The duPont instrument also utilizes the firefly luciferance-luciferin reaction and is available at a cost of $6,650. In addition, a system for detecting and quantizing the viral content of waters would be highly desirable. Both of these systems would find many applications throughout the public and private sectors of our economy.

A reliable phosphate detection system is also needed; however, we understand some interesting electrochemical and immobilized enzyme concepts are under investigation by NASA Lewis Research Center, Cleveland.

Another requirement that is receiving more research emphasis is the general area of specific-ion electrodes. Many anions and cations that have a potential of occurring in our potable water supplies and our waste waters effluents are difficult to analyze by continuous monitoring systems. Many of the specific-ion sensors that are commercially available can be thwarted by the presence of interfering ions. New concepts for specific-ion sensors are needed.

OVERVIEW OF THE NEED FOR WATER-QUALITY MONITORING

As it is being developed, the WMS has a huge workload capacity in terms of the number of water-quality parameters it can measure and the frequency of their measurement - near real time. It also has a large data storage capacity and the ability to format those data in various configurations for analytical purposes. The system is also capital intensive. These system characteristics indicate that the potential applications for the system should be sought in areas where "intensive" monitoring is required. There is no actual definition for "intensive" monitoring, but within the context of this study, we will interpret it to mean measurement of at least 10 parameters at least once an hour.

Battelle's investigations revealed that water-quality monitoring is performed for three basic purposes:

(1) To establish compliance with imposed water-quality requirements. These are reporting requirements and are most commonly imposed by regulatory agencies. In some cases they are self-imposed.

(2) To control the treatment process. The purposes for control are to save money or to improve the quality of the finished effluent or both.

(3) To perform research (a) to develop performance characteristics, control procedure and standards for new treatment processes, or (b) to better understand the physical/chemical dynamics of bodies of receiving waters.

With respect to each of these purposes some general observations can be made regarding the intensity of water-quality monitoring needs. Each of them will be discussed more fully in subsequent sections of the report.

Compliance

Regulatory Requirements

For establishing compliance with regulatory requirements, the frequency of measurement required is very low. This is true for potable water from conventional sources, for wastewater effluent from industrial or municipal treatment facilities, or for the monitoring of receiving waters.

With respect to self-imposed requirements for potable water supplies, some water utilities voluntarily exceed regulatory standards and the quality measurement frequencies prescribed by regulatory authorities. This is most true among major utilities in areas where raw water supplies are of relatively poor quality.

Industries - if supplying their own process water, boiler feeds or cooling water - will develop their own standards in the interests of process efficiencies and safety. The number of parameters measured and controlled is usually confined to a critical few.

Process Control

Potable Water

Process control among major water utilities has been practiced for a number of years. Process control is practiced both for cost savings and for the maintenance of a high quality effluent. Since the quality of raw waters changes slowly, the need for intensive monitoring of the treatment process is minimal. The parameters that are monitored intensively or continuously most often include turbidity, pH, fluoride, chlorine, odor and temperature.

Wastewater Treatment

Process control (or automation) of wastewater treatment systems is in a technological state of infancy. Treatment processes are not well understood, control strategies are lacking, appropriate sensors are not available or are unreliable, and cost/benefit data are undeveloped. Unlike water treatment plants, the influent of wastewater treatment plants can be highly variable in quantity and quality. The potential for improving the costs and quality of wastewater treatment through automation seems high. The lack of reliable on-line monitoring systems presently constitutes one major deterrent to further development of automated treatment plants.

Research - New Processes

Monitoring requirements for research concerned with development of processes, standards, and control for reuse of wastewater represent the area of potential need most directly relatable to the motivation for the development of WMS. Regulatory standards for direct potable reuse are completely lacking at present; for indirect potable reuse (with dilution) they might be considered as partially developed. The direct reuse of treated wastewater for industry, agriculture, recreation, etc., is currently practiced to a limited extent, and standards are related to the particular form of reuse.

Reliable on-line monitoring systems will be critical to the development of processes for the potable reuse of wastewater - and in some instances for non-potable reuse.

Research - Receiving Water Dynamics

Research into the physical/chemical dynamics of receiving waters does not seem to impose requirements for intensive monitoring. The definition of "mixing zones" and the determination of impoundment impacts were both investigated. The use of mathematical models and periodic sampling programs seem entirely adequate for regulatory and water management decisions.

CHARACTERIZATION OF SPECIFIC MONITORING REQUIREMENTS

Compliance Monitoring Requirements-Potable Water Supplies

Potable water treatment facilities are subject to the guidelines set forth in the National Interim Primary Drinking Water Regulations of March, 1975. The Act applies to any "system for the provision to the public of piped water for human consumption, if such system has at least fifteen service connections or regularly serves at least twenty-five individuals at least 60 days out of the year". These regulations are to take effect on June 24, 1977.

Maximum contaminant levels, as defined in the Act, are presented in Table 8.

TABLE 8. MAXIMUM CONTAMINANT LEVELS FOR DRINKING WATER (FEDERAL REGISTER, DECEMBER 24, 1975)

Contaminant	Level, mg/l (where applicable)
Arsenic	0.05
Barium	1.0
Cadmium	0.010
Chromium	0.05
Lead	0.05
Mercury	0.002
Nitrate (as N)	10
Selenium	0.01
Silver	0.05
Flouride*	1.4-2.4
Chlorinated hydrocarbons	0.0002
Lindane	0.0004
Methoxychlor	0.1
Toxaphene	0.005
2.4-D	0.1
2.4.5-TP Silvex	0.01
Turbidity	1 turbidity unit
Coliforms	Dependent on plant size and method used.

* Dependent on annual air temperature

The regulations also require that samples of raw and treated water of designated public water supply systems be collected for submission to EPA for organics analysis.

Analysis of all required parameters must be performed by a state certified laboratory using the EPA approved methods (Federal Register, October 16, 1973).

The frequency of testing varies with the type of treatment provided by the plant. Generally, the most frequent sample analysis for any parameter is daily. The exception is free residual chlorine, which must be analyzed every four hours. Monthly reports on daily water softening and purification are required by some state Departments of Health. A separate report on plant operation is also required by some state EPA's.

Other parameters, such as several alkalinities (total, bicarbonate, phenolphthalein, and hydroxide alkalinity), hardness (total and non-carbonate hardness), total phosphate, calcium, magnesium, iron, and others are monitored routinely to test plant performance. Combined physical-chemical tests of routine and required frequencies for the Morse Road and Dublin Road Water Treatment Plants, Columbus, Ohio, appear in Table 9. These are 100 to 180-mgd capacity facilities operating on daily averages of 60 to 70 mgd. Certain parameters are measured at several points throughout the process - turbidity, odor, and pH. Other parameters need only to be measured at the point in the process where the parameter is to be affected. Although not required, continuous monitoring of parameters such as chlorine, fluoride, temperature, and pH is often practiced within the system and on the finished water. Continuous monitoring of turbidity in the treated water ("effluent") is also important, but not required.

TABLE 9. COMBINED TESTS AND FREQUENCIES OF THE MORSE AND DUBLIN ROAD WATER TREATMENT PLANTS, COLUMBUS, OHIO

Test	Required Frequency	Routine Frequency
Color	Monthly	Daily
Odor	2/month	
Conductivity	Monthly	
Turbidity	Daily in source Weekly in system	Continuous (on "effluent")
pH	Daily in source Weekly in system	Continuous
Calcium carbonate determination (pH stabilization)	Weekly	
Alkalinities	Daily in plant Weekly in system	Every 2 hours
Hardness	Daily in source Weekly in plant and system	Every 2 hours
Nitrate-nitrogen	Weekly in source Monthly in system	
Phosphate (Total)	Monthly	
Chlorine	Not required	Daily-Continuous
Fluorides	Weekly in source Daily in plant and system	Continuous
Calcium	Daily	
Magnesium	Daily	
Iron (Total)	Not required	Daily
Manganese	Not required	Monthly
Copper (when used for algae control in reservoir)	Weekly	
Free residual chlorine	Every 4 hours in plant Daily in system	
Total residual chlorine	Weekly	Every 4 hours
Sodium		Monthly
Bacteriological	20/day on finished water	1/day on raw and reservoir water

Compliance Monitoring Requirements-Wastewater Treatment

The goal of the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) is to eliminate the discharge of pollutants into navigable waters by 1985. Water quality sufficient for the protection of aquatic life and for recreation, where attainable, is an interim goal to be met by July 1, 1983. To accomplish these goals, the Act requires that effluent limitations be established based on "best practicable control technology currently available" by July 1, 1977, and "best available treatment economically achievable" by July 1, 1983. These effluent limitations are applied to point source discharges to "navigable waters".

The Act becomes very explicit in its definitions. "Point source" refers to "discernible, confined conveyances" encompassing structures from pipes to ditches. The definition of "navigable waters" eventually includes virtually all surface waters of the United States.

"Practicable" control technology for industrial sources is based on end-of-the-line treatment techniques rather than on the process itself. Technology to be used would be determined by technological considerations and not by the water quality of the receiving system. "Currently available" refers to any demonstrated, "general use technology of a reasonable level of engineering and economic confidence and viability...at the time.. of construction of the control facility". "Best available demonstrated technology" includes process control technology as well as effluent treatment. Legally, "best available" technology means the same for old and new sources. However, it is likely that lower discharge levels will be required from new plants because of greater feasibility of incorporation of in-plant controls. A list of those industries for which specific effluent guidelines have been formulated was previously presented in Table 7.

A second set of definitions applies to municipal wastewater treatment facilities. Generally, "best practicable technology" attainment refers to implementation of secondary treatment by 1977. Secondary treatment incorporates biological processes to achieve the following arithmetic mean values for effluent samples collected in a 30-consecutive-day period (Section 133.102):

5-day BOD	-	30 mg/l
Suspended solids	-	30 mg/l
Fecal coliform bacteria	-	200/100 ml
pH	-	within 6.0 to 9.0.

Tertiary processes are those designed to remove pollutants not removed by secondary treatment. Tertiary processes applied to secondary treatment effluents enable 95 to 99 percent removal of BOD, suspended solids, phosphorus, and nitrogen. The Act is nebulous as to the tertiary requirements for "best available technology" by 1983. Something further than secondary measures is obviously anticipated. However, since a large percentage of the cost of municipal wastewater treatment is assumed by the Federal government the requirement for tertiary treatment by 1983 has not yet been promulgated, partially due to the high cost of advanced wastewater treatment.

Acceptable test procedures for required analyses are identified in the Federal Register, October 16, 1973.

The Federal Water Pollution Control Act, as amended, prohibits effluent discharge unless authorized by a permit issued by the U.S. Environmental Protection Agency or by an EPA approved state agency. Section 401 of the Act stipulates the submission of an application for such a permit.

Substantial monitoring may be required to obtain the necessary information required in the permit. The applicant must summarize its wastewater characteristics as well as describe the intake and discharge waters. Representative concentrations of listed parameters must be given based on the previous 12 months of operation or estimated for proposed discharges. Supportive analytical details including sample type, method and number of analyses, daily average, minimum and maximum concentration ranges, and frequency of sampling, must accompany the representative values.

The resultant permit has a basic format of effluent limits, a compliance schedule, and monitoring requirements (including sample type, frequency of analysis and reporting) tailored to the capacity of the discharge on a case-by-case basis. Factors such as the age of the equipment and facilities, the process employed, and the engineering aspects of the application of control techniques are taken into account in defining the "best practicable" and "best available" technology for a particular category of discharges. A balance test between total cost and effluent reduction benefits is made to assess "best practicable control"; economic feasiblity of implementing the highest demonstrated degree of technology for plant operation aids in the determination of "best available" technology.

Reporting of permit compliance monitoring is recorded on EPA's Monitoring Discharge Form EPA-3320-1. Average monthly values of each analysis performed, plus minimum and maximum quantity and/or concentration, are reported. Minimum and maximum values required are representative of a 24-hour day of actual operation. Analytical values may result from a single composite analysis or be the average of three 8-hour composite samples. The form may be used for combined effluent measurements for the entire facility, for combinations of several outfalls, or a single outfall.

State discharge permits occasionally require continuous monitoring of a few parameters at larger wastewater treatment facilities. For example, California requires continuous monitoring of flow in large plants which have the capability; flow, pH, and free residual chlorine are required in larger facilities in Florida; and flow, turbidity, and temperature are required of large plants in Ohio. Illinois, considered to have stringent effluent limitations, requires no continuous monitoring of sewage treatment facilities. Monitoring in these permits is usually accomplished by one analysis of a 24-hour composite sample (collected hourly). Continuous analysis of these or any other parameters or constituents in the future is unlikely with the remotely possible exception of very large users with a highly variable discharge.

While specific requirements for monitoring of plant effluent are variable, requirements for more than daily analysis are only rarely in the picture. Even the most severe compliance requirements are judged on a rate of daily discharge. Requirements for intensive monitoring for <u>compliance purposes</u> are therefore lacking.

The status of the issuing of permits under the NPDES program as of February, 1975, is summarized in Table 10.

TABLE 10. STATUS OF NPDES PROGRAM

	Major	Minor	Total
MUNICIPAL PERMITS			
EPA	1,706	6,273	7,979
States	663	2,620	3,283
Total issued	2,369	8,893	11,262
To be completed	2,735	15,497	18,232
% completed	87	57	62
INDUSTRIAL			
EPA	2,009	7,968	9,997
States	690	3,491	4,181
Total issues	2,699	11,459	14,158
To be completed	2,898	22,046	24,944
% completed	93	52	57
AGRICULTURAL			
EPA	296	362	658
States	41	196	237
Total issued	337	558	895
To be completed	660	1,363	2,023
% completed	51	41	44
FEDERAL FACILITIES			
EPA	169	1,441	1,610
To be completed	169	2,008	2,177
% completed	100	72	74
TOTAL			
EPA	4,180	16,044	20,224
States	1,394	6,307	7,071
Total issued	5,574	22,351	27,925
To be completed	6,462	20,914	47,376
% completed	88	55	59

Rawls, L., 1975

Compliance Monitoring Requirements-Rivers and Lakes

Water quality monitoring of lakes and streams is conducted by a variety of organizations for various reasons. Monitoring is used to establish baseline quality in order to develop realistic water-quality standards for the protection of aquatic life as well as human health. Continued monitoring can provide data to periodically revise or upgrade existing standards. Surveillance of lakes and rivers also provides an assessment of ongoing pollution control programs and characterizes long-term water-quality trends. Monitoring is also necessary to identify inputs and impacts from a wide range of pollution sources including both point source (industrial) and non-point source (agricultural) discharges. Effluent discharge compliance, stream loading levels and lake eutrophication rates are other examples where monitoring information is needed.

Monitoring of water can include a variety of physical, chemical, and biological parameters. Some require more frequent monitoring depending on the local situation and the chemical activity of the particular parameter. Table 11 presents the frequency with which various parameters are included in state water-quality criteria standards. This list includes parameters having appropriate upper or lower limits set by the states for the protection of aquatic life and/or human health. Most of the monitoring in the U.S. is conducted on parameters from this list.

Ohio EPA

As an example of state involvement in monitoring, the Ohio EPA program was investigated. The Ohio EPA utilizes data collected from 90 primary stations throughout Ohio. There are also 60 secondary water-quality

TABLE 11. FREQUENCY OF PARAMETER USAGE IN WATER QUALITY CRITERIA OF STATE STANDARDS IN THE UNITED STATES

Uniform (100%)	Frequent (99-50%)	Less Frequent (49-20%)	Least Frequent (19-0%)
DO	Radioactivity	Arsenic	Bottom Deposits
pH	Public Health Service Drinking Water Stds.	Barium	Chromium (+3)
Coliform	Total Dissolved Solids	Cadmium	Electrical Conductance
Temperature		Chromium (+6)	Ammonia
Floating Solids (Oil-Grease)		Fluoride	Acidity
Settleable Solids		Lead	Akalinity
Turbidity and/or Color		Selenium	CCE
Taste-Odor		Silver	Hydrogen Sulfide
Toxic Substances		Suspended Solids	Pesticides
		Chloride	Sodium
		Copper	Iron
		Nitrate	Plankton
		Phenols	Foaming Substances
		Phosphate	Boron
		Sulfate	Mangnanese
		Cyanide	Hardness
		Median Tolerance Limit	BOD
			MBAS
			Zinc

Note: Taken from McDermott, James H., "Water Quality Monitoring", paper presented at the Environmental Engineering Conference, University of Florida, Gainesville, March 26-28, 1969.

monitoring stations which survey fewer parameters less frequently. Additionally, there are approximately 100 reconnaissance stations, geographically remote from the district offices, which are surveyed quarterly at most. Twenty-three parameters are monitored at the primary stations on a monthly basis, with an additional 23 parameters checked quarterly. At secondary stations, 15 parameters are monitored less frequently than at the primary stations. Water-quality parameters and monitoring frequency are not uniform among the secondary stations but vary with the purpose for which the station was established. For example, parameters measured in an area of agricultural runoff would be different from those surveyed in acid mine drainage areas.

The Ohio EPA utilizes 34 automatic monitors of various makes to test for pH, dissolved oxygen, temperature and conductivity. Samples are analyzed on an hourly basis, with results printed out on tape. Tapes are collected and stations serviced on a routine basis by the United States Geological Survey (USGS). Routine data turnaround time is a minimum of 2 weeks and a maximum of 4 weeks. This time frame suffices for routine reporting needs such as the annual report on water quality to the federal EPA, monthly storage of data in their computerized information system (STORET), and reports on waste load allocation and compliance monitoring.

Rarely does the Ohio EPA utilize any kind of continuous monitoring. Occasionally there is a need for hourly composite discharge sample collection with daily analysis for compliance monitoring. For routine data needs intensive monitoring is not required.

U.S. Geological Survey

River and stream monitoring by USGS is generally much more infrequent than that by state EPA's. In order for the USGS to work in a state, that state must provide matching funds for the monies supplied USGS by the federal government. In many cases, USGS works with the state EPA (the cooperator) in pollution surveillance activity. In Ohio, USGS operates 45 stations. Each station is equipped with a monitor for hourly readings of pH, dissolved oxygen, conductivity, and temperature. (Monitors used by USGS were developed by Ionics [Union Carbide] and Radion.) In addition to the hourly readings, trace elements, total organic carbon, hardness, and nitrogen series are analyzed twice a year during high and low flows. USGS also runs gauging stations to monitor flow characteristics of streams.

Data turnaround time for the USGS is generally 4 weeks. This has proven adequate for monthly reporting to the Ohio EPA and for their annual report, Water Resources Data for Ohio. Intensive monitoring by agency would only be anticipated at the cooperator's request. To date, there has been no real need.

ORSANCO

A third type of monitoring agency is the Ohio River Valley Water Sanitation Commission (ORSANCO). This commission operates under a joint contract among all the states bordering the Ohio River. It serves as a water pollution control agency for the Ohio River and its major tributaries. The ORSANCO monitoring strategy, therefore, is to identify sources of pollution to this river system.

Many of the ORSANCO monitoring stations are located in water treatment plants and power generating plants along the river. By tapping the intake lines of these facilities a more representative sample of river water can be obtained. Additionally, separate housing for the monitoring device is usually unnecessary and on-site personnel are readily available for servicing the sensors and maintaining adequate flow (Klein, et al., 1968).[1*] ORSANCO presently utilizes 25 robot monitors (ORSANCO, 1975)[2] of the type developed by the Schneider Instrument Company

Field stations are equipped with analyzer units with sensors for measuring pH, oxidation-reduction potential, chloride, dissolved oxygen, conductivity, temperature, and solar radiation. Each station is equipped to make only those measurements significant at the particular location. Each field sensor is equipped with a transmitter for telemetering data to headquarters in Cincinnati. ORSANCO headquarters interrogates each station once each hour automatically. Data are punched on paper tape, stored on a magnetic disk in the computer, and/or typed on a log chart for visual examination. Data can also be directly stored on disk pack of the computer through an access channel from the central station, a faster input mode than with paper tape.

The hourly sampling interval has proven adequate for evaluating water-quality changes. This frequency is desirable,as interrelationships between water-quality characteristics often require many pairs of data to obtain statistically meaningful results on a daily basis.

In addition to the data received automatically from the robot monitors, manual sampling is also conducted monthly at each ORSANCO station. Analysis of 35 components and parameters of water quality is made on each sample.

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* References, designated by superscript numbers, are at the end of the text.

Schneider Instrument personnel service each ORSANCO monitor on a 2-week interval. Calibrations are made to insure readings within a 1 percent tolerance limit. Thorough, weekly cleaning and maintenance of the sensors and flow cells by on-site personnel are essential for efficiency in the system. Cost of this service in 1968 averaged about $1250 per station. This figure represented a 25 percent increase from 1965, attributable to increased labor and replacement part costs as well as an increased service program (Klein, 1971).[3] A breakdown of the ORSANCO monitoring costs for 1971 appears in Table 12.

The complete system used by ORSANCO also integrates water quality information from manually operated stations at municipal and private water treatment plants, from a cooperative program with the USGS, and from certain state programs. Accompanying flow information is imperative for the evaluation of river quality conditions. Daily flow and velocity forecast are provided by the U.S. Weather Bureau for each robot monitor station. These data are used until the annual summaries of flow become available from USGS.

The advantage of the ORSANCO system lies in the telemetering capability which makes data from the entire network available in one location almost instantaneously.

CLEAR

A system for lake monitoring is presently operated by the Center for Lake Erie Area Research (CLEAR). In recent years there has been much public concern for the eutrophic condition of the Great Lakes, in particular for the status of Lake Erie. Many regulatory measures for nutrient control both in the lake and in discharges to the lake have been implemented. Monitoring of Lake Erie has been conducted by CLEAR to determine

TABLE 12. ORSANCO MONITORING SYSTEM COSTS (Klein, 1971)[3]

Capital Costs	
Robot Monitor - Schneider Instrument Company RM-25 W/5 parameters and telemeter	$8,000
Monitor Housing - Including pump, intake well, construction but no real estate	4,500
Central Processing Station	$30,000 - $40,000
Operating Costs	
Monitor Maintenance	
Maintenance and parts (no pump)	$2,000/yr
With pump and utilities	4,500/yr
Costs of Telemetering	
Telegraph grade lines	$1.00/mi/mo
at interstate rates (U.S.)	$25.00/terminal/mo
Data Processing Equipment	
IBM-1130 processing unit W/32 K memory	$2,575/mo
Multiplexer	$825
Hi-Speed Printer	$630
Card reader-punch	$370
4 additional disk drives (1 std W/1130)	$820
Paper tape punch	$42
Key punch unit	$111
	$5,393.00/mo

the effectiveness of these measures in improvement of the biota, sediment oxygen demand and anoxic levels.

The monitoring scheme devised by CLEAR involves monthly sampling at 50 stations throughout the lake. In order to cover this area in the given time, CLEAR has equipped a large vessel to house and transport monitoring equipment to the various locations and to serve as a floating laboratory. The initial cost of the vessel was $500,000. Seven full-time people are required for ship and laboratory operation and maintenance. Yearly operating costs are $150,000.

At each location samples are pumped onboard from 4 or 5 different depths. Analyses of the following physical and chemical parameters are made on each sample: pH, dissolved oxygen, conductivity, temperature, nitrogen, and phosphorus series (including total Kjeldahl nitrogen, nitrate/nitrite, ammonia, dissolved, partial and total phosphorus), silica, C^{14}, chloride, calcium, zinc, copper, mercury, lead, nickel, cadmium, chromium, carbon, total suspended solids, particulates, chlorophyll series, turbidity, and transmissivity. Every fifth sample analyzed is a standard. All results are printed out on paper tape. Interpretation of results is performed after each cruise, at which time appropriate adjustments are made. Data turnaround time routinely involves several months. In the instance of an intensive study this time can be shortened considerably, with interpretation being performed on ship as data become available. For the purpose of meeting the yearly report deadline, data turnaround time has been adequate.

The vessel is equipped with several commercial monitoring devices including those developed by Orion, Beckman, Yellow Springs Instruments, Technicon, and Martec. None of the devices currently used are fully automated. The probes developed by Orion for ammonia, chloride, and calcium were found to be unsatisfactory in CLEAR field use. Instruments require one full-time person for maintenance and operation.

For studies similar to the Lake Erie survey, intensive monitoring is not necessary. Conditions throughout an entire lake, particularly a large lake, are not in a state of rapid flux. Changes in water quality occur over greater periods of time than in smaller bodies or flowing systems.

Process Control - Potable Water

Various forms of process control are carried on within the potable water supply industry. These range from simple single point control via monitors to fairly elaborate multiple control point systems that are integrated into central panel control consoles.

Most water supplies, whether reservoirs or ground water, are fairly uniform in character and do not require intensive monitoring, as water quality changes usually occur over a period of days or weeks. Routine analysis or continuous monitoring is conducted on the raw (influent) water, flocculation basins, clarified, settled, recarbonated, and filtered waters, and on the finished (effluent) water. Some parameters such as turbidity, odor, and pH are often measured at all points, while others such as alkalinities, hardness, coliforms, chlorine, fluorides, phosphate, calcium, magnesium and iron are measured at only one or two process points.

In general, intensive monitoring of multiple parameters at multiple points for process control is not necessary. Where instrumentation is involved, measurement is usually made individually at the particular point in the process where treatment is effected. Flow rates, chemical feed, etc., can be automatically adjusted.

From an institutional point of view, some other factors currently mitigating against continuous monitoring by instrumentation are worthy of mention. At present the methods of analysis incorporated in the WMS are <u>not</u> EPA approved methods (with the exception of the pH electrode); therefore, data developed by such a system for process control purposes could not be used to establish compliance within the context of reporting to the regulatory agencies. In addition, federal funds are available to equip certified laboratories for testing potable water supplies. As a result, the cost of a multiple parameter continuous monitoring system that would not qualify under EPA's approved methods becomes even less attractive.

Process Control - Wastewater Treatment

Despite the fact that the dynamics of the treatment processes are poorly understood, process control is practiced in nearly all conventional wastewater treatment plants. Various operating parameters are measured by instrument or analysis at various points in the treatment or sludge disposal process and operators make appropriate adjustments in the system based upon their experience and the history of plant performance. Under "normal" operating conditions, changes in influent quality and process effects are slow and response to process change is equally slow so that manual control through relatively infrequent monitoring of the system is adequate but certainly not optimal.

In addition to non-optimal operation under normal conditions, waste-treatment plants are often subject to abnormal conditions of flow, organic loads, toxic materials and the like. These conditions coupled with the need to produce higher quality effluents have stimulated much greater interest in the automation of wastewater treatment systems.

A Workshop sponsored by EPA in September of 1974 "Research Needs For Automation of Wastewater Treatment Systems"[4] presents an excellent overview of the state of the art. The opening statement of the summary presents the challenge:

"The automation of wastewater treatment systems offers a number of potential benefits including improved performance, reduction in size and construction cost of new systems, improved reliability, more efficient use of operating personnel, and minimized operating costs. These benefits are clearly "potential" since application of instrumentation and automation in the wastewater field is still minimal. Compared to most industrial processing, automation of wastewater treatment systems is in its infancy. The purpose of this Workshop was to define how to move this specialized technology progressively through adolescence and into adulthood".

Some of the pertinent recommendations of the Workshop summary included:[4]

(1) Development of an information clearing-house on instrumentation and automation

(2) Development of efficient and dependable sensors including sludge blanket level indicator, settling velocity indicator, respiration rate sensor, suspended solids sensor, on-line replacement for the BOD test and on-line analyzers for ammonia, nitrate and phosphorous

(3) Development of performance specifications for sensors and a protocol for evaluation of instrumentation and automation system design

(4) Development of models and control strategies for the major treatment processes.

Throughout the proceedings numerous authorities discussed the lack of, or inadequacies of, sensors at the present time. Even present flow measurement techniques need improvement according to many. Dependable and accurate on-line monitoring systems are deemed to be critical not only eventually to plant operations but even more basically to the development, evaluation and demonstration of control strategies.

It would seem, then, that the needs for improved models, control strategies, dependable on-line monitoring and system design are all closely interrelated. It also seems that none can really progress unless adequate on-line means to measure are available.

To determine current attitudes about automation, BCL discussed the WMS system with five firms active in wastewater treatment plant design and construction, and operators of three advanced treatment facilities.

In general their attitudes toward automation are very conservative. Of primary and universal concern is the quality of on-line sensors available to support effective computer control. Much instrumentation is described as unreliable or inaccurate. In addition, calibration and maintenance of continuous meters requires many man-hours of skilled manpower to keep them operational.

There is also a general feeling that for process control, monitoring should physically occur at the points of influent and effluent of unit processes. A schematic of a Delta Scientific model monitoring system representative of this design philosophy is shown in Figure 1.[5]

In most cases only one or a few water quality parameter measurements would be required at each location within the system. However, in many plants continuous monitoring of several parameters and/or constituents

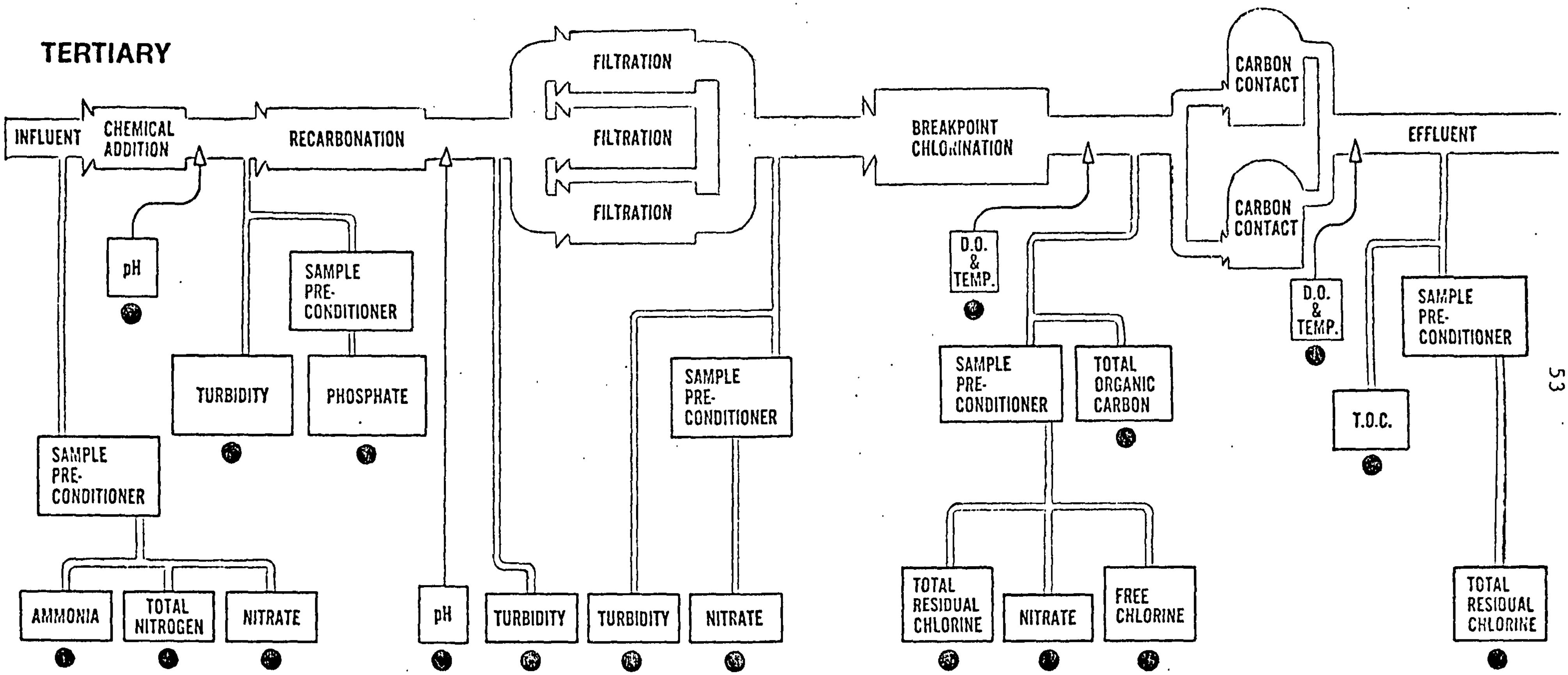

FIGURE 1. SCHEMATIC DIAGRAM OF A HYPOTHETICAL TERTIARY TREATMENT PROCESS INDICATING MONITORING POINTS (DELTA SCIENTIFIC)[5]

such as dissolved oxygen, ammonia, nitrates, phosphates, turbidity, alkalinity, total organic carbon, and pH occurs at several points within the process.

Design engineers and plant operators of advanced wastewater treatment facilities had differing opinions concerning the continuous monitoring needs of their plants. Those differences were attributable to the physical layout and process differences in the facilities.

Plants currently under operation were designed at least three years ago. Operation of those plants disclosed needs for specific process monitoring. Current plans for advanced treatment facilities, both physical-chemical and tertiary add-on, are now designed to fulfill those needs. Some plant specifications now include periodic monitoring of constituents such as carbon dioxide, chlorine gas, sodium hypochlorite, sodium hydroxide, volatile hydrocarbon, ammonia, nitrate/nitrite, orthophosphate, total hardness at various points in the process as well as continuous monitoring at several points of other parameters - D.O., pH, etc. - as previously mentioned. It was generally felt, however, that continuous monitoring of several parameters at every monitoring point is not necessary. The most "dense" area, requiring analyses of the greatest number of constituents, would likely be the effluent.

With respect to some other specifics of the WMS configuration, a number of additional observations were offered:

- The sample transport system via piping can be subject to clogging
- The transport lag in a long piping system could be substantial such that the sample is not "real-time" at the process point in question

- Piping and pumping the sample may destroy its integrity
- Reliable small pumps for such a transport system might not be available
- Filtering samples may destroy their integrity.

Some other general observations were offered:

- The high cost of automation often prevents a high level of sophistication at the time of construction
- Automation is not likely to reduce labor costs. Unskilled labor may be replaced by highly skilled personnel essential for operation and maintenance of elaborate equipment.

We can safely conclude that demand for on-line monitoring systems will grow as tertiary systems are adopted, both in new plants and in upgraded facilities. Demonstrated technical performance will be the critical ingredient in the selection of specific monitoring systems.

Research - New Processes
Wastewater Reuse

Planned reuse of municipal wastewaters is a common phenomenon in the U.S. At least 358 U.S. sites are in operation. Ninety-five percent of these sites, however, are small facilities reusing wastewater for irrigation and agricultural purposes. Industrial reuses use a large volume of water (40 percent of all water reused or 54 bgd in 1971) but are not widespread. Other types of reuse are scattered and statistically insignificant. These include reuse for recreational purposes, groundwater recharge, and domestic nonpotable uses.[6] No planned reuse for potable water supply augmentation exists at present, though such systems are contemplated in Colorado and California.

Most activity in reusing wastewaters in the U.S. today occurs in the west and southwest where water is relatively scarce and demands are growing rapidly.

In a presentation to the March, 1975 Workshop on "Research Needs for the Potable Reuse of Municipal Wastewater" in Boulder, Colorado,[7] F. M. Middleton of EPA offered the following definitions for reuse.

> Indirect Reuse - Indirect reuse of wastewater occurs when water already used one or more times for domestic or industrial purposes is discharged into fresh surface or underground waters and is used again in its diluted form.
>
> Direct Reuse - The planned and deliberate use of treated wastewater for some beneficial purpose such as

irrigation, recreation, industry, prevention of salt water intrusion by recharging of underground aquifers, and potable reuse. Typical of an industrial reuse quality contract is that of the Central Contra Costa Sanitary District shown in Table 13.

Potable reuse can be further divided into two categories as follows:

Indirect Potable Reuse - The planned addition of treated wastewater to a drinking water reservoir, underground aquifer, or other body of water designed for potable use that provides a significant dilution factor.

Direct Potable Reuse - The planned addition of treated wastewater to the headworks of a potable water treatment plant or directly into a potable water distribution system.

The problems of potable reuse - particularly "indirect potable reuse" and "direct potable reuse" - probably offer the greatest research challenge for process development and related on-line monitoring systems.

Despite the growing pressures in some parts of the country for expanded reuse of wastewater, a number of significant obstacles are present; particularly for potable reuse systems. In contrast to most other types of reuse, the technology for treating wastewater to drinking water standards is not yet well developed. A major problem is the lack of system reliability. Variable effluent quality and all-to-frequent breakdowns and malfunctions are characteristics of current wastewater treatment plants that would not be tolerable in a safe reuse system. Similarly, the technology for monitoring water quality, for exotic chemicals and viruses for example, are

TABLE 13. CONTRACTUAL WATER QUALITY LIMITS

Constituent	Limit	Unit	Frequency of Measurement	Method*	Remarks
TDS	375	mg/l	A. Continuous	A. Conductivity correlated to standard methods	Maximum increment above canal water
			B. Weekly	B. Standard methods	
Hardness	300	mg/l	Weekly	Standard methods	Maximum limit (as $CaCO_3$)
Alkalinity	255	mg/l	Weekly	Standard methods	Maximum limit (as $CaCO_3$)
Cl_2 residual	0.5	mg/l	Continuous	Amperometric	Minimum combined Cl_2 residual
Coliform	2.2	MPN/100 ml	Daily	Standard methods	17 Calif. Adm. Code Sec. 8047
pH	6.5 to 8.5	—	Continuous	Standard methods	Range
Turbidity	3	JTU	Continuous	Standard methods	Maximum daily average
BOD_5	10	mg/l	Bi-weekly 24-hr composite	Standard methods	Maximum
TOC	20	mg/l	Daily composite	Beckman instrument or equivalent	Maximum
Total phosphorus	1	mg/l	Weekly composite	Standard methods	Maximum (as P)
Total nitrogen	5	mg/l	Weekly composite	Standard methods	Maximum (as N)

* Standard methods are those set forth in the 13th edition of "Standard Methods for the Examination of Water and Waste Water."

not adequate to detect the very low but potentially dangerous concentrations of these wastewater constitutents.

Public health concerns are another constraint on reuse for potable purposes. Chief "problem" constituents of wastewaters are viruses, parasites, bacteria, and exotic chemicals such as chlorinated hydrocarbons, pesticide and herbicide derivatives and complexes, benzene derivatives, and carcinogenic (cancer causing) agents such as benzpyrene. The toxic levels and long-term effects of these constituents are largely unknown. The buildup of these constituents with repeated reuse is also a factor of concern.

Economic factors also may operate against greater reuse. Advanced waste treatment is expensive and generally not feasible when alternative supplies still exist. Greatly increased reuse for nonpotable municipal uses such as fire protection, street flushing, lawn sprinkling, and some commercial or industrial uses is often technically feasible but not economically justifiable due to the cost of providing separate potable and nonpotable water delivery systems.

A less tangible but very real constraint on greater reuse is the public attitude. Surveys consistently show public aversion to consumption or body contact reuses. These surveys also show that other types of reuse are generally acceptable and public attitudes can change if adequate information is provided and reliable technology can be demonstrated. Interestingly, most surveys also indicate that water supply experts and elected officials are typically more cautious than the general public and consistently overestimate the level of public opposition to certain types of reuse.[8]

Characteristic of the go-slow attitude toward direct potable reuse is a 1971 statement of the Board of Directors of the American Water Works Association (AWWA), a national professional society made up of persons directly concerned with municipal water systems. The statement read, in part:

> "...current scientific knowledge and technology in the field of wastewater treatment are not sufficiently advanced to permit direct use of treated wastewaters as a source of public water supply and it (AWWA) notes with concern current proposals to significantly increase both indirect and direct use of treated wastewaters for such purposes".

Also at the Bouler Colorado reuse workship previously mentioned, L. J. McCabe of EPA is quoted:

> "The Environmental Protection Agency has developed a policy that is opposed to direct recycling for drinking water. All drinking water standards developed to date have cautioned that the limits were set in consideration of using the best source of raw water and cannot be used for guidance for wastewater reuse. Thus, any utility that proposes wastewater reuse for drinking water in the immediate future will be required to demonstrate the safety of the processes envisioned without a concensus of regulatory authorities on what will constitute a potable water."

In essence, Mr. McCabe is saying there are no standards for potable reuse of wastewater, and until there are, water utilities offering such water do so at their own risk.

The new Safe Drinking Water Act of 1974 also contains mandates of importance with regard to renovation and recycling of wastewaters; namely, Section 1444 authorizes a development and demonstration program to: (1) investigate and demonstrate health implications involved in the reclamation, recycling, and reuse of wastewaters for drinking; and (2) demonstrate processes and methods for the preparation of safe and acceptable drinking water from wastewaters.

There exists, therefore, a strong and clear legislative mandate for research development and demonstration of reliable, cost-effective technology for reclaiming and recycling wastewaters for beneficial uses.

In 1975 EPA did propose a municipal wastewater reuse strategy. The major objective was stated as:[9]

". . . The major goal of the Office of Research and Development reuse programs is implementation of research and experimental demonstrations that prove beyond doubt the feasibility and practicability of reusing wastewaters for potable purposes".

The EPA identified the following more specific subgoals related to municipal wastewater reuse:

(1) Develop treatment systems through pilot-plant studies that can impact large-scale potable reuse demonstration projects such as that planned for Denver, Colorado

(2) Identify and support reuse demonstration projects to provide effluents of potable quality for health effects comparability studies

(3) Provide cost/effectiveness and performance data for reuse systems producing potable quality water

(4) Gather reliability, cost, and performance data from large scale demonstration projects of treatment systems producing high quality water

(5) Determine the operational effectiveness of and develop technology for batch holding and dilution reservoirs for potable quality reused water

(6) Develop intensive surveillance techniques to insure the integrity of reused water and the prevention of quality deterioration during distribution.

Health Effects Research

By utilizing monitoring and toxicity procedures identified for presently approved water sources, establish:

(1) Chemical, physical, and biological comparability of reused water and approved potable supplies

(2) Health comparability of reused water and approved supplies containing municipal wastes

(3) Epidemiology comparability of approved water supplies and reused water of potable grade.

Socio-Economic Research

(1) Determine the relationship between cost and increased volume of water needed; determine the point in this relationship that reused water will be economically accepted for potable purposes, both nationally and in water-short regions

(2) Determine the need for potable reuse at specific locations; when will potable reuse be necessary and where?

(3) Establish the above goals at several periods of time over a long-term program to evaluate confidence and ultimate use of reused water for potable purposes.

To accomplish these goals, EPA established a series of milestones:

Milestone	Completed Date FY/Quarter
EPA decision on reuse strategy concerning potable reuse	75/2
Reuse needs workshop	75/3

Milestone (continued)	Completed Date FY/Quarter
Economic studies and identification of potential potable reuse areas I	76/4
Identified and piloted cost/effective AWT for potable reuse	77/1
Complete initial health comparability studies using existing AWT effluent	77/2
Complete large scale studies of reuse plant reliability and control of effluent variability	80/2
Complete preliminary epidemiology studies at indirect potable reuse sites	80/4
Economic studies and identification of potential potable reuse areas II	81/3
EPA decision on viability of potable reuse	81/4
Complete health effects studies in large metropolitan area	85/1
EPA decision on comparability health effects, cost/benefit, and confidence in potable reuse	85/3
Complete epidemiology studies on large metropolitan population using 100-mgd potable reuse water	92/2

To date the policy mandate and the ambitious strategy are not being backed up with federal dollars. There is no centralized coordinated program as outlined in the strategy document.

The Denver Water Department has completed design studies for a 1-mgd demonstration plant for potable reuse. The plant would provide the basis for a 10-year research program. The plant is estimated to cost $8,000,000. So far Denver have been unsuccessful in obtaining any federal support.

Despite the apparent lack of leadership and incentives from the federal government, and the immensity of the research program that will be required, there is a hard core of local water districts and others who are persisting in programs to advance reuse technology. Particularly active are the Denver Water Department, Orange County Water District, Santa Clara Valley Water District, and the U.S. Army Medical Research Development Command.

According to Kenneth Miller of the Denver Water Department, some 7 or 8 cities together with EPA and Army Medical have very recently organized a $50,000/year information exchange program. Each is contributing $5,000, and the EPA $10,000, to get the program started. It is being run by the American Water Works Association Research Foundation; Elroy Sptizer-Director. They hope to have 20 cities participating as the program matures.

The programs of some of the more active wastewater reuse advocates are briefly described:

Denver. As previously described, Denver is seeking assistance for a direct potable reuse demonstration plant associated with a 10-year research program in monitoring, operational control and health effects.

Santa Clara Valley. This district is putting a 2-mgd advanced treatment plant on stream in about one year (cost about $6,000,000). They plan effluent discharge to injection wells as a salt water barrier. They would hope to move toward indirect potable reuse. They also have a small pilot facility going on stream this summer for limited agricultural reuse.

In both cases they need to quantify and qualify the effluent. They see particular problems in monitoring trace organics and bacteria.

Orange County. Orange county has completed a 15-mgd plant for salt water barrier injection. Eventually they would hope to move toward indirect potable reuse. The injection program should begin in June. The California State Water Resources Control Board, Santa Ana Region, has established requirements for injection water as shown in Table 14. The State Health Department also requires monitoring for viruses.

Orange county monitors pH, conductivity, turbidity and residual chlorine on a continuous basis. Other parameters are monitored on a daily frequency at most (metals are monitored monthly). They also have an EPA grant to monitor for organics using laboratory procedures.

Army Medical Research and Development Command. This group is developing a small scale wastewater treatment unit (4200 gallons per 20-hour day). It is part of a transportable medical complex whose acronym is MUST - Medical Unit Self-Contained Transportable.[10] It would initially treat water from laundry, kitchen, operating room, showers, lavatory, etc., for non-sanitary reuse, i.e., where the quality standard would be less than potable. Those proposed standards are shown in Table 15. In longer term they would hope to treat to potable reuse standards -- yet they, as everyone else, do not know what those standards would be.

They are still seeking to devise a monitoring system for finished plant effluent. Their maximum effluent holding time is on the order of a few minutes. Hence, truly on-line real-time quality measurements are critical.

TABLE 14. CALIFORNIA REQUIREMENTS FOR INJECTION WATER

CONSTITUENT	MAXIMUM CONCENTRATION (mg/l)
Ammonium	1.0
Sodium	110.0
Total hardness ($CaCO_3$)	220.0
Sulfate	125.0
Chloride	120.0
Total nitrogen (N)	10.0
Fluoride	0.8
Boron	0.5
MBAS	0.5
Hexavalent chromium	0.05
Cadmium	0.01
Selenium	0.01
Phenol	0.001
Copper	1.0
Lead	0.05
Mercury	0.005
Arsenic	0.05
Iron	0.3
Manganese	0.05
Barium	1.0
Silver	0.05
Cyanide	0.02
Electrical conductivity	900 umhos/cm
pH	6.5 - 8.0
Taste	None
Odor	None
Foam	None
Color	None
Filter effluent turbidity	1.0 JTU
Carbon adsorption column effluent COD	30 mg/l
Chlorine contact basin effluent	Free chlorine residual

TABLE 15. POTABLE WATER STANDARDS

Characteristics	USPHS (1962) Recomm. Limit	USPHS (1962) Maximum Allow.	Modification[a] Incorporated For MUST Complex
Physical			
Turbidity, JTU	5	--	--
Color, PCU	15	--	50[b]
Taste, Threshold	(f)	--	--
Odor, Threshold	3	--	--
Foaming	--	--	--
Total Solids, mg/l	--	--	1500[b]
Total Dissolved Solids, mg/l	500	--	--
Chemical, mg/l			
Arsenic	0.01	0.05	0.05
Barium	--	1.0	1.0
Boron	--	--	--
Cadmium	--	0.01	0.01
Chemical Oxygen Demand[c]	--	--	--
Chloride	250	--	600[b]
Chromium (Cr^{+6})	--	0.05	0.05
Copper	1	--	1.0
Fluoride	0.7-1.2	1.4-2.4	4.0[a]
Lead	--	0.05	0.05
Nitrate & Nitrite (as N_2)	--	--	10.0
Selenium	--	0.01	0.01
Silver	--	0.05	0.05
Sulfate	250	--	400[b]
Alkyl Benzene Sulfonate	0.5	--	0.5
Iron	0.3	--	0.3
Manganese	0.05	--	0.05
Nitrate	45	--	--
Phenols	0.001	--	0.001
Phenols (with halogen)	--	--	--
Zinc	5	--	--
$CHCl_3$ Extract[d]	0.2	--	0.2
Cyanide	0.01	0.2	0.2
Ammonia (as N_2)	--	--	0.5
Oxygen Dissolved	--	--	--
Nitrite (as N_2)	--	--	--
Magnesium	--	--	150[b]
COD	--	--	10[g]
TOC	--	--	5[g]
Microbiological			
Organism/ml	(e)	(e)	--

(a) By Office of the Surgeon General
(b) Reference 5
(c) Oxidizable contaminants, generally the organic
(d) Organic contaminants
(e) Not applicable
(f) None objectionable
(g) Tentative maximum

Further complicating their requirements, the instrumentation must be rugged. Consequently, they are skeptical of on-line wet chemistry techniques. Their major problems today are TOC and COD sensors, organics and a toxicity/bioassay sensor. They are searching for novel solutions to these problems.

Process development and the related real-time monitoring requirements for wastewater reuse appears to be a viable area for NASA participation. Due to controversy over appropriate standards that will probably not be resolved for several years, the field will be very much research oriented for some time to come. The demand for monitoring systems to support the research will be severe in terms of being multi-parameter and real-time in character. WMS, or reasonable variations of it, could find significant application.

Research - Receiving Water Dynamics

Mixing Zones

A potential use for a continuous monitoring system is in the defining of the nature and extent of the mixing zone of an effluent discharge to an aquatic system. Legal definitions of mixing zones vary among the various states which attempt to define such zones. Generally, mixing zones are the areas located in the immediate vicinity of point discharges where waste waters are dispersed and diluted in aquatic receiving systems. Waste waters are discharged to a variety of aquatic environments, including lakes, impoundments, streams, rivers, estuaries and oceans, each having different physical/chemical characteristics. Mixing zones vary in size, and character with each system. A description of each individual discharge mixing zone is an important variable in determining effluent concentrations, discharge point and area of impact. Additionally, many states require a discussion of mixing zones in applications for NPDES discharge permits.

State requirements pertaining to mixing zones differ considerably. Some agencies make no reference to mixing zones at all, others attempt to allow no mixing zone. There are two main approaches to the problem used by different states. Some states allow mixing zones large enough to disperse and dilute the waste water in the receiving waters, insisting the zone be maintained as small as possible. These states allow mixing zones of varying size based on the effluent and receiving system characteristics. Often a demonstration of minimal impact is required with the permit application. The alternative method sets upper limits on mixing zone size based on receiving system size and character only. Ohio has established such a policy. Mixing zones in streams in Ohio are not allowed to constitute more than one-half the width of the receiving system nor occupy more than one-third of the area of any cross section. Additional requirements limit the downstream extent to not more than five times the width of the receiving water body (Ohio, EPA, 1973).[11]

Other limitations imposed by some states include the following restrictions: no mixing zone shall prevent free passage of migratory aquatic species; no mixing zone shall impair or restrict spawning behavior of any aquatic species.

Special considerations are also given to areas of cold water fisheries, recreational areas, and water supply zones. Many other factors are considered by various states depending on both effluent and receiving system characteristics.

In order to describe a mixing zone, whether it be for the dilution of a thermal effluent, an industrial discharge or municipal treatment plant wastes, monitoring in the receiving system is necessary. WMS could readily provide the data necessary to describe both the nature and the extent of the zone. In the case of a river, proper placement of the sampling points upstream, at the effluent and at several other points both across the width of the receiving stream and downstream would yield sufficient and appropriate data to describe the concentrations of many effluent constituents and their dispersion downstream. In states where the boundaries of the mixing zone are defined, sampling would be necessary for at least a year to determine zone alterations caused by seasonal flow variation.

Presently, most mixing zones are described with the use of mathematical models developed in recent years which allow quite accurate predictions of mixing zone characteristics with a minimum of actual field data. Such models also allow for flow variations encountered during the water year. Use of a continuous monitor, coupled with the predictive and allowance capability of the model could, in some cases, be useful for verifying the model in the field. However, only periodic sampling under varying conditions is presently required to verify the accuracy of most models to the particular situation. After a working model has been obtained, little or no further monitoring of the mixing zone is necessary.

The use of the WMS or any continuous monitoring system would in all probability not be required in mixing zone description or surveillance. The cost of leasing or buying and maintaining the system and the time required to set up and operate the system for an appropriate period render this type of monitoring impractical and uneconomical when compared to the use of models. In cases of extremely toxic pollutant discharge or of discharge to very delicate ecosystems continuous monitoring of mixing zones could be valuable. However, in these extreme cases only one or a few parameters would need to be monitored. The application of intensive monitoring systems for surveillance of mixing zones will be minimal at best.

A possible application of intensive monitoring of mixing zones could occur in the case of variances to existing NPDES permits. A variance permit is required when a discharger is in violation of his permit. He may apply for a variance which would allow him to remain in violation but he must prove that his present effluent does not affect or hinder migration of any aquatic biota. Intensive monitoring could become necessary in such instances. However, to date, most cases have involved thermal discharges which do not require intensive monitoring equipment for surveillance. The application of intensive monitoring equipment for use in mixing zone definition and compliance monitoring is therefore likely to be minimal.

Impoundment Monitoring

Impoundment of running waters occurs for a variety of reasons, including flood control, water supply, navigation and recreation. These impoundments effectively change a stream into a lake environment. This shift to standing water and subsequent discharge downstream causes various water quality parameter changes to occur both within the impounded area and downstream from the dam. Parameters of major importance in many impoundments are temperature and nutrient content. Other parameters of interest vary between sites but might include pH, hardness, conductivity, dissolved oxygen and metal concentrations.

Often the area of greatest concern is water quality in the reservoir and the immediate downstream section of river. An attempt is made to maintain good water quality in the impoundment while keeping conditions downstream similar to those existing before the impounding was built. With careful monitoring of water quality upstream, downstream and within the impoundment, proper management decisions can be made related to selective discharges to maximize water quality conditions in both the reservoir and downstream areas.

WMS could provide the data needed for proper reservoir management. Proper placement of the sampling streams would provide simultaneous data from several depths in the reservoir and downstream of the spillway. Continuous monitoring of selected parameters could provide real time measurements of conditions of all points throughout the year. However, the use of mathematical models to predict impoundment and downstream water quality parameter values provides adequate information with only periodic sampling to confirm or verify the model's accuracy. An intensive monitoring system to verify a model's predictability would be much more expensive to operate and provide far greater amounts of data than necessary.

The Army Corps of Engineers uses mathematical models extensively in their reservoir monitoring programs. Periodic sampling of selected areas provides adequate data for management decisions.

In most cases mathematical modeling coupled with periodic sampling seems to present a more realistic approach to reservoir management data acquisition than does intensive monitoring.

The need for any form of continuous monitoring of impoundment effects is minimal. However, in cases of delicate ecosystems or extreme sensitivity continuous monitoring instrumentation is used. One case where continuous monitoring is currently being employed by the Corps of Engineers is on the Allegheny River above Pittsburgh, Pennsylvania. Four continuous monitors are being operated by ORSANCO for the Corps of Engineers. Hourly readings of pH and related parameters (hardness, conductivity) are collected in order to evaluate water quality in the lower Allegheny. Conditions in this area have been severely stressed due to the mining operations in the headwaters.

FUTURE TECHNICAL PROGRAM PRIORITIES

The dominant factor in the potential for transfer of WMS will be its technical performance. NASA should guard against viewing WMS as a "one-shot" development. WMS dealing with many complex water quality parameters has the potential for many technical flaws both in its discrete components and sub-systems and its overall configuration. It is therefore very probable that WMS may need to be modified two or three times based upon its shake-down trials and feedbacks from potential users. Within the context, then, of considering WMS as a continuing development, BCL recommends the following as technical program priorities.

(1) Thoroughly demonstrate the present system. This is without question NASA's top priority within the current WMS program. Establishing technical credibility is critical.

- The sensor components are potentially the most vulnerable part of the system. Their accuracy, reliability and expected life will need to be established.
- The sampling transport and filtering system must be evaluated in terms of its reliability and its possible effects on sample integrity. The concept may need to be defended.
- Operating and maintenance costs must be established.
- Expected capital costs for the system should be determined. An accuracy of ± 20% would probably be adequate.

(2) Disseminate demonstration results. When NASA is satisfied with the performance of the present WMS configuration, appropriate forums

for dissemination should be developed. Informal small seminars emphasizing demonstration and documentation should be first. The basic purpose should be to seek feedbacks from users, designers and regulatory personnel.

- The wastewater reuse advocates would be the best group for an initial seminar effort. Kenneth Miller of Denver has already suggested this activity. Such a seminar/ demonstration program could probably be put together through the AWWA Research Foundation.
- The wastewater treatment plant automation advocates would represent a second priority seminar group. This activity might best be arranged through working with the EPA Advanced Waste Treatment Research group in Cincinnati.
- Only after such seminars are held and results evaluated should extensive publication be considered. Publication would best be initiated through conference papers given at national or regional conferences of water treatment and wastewater treatment professional associations. Later, papers might be prepared for professional and trade journals.

(3) Consider redesign alternatives and priorities.

- The seminar results will almost certainly bring about requirements for further demonstrations in on-going pilot plant or research activities. Redesign of parts of the system will also be indicated. Two redesign paths are probable - one aimed at reuse research/pilot operations and one aimed at wastewater treatment plant automation. The latter would probably require major effort.

(4) Continue NASA sensor development. Establishment of priorities on the whole range of needed sensor development should not be formalized, pending (a) the results of NASA's trials with WMS, (b) feedback from potential users via the seminar mode and (c) the establishment of priorities for possible redesign alternatives. However, certain priorities seem likely:

- First, it is very likely that some of the commercial sensors in the present WMS system will need replacement or even redesign.
- The NASA biosensor development should be continued. The coliform detector is particularly significant.
- Sensors for refractory (non-biodegradable) organics will be important
- Acceptable sensors for phosphate will be needed.
- Specific ion electrodes - particularly for heavy metals - would be desirable.
- A suitable sensor development to replace the 5-day BOD test is universally needed.
- For wastewater reuse particularly, virus detectors could be important.
- For automated wastewater treatment plants, various sludge quality and density sensors are needed.

(5) Consider configuration of WMS as a sensor evaluation laboratory. As discussed in the Technology Transfer section of our report, the WMS system should be seriously considered as a valuable adjunct to a sensor evaluation laboratory. Its high sampling frequency and data recording/storage characteristics might make it ideal for simulated on-line testing of sensors for accuracy, reliability and expected life.

TECHNOLOGY TRANSFER

The factors influencing the potential for beneficial transfer of WMS technology include technical, institutional and market forces. None of these forces is distinctly independent from the others. Technology influences institutional factors and vice versa and both influence the market.

Technology Factors

Clearly the dominant factor in the transfer of WMS will be technology. Basic to WMS technology is sensor performance. There is much skepticism about on-line sensors in general. For other than the simplest parameters, they are generally viewed as inaccurate, unreliable or over-demanding in maintenance requirements. There presently are no institutionally accepted performance standards that can be used to compare the performance of sensor A vs B vs C to measure the same quality parameter. Design engineers, users and regulatory authorities all have differing opinions about the relative quality of specific sensors from different suppliers. Consequently, until some means of quality comparison consensus or certification is evolved, there will continue to be a lack of agreement on what an integrated monitoring system should consist of with respect to its individual sensor components.

Discussions with EPA staff indicate that they may be prepared soon to fund an effort to establish an institutional protocol and laboratory for sensor evaluation. In effect they would seek to establish an independent "underwriters laboratory" to qualify or certify sensors. Such an effort will necessarily involve several years of intensive effort. In the interim, therefore, WMS must stand on its own and demonstrate that the sensors it has selected will do the job.

The WMS concept is likely to be challenged on some other technical counts. For full-scale treatment plant-process control purposes, the centralized location for sensors - and piping the samples to them - is in contrast to a prevalent design philosophy of locating relevant sensors at the influent and effluent of unit processes. Potential clogging of the WMS sample transport system will be viewed as a problem. Sample integrity will be challenged both as to its quality and its "real-timeness". The sample filtering system will be scrutinized. The reliability of small pumps will be questioned.

On the other hand for small-scale pilot plants operating in a research mode, the system may be viewed favorably, since it _is_ multi-parameter, compact and centralized.

Another concept worthy of consideration is the use of WMS as an adjunct to a sensor evaluation laboratory. EPA's expected effort to develop the equivalent of an "underwriter's laboratory" for sensors could develop a potential for WMS as an on-line sensor evaluator. The capacity of WMS for very frequent sensor readings and data storage on a "known" waste stream could be very valuable to an organization seeking to develop a protocol and specific methods to evaluate sensor performance and reliability. If EPA's thinking is formalized into a requirement, NASA might well team up with some private laboratory organization to propose WMS as an effective testing instrument.

Finally, while we understand NASA's primary interest is in the totality of the WMS, the potential significance of the WMS biosensor sub-system should not be overlooked. This sub-system could represent a clearly recognizable advance in the art of water monitoring and could become the "cutting edge" of further WMS development. Alternatively it could be offered as a distinct sub-system in anybody's water quality monitoring package.

Institutional Factors

The dominant institutional factor in WMS technology transfer is EPA. First, as discussed above, there are no standards for sensors. For compliance purposes there are therefore very few on-line sensors that are acceptable for reporting quality parameters. Until more sensors are acceptable for such purposes, treatment facilities must still resort to laboratory procedures for the great bulk of their compliance reporting to regulatory agencies. For strictly process control or research purposes this constraint is unimportant, but it does currently negate the dual-purpose possibilities of WMS.

With respect to construction grants for wastewater treatment process control, EPA has relatively recently clarified its policy. Costs for computer-based process-control systems are allowable if the computer is dedicated strictly to process control. The speed at which such systems will be adopted will depend on several imponderables; (1) the technical art of such systems, (2) the federal policies with respect to tertiary treatment requirements, and (3) the relative availability of construction grants. Currently most new plants being constructed are secondary treatment plants. The greatest demand for automation will not occur until tertiary systems are being required.

The lack of standards for wastewater potable reuse presents both a negative and a positive transfer potential. The lack of standards or monitoring requirements negate design of a monitoring system tailored to known needs. On the other hand, the very lack of such agreement means that research and pilot demonstration projects will strongly opt for over-measurement since they will not know which quality parameters may be judged to be significant in future standards requirements. Therefore, a multi-parameter system such as WMS with its data acquisition and storage capability should have appeal.

Despite the fact that at present little EPA support seems forthcoming for reuse pilots and demonstrations, there does appear to be a sufficient community of interests to assure continued and serious research activity. WMS could potentially contribute to the furtherance of those interests.

Market Factors

At present no ready waiting market for WMS exists as a universal monitoring system. There will be no market, in the commercial sense, until the technology is thoroughly and successfully demonstrated. Capital costs, operating costs, and maintenance costs must also be documented. Assuming the demonstrations are successful, and that the operating and maintenance costs are within reasonable range of our present gross estimates, the earliest market would probably lie within public organizations conducting research on advanced wastewater treatment systems aimed at reuse. This would be an "engineering" market since each research activity would probably need variations on the present WMS configuration. NASA would need to work in an advisory/consulting role probably with engineering firms in assembling custom WMS units.

Assuming the research activities further confirmed the viability of the WMS technology, the system would be ready for consideration for commercial scale wastewater treatment process control functions. At this point, if prevailing objections to the sample transport system have validity, the sensor components of the system would probably need to be at least partially "de-centralized". This would not seem to present major technical problems, but would tend to fragment the WMS concept of a neat, compact package.

This commercialization threshold will then present the problem of interesting and motivating appropriate private organizations to truly commercialize the technology. The concept of selecting the best sensors from among several suppliers together with NASA in-house technology and packaging them into an integrated system has merit, but the existing suppliers of "on-line systems", (of which there are at least a dozen) would not likely be persuaded. They are essentially interested in developing and marketing their own sensors and packaging them as their own "systems". This would indicate that commercialization of WMS would probably need to be developed by organizations outside the present industry structure. This interest conceivably might be found among computer manufacturers using WMS as a base to promote computer sales, or among sophisticated systems packagers such as found in the aerospace industry. In any event a manufacturer entering the market from outside the present industry structure would face formidable learning curve investments in getting abreast of the intricate requirements of a fragmented market. To attract outsiders into such a risky venture, the technology of WMS must display distinct superiority in a competitive market place.

Since there are many capable system designers/packagers it is even probable that superior technology would not be sufficient to attract venture investment unless the technology has protective or exclusive features - e.g., patents, restrictive licenses or proprietary know-how. This probable eventuality should be considered by NASA if commercial transfer is contemplated.

It is quite possible in the long run that superior process control/monitoring technology like WMS will become institutionalized in regulatory requirements for "best available treatment" under P.L. 92-500. This would represent the ultimate in the regulatory/technology interface. Given the present state of the art of wastewater treatment automation, that possibility would seem to be at least 10 years away.

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