ASSESSMENT AND STRATEGY FOR AUTOMATED PROCESS CONTROL

IN

WASTEWATER TREATMENT

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The problems in O&M and plant performance at wastewater treatment plants have been classified and well documented by the Municipal Environmental Research Laboratory's National Operational and Maintenance Cause and Effect Survey (1,2,3). The Survey evaluated and ranked 70 different factors contributing to poor plant performance. The results of this survey at plants of 10 MGD and less are likely also to be generally applicable, with perhaps changes in ranking, to the larger treatment plants. The major causes of poor plant performance, in order of importance, from that survey are:

1. Improper operator application of concepts and testing to process control.
2. Inadequate Process Control Testing Procedures.
3. Excessive infiltration/inflow.
4. Inadequate operator understanding of wastewater treatment.
5. Improper technical guidances.
6. Inadequate sludge wasting capabilities.
7. Inadequate process controllability.
8. Inadequate process flexibility.
9. Ineffective O&M Manual Instruction.
10. Deficiencies in Aerator Design.

The MERL's O&M Program has further demonstrated and the Agency has implemented an approach (4) for improving plant performance. In MERL's survey, poor performance at plants was always caused by a combination of factors. The MERL approach, called the Composite Correction Program (CCP), was developed and found to satisfactorily correct the performance limiting factors at several plants. In the CCP approach, improved plant performance is achieved through implementation of corrective actions recommended by a team of experts; based on their comprehensive evaluation of a plant using the limiting performance factors developed from the National O&M Cause and Effect Survey.

The corrective actions may include either improved manual or automated process control or physical changes in the plant or collection system. Limiting performance factors, where operator decision and measurement or control of various process parameters play important roles, generally can be corrected by improved manual process control (operation) or by instrumentation and automation. A review of the 10 major causative factors for poor plant performance reveals that operator decision (performance, or understanding) plays or can play an important role in five major factors (factors 1, 2, 4, 5, and 9) and the inability or failure to measure or control various process parameters plays or can play an important role in four major factors (factors 2, 3, 6, and 7).

Those performance limiting factors which involve major design deficiencies or major plant inflexibilities usually can not be corrected by either manual or automated process control and require physical changes in the plant or collection system. Only four of the 10 major factors listed above (factors 3, 6, 8, 10) can be addressed by making physical changes in the plant. Clearly, improved process control, manually or automatically, is the more important area impacting plant performance in municipal wastewater treatment.

PROCESS CONTROL IN INDUSTRY

In industry, process control is nearly synonymous with automation. The use of automation and automated machinery for process control to improve productivity and reliability is in such an accelerated state of development that even the most visionary of our engineers and scientists may often underestimate its potential. In just the past decade, automation has made it possible to produce mechanical hands capable of picking up either eggs or lead bricks without breaking or dropping either. These same hands can be directed by other sensors to sort out flawed parts randomly scattered on a moving belt.

The oil industry is automated from the well head through the refining process to the station pump that shuts off when the tank is full, registers the volume dispensed and calculates the cost to the customer. The chemical, pulp and paper, steel and rubber industries are all automated. All of this has occurred without federal funding, federal guidelines, or any other type of federal provocation. In the water treatment industry the delivery of processed water, while not as fully automated as the petrochemical industry, is evolving into full automation. In the near future manual meter reading are likely to be replaced by telemetered data.

These industries did not arrive at full automation in a single step, nor was automation set as an ultimate goal. The present level of automation in any industry is a result of careful analysis and refinement of multiple incremental advances in the understanding of a specific part of a process and companion advances in technology. Before any advances become state-of-the-art, three things must occur. Firstly, an understanding of the problem is developed (often through the use of automatic measuring techniques). Secondly, automated control technology is applied to the problem. And thirdly, the solution is proven to be cost effective.

The reading of water meters is an example of the incremental development process. Processing, transport, metering, billing, remote sensing and telemetering, and the processing of remotely sensed data are all present state-of-the-art. Recent improvement in the technology of data transmission combined with the impact of inflation on wages and energy costs have unbalanced the existing cost benefit equation. When it becomes more profitable to read and transmit water use data automatically, the final link will be in place. The market place will force implementation of this technology.

In process industries process control is not only extensively automated but is rapidly shifting from analog to digital control. The shift to digital occurs not only because of improved control with digital systems but, more importantly, because it is more economical. The recent technical advances in mini-computers and digital process controllers (micro-processor) have produced major decreases in equipment costs per unit of control capacity. Thus, in the classical control loop of sensor, controller, and actuator, a single inexpensive digital process controller or moderately expensive mini-computer can replace, respectively, a few or many analog controllers. In addition the digital process controller or mini-computer permits an integrated or full systems control approach.

In contrast to industry, the extensive use of integrated and automated system process control has not achieved a major market penetration in the municipal wastewater treatment field. Before addressing the market for integrated automated process control as a remedial approach to poor plant performance in wastewater treatment, a brief summary of the state-of-the-art of automated process control in the municipal wastewater treatment is needed.

AUTOMATION AND INSTRUMENTATION IN WASTEWATER TREATMENT

For the last ten years, classical process control theory and digital automation equipment have been fully capable of meeting the technical needs for automation of wastewater treatment. With the recent technical and economic improvements in digital process controllers, the capabilities of digital automation equipment now easily exceeds the technical and economic requirements for automation of even small wastewater treatment plants. Indeed process controllers, available for 10 to 15 thousand dollars, contain sufficient control capacity to operate a complete conventional wastewater treatment train exclusive of solids dewatering. Control techniques for dewatering which are being developed at Minneapolis-St. Paul (5), are complex and, in conjunction with other plant control needs, require greater digital capacity than that in one current small (10-15 thousand dollar) process controller.

While basic control theory and digital systems exceed the needs of wastewater treatment, only in the last two years have sufficient sensors (Table 1) which are satisfactory for wastewater process control become available. These sensors from selected manufacturers perform well with reasonable maintenance requirements in the municipal wastewater environment. The sensors and the tested process control loops (Table 2) now permit first generation integrated automation of treatment plants.

This first generation automation involves two general levels of process control. The elementary level, is monitoring and programmed gap action (on-off control) for equipment that does not permit throttling control. The higher level is continuous proportional-integral-derivative control (PID) for continuous

TABLE 1. SUITABLE MONITORING SENSORS

Sensor	Type	Method	Interfaced to Microprocessor
TOC	continuous	U.V.	yes
CH_4	continuous	Thermoconductivity	yes
Toxics	continuous	Aerobic respirometry	no
COD	discrete	Colorimetric	yes
CO_2	continuous	Infrared or thermo-conductivity	yes
NO_x	continuous	Colorimetric	yes
Halogenated organics	continuous	Infrared	yes
ATP	discrete	Spectrophotometric	yes
Turbidity	continuous	Light Scattering	yes
Suspended solids	continuous	Light Scattering	yes
Flow	continuous	Magnetic, mechanical, sonic	yes
Specific Probes*	continuous	NH_4^+, NO_3^-, NO_2^-, metals	yes
pH	continuous	Potentiometric	yes
D.O.	continuous	Galvanometric or Amperometric	yes

*In some applications, interferences prevent satisfactory use.

TABLE 2. CONTROL LOOPS

Control Function	Control Types*	Microprocessor Software
Fully Tested Loops		
DO	Feedforward with PID, or GAP Action Feedback	yes
Flow	Throttling PID, or GAP Action	yes
Sludge Wasting	Throttling PID, or GAP Action	yes
SRT	Continuous Programmed Wasting Programmed GAP Action	** yes
Average F/M	Continuous Programmed Wasting Programmed GAP Action	** yes
Thickening	GAP Action	yes
pH (chemical feeds)	Feedforward with PID	yes
Chemical Feed	Feedforward with PID	yes
Chlorination	Feedforward with PID	yes
Purging (NH_3 stripping)	Combined PID and GAP Action	yes
Pure O_2 Feed	Logic Network	yes
Wastewater Filtration	Logic Network	yes
Carbon Adsorption	Logic Network	yes
Developing Loops		
Vacuum Filtration	Logic Network with PID	yes
Incinerator Control	Feedback with PID	no

*PID is proportional integral-derivative control (feedback)
GAP action is on-off control (feedforward or feedback)
**Available on mini-computer, under development for microprocessor

variable control of systems. With the proven sensors (Table 1) and tested process control loops (Table 2), appropriate integrated and automated process control approaches, especially using the micro-processor, can now be applied to conventional wastewater treatment plants from the small (0.5 MGD) to the largest plants. Cost benefit analyses (6, 7) have indicated a pay back period for the tested control loops of typically 3-5 years.

The micro-processor represents a major advance in computer costs and reliability for process monitoring and control that should not be ignored in wastewater treatment. The recent literature (8) indicates significant improvement in reliability of digital control (micro-processor) with the appropriate sensors for wastewater applications. The micro-processor, itself, exhibits significant advancement (9) in reliability when compared to analog and logic network controller systems. Micro-processor systems with integrated automated process control, however, have not been installed or tested for full plant operation.

Deficiencies in Process Control

The principle deficiencies remaining in process control for conventional municipal wastewater treatment occur in two areas:

- The flocculation/separation of solids in biological systems.
- The conditioning of solids for efficient dewatering in sludge processing.

Research, as an example the work by Jenkins (10) at the University of California, has begun to assess the mechanisms and variables which control effective bio-flocculation and solids separation in the activated sludge process. However sufficient knowledge is not at hand to allow definitive process control. Until substantially all of the cause and effect variables are understood and become controllable, changes in process conditions can cause population shifts or "upsets" in the biota of the process degrading the flocculation or settling characteristics of the biological mass. These changes will continue to occassionally produce process failure, whether under efficient manual or automated process control.

Similarly the interrelated mechanisms and variables controlling sludge conditioning for dewatering are not completely defined. Thus the complex process control approach for vacuum filtration (Table 2) under development at Minneapolis-St. Paul, should improve the dewatering performance and prove cost effective (savings in chemicals, etc.,) but may not insure the level of control expected from the tested control loops of Table 2. In addition, the vacuum filtration control approach may require substantial tuning for use at other locations.

Deficiencies also exist in potentially desirable sensors. These sensors (Table 3) fortunately are not essential for reasonable levels of automated process control at conventional treatment plants. The most desirable are sensors to measure changes in settleability and in dewaterability of solids. The current measurements for settleability and dewaterability require discrete manual procedures.

TABLE 3. UNAVAILABLE ON-LINE SENSORS*

Sensor	Function
Low chlorine residual (0.01 mg/l)	Dechlorination
Real time settleability predictor**	MLSS Separation
Filter cake moisture analyzer	Dewatering
Improved filterability predictor**	Vacuum filtration
Combustion analyzer	Incineration
Ozone analyzer (in water)	Disinfection
Viable coliform indicator	Disinfection

* Sensors could improve present methods of control

** Predictors probably require multiple measurements with correlation equation

Outputs from the Automation and Instrumentation Program

In September of 1974, the EPA conducted a workshop on "Research Needs for Automation of Wastewater Treatment Systems." The principle technical needs, as indicated by that workshop, and the MERL Automation and Instrumentation (A&I) Program's remedial actions are shown in Table 4. These EPA's A&I technical outputs (Table 4 and Appendix) have contributed significantly to the current state-of-the-art in Automation. The on-going and recommended short term program outputs listed elsewhere further address these needs.

IMPACT ON PLANT PERFORMANCE, COSTS, AND ENERGY

Before assessing the impact on automated process control on plant performance, a perspective on current performance is needed. As documented by several National studies (11, 12, 13) a significant portion of the existing U.S. plants are not consistently meeting their NPDES requirements. Indeed the GAO study (13) in 1977 revealed 40% of all treatment facilities failed to meet design BOD removals and 49% failed to achieve design suspended solids removal. MERL's National Operational and Maintenance Cause and Effect Survey (1,2,3) on plants of 10 mgd and less documented even poorer performance of small treatment plants. Of the 103 facilities evaluated, only 37 plants (36%) were consistently meeting their NPDES standards.

Proper process control (manual or automated) will improve plant performance. Application of MERL's Composite Correction Program (CCP) (4) to several of the plants in the MERL's Survey consistently revealed significant improved plant performance. These manual process control practices in the CCP, at least for activated sludge plants, are often substantially man-in-the-loop analog control since the operators use information from instruments and sensors in the plant to make the control decisions and implement their response. As a result of the studies, it was further estimated that, by applying the CCP (good manual process control), 86 percent of the plants could consistently achieve NPDES standards with optional levels of performances without upgrading (i.e. designing and improving) the facilities.

Over the years, practical pilot plant experience has revealed that good manual control (usually man-in-the-loop analog) or automated control produced similar process performance for conventional wastewater treatment plants. Such manual operation involved continuous (24 hour) surveillance. In both control approaches, good maintenance was required to insure consistent performance.

In evaluating the impact of automated process control on costs and energy, existing municipal treatment plants may be divided into two significant groups, suspended growth (activated sludge) plants of 0.5 mgd or larger and all others which principally include primary plants, small package plants, trickling filters and lagoons. In this division, suspended growth plants of 0.5 mgd and larger currently (1979 inventory) treat about 50 percent of the municipal wastewater receiving the equivalent of secondary treatment and operator decision plays a major role in the plant performance. In most of the other types of plants (lagoon trickling filters ... etc.) operator decision plays a lesser role in plant performance.

TABLE 4. PRINCIPAL A&I PROGRAM OUTPUTS

Needs Area	Remedial Outputs	Publication Ref. (Appendix A)
Inadequate Instrument Reliability (especially sensors)	o Instrument Survey	22, 31
	o NBS Standards on Instruments	ongoing
	o Certification Laboratory for Testing Instruments	initiated FY80
Inadequate Sensors Support Equipment	o Wastewater Sample Transport and Condition System	21
Inadequate Development and Demonstration of Process Control Loops	o Full Scale D.O. Control	8, 24
	o Control Strategies for Activated Sludge	9, 12, 13, 15, 30
	o Physical-Chemical control Strategies	10, 32
	o Solids Processing Control Strategies	38, 40, 41, on-going
Inadequate Documentation of Automation	o State-of-the-Arts on Automation	23, 27, 34
	o Design Manual on D.O. Control	28
	o Design Manual on Automation of Conventional Treatment Plants	42 (in press)
	o Cost Benefit Analysis	26, 35
	o Major Input to WPCF Manual of Practice No. 21	33

The divison is not absolute since activated sludge plants, such as extended aeration or "orbital" (race track) activated sludge plants with large plant contact times, may not require extensive operator decision for successful performance and some small package plants may require regular and substantial operator decision for successful performance. The important reason for the division, however, is that activated sludge plants of 0.5 mgd and larger generally can benefically employ throttling (PID) control for several operations or processes. (It should be noted that in-place equipment at many activated sludge plants, unless modified, currently may only permit on-off control).

The other existing plants such as trickling filters and lagoons generally do not significantly benefit from throttling control except where effluent chlorination or mineral addition (phosphorus removal) is practiced. At such plants, automated monitoring of effluent quality and equipment malfunction represent the principal future uses of automated techniques. Such monitoring, if used to initiate prompt plant maintenance, should improve plant performance but not significantly reduce costs or energy requirements. For current practices in municipal wastewater treatment, the chief difference between effective manual and automated control occurs in the use of energy and chemicals. Since closed loop (automated) control continuously evaluates and responds to diurnal loading, it minimizes the use of energy and chemicals required to achieve desired performance.

While plants other than suspended growth (activated sludge plants) can, on an individual plant basis show costs savings from automation, generally from chemical savings (chlorine or mineral addition), an estimate on the potential direct costs savings for wide spread application of automation is developed only for the suspended growth plants of 0.5 mgd and larger. These plants are likely to represent the principal costs savings. In the analysis, the value of improved plant performance is not included.

The cost analysis (Table 5) is for two types of control approaches, centralized analog and centralized digital control. In the analyses the conventional activated sludge plants for the 0.5 to 5 mgd plant sizes consisted of conventional primary, conventional aeration, chlorination, gravity thickening, digestion, and sand bed dewatering. The conventional activated sludge plants above 5 mgd consisted of conventional primary, conventional aeration, chlorination, gravity thickening, digestion, vacuum filtration and incineration.

The cost analysis was based on a present worth analysis of the treatment plants for the two control options (central analog and central digital) and produced the annual cost savings (14) for the addition of the analog or digital automation to conventionally operated plants (manual or man-in-the-loop analog). The present worth analysis accounted for the additional capital required for the automation. The cost savings per plant used in Table 5 for the 0.5 to 1 mgd plants were not included in the published design handbook (14) because of wide variability in the costs for these plant sizes. The cost savings for these plant sizes, however, had been estimated during the preparation of the design handbook. The costs are based upon a June 1978 base. Conversion to June 1980 would increase the amounts by approximately 15%. These cost estimates are only for planning perspective since actual cost estimates are very site specific.

TABLE 5. COST SAVINGS IN ACTIVATED SLUDGE TREATMENT FROM AUTOMATED PROCESS CONTROL*

Plant Size mgd	No. of Plants**	Annual O&M Costs 10^3 $/yr/plant	Total Annual O&M 10^3 $/yr.	Savings/plant 10^3 $/yr.		Annual Savings 10^3 $/yr.	
				Analog	Digital	Analog	Digital
0.5-0.6	85	105	8,925	15.5	13	1,318	1,105
0.6-0.7	70	110	7,700	16	14	1,120	980
0.7-0.8	52	115	5,980	16.5	14.5	858	754
0.8-0.9	47	118	5,664	17	15	816	720
0.9-0.1	51	120	6,120	17.5	15.5	893	791
1-2	262	160	41,920	18.5	19	4,847	4,978
2-3	107	225	24,075	20	25	2,140	2,675
3-4	69	285	19,665	21	30	1,449	2,070
4-5	39	340	13,260	22	34	858	1,326
5-6	28	400	11,200	23	37	644	644
6-7	29	460	13,340	24	36.5	696	696
7-8	21	520	10,920	25	36	525	756
8-9	13	570	7,410	27	35.5	351	462
9-10	20	625	12,500	28	35	560	700
10-15	41	760	31,160	35	45	1,435	1,845
15-20	25	950	23,750	52	65	1,300	1,625
20-25	15	1,120	16,800	70	87	1,050	1,305
25-30	6	1,300	7,800	88	110	528	660
30-35	4	1,450	5,800	105	130	420	520
35-40	4	1,600	6,400	125	155	500	620
40-45	6	1,750	10,500	145	180	870	1,080
45-50	2	1,850	3,700	160	200	320	400
50-60	5	2,100	10,500	185	230	925	1,150
60-70	4	2,400	9,600	200	260	800	1,040
70-80	4	2,650	10,600	215	280	860	1,120
80-90	1	2,950	2,950	230	310	230	310
90-100	2	3,200	6,400	240	370	480	740
>100	16	4,500	72,000	375	550	6,000	8,800
		TOTALS 10^3 $/yr.	406,639			32,793	39,872

* Based upon Design Handbook for Automation of Activated Sludge Wastewater Treatment Plants (14); Cost Analyses for June 1978

** Municipal Inventory of Wastewater Treatment Facilities (1979).

The cost analyses (Table 5) reveals an annual savings (1978 base) of approximately 33 million dollars for centralized analog control and 40 million dollars for central digital control for the 0.5 mgd and larger activated sludge plants. These savings represent about an 8% savings for analog control and a 10% savings for digital control on the annual O&M costs of the activated sludge plants (0.5 mgd and larger).

Total direct energy costs savings of between 10 to 15% were projected for the cost analyses (14) in D.O. load following (10% savings on total plant energy demand) and power demand control (5% savings on total plant energy cost). The power demand control is practical only with the digital control systems. Greater energy savings would require addition of power recovery equipment such as gas turbines to use the methane generated at the treatment plants. In this case automation should be employed to maximize the energy recovery. Indirect energy savings also result from reduced (8%) chemical usage such as in chlorination or in sludge conditioning.

A more speculative cost savings may develop with widespread application of automation. Current O&M practices at large treatment plants use continuous three shift operation to insure effective plant performance. The cost analysis presented here represents conservative options where shift operating manpower decreases and maintenance manpower increases with automation but the basic three shift operations mode is retained. Long term experience with automation may eventually lead to additional manpower savings through single shift operation with only monitoring and emergency response on other shifts.

MARKETING OF AUTOMATION

Automation of wastewater treatment plants has been recognized as candidate technology in the EPA's new Innovative and Alternative Technology Program. With the existing sensors and digital equipment, integrated and automated process control can better perform the same functions as the combinations of manual, independent analog, and independent man in the loop process control steps currently used in wastewater treatment systems. With proper systems maintenance, as required for any successful process control approach (manual, analog or integrated digital), the integrated digital process control will minimize operator decision errors, and operator failures to make appropriate control measurements. This should provide more reliable plant performance, when compared to manual, independent analog, and man in the loop controls.

Granting the obvious impact of automation on other industries, why has automation in the wastewater treatment industry not developed as rapidly? Apparently the cost impetus although present, has been obscured by other influences. In the municipal market the penalties for poor performance have in the past been so low or non-existent that little incentive for maintaining proper performance existed. Even now, this condition is only slowly changing.

The literature (15, 16, 17) indicated several possible reasons for the slow adoption of automation in wastewater treatment. The following reasons were the most prominent:

- The portion of capital spent for automation is much smaller in waste treatment plant construction than in other processing industries. (3 to 5% vs. 8 to 15%), thus manufacturers do not perceive a market.
- The technical skill required to maintain automated equipment is not available at waste treatment plants.
- The waste treatment plant salary structure is insufficient to attract qualified technical help.
- The quality of available automated equipment is insufficient for the atmosphere of the wastewater treatment plant.
- The frequency of maintenance required precludes the successful operation of automated process control.
- Federal procurement regulations prevent the selection of quality equipment on the open market.

All of the above statements are at least partially true. It is true that the portion of funds allocated to automation in the construction of a wastewater treatment plant are less than that portion allocated by other industries. There are, however, sound reasons for this allocation that have little to do with the role or use of automation in wastewater treatment. For instance, the cost of constructing an aeration basin and related piping for a large activated sludge treatment plant is enormous when compared to the cost of the few sensors, valves and controllers required to operate the process effectively.

The installation of instrumentation and digital equipment for multiple uses in large plants is beginning to occur and has sufficient market value per installation to encourage agressive marketing by the suppliers. The ISA Water and Wastewater Industries Division has identified approximately 50 operating plants, generally 10 MGD or above, with substantial automation. This will help to accelerate automation in the larger plants. The 3-5% of total capital cost is sufficient for large plants.

Unfortunately, for the small plant, 10 MGD and less, the needed digital capacity, satisfied by low cost (10-20 thousand dollar) micro-processors and (40-80 thousand dollar) mini-computers, does not involve on a per plant basis a large market value. While the overall potential market is moderately large (~ 20,000 plants), the low market value per plant for digital control, the difficulties in entering a conservative market and the lack of proven performance and cost effectiveness are likely to inhibit aggressive private marketing.

The second and third statements are interrelated. There is unfortunately sufficient truth in these statements to retard adoption. This problem can only be solved by time, aggressive recruiting, and training and by the use of the operations contracts with progressive consulting firms (which will also prove performance and cost effectiveness).

The last three statements are being addressed by the EPA and the field and, as previously indicated, improvements have been achieved or remedial efforts initiated. With out question it is a, "caveat emptor", market; there are inferior products, that will require excessive maintenance, if indeed they can be made to work at all. Too often competitive bids are evaluated by price alone and product quality becomes secondary. When this occurs the chances of purchasing inferior products are greatly enhanced. The direct impact of inferior equipment on a user are readily apparent and costly.

It is the clear intent of federal procurement regulations that cost criteria (low bid) only be applied after those bids that do not meet specifications have been eliminated. The regulations do allow prequalification of bidders, life cycle cost analysis, and performance standards, as well as technical engineering specifications. Improvement of the specifications and application of prequalifications, on-going tasks of the current EPA program, will help to reduce the problem.

The most important missing outputs to help accelerate the market acceptance, however, are:

- Documentation of proven overall plant performance for digital automation of municipal plants.

- Technology transfer and training on existing state-of-the-art.

In 1975 a grant with the Metropolitan Waste Control Commission was initiated to document cost effective state-of-the-art automation of a large conventional treatment plant. Reasonably reliable strategies were already available for the liquid train, however, significant process control development was required in the solids processing train.

The sludge handling control strategy work was initiated at an existing commission plant. This development work did not progress as rapidly as originally projected because viable control strategies for the chemical conditioning and vacuum filtration processes were non-existent. Various control strategies were developed and tested. Some of the strategies were unsuccessful and sensors for other strategies were not available or required improvement. Despite these difficulties it appears that by the end of FY80 coordinated on-line control of the ultimate disposal line (thickening, chemical conditioning, vacuum filtration, and incineration) will be in place and demonstrated. A digital computer will perform on-line optimization of the solids processing line to maintain chemical, fuel, and manpower costs at a minimum. Data to date indicates savings of at least 25% in chemical conditioning costs.

The anticipated demonstration of liquid and solid handling using automation could not, however, be started under this grant. Construction delays on the new plant caused by various factors, including contractor suits and adverse regulatory commission rulings, made it clear that construction would not be complete before 1984. Minneapolis-St. Paul is still committed to full automation of the new plant. It is an option to the A&I program to institute a new grant after the new plant is completed.

RESEARCH AREAS

In addition to the documentation and technology transfer areas the A&I strategy will include research into:

- Process control strategies for new process
- Process control strategies for energy conservation
- Centralized management and operation of multiple small plants
- Integrated control of wastewater systems (plant and collection systems)

Automated control strategies for new processes such as; deep shaft, reactor-clarifier systems with external O_2 dissolution and, fluidized bed biological treatment (both aerobic and anaerobic) should be developed as early as possible. Early consideration of automated process control for new processes will insure proper documentation of the treatment system and efficient process operation.

In energy conservation, Dr. Richard Stone of Brown and Caldwell has stated "that between 50 and 60 percent of the energy demand of conventional municipal treatment can be eliminated by integrating efficient energy usage into conventional plant design." "Integrated" plant design includes process and energy recovery equipment that can be efficiently operated with conventional controls. Further, G.L. Funk (18) indicates that "as processes become more and more integrated with respect to energy usages and generation, automation and closed loop control become increasingly significant and essential." Retrofit methods for effective energy utilization at existing plants will require further R&D.

Centralized management and operation of small plants is likely to be the most cost effective mechanism for providing effective operation and maintenance (skilled professionals and technicians) to the small plants. The development of micro-processor and mini-computer systems in monitoring, process control, and remote data transmission are essential for efficient centralized management of operations and maintenance.

The use of computers to reduce combined sewer overflows has been successfully applied in Seattle, Washington (19). With the accelerating improvements in costs and capabilities of computer systems, development of automated area wide management systems employing integrated digital control offers potential for improved management of municipal treatment systems (plants and collection systems). The potential impact of the demand for automated area wide management systems for municipal wastewater treatment, including monitoring of toxics inputs or spills, should at least be evaluated as a desk top analysis for guidance to the operating programs and to identify specific research needs.

RECOMMENDED STRATEGY

A recommended strategy to accelerate improvements in plant performance using automated process control in municipal wastewater treatment is presented here as a comprehensive approach. Recognizing that competing priorities limit resources, the strategy is divided into short and longer range objectives with individual objectives within the two output groups prioritized as to timing requirements and importance of projected impact. Thus, the strategy attempts to provide maximum benefit at whatever level of available resources.

The strategy by objective is briefly summarized below in prioritized rank:

<u>Short Range Objectives:</u>

1. Transfer state-of-the-art, demonstrate and document integrated microprocessor control of small plants and document design approaches on available automation for energy conservation.

    a. Transfer present SOA technology to the field so that the cost effective instrumentation and automation presently proven feasible is appreciated, understood and properly applied.

    b. Demonstrate and document integrated micro-processor control of small treatment plants.

    c. Document design approaches for use of automation and instrumentation for energy conservation.

2. Develop centralized management of multiple small plants using digital technology.

3. Document benefits of overall plant automation.

<u>Long Range Objectives</u>

o Develop improved automated approaches to achieve energy conservation.

- o Develop automated process control for new technology and improved approaches on existing technology.

- o Develop automated areawide management for plants and collection systems.

- o Support, as needed, the continuing development of instrument specifications (NBS) and the establishment of the non-Federal instrument certification laboratory.

The specific outputs with estimated resources to achieve the short range objectives are presented in Table 6. The Table includes a summary of the on-going outputs from the current A&I program. A review of these outputs reveals that the ongoing tasks provide previously missing control strategies or models (solids processing, anaerobic digestion), support the need for improved equipment selection (NBS specifications, Instrument Certification Laboratory) or support the above strategy objectives.

Three needs are included in the first priority short range objectives. Our recent (in press) design manual on tested control strategies, the D.O. control design manual, and selected outputs from our completed (Appendix A) and on-going work provide the state-of-the-art for transfer to the field. The large number of small plants with poor performance compels a high priority for improving control at small plants. Finally the potential reduction in energy and chemical usage using automation to minimize fuel consumption and operating costs completes the high priority objective.

The four outputs (Table 6) to meet the first priority objectives require modest funding of 550K over two fiscal years. The development of the micro-processor control for small plants, shown with two levels of control could be strengthened by testing each control level at more than one type of conventional plant. The micro-processor control projects, (implemented through cooperative agreement) in the first priority level of the program would feature a CCP approach. This project will provide examples of a plant management approach to provide the knowledge of a highly trained engineer (programmed into the micro-processor) at a small treatment plant. The on-site personnel would be trained to maintain and operate the sensors and micro-processor.

Successful process control requires proper maintenance and knowledgeable personnel. With automation, routine operator decisions are less critical but effective routine maintenance and the availability of competent personnel for operating emergencies are needed. To insure such competency at small plants, the implementation of the micro-processor control projects would be achieved through the use of private consulting firms which have an interest in operating treatment plants as an offered service.

The demonstration of micro-processor control would further serve as the nucleus for the second priority objectives of centralized management of multiple small plants. In the output for this objective, the micro-processor control systems of the above tasks would provide the automated monitoring and

TABLE 6. SUGGESTED SHORT RANGE OUTPUTS

Output Description	Funding	Delivered Output
<u>In Progress</u>		
1. Develop and demonstrate Cost Effective Sludge Processing Automation & Instrumentation	Fully Funded	FY80
2. Evaluate new concepts in O & M using coordinated manual and computer techniques (man in the loop)	Fully Funded	FY80
3. Develop time dependent model of Anaerobic Digestion	Fully Funded	FY81
4. Evaluate remote monitoring to reduce O & M costs of small remote plants	Fully Funded	FY80
5. Develop Instrument Testing; Installation and Maintenance Procedures and Specifications	Fully Funded	FY81
6. Establish Organizational and Administrative Structure for Non-Federal Instrumentation Certification Laboratory	Fully Funded	FY82

(continued)

TABLE 6. SUGGESTED SHORT RANGE OUTPUTS (cont'd.)

Output Description	Funding	Delivered Output
First Priority New Tasks		
7. Develop and Present Technology Transfer Seminars for Design Consultants, Regional Officers and Corps of Engineer Professionals	FY81 100K	FY81
8. Develop and Demonstrate Integrated Microprocessor Control of Small Conventional Plants	FY81-82	FY83
2 levels on-off gap action	150K	
continuous PID control	150K	
9. Prepare Training Course for Plant Operators in Automation & Instrumentation	FY81 50K	FY82
10. Prepare Design Manual on Use of Automation and Instrumentation for Energy Savings	FY82 100K	FY83
Second Priority		
11. Develop and Demonstrate Centralized Management of Multiple Small Plants Using Digital Automation	FY82-83 200K	FY83
Third Priority		
12. Perform Survey and Market Study of Automation and Instrumentation in Water Pollution Control Industry (Municipal and Industrial)	FY81 200K	FY83
13. Document Performance and Benefits of Automation at Large Plants	FY82 100K	FY83

transmission of selected data from remote plants to a mini-computer at a central support site. The centralized management approach for multiple plants would economically permit the assembly of a competent staff to provide the needed routine maintenance and emergency O&M of the process and process control equipment, and also provide the continuous surveillance that produces effective plant performance in well run large treatment plants.

The third priority in the short range outputs, the documentation of benefits of plant automation, is addressed by two tasks. The survey and market study of A&I in water pollution control performs two important functions:

- o Provides a linkage between municipal and industrial wastewater treatment process control advances and markets (jointly performed by MERL and IERL).

- o Provides needed guidance on future automation and process control both for ORD and the operating programs.

The last task, the documentation of the benefits of automation at large plants, completes the overall assessment of first generation automation in municipal wastewater treatment.

These short range objectives are the culmination of MERL's existing Automation and Instrumentation Program. The outputs from these objectives as remedial solutions to problems provide the first generation automation products and support their transfer to the field. These outputs should accelerate the use of modern automated process control to achieve improved plant performance in municipal wastewater treatment at only very modest R&D costs, and, more importantly, provide improved process control for the full range of plant sizes in the municipal field at minimum capital costs to the municipalities. As an example, the programmed micro-processor at 10-15 thousand dollars for small plants, mini-computers at 40-80 thousand dollars for the larger plants and sensors at less than 50 thousand dollars per treatment train would constitute the principal capital investment per plant. Indeed, many of the sensors may already be in the treatment plants.

With a technical field as progressive and innovative as the digital computer field, the potential for continuing benefits to process control and wastewater treatment should not be ignored by the Agency's R&D effort. Thus the proposed long range objectives for automation and instrumentation represent the more important areas where substantial benefit can occur. The specific output tasks (Table 7) associated with the longer range objectives also represent the "best estimates" for future work. These tasks will be modified as appropriate from evaluation of the on-going short range outputs.

As with the on-going A&I program, the suggested short and long range tasks cross various Decision Unit areas within MERL. The past work and the short range objectives are specifically related to MERL's Plant Design and Reliability areas. The long range tasks also impact significantly New Process Development (which supports the Agency's Innovative and Alternative Program) the Ultimate Disposal area, the Energy Conservation effort and the Urban Runoff Program.

TABLE 7. SUGGESTED LONG-RANGE OUTPUTS

Output Description	Funding	Delivered Output
Energy		
Automation of Anaerobic Wastewater Treatment	FY-82 150K	FY-83
On-Line Computer Optimization of Complex Treatment Plants	FY-82 175K	FY-84
Applicability of "Artificial Intelligence" Computer Systems to Optimize Operations at Treatment Plants	FY-82 75K	FY-84
Improvements in Treatment Process and Process Control		
Automation of New Liquid Treatment Control Strategies	FY-82-85 50-75K per year	FY-84-85
Automation of New Ultimate Disposal Control Strategies	FY-82-85 50-75K per year	FY-84-85
Area Wide Management		
Remote Sensors in Sewers for Enforcement and Treatment Plant Protection	FY-82-83 100K	FY-84
Area Wide Control of Pollution and Water Quality	FY-82-85 250K	FY-85
Improved Reliability through Equipment Selection		
Support for Specifications Development and Instrumentation Certification Laboratory	FY-82-85 110K per year	On-going Outputs

The A&I work on new process control strategies thus relies on definition of the pertinent process control mechanisms by the Treatment Process Development and Sludge Management Programs. Indeed such definition may require automated data acquisition. Similar interactions occur with the Energy Conservation and Urban Runoff Programs. Development of new automated process control strategies for process control or energy conservation and areawide management techniques should be in partnership with the appropriate wastewater treatment program.

The A&I program, as part of the Wastewater Research Division's Technology Development Support function, provides both the skilled professional support with "hands on" experience and facilities with the necessary equipment. A distributed digital control research tool is now being installed at the Test and Evaluation Facility to support the research projects at the Facility. These resources, thus, permit efficient development of proposed Automation and Instrumentation strategies. In short, the A&I activity should be considered primarily as a technology support function. The prime customers being the other MERL programs with needs for assistance in establishing cost effective real time control and monitoring of processes and systems.

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APPENDIX A

Instrumentation and Automation Program

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APPENDIX B

Description of Suggested Short Range Outputs

(In Progress)

1. Develop and Demonstrate Cost Effective Sludge Processing Automation and Instrumentation

   Output and Benefits - Demonstration of computer control and on-line economic optimization of gravity thickening, chemical conditioning, vacuum filtration and incineration. Will have national impact on economics and energy use in sludge processing.

2. Evaluate New Concepts in O&M Using Coordinated Manual and Computer Techniques (Man in the Loop)

   Output and Benefits - Evaluation of improved and more economical operation and maintenance by use of operator controlled CRT display of plant operational data, performance trends, maintenance records, parts inventory, and equipment status. Will have national impact on operation and maintenance costs and reliability.

3. Develop Time Dependent Model of Anaerobic Digestion

   Output and Benefits - The model will allow more efficient operation at higher loadings with lower failure possibility. Potential for higher methane per unit volume. Will impact both the future design of, and the present operation of anaerobic digesters.

4. Evaluate Remote Monitoring to Reduce O&M Costs of Small Remote Plants

   Output and Benefits - Will illustrate minimum cost and maximum reliability of remote monitoring system for operation and maintenance of a network of small-remote treatment plants and sewage pumping units. Precursor of area-wide control of drainage basin water quality. Will have national impact on economics and reliability of small, remote treatment units.

5. Develop Instrument Testing, Installation, and Maintenance Procedures

   Output and Benefits - Will provide rules, specifications and guidelines on field procedures for evaluation of applicability of an instrument for wastewater applications. Will have impact on construction grant funding rules, plant reliability, and instrumentation cost. Availability of reports at approximately 6 months starting in the last quarter of FY80.

6. Establish Organizational and Administrative Structure for Non-Federal Instrumentation Certification Laboratory

   Outputs and Benefits - Will provide an independent organization for certification of performance of instrumentation which will provide the mechanism for keeping substandard equipment from the marketplace. Potential construction cost savings of several million dollars annually. Available first quarter FY82.

(First Priority New Tasks)

7. <u>Develop and Present Technology Transfer Seminars for Design Consultants, Regional Offices and Corp. of Engineer Professionals</u>

Output and Benefits - This program would place the output of on-going work with NBS in the field quickly and prevent improper installation problems referenced by the CCP program.

8. <u>Develop and Demonstrate Integrated Micro-processor Control of Small Conventional Plants</u>

Output and Benefits - This project will illustrate that a conventional treatment plant's performance can be significantly improved in a cost effective manner. The routine operations such as monitoring and control of dissolved oxygen pump operation, tank level, flow splitting, sludge collection and pumping, etc., will be handled 24 hours per day by a preprogrammed micro-processor. This will free the operator to concentrate on equipment and sensor maintenance. The operator will not be required to make process control judgments.

9. <u>Prepare Training Course for Plant Operators in Automation and Instrumentation</u>

Output and Benefits - Will provide training in instrumentation maintenance, use of programmable calculators to make process control decisions and elementary computer-operator interactions for plant operation and maintenance record keeping. This will result in dissemination of new operation and maintenance techniques to the field. This project will be conducted in cooperation with National Training Center. Available in FY82.

10. <u>Prepare Design Manual on Use of Automation and Instrumentation for Energy Savings</u>

Output and Benefits - This manual will be useful to designers and operators (owners) of treatment systems as a guide to saving energy and chemicals and consequently power and fuel costs. The manual will address new designs, the retrofit of old plants, and changes in present operational procedures. Included will be discussions of new technology such as new methods of motor speed control of pumps and blowers, turbines which can burn low BTU gas, and heat pumps for energy recovery from sewage. Potential impact on treatment energy requirements and economics.

(Second Priority)

11. <u>Develop and Demonstrate Centralized Management of Multiple Small Plants Using Micro-processor Automation</u>

Output and Benefits - Will document the impact of centralized management on the operating cost and reliability of small treatment plants. Precursor of centralized control of drainage basin water quality. Will have national impact on the economics and reliability of area-wide basin management systems.

(Third Priority)

12. Perform Survey and Market Study of Automation and Instrumentation in the Water Pollution Control Industry (Municipal and Industrial).

Output and Benefits - Access the potential impact of instrumentation and automation on the combined municipal and industrial wastewater treatment field. This work will provide background and guidelines to aid in determining national research needs.

13. Document Performance and Benefits of Automation at Large Plants.

Output and Benefits - Provide a data base for cost benefit analysis of automation in large wastewater treatment plants. Such information is necessary for the promulgation of national guidelines for construction grant applications involving automation.

Description of Suggested Long Range Output

1. **Automation of Anaerobic Wastewater Treatment**

   This component of the A&I program will develop and demonstrate control strategies for the anaerobic expanded bed biological contactor for wastewater treatment. This process has the potential to provide a net energy production. Control strategies that will be considered will be bed expansion control, recycle control, pH control, etc.
   Output and Benefit - Final report documenting the energy inputs and outputs of the process and the process controls required to stabilize the process.

2. **On-line Computer Optimization of Complex Treatment Plants.**

   This is applicable to a treatment plant which has alternative methods of achieving the output goal. For example, use of more coagulants prior to sedimentation versus shorter filter runs or lower filtration rates. The computer will analyze the available data on the treatment process performance, construct models of each process and synthesize these into an overall systems control model based on least cost.
   Output and Benefit - Applicable to performance optimization of large (greater than 10 MGD) or complex treatment plants.

3. **Applicability of Artifical Intelligence Computer Systems to Optimize Operation of Treatment Plants**

   This will evaluate the use of artifical intelligent computer systems in operation and maintenance of POTW. These systems have the ability to learn by experience. Thus, the computer system can gradually learn how to best operate a treatment plant.
   Output and Benefit - This type of computer system is the easiest for a plant operator to adapt to and is potentially the most cost effective for operation and maintenance.

4. **Automation of New Liquid Treatment Control Strategies.**

   The development of new innovative liquid treatment processes by other EPA programs will require control strategy development and evaluation. This component of the A&I program will develop, evaluate, and demonstrate new processes.
   Output and Benefit - Produce reports detailing cost effective strategies and detailing techniques for applying them. This work will be done in partnership with TPDB.

5. **Automation of New Ultimate Disposal Control Strategies**

   The development of new innovative ultimate disposal process by other EPA programs will require control strategy development and evaluation. This component of the A&I program will develop, evaluate, and demonstrate new processes.
   Output and Benefit - Periodic reports detailing cost effective strategies and detailing techniques for applying them. This work will be done in partnership with TPDB.

6. Remote Sensors in Sewers for Enforcement and Treatment Plant Protection

The use of remote sensors in sewer systems to pick up discharges of unusual, toxic, regulated, etc., wastes will aid enforcement and protect treatment plants from upset.
Output and Benefit - Periodic reports on demonstrations, sensor cost, maintenance, and experienced results.

7. Area Wide Control of Pollution and Water Quality

This component of the A&I program will demonstrate area wide control of a network of treatment plants to insure optimum performance and water quality. This will involve both large and small plants in a river basin. Both remote monitoring with reporting to a centralized computer and on site process control computers will be used in an appropriate mix. The central management site will make the management decision as to how each plant is to be run so that water quality criteria in the drainage basin is met as the load shifts between plants.
Output and Benefits - Most cost effective control of water quality over a wide area. Each treatment plant will be adjusted to perform only that function necessary to meet local and regional goals.

8. Support for Specifications Development and Instrumentation Certification Laboratory

This component of the A&I program will provide continuing support for developing instrument testing procedures and establish a non-federal organization for certification of wastewater treatment instrumentation. This will prevent sub-standard equipment from reaching the market place and installation in wastewater treatment plants.