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Novel Methods and Materials of Construction

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NOVEL METHODS AND MATERIALS OF CONSTRUCTION

by

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Contract No. 68-03-2512

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Wastewater facility construction project cost reductions of only 1 or 2 percent could save many millions of dollars nationally in the Construction Grants Program of P.L. 92-500. In this study an analysis of structural high cost centers and nonstructural construction policies, procedures, and practices was performed. Solutions are presented for reducing or eliminating the nonstructural factors of construction that significantly increase construction costs. Unconventional and novel materials and methods of construction are identified that can effect cost savings in municipal wastewater treatment plant construction.

Francis T. Mayo, Director
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ABSTRACT

Wastewater facility construction project cost reductions of only 1 or 2 percent would save many millions of dollars nationally in the Construction Grant Program of PL 92-500. This report describes areas for effecting such cost savings. Suggestions were developed from a wide-ranging search for ideas having potential for wastewater facility cost reduction. This work was essentially completed prior to passage of the 1977 Clean Water Act Amendments; innovative technology provisions of these amendments should stimulate more suggestions.

Two areas for potential cost saving are investigated in this study; non-structural and structural. Non-structural areas cover administrative, regulatory and technical policies, procedures and constraints affecting wastewater facility construction. Structural factors cover the actual construction process. Many sources were checked for ideas; although it is recognized such a search could be endless.

Suggested solutions for problems involving non-structural processes were developed by considering input from people directly involved in the wastewater facility planning, design and construction process. Solutions are posed for some of the identified problems and these are ranked in terms of their potential for implementation and cost savings. Within the top six ranked solutions two involved expansion of the facility planning phase, two involved design criteria while the remaining top ranked solutions involved fast track construction management procedures and adoption of novel ideas.

Structural aspects are developed following an analysis of high cost centers associated with typical collection and wastewater treatment plant facilities. The procedure for developing unconventional and novel ideas for methods and materials of construction is explained and ideas developed are described. Related research included use of computer searches and contacts with contractors, suppliers, engineers, wastewater treatment plant operators, industry, and various associations.

The best unconventional ideas identified were flexible (in situ form) pipe liner which enables sewers to be relined using existing access, plastic fluid control equipment, and several fiberglass reinforced plastic (FRP) applications including

digester covers, small diameter piping, and access bridges for walkways over clarifiers and other process units.

Novel ideas identified fall under three categories: Those readily implemented, those requiring further development to confirm feasibility, and those which do not appear to be cost-effective. The best readily implementable ideas were vertical shaft construction methods and applications, precast concrete tanks, and reinforced asphalt pond liners. The best ideas identified as requiring further study are shipboard treatment and botanical foul air treatment. Other ideas including those considered non cost-effective are identified in an Appendix.

This report is submitted in fulfillment of Contract No. 68-03-2512 by Brown and Caldwell, Inc. under the sponsorship of the U.S. Environmental Protection Agency. This report was essentially completed during the period March 7, 1977 to November 30, 1977; however, some additional work was conducted during the summer of 1978 which accounts for references to the Clean Water Act Amendments which were passed by Congress in December 1977.

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SECTION 1

INTRODUCTION

Many billions of federal dollars have been awarded to assist in the construction of wastewater collection and treatment facilities. Congress authorized 42.5 billion dollars for the Construction Grant Program for the period 1972-1982. Most of the 18 billion dollars originally authorized in 1972 with the passage of PL 92-500 has been obligated; however, an additional 24.5 billion dollars was authorized with the 1977 Clean Water Act Amendments. If cost savings involving construction cost reductions of only 1 or 2 percent could be accomplished, the potential return in dollars saved would be substantial. Recognizing this, the U.S. Environmental Protection Agency (EPA) and the Municipal Environmental Research Laboratory (MERL) authorized this study to identify areas having potential for minimizing costs for wastewater collection and treatment facilities.

General objectives of this study as defined by MERL are as follows:

> "The general objectives are to review conventional design practices, the design/bid/contract-award sequence, and conventional construction procedures used in the construction of sewer systems and wastewater treatment facilities; to identify the administrative, regulatory, and technical policies, procedures, and constraints which impact the cost of construction projects; and to develop a universe of novel construction methods and new materials of construction, evaluating their applicability for use in sewerage facilities construction if unconstrained by existing criteria, standards, and policy, in order to minimize the cost of collection and treatment facilities."

Thus the study involves procedural and other administrative matters as well as design and construction considerations. The terms "non-structural" and "structural" are used throughout this report to separate administrative procedures from construction. Accordingly, the term "non-structural" is defined to include all aspects which affect construction cost, but are not directly associated with construction. Included are the administrative, regulatory and technical policies and constraints referenced above. The term "structural" includes all aspects of construction practices and costs of construction.

Non-structural aspects of the study are approached in two phases. Initially, various agencies and individuals were contacted for their opinions; personal concerns regarding the Grant Program were also solicited. Secondly, these inputs were used as a base for the development of potential solutions to identified problems.

The structural side of the study involved a more intensive effort (the study effort involved time apportionment of approximately 20 percent non-structural and 80 percent on structural topics). The first phase of the structural work involved a state-of-the-art review of current conventional methods and materials of construction of facilities in the construction field. This review served as background for a cost center analysis of collection and treatment systems. The cost center work was useful in identifying items having potential for cost savings where use of novel and unconventional methods and materials might prove feasible.

The concluding sections of this study present unconventional and novel ideas for methods and materials of construction which were identified. Emphasis is placed on those which are apparently cost-effective. Section 6 describes the "unconventional" ideas which, for purposes of this study, are defined as relatively new construction methods or materials used infrequently in the wastewater field to date. Section 7 covers the "novel ideas" which cover ideas ranging from those used elsewhere in the construction industry (but not in the wastewater field) to so called "blue sky" ideas developed by brainstorming techniques.

The novel and unconventional ideas were developed by several methods; each of the two sections relating to new ideas begins with an introductory text describing development methodology and problems encountered. Other ideas considered but which are not necessarily cost-effective or are beyond the defined scope are included in an Appendix. Recommendations for both non-structural solutions and construction ideas are outlined in an abbreviated form in Section 2.

It should be stressed that the scope of this study was very broad, and in consequence the amount of time which could be expended on each idea was limited. The cost-effectiveness and/or practicality of the unconventional methods is proven by actual use elsewhere. For novel methods and for the non-structural concepts, only superficial tests of economy and practicality could be applied. Other good ideas will undoubtedly emerge as others focus on this subject. This particular search was initiated before the 1977 Clean Water Act Amendments were passed; the emphasis placed on novel methods by this new Federal Law should stimulate a wider search. It is hoped that this initial investigative effort will provide further stimulus and that the methods used and ideas developed here can be applied to accomplish real cost savings in future wastewater facility construction.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

This study evolved from the realization that small percentage cost reductions in individual wastewater facility projects would represent major savings in the national water pollution control effort. Such savings would then affect the federal municipal wastewater facility construction grant program allowing more projects to be built for a given allotment of funds. With this premise in mind the conclusions and recommendations from this study of novel procedural and structural methods and materials of construction are offered.

The study identifies many different ways to effect wastewater facility construction cost reductions. Ways to accomplish this goal are grouped depending whether the change considered is non-structural (e.g., administrative or procedural in nature) or structural (e.g., actual change in construction materials or technique). The relative importance of non-structural or structural changes can best be assessed on an individual project. Both groups are important. Conclusions and recommendations are offered for each group.

NON-STRUCTURAL

Many diverse non-structural topic areas were identified as having potential for effecting cost reduction. A review of 29 areas covering all phases of the Federal Construction Grant Program revealed a pre-grant topic, effluent limitations, as having the greatest potential for cost savings. It was observed that overly strict effluent standards can force design of oversized units or even advanced treatment where more conventional treatment is adequate; this problem is particularly evident where design is governed by wet weather conditions. The effluent limitations topic has the potential to change construction costs by over 20 percent.

Other important non-structural topics include time delays caused by agency review procedures, source control (including infiltration-inflow), conservative engineering design practices, standard design requirements, delays related to grant eligibility determinations and construction delays associated with change orders. These other items were all rated as having potential to reduce construction costs by 5 percent or more; most of these items were associated with cost reductions in the 5 to 10 percent range.

Proposed solutions to procedural or other non-structural aspects are offered; 16 proposed solutions are described in Section 4. Six of this group were rated high in terms of their overall potential for implementation and cost savings. These six are summarized below with their recommendations:

1. <u>Expansion of the Planning Phase</u>. A two-part recommendation is offered for this item as follows: First, a project implementation plan should be developed as soon as possible after a decision is made to prioritize a project for funding. This plan should include a clear description of each federal, state and local requirement which affect facility planning, design, construction or operation and how compliance with each requirement will be achieved. Incorporation of compatible multi-purpose projects in the plan is encouraged. This leads to the second part of this recommendation which is that equitable cost distributions between federal, state and local interests should be developed considering multi-purpose project requirements and goals. Basic water pollution control functions would be defined and costs and benefits for achieving water pollution control requirements would be compared with plans to meet other federal requirements as well as state or local multi-purpose alternatives. In this way all applicable federal requirements are defined as a first step toward implementation; costs for compliance with non-water quality mandates would be recorded and more flexibility in planning for local needs would be attained.

2. <u>Evaluate Innovative Technology in Facility Plan</u>. To assure benefits of innovative and alternative technology are considered thoroughly, it is recommended that an evaluation should be made to determine the appropriateness of including innovative technology in the project. This process should begin as soon as possible once grant funding decisisons are made. Where innovative technology would appear to warrant further consideration a detailed action plan should be developed for inclusion in the facility plan. As a minimum, the innovative technology plan should:

   - identify innovative technology appropriate for the project;

- include an economic evaluation of the potential impact of the proposed innovative technology on the project;

- include a general evaluation of the impact of such an innovation on the national wastewater program;

- include an assessment of the risk of failure of the innovative technology;

- describe actions to be taken in the event of failure of the innovation; and

- describe criteria and procedures to be used to evaluate performance of the innovative technology.

3. <u>Design Parameter Development</u>. In order to determine optimum design parameters it is recommended that EPA sponsor performance evaluations at treatment plants approaching design capacity for one or two years prior to commencement of facility planning. The recommended evaluations would be facilitated by making several related procedural changes as follows:

    - EPA should provide funding for construction of minor modifications to existing facilities so that full-scale multi-stream process evaluations can be undertaken.

    - Both EPA and state agencies should permit waiver or reduction of routine sampling requirements during evaluation periods to free existing laboratory facilities and staff to monitor experimental work.

    - Occasional violations of NPDES permit limitations will occur and these should be accepted by regulatory agencies.

    - Funding for additional analysis and development of design criteria should be allowed as part of the Step 1 grant.

4. <u>Consider Fast Track Construction Management Early In Project Development</u>. To reduce cost through minimization of time taken in the conventional project design and construction sequence it is recommended that an evaluation should be made to determine the appropriateness of utilizing fast track design-construction techniques. This evaluation

should begin as soon as possible after the decision is made to consider grant funding for a proposed wastewater treatment project. Where a design-construction approach would appear to be appropriate, a detailed fast track action plan should be developed for inclusion in the facility plan.

5. Adoption of Less Conservative Design Data. Engineers should be encouraged to adopt less conservative design data. Currently, the trend is to use increasingly conservative design data. It is recommended that EPA regulations be modified to include provision for further funding for design and construction beyond Step 3 subject to certain conditions. These conditions would be drawn up around requirements that the engineer and municipality show their intent to use less conservative data during Step 2.

6. Novel Idea Adoption. To provide conditions in which novel cost reducing ideas can be tried and tested to determine their suitability and cost-effectiveness, it is recommended that EPA issue regulations encouraging engineers to adopt novel methods and materials, and indemnify those who do so. Further, that a group be established to record and publish the successes and failures of adopted novel ideas.

STRUCTURAL

Cost centers were identified for typical wastewater collection systems and waste treatment facilities; this process helped to focus attention on high cost centers where employment of unconventional or novel materials or methods of construction may prove feasible.

Evaluation of pipeline cost centers revealed that pipe and appurtenances represent the major cost of construction under normal and minimum cost conditions whereas sheeting becomes the most costly item under maximum cost conditions. Excavation averages about 17 percent of total costs as a fairly constant percentage. Dewatering was not a particularly high cost center although this cost center did represent 15 percent of the total cost under maximum cost conditions.

Evaluation of costs for representative waste treatment facilities indicated structural elements account for slightly more than 50 percent of total plant costs. Vertical wall construction for buried rectangular/circular structures alone accounted for almost 20 percent of total plant costs. Various slabs accounted for 20 percent of total cost, with buried rectangular/circular types again representing nearly half. Digester covers represented 9.0 percent of total costs. Excavation and earthwork costs for buried rectangular/circular structures represented 8.5 percent of total costs. A lower relative cost of formwork to concrete for below ground versus above ground structures was apparent. This represents the difference between the more massive underground structure where finish is relatively unimportant and the thin walled abovegrade structures where finish for visual appearance is of prime concern.

The relative costs of mechanical equipment to total plant costs is significant. Thirty-two percent of total costs relates to major mechanical equipment, 14.5 percent relates to other items of mechanical equipment. The total cost of these two items approaches 50 percent of total plant cost. Assuming potential cost savings are proportional to present cost, it is apparent that mechanical equipment offers a promising area for potential cost savings.

The cost center analysis proved useful in identifying areas having potential for cost savings using unconventional or novel methods or materials of construction; the analysis pointed to some non-structural elements as well, particularly as related to procedures used in specifying mechanical equipment.

Unconventional and novel ideas were identified utilizing data from computer searches, contractor contacts and various contacts with engineers, research groups, equipment suppliers, associations and others. Brainstorming sessions were also conducted and were an important part of the search.

Unconventional methods and materials of construction include those which, though not routinely employed, have been proven or at least demonstrated in actual installation. Nine potentially cost-effective unconventional methods or materials of construction are described in the report; others are identified in the appendices. These nine unconventional items are:

- Insituform pipe liners
- Trenchless sewer pipe installation
- Sewer-within-sewer
- Fiberglass reinforced polyester (FRP) piping
- Fiberglass reinforced polyester (FRP) bridges
- Plastic fluid control equipment
- Miscellaneous fiberglass reinforced polyester (FRP) items

- Fiberglass reinforced polyester (FRP) digester covers
- Unconventional covers and enclosures.

The best unconventional ideas identified were flexible (in situ form) pipe liner which enables sewers to be relined using existing access, plastic fluid control equipment, and several fiberglass reinforced plastic (FRP) applications including digester covers, small diameter piping, and access bridges for walkways over clarifiers and other process units.

In contrast, novel methods and materials of construction are those representing promising new approaches to reducing the cost of wastewater conveyance and treatment facility construction. Novel ideas which were found suitable for inclusion include four which appear to be cost-effective and two which appear to warrant further study. Other novel ideas are identified in the appendices. The four apparently cost-effective ideas are:

- Drilled vertical shaft construction
- Reinforced earth tank
- Precast concrete tanks
- Reinforced asphalt pond liner.

Other novel ideas which were not tested from a cost standpoint but which may be worth further study include:

- Shipboard treatment
- Deodorizing foul air with botanical systems.

The best readily implementable novel ideas were vertical shaft construction methods and applications, precast concrete tanks, and reinforced asphalt pond liners.

SECTION 3

DEVELOPMENT OF NON-STRUCTURAL FACTORS AFFECTING CONSTRUCTION COST

NON-STRUCTURAL FACTORS

Construction of a water pollution control facility is the most costly step in the implementation of the federal wastewater facility grant program. The construction cost of these facilities reflects decisions made through numerous steps from the point of determining facility needs through to operational startup. Thus the construction cost reflects, in addition to the structure to be built, a myriad of non-structural factors that in specific instances have a significant effect on final costs.

Evolution of a project from initial identification of need through plant start-up is a multi-step linear process as illustrated in Figure 1. In addition to those participants identified in Figure 1,a large array of agencies, organizations and individuals affect the form and cost of the final product. Potential participants and their role as related to costs of implementation of a specific wastewater program are identified in Table 1.

STUDY METHODOLOGY

In the previous paragraph (Table 1) agencies, organizations and individual groups that have an impact on pollution control projects were identified. Their impacts were broken down into passive and active roles. By virtue of differing roles and responsibilities, and to obtain a balanced viewpoint, it was necessary to interview all parties involved. Emphasis was placed on parties that had active participation in the program. Consideration of the passive group was limited to areas where their prior actions appeared to preclude implementation of active group recommendations.

In the initial information search maximum use was made of existing contacts, in-house experience, regulatory agency personnel, past and present clients, equipment suppliers and contractors. To obtain a national perspective the scope of infor-

FIGURE 1. **schematic flow diagram construction grants process**

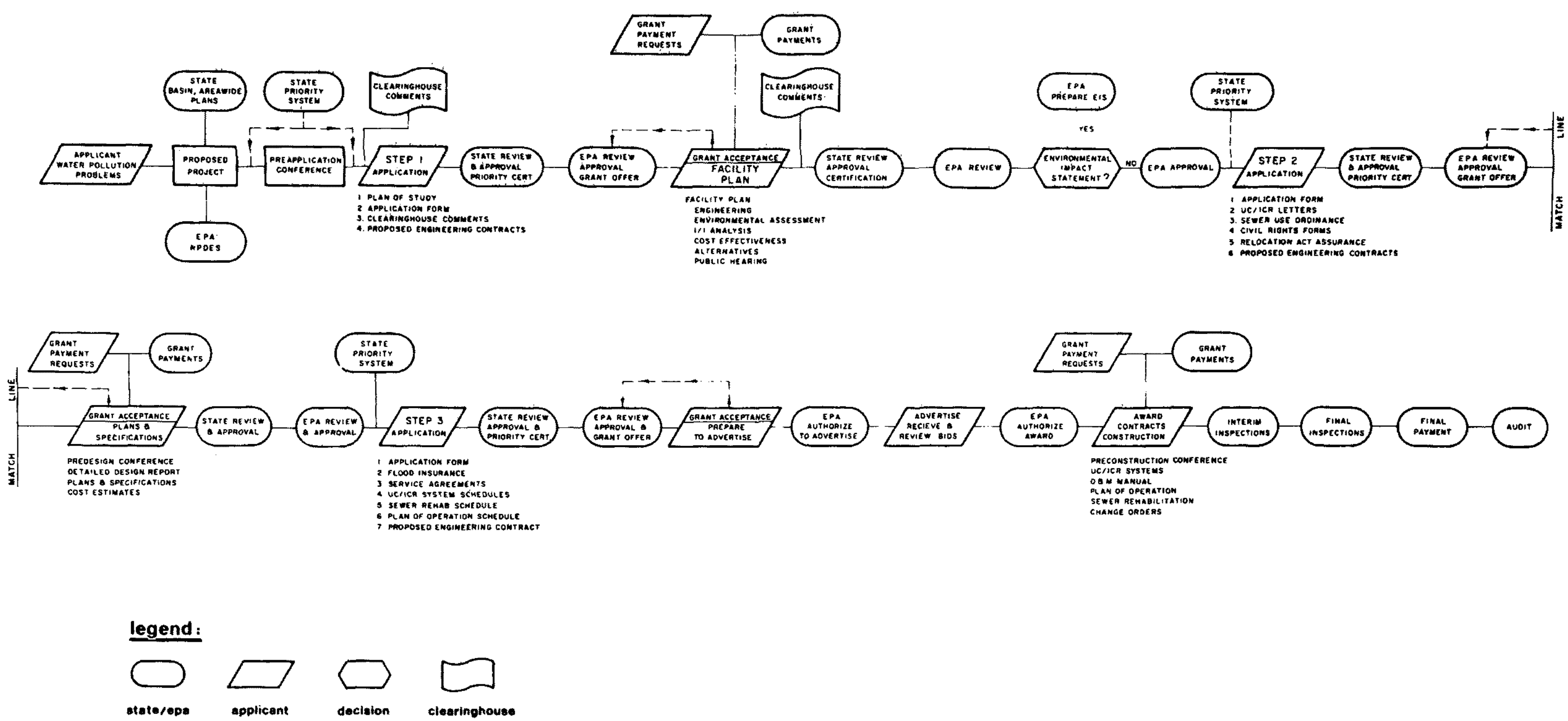


TABLE 1. CONSTRUCTION GRANT PROCESS--PARTICIPANTS

Participants	Pre-Step 1	P.L. 92-500 Grant Program		
		Step 1	Step 2	Step 3
Owner	●	●	●	●
Federal				
EPA	◐	●	O	O
Other			O	O
State				
Water quality agency	●	●	◐	O
Other			O	O
City/County/District (if not owner)	●	O	O	O
Universities	◐	O		
Consulting Engineers	O	●	●	●
Contractors				●
Equipment Manufacturers			●	●
Environmental Groups	●	●		
Labor Unions				●

Key

● Active

◐ Some Active Involvement

O Passive

mation gathering was extended to include literature searches, and contacts with a representative number of professional organizations;including the Associated General Contractors of America, the Wastewater Equipment Manufacturers Association, the Association of Metropolitan Sewerage Agencies, the American Consulting Engineers Council, and the Water Pollution Control Federation. Contact was made initially by telephone, followed by a letter describing the study objectives, and then further telephone and personal contacts as appropriate. Information response was either in the form of written comments or transcripts of the various telephone and personal interviews.

At the start of this study, EPA staff identified specific non-structural factors that had a potential for affecting facility construction costs. These items, together with additional factors developed during the study, were categorized into subject groups representing progressive stages in the wastewater management program. Specific points developed within the subject categories are summarized in the following section. The subject categories and their relationship to the EPA three-step funding program are identified in Table 2.

NON-STRUCTURAL IMPACTS

The input by identified "non-structural" elements is summarized below. The order of the writeup is as indicated in Table 2.

Effluent Limitations

The selection of a required effluent quality to be met by a specific wastewater facility dictates the extent of treatment facilities required and thus cost. As of this time PL 92-500 requires that all municipally owned treatment works shall achieve a secondary standard of effluent quality.[1] This provides the baseline for all discharge requirements with stricter standards being imposed on a case-by-case basis. As indicated in Figure 2, the higher the required effluent quality is, the higher the cost of construction will be.

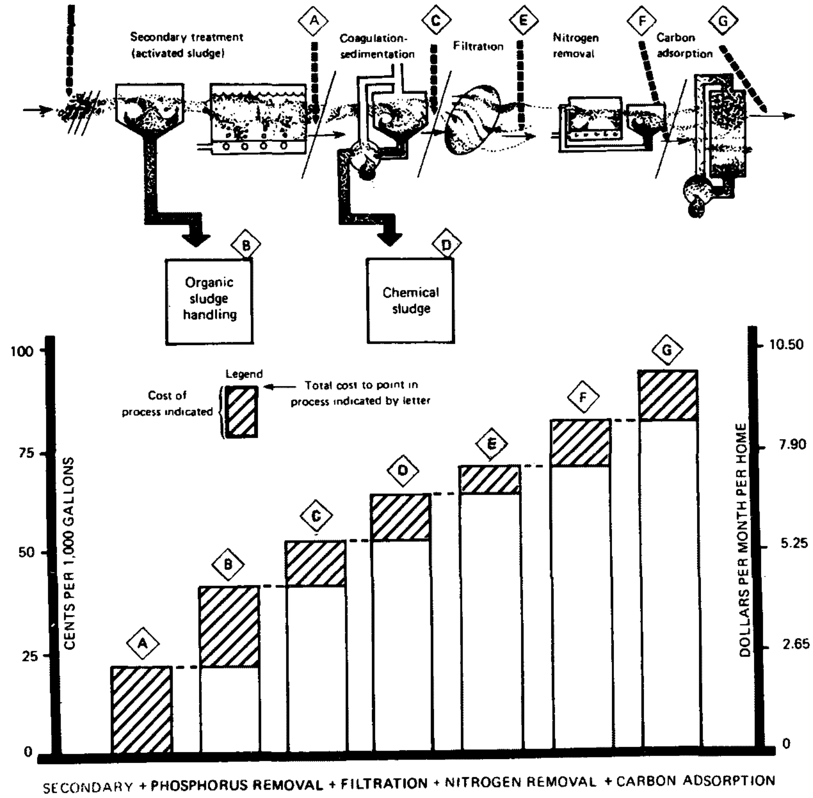
For surface water discharges, receiving waters are categorized as either effluent limited or water quality limited. By definition, discharge to water quality limited segments require effluent qualities better than secondary. Selection of water quality limited segments is often based on limited data, which has resulted in large sums spent on plants without any measurable benefit.[2]

Well operated biological secondary treatment facilities can consistently meet year-round effluent BOD and SS concentrations of 20 mg/l. Furthermore, under optimum conditions (warm

TABLE 2. EPA CONSTRUCTION GRANT PROGRAM NON-STRUCTURAL INFLUENCES

Item no.	Non-structural factors	EPA Construction Grant Program			
		Pre-Step 1	Step 1	Step 2	Step 3
1	Effluent limitations	●			
2	Pre-grant, post-grant time delays		●	●	●
3	Source control		●		
4	Plant location		●		
5	Consultant fee structures		●	●	●
6	Conventions of engineering practice			●	
7	Standard design requirements			●	
8	Acceptance of new design ideas			●	
9	Design for prefabrication/ standardization			●	
10	Specifications strictness/looseness			●	
11	Effect of "or equal" clause				●
12	Engineer's liability			●	●
13	Regulatory agency cost reduction program			●	
14	Grant funding eligibility			●	
15	Construction management alternatives			●	●
16	Time of year contract is bid				●
17	Bid - period, times and type				●
18	Time duration allowed for construction				●
19	Contractor perception of inspection requirements				●
20	Prevailing labor rates				●
21	Magnitude and distribution of labor skills				●
22	Distribution of construction trades				●
23	Effect of labor negotiations				●
24	Size of project				●
25	Equipment cost				●
26	Equipment supplier bidding restrictions				●
27	Competition in construction and equipment field				●
28	Use of CP, PERT scheduling tools				●
29	Change orders, contract delays				●

Raw sewage						Effluent quality
200	BOD: mg/l	20	5	2	2	1
	% removal	90	97.5	99	99	99.5
400	COD: mg/l	80	40	35	35	10
	% removal	80	90	91	91	97.5
200	Suspended solids: mg/l	20	5	0	0	0
	% removal	90	97.5	100	100	100
20	Nitrogen: mg/l	18	18	18	2	1.5
	% removal	10	10	10	90	92.5
10	Phosphorus: mg/l	9	9	0.1	0.1	0.1
	% removal	10	10	99	99	99



ENVIRONMENTAL POLLUTION CONTROL ALTERNATIVES:
MUNICIPAL WASTEWATER EPA-625/5-76-012

FIGURE 2. WASTEWATER TREATMENT PLANT CONSTRUCTION COST AND EFFLUENT QUALITY

temperatures, low hydraulic loadings) characterized by summer wastewater flows, secondary effluent BOD and SS concentrations of 10 mg/l are attainable. Discharge standards requiring effluent levels of 10 mg/l BOD and SS on a continuous basis achieve an improvement in water quality which is, in many instances, barely quantifiable. Yet such standards dictate that a tertiary stage is required.

Standards based on strict interpretations of statistical discharge requirements often result in oversizing of units to meet periodic high flow conditions. An example of this is the rigid application of the 85 percent removal criterion to all flows. For a sewage diluted with storm flows, influent strengths as low as 70 to 80 mg/l BOD and SS are not unknown. A discharge level of 10 mg/l BOD and SS is therefore required. This requirement involves construction of tertiary treatment to protect the receiving waters when they may least need protection, under heavy storm stream flow conditions. Little improvement in water quality may be realized at the cost of significant dollar and resource expenditure.

Pre-Grant, Post-Grant, Pre-Award Time Delays

Consistent with all previous federal/state funded programs, detailed procedures, rules and regulations have been promulgated by the grantors for the disbursement of P.L. 92-500 grant funds and where applicable local state matching funds.

Grantees, their consultants, contractors and, in many cases, funding agency personnel, have been critical of the management of the grant program. Particular concerns arise over delays due to agency reviews. Implementation of a wastewater project is a three-step process with reviews, approvals and authorizations required at each step. These review procedures plus delays in allocation of fiscal year funds have resulted in some delay for many projects.

These delays do result in increased costs, due to inflation and more recently by compressing design and construction times to compensate for time lost during the review phase. Review of contracts implemented prior to 1972, the first year of P.L. 92-500 grants, with current contracts indicates a contract implementation time increase of from 20 percent to 50 percent for comparable projects.

With the exception of short delays within a construction season, all delays will result in increased costs. Currently construction costs are inflating at over 8 percent annually.

A less obvious effect of granting agency delays on costs is compression of design periods. When insufficient time is available, potential new design ideas are not pursued and design decisions tend to default in favor of previous design. Inadequate time to check contract documents results in mistakes and inconsistencies moving forward to the construction period. The cost of a site change order exceeds the cost of changes or corrections made at the design stage. The implication of compressed construction periods is identified under "Time Duration Allowed for Construction."

Source Control

The total waste volume impacts construction cost directly. Hydraulic elements such as pumps and sedimentation tanks are sized on the basis of average and peak flows. Reduction of waste volume at source will tend toward a reduction of average flows. Reduction of infiltration/inflow will act to reduce both average and peak flows. Thus, either greater source control or reduction of infiltration/inflow will reduce costs, since either peak or average flows are reduced. The exception is where one parameter is limiting: For example, at a plant designed to handle storm peaks of six times average, no capital cost savings would result from a source control measure acting to reduce average flows.

Waste discharged to a sewage collection system reflects the use characteristics of the discharger. Sewer ordinances, EPA pretreatment requirements, water supply characteristics, and water use rates affect both the waste volume and pollutant content discharged in wastewater. After discharge into the sewer, the waste may be diluted by extraneous water in the form of infiltration and inflow. The total pollutant load and the makeup of the pollutants relate directly to the size and type of units. In general, only the biological and sludge stages are influenced. In extreme cases hydraulic units may also be directly affected: For example, several wastewater plants in central California taking high volumes of fruit and tomato wastes use dissolved air flotation for primary solids removal rather than sedimentation during periods of peak cannery loads.

Industrial pretreatment requirements have lessened the impact of industrial wastes in municipal treatment plant performance. Provision may still be made to protect treatment plants against accidental or illegal discharges of high strength waste or toxic materials. The biological processes are most subject to impact by such discharges. Protection may be provided in the form of plant flexibility - the sludge re-aeration mode provides a reservoir of micro-organisms protected from main stream toxics; or in the form of dual units - multiple anaerobic digesters fed individually reduces the potential for upsetting all units under one shock load. Generally, however, such provisions are relatively low in cost. It is not usual to provide major facilities to cope with infrequent, irregular events.

Plant Location and Site Conditions

Traditionally, treatment plants have been located adjacent to the point of final effluent disposal, and close to the served customers. Most large plants are located on shorelines and riverbanks. As a result, our water pollution control programs have located treatment plants in fully urbanized areas, on waterfront property, in generally poor soil conditions. With recent emphasis on wastewater reuse, this traditionally located treatment plant is remote from areas of potential reuse. If plant expansion/upgrading is carried out at existing sites, additional costs are often required to ensure added features are publically acceptable. Examples are identified in Table 3.

Conversely, location of facilities remote from urbanized areas, whilst avoiding some of the costs identified below, may present new areas of high cost and environmental problems which must be evaluated. The location of existing facilities is generally a result of logical evaluation of conveyance costs at the time of original conception. Construction cost of major trunk sewers, or force mains to convey sewage to a new site may often be greater than the cost of provision for necessary

TABLE 3. SITE LOCATION--CONSTRUCTION COST IMPACTS

Site location	Additional facilities required	Additional costs, %
Residential area*	Covered units, odor control, aesthetic treatment	5-20
Waterfront†	Public access to waterfront, aesthetic treatment	5-10
For poor soil conditions†	Piled foundations	5-10

* City of Olympia, Washington

† West Point treatment plant, Municipality of Metropolitan Seattle, Washington

facilities at an existing site. Environmentally, new site locations are inevitably sensitive, and the question of encouraged development pressure along the line of a new trunk system is often a point of concern.

Consultant Fee Structure

Up until the promulgation of P.L. 92-500 the fee curves published in ASCE No. 45 provided the basis for the negotiations for consulting engineer's charges. The charge was based on a percentage of construction cost, the percentage varying according to total project cost. A variety of adjustment factors could be applied to tailor the fee to the project in question. Since the fee was directly related to construction cost, the engineer's integrity stopped him from increasing his fee by increasing the project's cost. As a result of the new EPA consultant procurement requirements, the consultant's fee is negotiable at the start of the contract with the scope of the consultant work being the basis for his estimated cost, and from this his profit or fee.

On the face of it, the new approach should be a fairer system. However, due to the introduction of the client/consultant fee negotiation phase the system is now open to price shopping as opposed to just quality shopping as under the old system. It also opens up the specter of the practice of "buying" jobs as happens in the construction field; i.e., the final price is not the initial figure, but includes an additional substantial amount resulting from legalistic scope of work interpretations and subsequent contract claims. Consultants and contractors expressed serious concern that trimming design fees and selection of consultants on price without regard to competence will result in increased final contract costs exceeding any potential savings accrued in the design phase. A proposal for construction contract change order cost history of a consultant to be evaluated during selection procedures is included in Section 4.

Convention of Engineering Practice and Procedure

Engineering is not a pure science. Engineering theory provides a guide to which the engineer then applies his and the industry's experience to finalize the design. Thus, by its very nature engineering tends to be conservative. Refining designs would result in some cost savings. However, additional costs arise from refinement of specific designs; for example, pilot studies may be undertaken to optimize unit sizing criteria for a given treatment plant.

Maintaining information transfers between the engineering community and research and academic institutions through their technical organizations reduces the effects of engineering conservatism. The conservatism ensures that the acceptance of promising new technologies will be limited until such time as they are proven.

Deviation from this conservatism, specifically in the areas of sludge processing, has resulted in some very costly mistakes. Several installations of sludge incinerators, sludge drying equipment and, more recently, sludge heat treatment systems stand unused today as mute evidence of the dangers in departing from well-proven technologies.

Standard Design Requirements

In the area of standard design requirements, there are two opposing viewpoints. On the one hand, "standards" are promulgated within regulatory agencies in belief that unsuccessful projects will be eliminated if the standards requirements are observed. They reason that both over and underdesign will be prevented by this action. Conversely, the view of the specialist engineering consultant is that standard design requirements prevent innovation; result in overdesign, thus higher cost; and, most seriously, may result in project failures and deficiencies if blind acceptance of design data results in inadequate consideration of actual circumstances.

Pilot studies are sometimes used to develop more specific design criteria. These are usually justifiable for only large scale projects where substantial capital, and operations and maintenance cost savings may be anticipated. Otherwise, inflation over the time delay involved may consume potential cost reductions. A stronger case can be made for pilot studies where such work is needed to prove out methods as applied to different wastes or where more conservative designs cause non-financial impacts as well.

To design a facility for which neither good operational data nor pilot plant data are available the engineer must make many decisions based on assumption. If he assumes a conservative point of view large sums of money may be expended on a design with unnecessarily large capacity. Currently, if the engineer uses design data which would result in less capacity, he runs the grave risk of liability with no benefit to himself and little to his client.

A simple example of using optimum design data to minimize the cost of construction follows: Consider primary sedimentation tankage for a given facility. A "standard design" figure would be an overflow rare of 0.38 $L/S/m^2$ (800 $gal/day/ft^2$)[3]. Assume an arrangement whereby 4 tanks each 27m diameter (72') would be provided for this design. Now consider the situation in which the engineer believes that a higher overflow rate may well prove acceptable. Suppose a rate of 0.51 $L/S/m^2$ (1,070 gpd/ft^2) is felt applicable, with 3 of the 4 tanks referenced above to be constructed. The design data is set forth in Table 4. Assume that in the 3 tank situation the engineer has made all necessary provisions for the addition of a fourth tank, and, therefore, no significant engineering cost savings are realized in designing three rather than four tanks. Under these conditions the cost of constructing a fourth tank under a separate contract would be around $170,000.

Now let us review the financial situation outlined in Table 5. The engineer will save $12,000 for his client. Regulatory agencies, with minimal direct involvement in the decision making process, stand to save approximately $100,000. In the event that during initial plant operation the need for the fourth tank is identified, the Municipality might well be required by the regulatory agencies to construct the additional facility with no grant funding and cost to the city of $170,000.

TABLE 4. COMPARATIVE COSTS OF SEDIMENTATION TANKS

	Conventional design*		Optimum design	
	Metric	English	Metric	English
Plant flow	570 l/s	13 mgd	570 l/s	13 mgd
Tank overflow rate	0.38 l/s/m^2	800 gpd/ft^2	0.51 l/s/m^2	1,070 gpd/ft^2
Tank diameter	22 m	72 ft	22 m	72 ft
Number of tanks	4	4	3	3
Cost*	$615,000	$615,000	$505,000	$505,000

* Based on data from Areawide Assessment Procedures Manual, Report EPA-600/9-76-014, July 1976, Appendix H.

TABLE 5. COST APPORTIONMENT

Agency share*	Conventional design	Optimum design	Difference
EPA (75%)	461,000	379,000	82,000
State (15%)	92,000	76,000	16,000
Municipality (10%)	62,000	50,000	12,000
TOTAL	615,000	505,000	110,000

* Assumed distribution, proportions vary state to state.

To recapitulate:

1. Regulatory agencies would stand to gain $90,000 and lose nothing.

2. The Municipality would stand to gain $12,000 and lose $170,000.

Nevertheless, engineers continue to provide the most cost-effective solution, even if this involves going outside "standard" design limits occasionally. Obviously, regulatory agencies, who stand to gain the most financially from optimum design, should actively encourage both Municipality and Engineer by eliminating the disincentives outlined above. Section 4 includes a discussion of supplemental Step 3 grant funding to cover a situation where the engineer has indicated to EPA during Step 2 that abnormal design data are being adopted. This provision reflects innovative technology provisions of the 1977 Amendments to P.L. 92-500.

Acceptance of New Design, Methods and Materials

The incentive for acceptance of new ideas is that they may either reduce cost and/or improve performance. Since conservatism prevails in the wastewater field, acceptance of new designs requires substantial support from all members of the team: regulatory agencies, designers, clients, equipment suppliers, and contractors. Economic incentive, the prime mover in accepting new ideas, is direct for the grantor, client, equipment supplier and the contractor, while it is indirect or even negative for the designer, who is responsible for specifying new, lower cost design. Recognition and resolution of the negative position of the designer is essential if the full benefit is to be obtained from new developments. There ought to be more incentive for the engineer to develop and use new design ideas.

Design for a Maximum of Prefabrication, Precasting, Standardization

All contractor's personnel and all consultant's construction personnel interviewed express the opinion that cost saving could be obtained by maximizing use of prefabrication and precasting. Contractors often saw potential saving in contracts, but were unwilling to adopt the lower cost methods because the burden of redesign was placed on them. To maximize savings potential the original designer must, from the earliest stages, incorporate concepts of prefabrication/precast techniques into the design.

Both contractors and owners were concerned about specialist; nonstandard items that were specified in the design when "off-the-shelf" items would have served the same purpose.

Degree of "Openness" or "Tightness" of Specifications

Contract specifications provide the pathway from the design to the completed contract. Together with the contract drawings the specifications form the legal documents on which the contractor bases his bid. Once bids are accepted, these documents provide the designer and the client with legal backup in case of any inadequacies in the product due to contractor's irresponsibility, and the contractor with similar controls over his subcontractors and suppliers.

An "open" specification is one where the Contractor is informed of the end results he is to achieve in the finished product, as well as the quality control specifications for materials used in its construction. The Contractor is free to choose by which method he will arrive at the end result. Naturally, he chooses the method most economical to himself. However, provided it is clear at the time of bid that this freedom of choice exists, he will pass some or most of the savings on to the owner at the time of bid.

A "tight" specification dictates to the contractor precisely what he is to provide, whether as a construction sequence or in the purchase of equipment. This restricts the contractor's ability to use his construction experience "know-how", and his ability to use available equipment is prejudiced. In equipment purchase his biggest cost reducer, bargaining power, is severely curtailed. From the owner's viewpoint, "tight" specifications provide him with easy assurance of quality, although at a potential cost premium.

It must be made clear that "open" specifications do not imply incompleteness. Nor is an "open" specification an abrogation by the engineer of his responsibilities. It is a method by which the contractor can apply his unique combination of experience, manpower and equipment to provide the most economical solution for a given problem. An example is the construction of a deep pumping station in wet ground. One contractor, equipped with equipment and knowledge for well point dewatering from a previous project, may be able to offer a competitive price for a cast-in-place structure. Another, without such equipment, may be able to construct a caisson more economically. A "tight" specification around one or the other method has obvious limitations over an "open" specification defining the finished product only.

"Open" specifications require careful preparation by the engineer. If alternate schemes are proposed by contractors, detailed evaluation of their feasibility is often necessary. Tight specifications are most economical for the engineer to prepare. When pressure is applied to the engineering profession for competition on a fee basis, the net value of open vs. tight specifications and similar practices must be taken into account.

Effect of "Or Equal" Clause

The concept of specifying mechanical equipment using at least two manufacturers names and the words "or equal" is now generally accepted. One remaining exception exists; agencies are permitted to standardize new equipment with existing operational units, for the purpose of simplified maintenance. In addition, cases occur where the engineer knows of no equal to the particular equipment desired. Provided this is documentable, EPA will accept single source supply.

The viewpoint of equipment suppliers is that the present system does not sufficiently protect reputable manufacturers from suppliers who succeed in meeting the letter of the specification while still producing substandard equipment. We accept this, but, rather than returning to past methods of bidding, we feel this is best guarded against by tightening specifications as necessary. In most instances, the more experienced consulting firms have developed their own standardization of specifications which prevent substandard equipment substitution.

Contractors point to the occasional yet continuing use of proprietary specifications where no reasonable alternative is available, or where proprietary patented items are called for, or where relatively unimportant features are required that are standard for one manufacturer yet non-standard and expensive for competitors to provide. One example cited to us by a manufacturer relates to an item of industrial machinery specified in a non-EPA related project. The owner required certain features which restrict the contractor to purchasing from one manufacturer. Quoted cost was $90,000. The contractor was also involved in a similar project in another state requiring identical equipment. Here competitive, or "open", bidding was permitted. The same manufacturer who quoted $90,000 on the first project was low bidder on the second project at a bid price just under $50,000.

More generalized information quoted by a construction contractor was as follows:

Number of Bidders	Cost as %
6 or more	100
2	120
1	up to 200

As associated cost item to contractors (and ultimately, therefore, to EPA) is a provision in contracts that suppliers be listed with the bid and not be changed without the consent of the owner. Contractors argue that this enables suppliers, who have given a firm price at bid time, to refuse to accept all of the terms of the contractor's contract with the owner, such as warranty requirements or spare parts, which will then be charged as extras if the Contractor's negotiating position is eliminated. Conversely, suppliers argue that "bid shopping" by the contractor cheapens the equipment supplied by forcing a lower price on the supplier.

Engineer Liability

Concern about engineer liability is one more factor in the maintenance of engineering as a conservative profession. The desire to limit their liability has inhibited engineers from the initial acceptance of new ideas without the benefits of proven installations. Sharing of this liability by clients and/or funding agencies where new and/or improved methods appear cost attractive will encourage their implementation and potential cost savings.

Regulatory Agency Cost Reduction Programs

The EPA, in recognition of the escalating costs of achieving the goals of P.L. 92-500, has instigated two specific programs in addition to their normal review roles. Namely, Value Engineering and utilization of Corps of Engineers staff for construction inspection duties.

Value Engineering is a technique developed originally by the General Electric Company and subsequently adopted by the military establishment and the Corps of Engineers. Value Engineering is a systematic approach to obtaining optimum value for money expended. The EPA has made value engineering mandatory at the Step 2 design phase for all projects exceeding $10 million. Review of value engineering analyses conducted as part of the EPA mandatory requirements shows documented cost savings, in addition to functional improvements. It was the opinion of all value engineers interviewed that even greater cost savings could have been achieved if the value engineering had been conducted at the Facilities Plan Step 1 phase allowing the addressing of basic concepts. Although this is not official EPA policy, in a few cases Step 1 value engineering[4] has been funded by EPA.

To provide close inspection of the construction phase the EPA has contracted with the Corps of Engineers to provide construction inspection personnel. Both owners and design consultants were concerned that transferring inspection responsibilities to an outside agency would result in EPA staff being even more remote from real world problems, and thus costs of construction. Other concerns were expressed relating to the responsibilities of inspection personnel making construction related decisions. It was the opinion of designers and contractors that the additional inspection layer would not reduce construction costs, and could result in overall cost increases due to the inclusion of an additional administrative layer.

Grant Funding Eligibility

Public Law 92-500 provides grants of 75 percent of eligible project costs, not total project costs. The decision of project eligibility is made at the local EPA level by EPA staff specifically assigned to the project. Eligibility rules and guidelines have been promulgated since the inception of the grant program to provide guidance to both owners and regulatory agency personnel alike. However, final eligibility is based on the judgment of the local reviewers. Because of the differing interpretations, inequities have resulted between different owners.

Owners and designers quoted examples of eligibility decisions not being finalized until completion of contract drawings. (Indeed, EPA is not committed to make final eligibility determinations until final audit stage.) The delay of eligibility determination has resulted in higher than expected local costs, and then subsequent delays while non-eligible items were either modified or deleted to match the locally available funds, or while arrangements for revised fundings were made. The cost of delay can exceed the original "non-eligible" items. It was suggested that project eligibility should be determined and agreed upon, in writing, by all parties at the 10 percent design stage.

Contract Programming Techniques; Turnkey, Fast Track, Pre-Ordering

The majority of wastewater contract funded under P.L. 92-500 are implemented in a series-stepped fashion consistent with the 3-step grant program. Contracts are awarded for each step with specific contractor responsibility ending on the termination of that step. This approach is shown schematically in Figure 3.

Problems of this type of bidding include: delays between steps; difficulty in identifying who is responsible in the case of errors; and at the end of the project the owner has no guarantee of plant performance.

Suggestions made in interviews by owners, consultants and contractors to address shortcomings of the existing system were to consider the forms of contracts used by industry for construction of process and waste treatment facilities, namely "turnkey" and "fast track".

Turnkey--

Contractually "turnkey" provides the owner with a complete service from detailed design through construction and startup. Turnkey projects normally guarantee performance of the product. Only a few larger U.S. design/construction companies are at present offering such services, because of the greater risk involved in this type of contract. However, one of the contractors who was contacted expressed interest in creating joint ventures with established consultants to offer "turnkey" services. Engineers and many municipalities have always been anti-turnkey due to the difficulty in obtaining specification and quality control by the owner.

Fast Track--

The major feature of "fast track" technique is the overlapping of the Step 2 and Step 3 phases. Responsibility of administering the Step 2/3 phase is assigned to a contract manager. Advantages of this technique are:

1. It compresses the design/construction period.

2. Eliminates owner from designer/contractor conflicts.

3. Owner and funding agencies only have to deal with one area of responsibility -- the contract manager.

The fast track approach can have the very serious disadvantage of removing the owner from the decision making process as regards to design features and quality of construction.

Another bid area identified that has potential for cost savings is in flexibility for pre-bidding major equipment items.

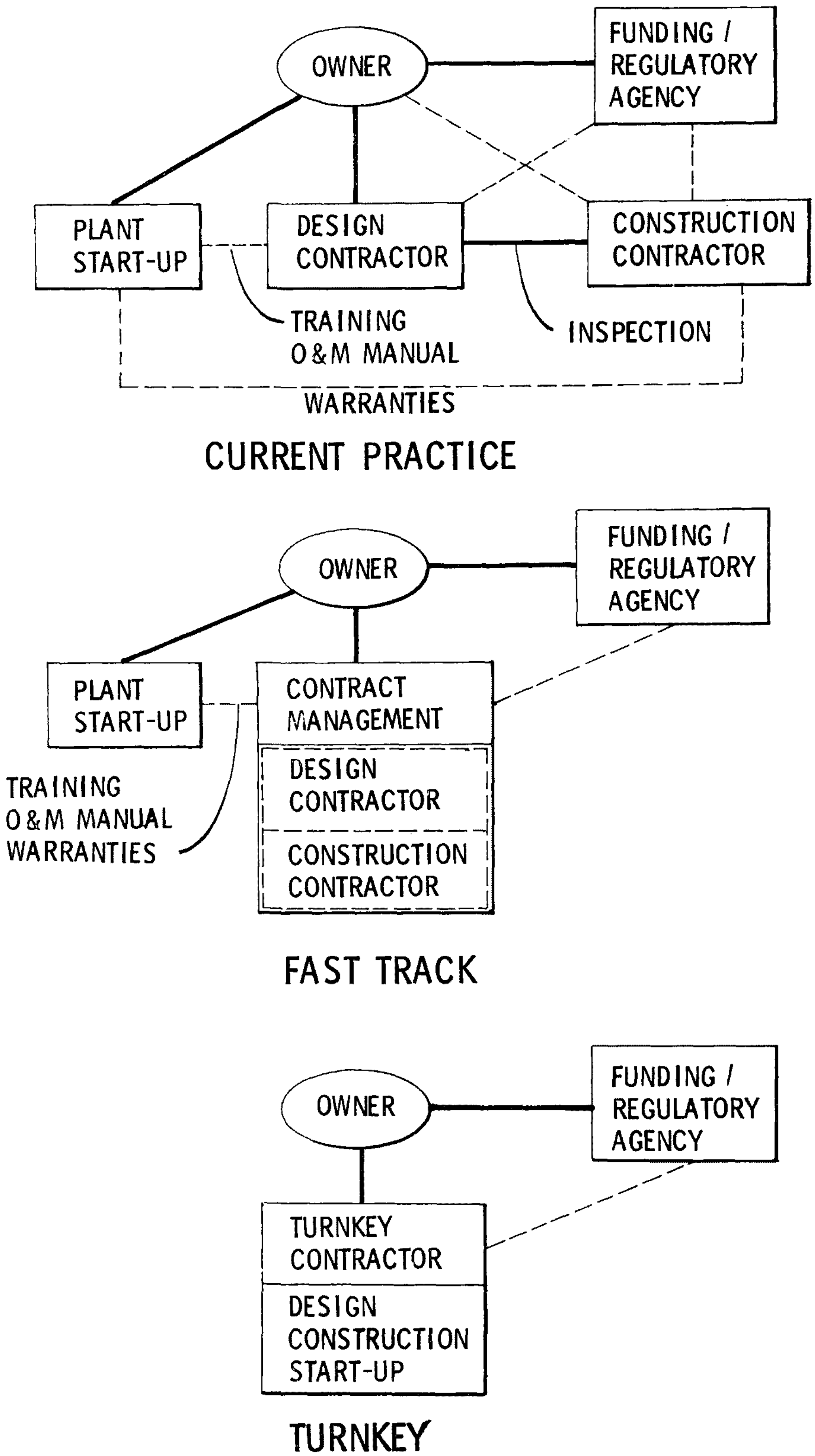


FIGURE 3. CONSTRUCTION MANAGEMENT ALTERNATIVES

This approach can address two areas:

1. Where equipment delivery time exceeds contract time.

2. Where selection of a specific equipment allows optimization of building space and ancillary equipment.

Time of Year Contract is Bid

The significance of bid timing on cost is determined by the question - "on contract award can the contractor proceed directly into his normal construction schedule?" Any bid period that is not synchronized to the contractor's ability to build will be reflected in the bid price. Seasonal influences on job characteristics are summarized in Table 6. Actual cost impacts identified in Table 6 will vary with specific area construction seasons. Contracts in southwest states with minimal winter disruption will have less cost significance if bid outside normal bid periods.

TABLE 6. IMPACT OF TIME OF YEAR OF BID

Type of job	Construction period	Favorable bid time	Rationale	Cost impact
Earthwork, subgrade	One year or less	Start of construction season	Construction sensitive to groundwater and weather conditions	High
Earthwork, subgrade	Multi-year	Start of construction season	Construction sensitive to groundwater and weather conditions	.w
Superstructure	One-year	Start of construction season	Construction sensitive to weather	Medium
Superstructure	Multi-year	Start of construction season	Construction sensitive to weather	Low
Equipment installation	One-year	End of construction season	Contractor has low work orders and is not restricted by weather	Medium
Equipment installation	Multi-year	Any time	Weather is not a factor	--

As an example, a six month earthwork subgrade contract recently bid at the end of the regular construction season for Corvallis, Oregon resulted in a bid of approximately 17 percent over the price that was subsequently obtained for the start of the next construction season after the first bid had been rejected.

Bid: Periods, Times (Other than Calendar), Types

The primary objective of the competitive bidding process is to obtain a prespecified product at the least cost. Rules, regulations and procedures related to the bidding process have the objective of making the process honest and of eliminating unfair advantages.

Current practice is to inform potential bidders by advertisements in trade journals and personal contacts. Lead time before bid openings varies from 4 to 12 weeks depending on job size and complexity. Sealed bids are received up to a pre-set time and then opened in public. On opening bids are checked by the client's representatives and funding agencies to ensure the potential low bidder is responsive to numerous bidding requirements; such as performance bonding, insurance, affirmative action, relationships with equipment suppliers and subcontractors. Any irregularity is normally considered non-responsive to the bid and disqualifies the bidder.

Lead Times--

All contractors were content with bid periods provided on EPA funded construction projects. It is normal practice for contractors in competitive situations not to arrive at a bottom line price until a few minutes before the bid deadline. Contractors expressed the desire that the bid deadlines of similar contracts within an area should be coordinated by owners and their consultants to minimize overlapping bidding periods; for smaller jobs by state, and for large jobs by region (e.g., West Coast). Few contractors maintain large estimating staffs and normally bid a job by utilizing staff from ongoing construction jobs.

Bid Type--

In an attempt to obtain the lowest price a number of bidding methods have been adopted including lump sum, unit price, and itemized major equipment plus lump sum. Supporters of the unit price method claim that bid unit rates provide the basis for subsequent contract change orders as opposed to the lump sum method where all prices have to be negotiated. Contractors were shown detailed "bill of quantities" bidding lists as prepared for European construction contracts to compare with lump sum North American documents. Their opinion was that bid prices would not be lower with this type of bidding approach.

Time Duration Allowed for Construction

Traditionally the responsibility for selecting the duration of a specific contract is with the designer. The allowable contract time is identified in the contract bidding documents, along with liquidated damages that will be assessed by the owner for each day required for project completion beyond the allowable period. The degree of difficulty/risk in completing the contract will be reflected in the contractor's price.

Contract periods are often selected on the basis of empirical rule of thumb methods based on the estimate of contract cost and previous experience. Contractors and/or construction consultants also provide useful inputs.

Deviation from this practice, in the wastewater field, would be when the city is required to meet specific effluent quality limits at a date earlier than would be required for construction in normal circumstances. Any compression of the contract period that involves regular overtime, shift work and overlapping of trades will increase contract costs. Of those contractors who were willing to offer a cost penalty the range ventured was 0 to 10 percent.

The contract time allowed should take into account the time of the bid, since jobs that are bid at the end of the construction season will normally be unable to start until the next construction season. For smaller short-term contracts this could drastically reduce the available working time within the allowed time frame. An additional factor to be considered in bid time/contract duration is the time of year the contract will be complete to allow plant startup and testing. For severe weather conditions (specifically cold), problems with freezing can delay startup/testing through to the next construction season. The difficulties related to winter startups will be reflected in the bid price.

Contractor's Reaction to Inspection Requirements and Methods

Within a specific region, owners, architect/engineering consultants and contractors build up a reputation. Contractors are very aware of owners particular areas of concern, consultants contract documents and their inspectors interpretation of those contract documents.

In interviews with contractors, each contractor quoted specific owners and engineers, who in their experience, either made the work easier or more difficult. To obtain the lowest bid for a specific job it was the contractor's opinion that contract documents should be clear, free of loose interpretations, and that inspectors interpretation of the documents should be consistent as well as flexible where final product quality was not affected. Contractors quoted increases of one to five percent on their bid prices in anticipation of difficulties with particular contracts.

Prevailing Labor Rates Including Government Requirements and Regulations

A requirement of all EPA funded projects is that contracting staff be paid union wage rates applicable to the contract location. Other government requirements include worker/public health and safety standards, affirmative action, environmental constraints (noise, air pollution, etc.), and detailed reporting requirements to allow policing of the rules and regulations.

Union contractors by definition pay union rates; only non-union contractors have the option to pay less than union scale wages. In discussions with non-union contractors they indicated that their pay scales equal or exceed union rates. Thus there did not appear to be any cost saving by eliminating the minimum wage scale requirement. The non-union contractor competitiveness is due to his greater work force flexibility, not lower pay.

Other government requirements such as the reporting requirements do impose a cost burden on the contractor. For a small job the additional staff required to satisfy these needs can represent up to 5 percent of project cost.

Magnitude and Distribution of Labor Skills

Construction of wastewater treatment facilities requires specific contractor experience, however it does not require specialist skills outside the range provided by contractors in their other contracting business. Generally, contractors within an area have no problems hiring the necessary skilled labor. Contracts that exceeded the capabilities of local contractors would, by virtue of their size, attract regional contractors with the hiring power required to undertake the work. Contractors interviewed did not see the labor skills market as a significant factor in their bid price.

Distribution of Construction Trades Required

Modern treatment plants can involve a complete range of construction skills. The more complex the design the greater the number of disciplines required. Contractors did not feel that this was an item that had significant impact on contract prices. Most contractors import most of their labor so their bid prices already include costs for employee travel time and per diem expenses.

Certain trades do command higher renumeration than others. For example, plumbers earn more than iron workers. However, by the nature of wastewater facilities, certain skills are required regardless of their relative cost. Cost savings will always be made if the design provides for simple, fast construction regardless of the trades involved.

Effect of Labor Negotiations for Rates, etc.

Labor contracts are for discrete periods of one, two and three years depending on the specific trade. There is not a common period for contract expiration; the dates of each trade reflect historic events. Thus for most contracts at least one of the involved trades will be involved in negotiations for a new contract, which in all past cases, has resulted in an increase in base wages or benefits or both.

The contractor, when preparing his bid, has to make an estimate on what he thinks the increase will be and develop his price accordingly. An alternative to letting the contractor estimate the increase, which could result in either overcharging the owner or reducing the contractor's profit, is to introduce escalation clauses into the contract. This would allow the bid price to increase by the amount of the increased costs resulting from the new contract. The majority of contractors opposed this alternative as being inflationary, as well as taking away their ability to make their own judgement.

It was the contractor's opinion that they have a close feel of what the increases will be, and, as such, future labor negotiations do not result in bid padding to cover unexpected costs.

Size of Project, Level of Competition

Every contractor has a preferred contract size range. The lower limit of the preferred range is governed by overhead; generally the smaller the contractor the lower his overhead rate. A large contractor is, therefore, at a cost disadvantage to a small contractor when bidding small projects. The upper limit of contract size is defined by the bonding limit of the contractor. This upper figure does vary with amount of work under contract, which defines tied bonding capacity. As an example, a mid-sized general contractor specializing in water/wastewater construction may bid competitively on projects between $1,000,000 and $15,000,000.

Some contractors extend the upper limits of their bonding capabilities by the formation of joint ventures with other companies. For example, bids for a major regional wastewater treatment plant[5] (low bid $147,500,000) were received from six bidders, five of whom were joint ventures and the other being a co-partnership.

In general, contractors felt that competition at all levels, over say $1,000,000,was adequate; in the event that more competition is needed in any area it is automatically provided by the industry itself. For smaller contracts, conflicts with peak summer construction should be avoided.

Equipment Cost and Availability - Standard Equipment

With the exception of sewer systems, all wastewater facilities include at least one item of purchased equipment. To the contractor, equipment involves four basic costs, namely:

1. equipment purchase,
2. equipment storage prior to installation,
3. equipment installation, and
4. equipment startup and testing.

The specific contribution of each cost element on the installed equipment cost will vary widely with the specific equipment item. For complex, close tolerance equipment the initial purchase price will represent the greatest cost, where as for lower cost equipment startup and testing could represent the greatest cost.

Equipment Purchase--

For all bidding conditions the contractor is free to shop the market to obtain the least cost; except for bids requiring the prices of major equipment items, and where no "or equal" provision is made. In many cases this is a lower cost than the contractor used in preparing his original bid. The lower cost the contractor obtained, he did so by virtue of his position in the equipment manufacturing industry's market. The exchange that takes place at that time is an expression of the contractor's role in the economic system; that being the owner's agent for buying equipment. As a result of this, owner-contractor relationship, cost saving is not directly passed on to the owner.

Equipment Storage Prior to Installation--

Most equipment is sensitive to the elements and requires covered storage. Certain equipment requires storage in a controlled atmosphere. Storage is a cost to the contractor. The option of storage at the place of manufacture, or off-site in a warehouse, is often precluded as payment on the equipment will only be made on delivery at the site. For sensitive large equipment pieces storage costs can be significant; for example, $0.20/cubic feet per month.

Equipment Installation--

Equipment installation is the emplacement of equipment in its proper position and in working order prior to plant startup. Installation involves securing the piece of equipment to a base, and then hooking up the appropriate process piping, power and instrumentation lines. The more complete and self contained the equipment, the less work and cost there is for the contractor. Care ought to be taken to specify controls normally supplied as a part of the equipment in order to save unnecessary costs.

Equipment Startup and Testing--

Equipment manufacturers usually provide some startup assistance; such as an on-site representative, training, manuals, and slide and topic shows. The further cost of these services is included in the purchase price. Startup and testing time can be reduced to a minimum by standardizing such ancillary control equipment as motors, equipment power drains, controllers, alarm systems, and instrumentation.

Any disruption of the contractor's normal construction sequence will involve increased costs. Due to the rapid increase in demand for wastewater control equipment difficulties were being experienced in obtaining deliveries within the contract period. Fortunately, delivery problems and long lead times experienced two and three years ago are being reduced as manufacturers increase their production capabilities. However, any large electro-mechanical piece of equipment will require a long lead time. This is especially true of one requiring interfacing with safety and control instrumentation devices, and control panels. Examples of long lead items are: large electric motors; engine drives; turbines; dewatering equipment, such as centrifuges, filters and presses; chemical oxidation systems; and computer systems. For these items prerequisiting long delivery times, pre-ordering addresses directly the problem of disrupting the construction schedule.

Equipment Supplier Bidding Requirements - Subcontract and General Contract Aspects

Under existing bidding operations guidelines the owner may require at the time of the bid, the identification of the manufacturer of specified equipment and its price. Equipment manufacturers generally prefer the inclusion of the identified manufacturer requirement because it prevents the contractor from equipment shopping after he is awarded the contract. Conversely, contractors prefer no listing. They claim that post bid shopping enables them to obtain the lowest price possible for equipment. General contractor opinion was that full flexibility should be given to the contractor in his dealing with equipment suppliers and subcontractors, commensurate with his overall contract responsibilities.

Competition in the Construction, Equipment and Suppliers Markets

Stock market analysts, industrial marketing experts, contractors and members of the sanitary engineering community projected the increase in demand that the passage of P.L. 92-500 would have on designers, suppliers, contractors and equipment manufacturers. The increase in production and product range has been in concert with increased demand. Consequently, even with high demand, competition within the industry has increased. However, there are exceptions to this; for example, motor control panels. The effect of competition in the market place is to encourage efficiency and thus lower costs.

Use of CP, PERT by Owner and Contractor

To meet tight deadlines major military contractors during the '40s and '50s developed sophisticated "critical path" or "pert" techniques for programming job progress. These sophisticated methods are being used in ever increasing number in the implementation of wastewater projects. In some cases they are prepared by the owner and in other cases by the contractor.

Most contractors did not use "Critical Path" or "PERT" techniques as they were not compatible with their needs. Contractors preferred and used simpler techniques. And if CP or PERT systems were required as part of the contract it became an additional overhead cost with little, if any, benefit. Concern was expressed by some owners that contractors were using the CP/PERT program as a claims tool. Any action by the owner or his representative that could be interpreted as a modification to the CP/PERT program was considered justification for a delay and thus cost claim.

Owners and contractors alike agreed on the need for a common planning method. However, to be useful and thus have cost saving potential it must be designed to address the needs of the wastewater contractor, not just copied from some other industry.

Change Order, Construction Delays

Most owners set aside a certain amount to cover change orders. The amount can vary from 1 to 20 percent dependent on the type of job. Procedures for the instigation of a contract change order are included as part of the contract bid documents. What is not included is the cost of the change order. This is customarily negotiated individually between the owner's representative and the contractor. Change orders can either reduce or increase the scope of work and thus the contract price. For increased scope of work a change order has two costs; one related to the additional work, and the other is potential delay caused by disruption of the contractor's schedule.

Excluding "turnkey" contracts the best way to reduce the number of change orders is to provide sufficient Step 2 design time and utilize competent experienced design contractors. An investigation of contracts let by a major sewerage utility[6] over 10 years indicated that change orders represented 15 percent of their completed facility costs.

SUMMARY OF NON-STRUCTURAL FACTORS

The potential impact of non-structural factors on final construction costs was described under twenty-nine sub-headings in the previous sections. The impact of these items on influencing construction costs are identified in Table 7. Specific recommendations for implementing changes in areas that have a significant impact on construction costs are identified in Table 7 and described in depth in the next Section.

TABLE 7. IMPACT OF NON-STRUCTURAL FACTORS

Item no.	Non-structural item no.	Construction cost change (%)			
		<5	5-10	10-20	>20
1	Effluent limitations				●
2	Pre-grant, post-grant time delays		●		
3	Source control		●		
4	Plant location	●			
5	Consultant fee structures	●			
6	Conventions of engineering practice			●	
7	Standard design requirements		●		
8	Acceptance of new design ideas	●			
9	Design for prefabrication/standardization	●			
10	Specifications strictness/looseness	●			
11	Effect of "or equal" clause	●			
12	Engineer's liability	●			
13	Regulatory agency cost reduction program	●			
14	Grant funding eligibility		●		
15	Construction management alternatives	●			
16	Time of year contract is bid	●			
17	Bid - period, times and type	●			
18	Time duration allowed for construction	●			
19	Contractor perception of inspection requirements	●			
20	Prevailing labor rates	●			
21	Magnitude and distribution of labor skills	●			
22	Distribution of construction trades	●			
23	Effect of labor negotiations	●			
24	Size of project	●			
25	Equipment cost	●			
26	Equipment supplier bidding restrictions	●			
27	Competition in construction and equipment field	●			
28	Use of CP, PERT scheduling tools	●			
29	Change orders, construction delays		●		

REFERENCES

1. Amendments passed by Congress in December 1977 provide some flexibility for marine discharges.

2. An Analysis of Planning for Advanced Waste Treatment (EPA 68-01-4338).

3. Areawide Assessment Procedures Manual, Appendix H.

4. City of Anacortes, Washington.

5. Regional Wastewater Treatment Plant, Sacramento Regional County Sanitation District.

6. Municipality of Metropolitan Seattle, Washington.

SECTION 4

PROPOSED NON-STRUCTURAL SOLUTIONS

PROCEDURAL OR OTHER NON-STRUCTURAL ASPECTS

Section 4 presents a series of proposals for EPA consideration which are aimed at procedural and other non-structural aspects of the wastewater facility construction grant program. Many of these proposed solutions are derived from conclusions developed in Section 3. In some instances, direct EPA action would be appropriate. In other instances, further research work should be considered before proposed solutions are implemented.

The principal focus of recommendations is cost reduction in the construction phase of the grant program, which is the main consideration of this portion of the study. Other factors are also referenced in the text. These other factors are considered since they can be as important as capital cost reduction alone. Proposals are ordered to follow approximate chronological sequencing through the project stages of planning, design, bid, and construction.

RECOMMENDATIONS

Expansion of the Planning Phase

The federal grant program supporting construction of wastewater treatment facilities is one of the larger federal public works programs. Although control of water pollution is the principal objective of this program, there are many other goals and objectives tied to it. Some of these, like the requirement for industries to bear the cost of treating their own wastes, are imposed by P.L. 92-500 itself. Further goals and objectives, such as environmental impact or equal opportunity and fair wage rate requirements, are imposed by other federal laws. State and local laws, regulations and related policies may impose requirements in addition to those found in federal rules. Finally, it may be convenient and desirable to plan multi-purpose facilities in order to economically achieve several related objectives. Examples of such common multi-purpose projects range from the development of recreational facilities and open space corridors along rights of way, to the generation of electrical power using sewage solids and municipal refuse as fuel.

Project Implementation Plan--

Because of the need to comply with the myriad of legislative and procedural requirements, even the smallest projects would be expedited by the development of a clear concise project implementation plan. This project implementation plan should be developed as soon as possible after a decision is made to prioritize a project for funding. A three-part recommendation has been formulated to meet this goal. Although the first part of the recommendation is most important, each added part would enhance the workability and effectiveness of the recommended approach:

1. A project implementation plan should be developed as soon as possible after a decision is made to place a project on state priority list for funding. This plan should include: (1) a clear description of each federal, state and local requirement which must be complied with to plan and construct the proposed facility and place it into operation; (2) for each such requirement, a description of the project features, activities, reports, public hearings, etc. that will be undertaken to comply with the requirement; and (3) for each activity, report, hearing, etc. identified, the assignment of responsibility, timing, budget and source of funds to accomplish it.

2. Costs for project features and implementing activities should be distributed equitably according to the nature of the requirements and purposes to be achieved.

3. Maximum flexibility should be preserved for grantees to plan multi-purpose projects to meet local needs by encouraging incorporation of compatible projects with the facility plan which can be associated with pollution control efforts, and therefore, receive added community support; examples, recreational facilities, open space corridors and energy recovery projects using municipal refuse and sewage sludges.

As previously indicated, the second and third parts of the recommendation are separable.

It should be emphasized that the project implementation plan would not be a conclusive document like an Environmental Impact Statement. Rather, it would be a working plan, setting forth (among other things) what NEPA requirements are, and how such requirements would be complied with during the facility planning phase.

Cost Saving Features--Several cost saving features would occur as a result of adoption of this recommendation. The first, and most important, is that the project would be placed on a critical path implementation schedule. This would act to reduce overall implementation time to the practical minimum. However, it would also guard against compressing critical actions (such as the detailed engineering design) into excessively short time intervals. Second, it would result in quantification of the actions to be taken in order to comply with requirements by a given project.

Depending on the size, location and complexity of a project, thirty or more major laws and regulations must be complied with. Without careful planning and documentation, endless delays can be caused by the failure to deal with one or more of these requirements in a timely manner. In other cases, similar delays can result from differences of opinion over the adequacy of consideration given, actions proposed, or measures provided to meet requirements. Such potentially costly delays could be avoided by interactive planning and negotiations done well in advance of design and construction.

Both the requirements and the action plan for dealing with them would be developed in the implementation schedule. Differences with responsible agencies could be resolved in advance so that facility planning and construction could proceed expeditiously. The EPA Region IX program for dealing with archeologic sites, and the California program (AB-884-Dec 1977) for dealing with California Environmental Policy Act requirements and state regulatory approvals exemplify how this approach would work.

Another important benefit of this approach would be to improve the effectiveness of meeting all applicable requirements. For example, compliance with fair labor standards and equal employment opportunity requirements. In each case, the Project Implementation Plan would call for a specific plan of action to be developed. Responsibility for these action plans would be useful to the grantee or to the grantee's agent for project management. Federal and state responsibility would not be delegated! Rather, the federal role would become one of auditing performance to insure that: (1) planned actions were taken; and (2) results expected to be achieved by taking the planned actions were actually achieved by taking those actions.

Summary--The project implementation plan would be an overall work plan, schedule and budget for planning, design and implementation of the project. Implicit in the approach is: (1) definition of each result to be achieved, (2) development of a specific set of actions to achieve that result, (3) assignment of responsibility for each action, and (4) establishing the financial, administrative, audit and control procedures.

Attention would also be directed to: (1) minimizing the overall schedule; (2) insuring that adequate time was provided for critical elements of the process, such as design; and (3) insuring that adequate resources were devoted to meeting related goals such as construction inspection, value engineering and equal opportunity compliance.

Equitable Cost Distribution--

A second part of the recommendation is that costs be distributed equitably between federal, state and local interests considering the nature of the requirements and goals of the project. This recommendation would be implemented by: (1) identifying separate goals and requirements as previously discussed; and (2) expanding the facility plan to include an economic evaluation/cost allocation section. This section would be similar to comparable sections in project plans for major federal water resources projects. The only difference is that "compliance with requirements" would be treated as "benefits" in cost allocation calculations. A brief discussion of the process envisioned follows.

The first step in developing cost allocation would be to define a base case project. A base case project is one which would meet all requirements directly related to the national water pollution control effort at a minimum life-cycle cost. Water quality related goals include such things as treatment requirements, discharge requirements, water quality standards, inflow-infiltration requirements, etc.

The second step would be to formulate the economic alternative project. This would be defined as the project which met <u>all applicable requirements</u> at the minimum life cycle cost. Any incremental costs (over and above the base case project cost) would be allocated among non-water pollution control purposes. This allocation of incremental costs between federal, state and local interests would be on the basis of standard economic procedures for cost allocation.

To implement the proposed recommendation, federal pollution control requirements would be considered first in the cost allocation procedure. The federal cost share for the project would be based on: (1) the standard formula in the enabling laws applied to base case costs (e.g., 75 percent of the base case cost); plus (2) 100 percent of the cost allocated to meeting other federally imposed requirements, as determined from the cost allocation calculations.

The basic purpose of this part of the recommendation is to identify and define the federal requirements and responsibilities as the first step toward implementing the overall recommendation. The formulation is based on two assumptions: (1) that federally imposed mandates are for the widespread general public benefit; and (2) that standard procedures developed for other similar federal water programs should be applied (rather than developing new and unique formulas and procedures).

Another benefit would be derived from this part of the recommendation. A record of the cost of compliance with various federal, state and local mandates which are not related directly to water quality would be developed. The approach would also insure that waste water dischargers do not pay (through user charges) for cost of meeting unrelated goals.

Cost saving and expediting benefits would also result from the cross-walking of legal, administrative and financial responsibility. Often delays are incurred, and resentment generated, because requirements are imposed on the grantee without a clear definition of: (1) what is required; and (2) how implementation of the requirement is to be financed. Cooperation, understanding and more rapid progress toward attainment of all goals will be achieved by addressing this problem directly.

A third part of the recommendation is to preserve maximum flexibility for planning of projects to meet local needs. The basic purpose of this recommendation is to permit formulation of multi-purpose projects which also address important local priorities. This will insure the grantee's active interest in promoting the project, and working diligently to negotiate solutions to any problems that may arise. For example, suppose a community with high unemployment is being mandated to divert scarce local funds into water pollution control. It might be possible to formulate a labor intensive water pollution control project alternative which met all applicable requirements. In this case, by paying the incremental cost of the labor intensive alternative (compared to the most economic alternative), the community could address its own priority needs while accomplishing the mandatory pollution control objective.

Under existing (August 1978) EPA policy, this option might not be open to the community. The reason is that only the capital construction portion of the project is eligible for grant funding. Thus, if the labor intensive alternative had a lower capital cost than the economic alternative, the federal grant would be reduced.

Implementation--Existing grant policy would need to be changed to implement this recommendation. The federal policy should be to pay the legal share of the economic alternative, as previously recommended. This should be the case even though some other alternative is actually constructed. The local cost share would be: (1) the cost of the economic alternative reduced by federal and (where applicable) by state grant contributions; plus (2) the incremental cost of the proposed alternative over and above the cost of the economic alternative. This formula should prevail even where the grantee seeks assistance from another federal source to defray the incremental cost of meeting secondary objective(s). Compliance with federal non-water quality goals imposed by law or regulation should (if the recommendation is accepted) be federally funded because compliance with these is a necessary part of project implementation. From the program overview perspective, maximum value is derived by building the most economic alternative works possible (considering the established priority ordering) as soon as possible.

Where a project meets the goals of another funded federal program, existing policy calls for sharing of all costs according to a benefits allocation procedure. The consolidated grant procedure is time-consuming. Rarely will the second federal program give the second project objective a high priority for funding. However, it is often possible to increase the priority for federal funding of the incremental cost of the secondary project purpose. This is because the effectiveness of the dollar expenditure can be increased dramatically when the second program only pays the incremental cost of the multi-purpose project. Thus, by treating fundable federal goals in the same manner as federal goals imposed by rule or regulations, multi-purpose projects would be greatly facilitated. To avoid any potential abuse of this recommended policy, it should apply only where the secondary purpose is incidental to the wastewater treatment purpose. This could be controlled by placing a ceiling on the economic alternative-recommended alternative differential. The recommended ceiling is 25 percent of the cost effective alternative cost. It would also be necessary to place a time delay limitation on this alternative. Two criteria are recommended: (1) the schedule for attainment of water quality goals should not be extended by more than 10 percent (as compared to the possible schedule for the economic alternative); and (2) the overall project could not be extended by more than one year or 25 percent (whichever is higher) beyond the economic alternative compliance date.

To implement this part of the recommendation, any secondary project purposes and their scheduling impacts would be discussed in the project implementation plan. The economic evaluation, cost allocation and detailed schedules would be presented in the amended facility plan.

<u>Evaluate Innovative Technology in Facility Plan</u>

To assure cost savings and environmental benefits of innovative and alternative technology is considered thoroughly, it is recommended that:

As soon as possible after the decision is made to consider grant funding for a proposed wastewater treatment project, an evaluation should be made to determine the appropriateness of including innovative technology in the project. Where innovative technology would appear to warrant further consideration, a detailed action plan should be developed for inclusion in the facility plan. As a minimum, the innovative technology plan should: (1) identify the innovative technology appropriate for inclusion in the project; (2) include an economic evaluation of the potential impact of the proposed innovative technology on the proposed project; (3) include a general evaluation of the impact of such an innovation on the national wastewater program; (4) include an assessment of the risk of failure of the innovative technology; (5) describe actions to be taken in the event of failure of the innovation; and (6) describe the criteria and procedures that will be used to evaluate the technical and economic performance of the innovative technology (including an explicit description of circumstances constituting failure of the technology which would initiate the failure response).

Amendments to P.L. 92-500 passed in December 1977 require grant recipients to analyze innovative and alternative treatment processes and techniques for use in wastewater treatment works. Provision is made for a 10 percent increase in federal grants to provide for 85 percent of related construction costs. Regulations for implementing these new provisions are currently (March 1978) being reviewed; such matters as the criteria for distinguishing between conventional and innovative technology are presently undelineated.

Independently, this project identified the use of innovative technology as having considerable potential benefit in the form of reducing construction cost and/or improving reliability and/or performance of waste treatment works. However, by virtue of the legal implications of performance failure, there is a strong bias toward conventional technology and proven performance criteria. The new law, if implemented in accordance with congressional intent, will do much to stimulate implementation of new cost saving technology.

The definition of innovative technology should be broad, including any facility or procedure that will: (1) reduce the cost of treatment while meeting accepted treatment criteria; (2) improve the performance of conventional treatment techniques; (3) improve the reliability of treatment; (4) reduce energy demands associated with treatment of wastewater; or (5) reduce other adverse environmental impacts (such as air pollution) associated with treatment of wastewater.

Innovative technology should be carefully evaluated to assure that benefits to the project outweigh the risk of failure of the innovation. In addition to a careful engineering analysis, it may be desirable to develop pilot processes to provide design and performance data.

Projects incorporating innovative technology with any significant risk of failure should also incorporate fall-back provisions to implement in the event of failure. For example, the plant layout should include space for conventional technology, and the hydraulic profile should accommodate conversion to conventional technology without major design changes, etc.

Finally, every project incorporating innovative technology should also address evaluation, correction in the event of failure, and technology transfer of either success or failure. To accomplish this the technology transfer action plan should define the performance objectives of the proposed innovation. Both technical and economic objectives should be addressed. A minimum for acceptable performance should also be defined in advance. If evaluation demonstrates that minimum performance criteria are not met, fall back to the conventional technology would occur automatically. To implement this process a performance evaluation program would be described in the innovative technology action plan. Upon completion of construction, the performance evaluation plan would go into effect.

At the conclusion of the performance evaluation period (a maximum time of 2 years is recommended) a determination of the innovative technology would be made. If performance failed to meet the predetermined minimum criteria, action would automatically be initiated to implement the failure response plan. An exception would be allowed in cases where a more limited modification could be demonstrated to be appropriate (e.g., where experience derived from the evaluation demonstrated that a minor modification to the innovative facility would correct performance deficiencies).

Summary--Innovative technology recommendations are:

1. Prepare a plan describing the innovation.
2. Make an evaluation demonstrating that the technical and economic benefits outweigh any risk, and that the level of risk of failure is acceptable.
3. Prepare a plan of action to implement in the event of failure.
4. Facilitate adoption of evaluation criteria and an evaluation program.

All of these features should be outlined at the earliest possible stage of a project. The description and the economic and risk evaluation should be contained in the Step 1 facility plan report. The failure response plan and the performance evaluation program should be completed prior to acceptance of the Step 2 plan and report. Implementation of the performance evaluation program could be treated as an extension of the Step 3 grant (in a fashion similar to plant startup), or alternatively as a fourth step in the grant program. Similarly, any replacement could proceed as a Step 3 grant amendment, or it could become a fifth step in the grant process.

As a final note, implementing the technology transfer suggestion would only require the inclusion of appropriate elements in the evaluation program.

Design Parameter Development

Treatment plant design is frequently based on standardized design criteria, such as the 10 State Standards, or on data from brief surveys and pilot plant studies. The high cost of construction resulting from this approach is described in Section 3. In contrast, accurate process design data for treatment plant expansion and upgrading can best be developed from extended evaluation of conditions at the existing facility. The relative cost of long-term studies undertaken by treatment plant staff would be minimal since most needed operational data are normally available. Therefore, it is recommended that:

> "In order to determine optimum design parameters EPA should sponsor evaluation at treatment plants approaching design capacity for one or two years prior to commencement of facility planning."

The recommended evaluations would be facilitated by making several related procedural changes. First, EPA should provide funding for construction of minor modifications to existing facilities so that full-scale multi-stream process evaluations can be undertaken. Second, both EPA and state agencies should permit waiver or reduction of routine sampling requirements during evaluation periods of one to two years in order to free existing laboratory facilities and staff to monitor experimental work. Third, occasional violations of NPDES permit limitations will occur and these should be accepted by regulatory agencies. And fourth, funding for additional analysis and development of design criteria should be allowed as part of the Step 1 grant.

It is not realistic to expect that this approach would be initially applied to every wastewater treatment plant in anticipation of a potential future expansion. Many smaller plants do not have the technical capabilities to handle such a program. Therefore, a pilot program is suggested. A sample of 10 plants having high priority for funding of plant expansion should be selected. These plants would be subjected to intensive studies to develop design criteria. An evaluation would then be made to determine how much the design engineer was able to save as a result of the availability of reliable design criteria. Based on the results of this pilot study decisions would then be made regarding fuller implementation of this recommendation. The data produced from plants of, say, 5 mgd and above can be applied to smaller facilities provided a careful comparison of sewage characteristics is made.

Design/Construction Periods

Both optimum and minimum time intervals exist for each activity associated with a wastewater treatment project. Attempting to accomplish activities in an interval shorter than the optimum will increase costs, sometimes rather abruptly. This is especially true of design and construction (and of combined fast track design-construction interval as well).

The increase in construction cost resulting from excessive schedule compression comes from obvious sources; such as working overtime, compressed delivery periods, increased risk of errors resulting in high liquidated damages payments, etc. Higher construction costs, which result from a compressed design period, are more subtle. Cost increases include: (1) inability to maximize value engineering; (2) use of conservative, well-tried designs to minimize conceptual design time; (3) problems associated with use of large numbers of staff, some of whom may be trained or temporary; (4) higher change order amounts; etc. Certainly the use of, and the potential savings from unconventional and novel methods is precluded.

These factors can become even more serious in the context of an "enforcement" setting. Both the engineer and the contractor can come to see themselves as the "target" of enforcement if the orders do not permit them to accomplish their respective roles well.

In the past, both EPA and other regulatory agencies have recognized the need for reasonable design and construction periods when setting deadlines for compliance. Unfortunately, delays in other elements of the schedule have almost inevitably occurred. The net result always seems to be a compression of time allowed for design and construction. To deal with this problem it is recommended that:

> Regulatory orders, issued pursuant to the Federal Water Pollution Control Act as amended, specify and follow the development of a project implementation plan incorporating the minimum practical overall schedule. The steps required to comply with applicable requirements along with both the interim and final time tables would, by appropriate reference, become the implementing schedule for the order.

Consider Fast Track Construction Management Early in Project Development

In many cases, consolidation of the design and construction interval can achieve considerable savings in construction cost. A cost saving realized by more rapidly implementing the Step 3 construction phase is largely due to avoidance of inflation. Although it can be argued that the cost of deferring construction is not a true savings since future costs are paid with inflated dollars, the savings to the EPA grant program is more tangible. This is because appropriations are fixed for the next 5 years with the $20 billion budget authorized by Congress. Therefore, if inflation effects can be minimized by minimizing avoidable delays in the design-construction sequence (or at any other point in the process) then more pollution control facilities can be built with the fixed EPA budget. Fast track construction approaches are one way to save some time during the lengthy Step 2-Step 3 sequence.

Cost Reduction Recommendation--

To reduce cost through minimization of time taken in the conventional project design and construction sequence it is recommended that:

> As soon as possible after the decision is made to consider grant funding for a proposed wastewater treatment project, an evaluation should be made to determine the appropriateness of utilizing fast-track design/construction techniques. Where a design-construction approach would appear to be appropriate, a detailed fast track action plan should be developed for inclusion in the facility plan.

A model for this has been developed in California. A Guideline published by the California State Water Resources Control Board entitled "Managing Construction" is suggested for study if this recommendation is to be given more detailed consideration.[7] The California approach requires the grantee to formulate a Management Plan for construction during the facility planning phase, and to submit a plan for approval during Step 2 at approximately the 10 percent design review. The plan must specify:

1. Construction Contracting - number and type of construction contracts to be used.

2. Services During Construction - required services and who will perform them.

3. Grantee Organization and Personnel - responsibility, lines of authority, staffing levels, and personnel qualifications.

4. Financial Planning - expenditures, revenue sources, and cash flow requirements.

5. Grant Sequences - strategy for timing and sequence of grants.

6. Management Procedures and Techniques - scheduling, cost control and value engineering, and reporting systems.

7. Master Schedule - major activities in design and construction.

During the implementation phase of Preconstruction the grantee takes the necessary actions before Step 3 to achieve the desired results in construction. These include:

1. Contracting for Construction Services - public announcement, evaluation of respondents' qualifications, solicitation and evaluation of proposals, negotiation of scope of services and engineering fees, and award of subagreement.

2. Value Engineering Program - recommended involvement by an independent organization, and required in projects with an estimated construction cost of $10 million or more.

3. Conditions of the Contract - listing of mandatory and recommended contract conditions for Clean Water Grant projects.

4. Prebid Estimates - submitted with final plan and specifications; estimates must be broken into process segments or systems.

The California approach also calls for: (1) accelerated procurement activities including purchase of some items prior to completion of design; (2) development of specifications, and schedule preapproval of equipment prior to bidding; (3) scheduling bid opening dates, conferences, and addenda procedures; and (4) development of evaluation criteria for proposals.

Construction phases are planned through to the final audit. During the planning phase construction management and communications systems are established, including detailed construction scheduling and scheduling of value for progress payments. Communications procedures for processing submittals, monitoring equal employment opportunity and labor compliance are required to be maintained by the grantee. Procedures to be followed during inspection and testing, and for documentation and changes during construction are also discussed and described.

The evaluation of fast track procedures, which takes place during facility planning, should compare time required for the more conventional design-construction sequence with that required for a fast track alternative. A base case schedule would be defined following the conventional approach for the recommended facilities. Fast track should be implemented where it allows significant overall cost savings expected, or where overlapping schedules are required to provide time needed for design.

It should be noted that the California model is compatible with the overall approach recommended at the outset of this chapter. The only difference is that more attention would be given to specific requirements considered to be important (such as the innovative technology considerations).

Consider consolidated Step 1-Step 2 Project Plan early in Project Development.

Small Projects--

Amendments to the Federal Water Pollution Control Act passed in December 1977 permit the consolidation of Steps 1 and 2 for small facilities. It is expected that this will reduce both the time and the engineering costs associated with small projects. Many of the requirements pertaining to large projects are inappropriate to these smaller projects.

To accelerate small projects, it is recommended that:

> EPA review the construction grant regulations, and develop streamlined regulations for consolidated Step 2/3 projects.

Every effort should be made to streamline, simplify and eliminate requirements which are not relevant to small projects. This greatly accelerates the construction of small systems, and it should greatly reduce the costs as well. Implementation should proceed in two phases. Phase 1 would involve elimination of all identified requirements which are not required by law. Phase 2 would involve requesting legal authority to eliminate other non-essential requirements for small systems.

Design and Construction Workload Leveling

To eliminate wasteful expenditure caused by the fluctuating design, estimation/bid and construction requirements of the present EPA grant funding program, it is recommended that:

> "A firm governmental funding and project authorization be adopted over a five-year moving period, in place of the present annual budget appropriation procedure."

The wasteful expenditure caused by present annual determinations of workload is developed earlier in this report. This recommendation calls for a reversal of the present system, in which state and EPA funding determinations are made, and engineers and contractors are expected to staff for high workloads for periods as low as 6 months. It is recommended that long-term projections be made for funding so that engineers and contractors are able to increase or decrease staffing in proportion to demand. The training period for a design engineer is estimated as 3 to 5 years, and for a project engineer 8 to 10 years. These figures are similar for contractor's management staff. Training of design and construction personnel is a function of experience gained; shorter periods are not considered to be feasible.

It is appreciated that the major funding decisions are made by elected representatives rather than the permanent technical staff of EPA. However, if EPA can show that long-term funding will enable overall cost savings the Congress may be convinced to budget several years ahead. Certainly a commensurate approach has been carried out on other large programs (defense or public work). It is therefore recommended that EPA conduct a survey to determine the extent of temporary staff employment caused by fluctuating staffing needs. Furthermore, investigations should be undertaken to determine what additional degree of conservatism is built into project designs as a result of unreasonably short design periods due to the need for compliance with regulatory timetables. The effect of compressing design periods on construction costs can be significant for when pressed for time an engineer will gravitate to more conservative choices since risk of process or structural failure have more serious consequences to him than a cost increase.

Standard Equipment

To eliminate wherever possible the high premiums paid to obtain non-production line equipment; to simplify later replacement by the municipality; and to eliminate delays arising from the manufacturer's need to interrupt production line schedules, it is recommended that:

> "EPA encourage design engineers to maximize the use of standard manufacturer's packages of equipment wherever process reliability is not compromised."

To maximize the life of equipment used in wastewater treatment plants engineers have developed specifications requiring various non-standard modifications of equipment, such as electric motors. In the past, manufacturers of such items had less sophisticated production lines, and greater competition existed between manufacturers. At the present time there are fewer manufacturers with more sophisticated production techniques.

Relative costs for non-standard equipment are much higher, and delivery quotations much longer.

As an example, the following prices are for electrical motors, averaged between 5 hp and 40 hp, 1,200 rpm units.

Motor Type	Relative Cost
Open drip-proof	1.0
Totally enclosed	1.33
Totally enclosed, severe duty (1.15 service factor)	1.50
Explosion-proof (1.15 service factor)	1.71

A manufacturer of process equipment will normally provide the open drip-proof motor as standard. If the severe duty (often called mill and chemical) motor is required not only is a premium of 50 percent of first cost paid, but an increase is also added due to the quantity of motors purchased. The manufacturer may purchase standard motors in lots of 50 or 100. Special motors will be obtained in ones and twos. Obviously, a further cost must be faced due to the loss of quantity discount.

A further area for wider acceptance of manufacturer's standards is control equipment. Most complex equipment is normally supplied with manufacturer's control packages. In many instances, the design engineer has required additions or alterations to the standard package for various reasons. Such changes may involve a disproportionate increase in cost of control equipment, and should be carefully evaluated on a cost basis.

The design engineer should be discouraged from specifying non-standard equipment, except where process reliability is a concern or where it otherwise cannot be avoided. No justification can be shown for purchase of an ancillary item, such as an air conditioning feature that will last 15 years instead of 10, if a substantial cost premium (e.g., 200 percent or more) is involved. It is recognized that certain electrically hazardous areas require explosion-proof equipment; wherever possible equipment should not be located in such areas.

Process reliability for many processes is highly dependent on certain major equipment items (e.g., blowers, pump, engines). Although standard equipment is available for these duties, the risk of breakdown should always be considered for key process equipment; particularly where their repair costs approach original purchase price. Premium costs associated with the use of heavy bearings and larger shafts can often be justified when repair costs and environmental implications of more frequent equipment disruption are evaluated. It is difficult to generalize when differences in wear and climate are of concern; for example, in Seattle, Washington, the high grit load associated with the combined sewer system and frequent rains cause as much wear to pumps in one year as would be found in a typical Southern California system in five years.

It can be argued that municipalities will benefit from increased use of standard equipment. Regrettably, a small municipality wishing to purchase a specialized non-standard item must often wait for extended periods for delivery. This fact inevitably reduces the mechanical reliability of wastewater treatment plants with such equipment. In contrast, standard equipment is usually available "off-the-shelf"; if not directly within the municipality itself,at least in the nearest trading center. Where non-standard equipment is justified based on process reliability maintenance personnel must pay careful attention to spare parts inventories.

It is recommended that EPA caution designers to be conscious that excessive use of non-standard equipment leads to cost increases. Accordingly, there should be careful justification by the design engineer where significant non-standard equipment is specified.

Adoption of Less Conservative Design Data

It is necessary that municipalities and engineers be actively encouraged to adopt less conservative design data. Currently, the trend is to use increasingly conservative design data. It is therefore recommended that:

> "EPA regulations be modified to include provision for further funding for design and construction beyond Step 3 subject to certain conditions. These conditions would be drawn up around requirements that the engineer and municipality show their intent to use less conservative data during Step 2."

EPA's policy is to achieve maximum economy in wastewater facility design. Two forces exist opposing this desire. First, municipalities are aware that funding may not be available in the future, or that having received one grant, they might not be eligible for a future grant; their concern being to ensure that adequate facilities are provided. Secondly, engineers, in common with all other professions, are coming under increasing liability pressure. Therefore, their tendency is to design conservative plants. In the past this tendency has been accentuated by pressure from municipalities; who obviously do not want to be faced with the need to undertake remedial work, or to construct additional units entirely at their own cost within a few years of project completion. Recent amendments (P.L. 95-217) to the Federal Water Pollution Control Act have added special provisions for funding innovative technology which minimize this risk and actually encourage municipalities to implement less conservative projects. Funds are also available to correct or replace failures.

Following the spirit of these amendments, EPA should adopt procedures encouraging engineers to use optimum rather than conservative design data for conventional facility construction as well. In the event that operational data from the completed plant indicates the applied design data was insufficient, EPA should fund an additional project. This project, which may not be required for five or even ten years, would be of such capacity as is required to meet demonstrated treatment needs. It is recommended that additional funding, in the form of a supplemental or second grant, be provided to cover the cost of this work.

Implementation of the solution is less obvious than the solution itself. Several fears exist: first, that the engineer would avail himself of this subsequent phase as an insurance against poor design; second, that municipalities would use the subsequent phase to ensure maximum facilities are provided. The resolution of these fears would appear possible within the framework of existing Step 2 procedures.

At the time the pre-design, value engineering report is reviewed, the proposed design data should be evaluated by the designer, value engineering team, and state and/or EPA engineers. A decision to proceed with the proposed data, or to use less conservative figures should be reached. The difference in capacity between the initially proposed design data and that finally adopted for Step 3 should form the basis for a future supplemental contract if proven necessary. Note that the engineer, in adopting less conservative design data should contemplate the omission of a complete element; such as a sedimentation tank or pass of an aeration tank. The design should allow for easy supplementation of the additional element(s) if needed. For example, one unit of four in a square layout would be omitted.

The potential cost savings realizable from this suggestion are large. The potential of saving one unit in six or eight constructed exists, giving a fair indication of potential savings. The familiar argument that if additional facilities are to be needed within 5 to 10 years they should be added now because it is cheaper is fallacious. The real value of constructed facilities is not based on any fixed datum. The real cost of constructing 5 or 10 years hence is likely to be very similar to the cost today. In the meantime the released grant funds can be used for alternate schemes where some water quality benefits will be immediately realized.

One final point to note: if the previous section on design parameter development is adopted, the value of this recommendation will be greatly diminished for plants over 5 mgd in size. It will remain valid for plants of lesser size.

Novel Idea Adoption

Recommendations concerning novel idea adoption were prepared prior to passage of P.L. 95-217,which incorporated a program for implementing innovative technology, but are in the same spirit as the 1977 Amendments to the Federal Water Pollution Control Act. To provide conditions in which novel cost reducing ideas can be tried and tested to determine their suitability and cost-effectiveness, it is recommended that:

> "EPA issue regulations encouraging engineers to adopt novel methods and materials, and indemnify those who do so. Further, that a group be established to record and publish the successes and failures of adopted novel ideas."

Adoption of novel methods and materials of construction is unlikely due to present regulatory and legal restrictions. Draft (January 27, 1978) guidelines on innovative technology have been reviewed, and, where innovation applies to in-place treatment, very substantial cost or energy savings criteria apply before special funding can be provided.[8] Thus innovative and alternative technology inducements may not influence major treatment works construction. In order to encourage the use of new ideas, which may ultimately lead to markedly reduced construction costs, EPA must ensure that engineers and municipalities are not penalized if such ideas turn out to be failures.

It is therefore recommended that EPA undertake three steps:

1. EPA issue a memorandum to all regions and review agencies encouraging them to accept novel design methods and materials of construction. Some inducement for more conventional plant innovations may be appropriate also.

2. EPA establish a small internal group of engineers to maintain a record concerning the use of novel ideas. Alternatively, a consultant or consultants be retained to develop such information.

3. EPA adopt regulations embodying their desire to see cost reducing ideas adopted even where innovative or alternative technology grant provisions do not apply; such regulations should provide indemnity for engineers and municipalities who undertake to use such ideas.

The design memorandum's intention, recommended above in 1, should be straightforward. In addition to encouraging the use of novel methods, the memorandum should prohibit any review agency from rejecting a design, method or material purely on the ground that it is untested.

The review group's design, suggested above in 2, should be uncomplicated. Their intended purpose is to build on the foundations of this and similar studies; to provide information on novel ideas, and on the actual field use of those ideas.

Discouragement of Novel Ideas--

The requirement to make regulatory changes in order to encourage the use of novel ideas, as well as the innovative technology provisions of the 1977 amendments, are essential for greater cost savings within conventional systems. However, it is a well felt reality that adoption of novel ideas is discouraged by a number of different factors:

First, with the enforcement of vigorous consultant selection procedures and fee negotiations initiated by EPA, engineers are coming under increasing pressure to reduce fees. The ability to investigate and analyze novel ideas to determine their suitability is limited to the amount of time (as a function of the budget) that the engineer is allowed. If design time, including both lapsed time and total manhour budgets, must be reduced as a result of regulatory pressures, it is inevitable that the necessary reduction will be at the expense of areas such as novel idea evaluation.

Second, engineers are likely to be liable for the adoption of an idea that does not work; the idea's use was intended to save the engineer's client's money.

Third, at present neither the engineer nor municipality is offered any incentive to adopt novel ideas which may or may not work as well as existing technology; or may not work at all. The EPA has no means of financing unsuccessful ideas used in the course of normal or conventional design. Indeed, a municipality whose engineer adopts an unsuccessful idea may find EPA pressure applied to them to not only correct the idea at their own expense, but also that they consider suing their engineer for the cost of renovation.

Obviously, all of the above inhibiting factors must be removed before novel ideas can be considered for adoption with intrepidation. To effect more widespread cost savings, it is recommended that EPA provide for the use of novel methods by adopting the following regulation format:

1. Acknowledge novel ideas exist, and that EPA desires their implementation throughout all aspects of the grant program.

2. Acknowledge that novel ideas may be partially or completely unsuccessful. And recognize added risk has been taken by all parties (EPA, State, grantee, and the engineer) such that no penalties are to be imposed on any one party in the event of partially or completely unsuccessful novel ideas.

3. Provide for EPA to accept the incorporation of novel ideas into a design at the initial VE review point (10 to 15 percent stage of Step 2). It should be noted that rapid 7 to 14-day acceptance by EPA is required; longer delay penalizes the engineer, and discourages his use of initiative.

4. Provide for EPA to monitor, through a small internal group or consultant, the implementation and degree of success of the idea.

5. As indicated in the 1977 amendments, provide EPA with means and procedures to fund replacement of any facility constructed as a result of novel idea implementation.

6. Provide for EPA to compensate a municipality when an idea is partially successful, but its continued use involves operations and maintenance costs in excess of those for the conventional solution.

7. Provide for either EPA, or their appointed consultant, to ensure national dissemination of the results of such ideas.

Mechanical Pre-Bid Requirements

To provide the most open arena for competitive bidding on equipment, such as sludge dewatering devices and sludge incinerators, it is recommended that:

"EPA regulations provide for mechanical pre-bid of specialized equipment costing in excess of $500,000.

The mechanical pre-bid should take place at the earliest possible point in design."

Much thought has been given concerning ways to obtain an increased degree of openness in specifications. Several possibilities were considered before a practicable approach was identified. Options which were subsequently rejected included:

1. Performance specifications could be written for all items with the provision that the design would be modified as necessary to suit the equipment selected by the lower bidder. Virtually unlimited engineering fees would be required. This is not considered to be feasible.

2. Contracts could be worded so that the contractor may request a change of design be made. New design details and specifications must then be prepared and agreed upon between all parties or legal complications may arise. The legal problems and the costs to each party for making such changes act as disincentives.

3. The present value engineering system be expanded to enable the contractor to take 50 percent of the savings of cost reducing suggestions. As the value engineering system has only recently been introduced, it is too early to make a judgment of that sort. Therefore, no changes should be made relative to value engineering at present.

The only practical, implementable approach identified is the use of a performance specification bid at an early stage which does not restrict the bidder in any way. For example, in bidding on an incinerator the engineer would not be permitted to restrict bidders to multiple hearth, or fluidized bed; all furnaces could be bid and would then be evaluated by the engineer.

The following would have to be taken into account:

1. Ability to Reject Low Bidder. With a completely open performance specification, no restrictions would be placed on a bidder other than that his equipment be able to perform a function efficiently for a period of time. The engineer would be required by the Municipality to determine whether or not a bidders' claims were correct (either that or a bidder would need to warrant his equipment for a 15 or 20-year period - clearly an impossibility). The ability to reject a bidder, even though he be the low bidder, would be necessary to insure the engineer's professional integrity.

2. <u>Delay of Final Contract Bid</u>. The introduction of an additional step in the design process contributes some delay to the production of final plans and specifications for the general contract. Increased costs due to inflation are likely.

Nevertheless, the attraction of potential cost savings from bidding major mechanical equipment against an open performance specification exists. In terms of increased competition it could be anticipated that 5 to 10 percent of equipment costs could be saved. The format of such bids must be as open as possible. Present day attempts to bid mechanical equipment separately are generally based on fairly detailed pre-conceptions on the part of the Engineer.

The bid must occur as soon as possible in the design stage. Only performance and outline process selection data are required; further detailing will result in unnecessary restriction on bidders. In order to obtain maximum cost benefits for the grant program the mechanical bid must be a firm bid to the owner. And, if the Engineer recommends acceptance, the owner must purchase the equipment and provide it to the general contractor.

<u>Design/Construction Periods</u>

Higher construction costs presently occur as a result of regulatory pressure on both design and construction periods. Such pressure is often a result of preset regulatory deadlines. And, therefore, can be alleviated if minimum construction cost is desired. It is recommended that:

> "EPA develop and implement a table of optimum design and construction periods, and provide for their incorporation into regulatory agency minimum deadline requirements, where applicable."

Implementation of the proposed method of tabulating optimum design and construction periods is recommended as a solution to the insensitivity of regulatory agencies to higher costs resulting from compressed design and construction periods.

Higher construction costs result from obvious sources; such as overtime labor charges, compressed delivery periods, risk of high liquidated damages payments, etc. Higher construction costs from compressed design periods are more subtle. They include: the inability to schedule for and maximize feedback from value engineering sessions; the use of conservative, well tried designs to minimize conceptual design time; conservatism necessitated by the need to employ large numbers of relatively untrained temporary staff; higher change order amounts; etc.

Certainly the use of, and potential savings from, unconventional and novel methods is precluded.

Recommendation--

The recommendation is, therefore, to allow optimum design and construction periods to exist which enable the contractor and engineer to carry out their work, and produce the most cost effective end product. It is recommended that either an in-house EPA team be set up, or an outside consultant be retained to determine proper design and construction periods. The evaluation should take into account size and complexity of project. For example, a new $10,000,000 plant can be designed and constructed more quickly than a similar plant requiring extensive reuse of existing facilities. Local climate and other factors affecting working days should be used to determine design and construction periods.

On completion of the study, the EPA should issue guidance memoranda, or some similar means of communication, requiring agencies to adopt the developed time periods, or show cause why they are unable to do so (artificial deadlines should not be just cause). If an agency is unable to satisfy EPA that a real reason exists for reducing design and/or construction period, the EPA should assess the additional contract cost which will result from the shortened period and refuse to fund that additional cost.

Interchangeability Provision

In order to ensure that EPA funds only the lowest cost alternative when a municipality determines that its own best interest lies in accepting a bid from other than the low bidder for reasons of interchangeability, it is recommended that:

> "Paragraph 35-935-2(b) of the Construction Grant Regulations be modified to state that the grantee shall pay the additional costs entailed in purchasing proprietary equipment to provide for necessary interchangeability of parts and equipment."

Any deviation from the method of selecting the lowest bidder from the maximum number of bidders leads inevitably to higher cost. An exception to the low bid requirement is provided for as indicated above. The municipality is concerned with minimizing future operations and maintenance (O&M) costs. An identifiable present worth can be developed by comparing the annual costs of O&M for pump A and pump B when four other pump A's are already installed. This present worth represents the maximum differential which should be accepted between the costs of pumps A and B. Furthermore, this cost represents benefits only to the municipality, and as such should be borne by them. The payment of a yearly amount on bonds for the additional capital repayment will still be less than the municipality would have paid for the additional O&M costs of accepting the lower bid.

This recommendation requires competitive bidding on the equipment item. Comparison by the municipality of the difference between the low bid and the bid of the manufacturer of the desired equipment with the potential O&M savings will indicate whether or not rejection of the low bid is economical.

Bid Listing Requirements

To maximize the bargaining power of the general contractor, thereby obtaining the lowest possible bid, it is recommended that:

> "EPA regulations forbid the listing of equipment suppliers and subcontractors at the time of bid in any form. The general contractor shall have the right of open equipment subcontractor selection up to the point of initial submittal of working drawings."

The intent of this study is to reveal ways to minimize construction cost. This end is not realized unless the general contractor, who is acting in the position of purchasing agent for the Municipality, is provided with the maximum degree of negotiating power in his dealings with suppliers and subcontractors. Objections to this approach have been raised and these are discussed in later paragraphs. It is emphasized that this optimum negotiating position is not realized if the contractor is required to list selected suppliers and subcontractors at the time of bid. Formal binding agreements are only entered into following contract award to the general contractor. The contractor must be open to use whatever negotiating tools he deems necessary in achieving the best possible terms with suppliers and subcontractors.

Several institutional changes are necessary before implementation of this recommendation is possible. Many municipalities and some states have requirements that subcontractors and/or suppliers be listed at the time of bidding; and that the permission of the municipality or state agency is necessary before a substitution can be made. EPA has an equal employment opportunities requirement demanding that a post-bid, pre-award conference be held to review the affirmative action programs of contractor and subcontractors. All of these would require modification to permit the general contractor to make substitutions as desired.

Objections--

Several objections to this proposal have been voiced, primarily by equipment suppliers and engineers. The major area of dissent centers around a fear that severe pressure by the contractor to bring prices down to a minimum would inevitably lead to cheapening of the product and a deterioration in the services that a manufacturer and supplier provide to the municipality. In practice this is inevitably true. In theory it is supposed that the engineer in preparing the contract documents can foresee and cover all aspects of materials, construction, control, submittal requirements, start-up, and operations and maintenance information. However, in practice this is not possible.

A second objection comes from engineers. In specifying two or three manufacturers who the engineer knows to be acceptable, preparation of lengthy specifications can be minimized, and the municipality will be assured of obtaining a product of the desired quality. The requirement that the engineer completely detail the specification of an item of equipment undoubtedly means additional cost to the engineer. This fact should be borne in mind in effecting this recommendation.

Precise cost savings under all circumstances are difficult to estimate. Cited examples, however, include up to 100 percent over minimum cost if only one bidder is involved, and 20 percent over minimum cost if two or three bidders are involved.

Inspector Certification

To provide a predictable and consistent level of construction inspection on construction projects, it is recommended that:

> "A construction inspector certification system be introduced; either by EPA, or by the construction industry at large."

The recommendation for construction inspector certification arises from indications given by contractors that construction inspection requirements vary considerably. It is not anticipated that an inspection certification system alone will equalize inspection on all projects. Contracting agency requirements vary widely. A certification system is an essential first step toward standardization of inspection requirements.

A more uniform competency level among inspectors would remove some unknown factors from the contractors' bidding. Where risk is minimized cost savings would follow.

Suggested Form--

Each state operate a certification system based on national standards using management funds supplied from the P.L. 95-217 grant program. Each inspection division is to have unclassified trainees and five grades of qualified inspectors. The inspection division required for EPA funded contracts are:

1. Civil (pipelines, earthwork, paving, general duties)

2. Structural

3. Mechanical

4. Architectural

5. Electrical

6. Instrumentation

A provision enabling experienced craftsmen to become certified inspectors could be incorporated into the code. Inspectors presently skilled in wastewater collection and treatment projects should receive automatic certification commensurate with their documented experience within each division.

It is anticipated that multi-certified inspectors will be the major need for inspection staff for small and medium sized construction projects, where only one or two inspectors are normally expected to cover day-to-day inspection of all divisions.

A suggested experience requirement list is as follows:

Classification	Total Field Experience (years)	Minimum Field Experience Since Last Classification (years)	Minimum Field Experience as Craftsman (years)
Unclassified	1	-	2
2	3	2	5
3	5	2	5
4	8	3	-
5	10	2	-

It is recommended that Grades 4 and 5 not be open to automatic entry by craftsmen without examination. Class 4 and 5 inspectors should be required to pass an examination in the legal and procedural aspects of construction. Class 4 and 5 inspectors would fulfill many of the duties of a resident engineer, on small (Class 4) and medium (Class 5) contracts.

It is further recommended that EPA specify the inspection requirements for all construction contracts. For example, a 2-mgd secondary wastewater treatment plant with no special complexity might be defined as requiring either a resident engineer, a Class 3 inspector and an unclassified inspector, or a

Class 5 and two Class 2 inspectors. EPA would then provide construction inspection funding, providing that the minimum requirements are met.

The cost savings that such a program would effect are undefinable since the costs of the present system are illdefined. Contractors interviewed identified poor and indecisive inspection as an item which cost them money, but which they were unable to allow for in their bids; doing so ruined their competitive position. Several contractors indicated that they will not bid for some work because they know the inspection staff of the contracting agency will cost them an amount that they are unable to define.

Working Days

To eliminate the weather element risk from contractor's bids, it is recommended that:

> "EPA regulations require all construction periods be bid in working days not calendar days."

This method of specifying contract period is in use in some cities. It provides a fair method of reducing the cost of insurance against delays arising from foul weather. The adjudication as to whether any day is a working day, one-half working day or not should be made by someone other than the contractor or field inspection staff. The director of public works is an obvious choice. Whoever is selected should not be so far removed from the site as to experience materially different weather conditions.

No regulatory changes are required. A minor change to fixed term inspection contracts is necessary to provide for possible additional fees (inspection staff are salaried and must be employed during inclement weather). Such additional fees should be tied to the number of days designated as non-working.

Change Order Evaluation

To ensure that the consultant's ability to produce complete and accurate contract documents, which require the minimum number of site changes, is evaluated during the consultant selection process, it is recommended that:

> "Municipalities be encouraged to inquire into the change order history of a consultant's prior construction contracts."

The intention of this recommendation is to make consultants more aware that many construction changes resulting from poor designs will penalize them when they are evaluated for future projects. As indicated in Section 3, change orders may amount to a significant percent of contract costs. Care should be exercised in evaluating change order history, however; some site changes are beyond the engineer's control.

In evaluating change order amounts municipalities should consider three groupings. The first grouping are those resulting from extra work requested by the municipality, and should not be held against the engineer. The second group are the unknown contingency items which arise on any project. Some items may be borderline between those that the engineer could not reasonably have foreseen, and those that the engineer should have foreseen. The third group, which should be considered by evaluating municipalities, are those items which should have been foreseen by the engineer.

The last category should either have been avoided, or included competitively in the original contract bid. They inevitably result in higher project costs.

CONCLUSIONS

The preceeding conclusions were suggested in considerations taken up in Section 3. They are listed in approximate chronological sequence, and no attempt to identify relative importance has been made. The only test for their inclusion was that they meet the construction cost reduction goal.

Other concerns must be evaluated for a realistic ordering of ideas. Even if an idea offers great potential for cost savings, it is of little value if its implementation will not be permitted on political, social or engineering grounds. Table 8 shows the relative ranking of 16 ideas based on the assessed and combined potential of cost savings and implementation. Both potentials are assessed on a 1 = highest to 5 = lowest ranking. The combined ranking is therefore 1 to 10.

Four of the five best cost reducing ideas occupy the top four final positions. The fifth idea, elimination of all federal and state grant funding, has such political shortcomings that its potential for application is lowest. It ranks eleventh overall. The two ideas which are easily implemented rank fifth and ninth overall.

TABLE 8. RANKING OF PROPOSED NON-STRUCTURAL SOLUTIONS

Text Position	Proposed non-structural solution	Potential for implementation	Potential for cost savings	Total rating (1-10)	Final importance rating	Partly implemented by PL 95-217
1	Expansion of the planning phase	1	2	3	1	-
2	Evaluate innovative technology in facility plan	1	2	3	1	-
3	Design parameter development	2	1	3	1	
4	Design/construction periods	3	3	6	12	
5	Consider fast track construction management early in project development	2	1	3	1	
6	Design and construction workload leveling	3	2	5	10	
7	Standard equipment	1	4	5	7	
8	Adoption of less conservative design data	2	1	3	1	
9	Novel idea adoption	2	1	3	1	
10	Mechanical pre-bid	2	5	7	13	
11	Design/construction periods	2	3	5	8	
12	Interchangeability provision	3	5	8	15	
13	Bid listing requirements	2	3	5	8	
14	Inspector certification	5	4	9	16	
15	Working days	1	5	6	11	
16	Change order evaluation	2	5	7	13	

Ranking Key: 1 = highest
5 = lowest

REFERENCES

7. Division of Water Quality, California State Water Resources Control Board. "Managing Construction of Clean Water Grant Projects",November, 1977.

8. The January 27, 1978 Draft guidelines on Innovative and Alternative Technology (Appendix) states that in-plant treatment systems not tied to innovative or alternative technology definition would have to show that life cycle costs and net energy requirements were 35 percent and 75 percent or less (respectively) than those of the most cost effective alternative.

SECTION 5

COST CENTERS

METHODOLOGY

The remaining sections of this report deal with structural factors which affect the cost of wastewater facility construction. As construction activities encompass a diversity of operations and materials it is useful to identify elements which can be evaluated separately in terms of costs. Such elements which make up a typical construction project can be termed "cost centers". Cost centers were identified for typical wastewater collection systems and waste treatment facilities; this cost center identification process helps to focus attention on high cost centers where employment of unconventional or novel materials or methods of construction may prove most feasible.

The nature of the cost centers for collection system and wastewater treatment plant differs widely. Therefore, different approaches were required to presently identify those elements in each type of project.

Collection systems consist almost entirely of pipeline construction. Factors which affect the costs of pipeline construction can be categorized into a very few major divisions. These costs are primarily affected by site related conditions, e.g., soil types, groundwater levels, utilities, topographic features, causes, traffic conditions, etc. In contrast, wastewater treatment plants include a larger number and greater variety of cost centers. Since construction of wastewater pumping stations involves many of the construction elements required for treatment plants, many of the procedures and results obtained for the treatment plants may be applied to these installations.

COLLECTION SYSTEMS

The cost of storm and wastewater collection systems is derived from the summed cost of six major construction elements. These construction elements, which are fundamental for all pipeline construction, are:

- Excavation

- Trench support
- Dewatering
- Pipe and appurtenances (including manholes)
- Bedding and backfill
- Restoration

As a general rule, the high risk costs associated with pipeline construction are all related to excavation of the trench to a suitable level. Once excavation is completed, the remaining operations are predictable and sensitive to inspection. Thus the range of unit costs for sewers reflects variations necessary to accomplish the required excavation, trench support and dewatering.

Cost Research

Data for this report were compiled through several sources: Bid tabulations of construction contract awards, quotes from suppliers of pipe and backfill materials, installation rates, interviews with contractors, and construction engineering experience. With the exception of pipe and backfill, very limited data exists to indicate the relative costs of the six elements of pipeline construction. Virtually all sewer cost data are based on the overall in-place cost of the pipe for a given pipe diameter. Where extra cost items are required for bad ground or for rock excavation, for example, the higher cost is included directly in the in-place cost of the pipeline. The bidder is required to assess varying surface, soil and groundwater conditions, depths of excavation, and determine an average value for each diameter and include this value as his bid item. The usual exception to the overall in-place cost is the small percentage of contracts where pipe bedding and/or backfill are included as separate bid items.

Pipeline contractors were contacted and interviewed to determine the general approach to the preparation of project cost estimates. They confirmed that after evaluating the cost of known elements such as structures, pipe, granular bedding material, removal and disposal of surplus material, etc., the uncertain costs are evaluated largely on the basis of experience. All existing soil survey data are reviewed, the location of the work is inspected once or several times, similar work is visited and the contractor's specific experience in the area recalled. The contractor evaluates these factors, takes his available equipment and manpower into consideration and prepares a bid value incorporating all of these factors. Typically, the bid value is then adjusted to reflect the contractor's current workload. If his backlog of work is low, the contractor will likely reduce his anticipated profit level in an effort to obtain the work and keep his current staff and equipment busy. Conversely, if the contractor has a relatively large backlog of projects, the bid may include a high profit factor, reflecting the need to purchase additional equipment and expand his staff.

Cost Development

Each of the six previously defined work items is explained in more detail below. The variables considered in developing cost for each item are as follows:

Excavation--

Items included in excavation are clearing and grubbing, pavement cutting, removal and storage of topsoil and salvageable landscaping, trench excavation and disposal of waste material.

Trench Support--

This item covers a range of types of support from sloping trench walls where the cost is related to additional excavation and backfill, to continuous braced interlocking steel sheet piling. Included in the sheeting costs are materials and labor for installation of sheeting and associated support systems and factors for the higher degree of difficulty associated in operations such as excavation, pipe installation and backfill compaction due to interference of complex support systems. The average cost for trench support is based on the use of a traveling shield.

Dewatering--

This item ranges from zero effort for dry trench conditions to the use of complex and costly well-point dewatering systems employed in high groundwater, high permeability areas. The range of items considered includes all necessary equipment for well point systems, the cost of underdrains or other drain systems laid with the trench and the cost of rudimentary solids separation from discharge water.

Pipe and Appurtenances--

The cost of a range of pipe materials were considered, including PVC, asbestos cement, reinforced concrete and ductile iron. The cost of handling and joining the different materials are reflected through use of varying installation rates and its impact on labor and equipment costs.[9] Appurtenances include the cost of manholes averaged as a unit cost per linear foot of pipeline. Infrequent appurtenances such as siphons, terminal cleanouts, overflow structures, etc. were deemed to be a very minor item in overall sewer cost and were therefore ignored.

In the cost tables, minimum cost construction assumes use of the least expensive pipe available for the diameter under consideration while the maximum cost construction assumes the use of the most expensive pipe.

Bedding and Backfill--

The costs for material and labor for bedding by class and for initial backfill were evaluated. General backfill including compaction are evaluated for native and imported materials. Where imported material is considered, a factor to allow for removal of spoil is included.

The total allowed for minimum conditions assumes imported bedding, the average conditions figure includes imported initial backfill, and the maximum cost condition assumes all backfill imported.

Restoration and Disruption--

Disruption includes costs for site-specific items such as diversion of vehicular and pedestrian traffic, restricted access, detours and temporary stream diversions, sewer encasements, safety precautions, provision of contractor's working area, and costs associated with the maintenance of utility services through temporary or permanent relocation.

Restoration costs include both temporary and permanent surface replacement, including seeding, sodding, landscaping and pavement. Also included are removal of detours and stream diversions and restoration of the existing street or stream channel. The minimum cost figure assumes little disruption. The average value allows for moderate disruption and for the cost of highway restoration. The maximum figure includes either an allowance for major disruption, sewer encasement or the restoration of a poorly founded street which requires major reconstruction following sewer construction. These costs are not generally additive and an average was therefore used.

Cost Tables

Cost tables were prepared for two different diameters of pipe, selected because they generally represent different materials selection. Two depths were selected for analysis, and the range of encountered costs plus average costs shown. Results are tabulated in Tables 9-A (metric units) and 9-B (English units). Table 10 represents the same data in percentage of total cost terms.

The in-place costs of pipelines presented in these tables compare favorably with those presented in a 1978 EPA publication.[10] The EPA report was compiled through summarizing of bid tabulations from the ten EPA regional offices.

TABLE 9-A. IN PLACE COST FOR SEWERS IN VARYING GROUND CONDITIONS (1976 dollars per meter)

Pipe Diameter	305 mm						915 mm					
Depth to Invert	2.7 m			5.5 m			2.7 m			5.5 m		
Ground Conditions	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum
Excavation	9.80	26.20	65.60	23.00	49.20	131.20	16.40	37.40	141.00	39.40	74.50	282.10
Sheeting	3.30	42.70	164.00	16.40	62.30	459.30	3.30	42.70	164.00	16.40	62.30	557.70
Dewatering	0.00	3.30	65.60	0.00	6.60	65.60	0.00	3.30	65.60	0.00	6.60	65.60
Pipe and Appurt.	38.70	46.30	55.80	55.40	62.30	71.90	150.30	165.30	258.50	179.10	195.20	290.40
Bedding and Backfill	11.50	14.40	29.50	19.70	22.60	57.10	22.00	26.90	45.30	34.40	39.40	89.20
Restoration and Disruption	13.10	19.70	45.90	13.10	19.70	45.90	19.70	26.20	55.80	19.70	26.20	55.80
TOTAL	76.40	152.60	426.40	127.60	222.70	831.00	211.70	301.80	730.20	289.00	404.20	1340.80

TABLE 9-B. IN PLACE COSTS FOR SEWERS IN VARYING GROUND CONDITIONS (1976 dollars per foot)

Pipe Diameter	12 inch						36 inch					
Depth to Invert	9 feet			18 feet			9 feet			18 feet		
Ground Conditions	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum
Excavation	3.00	8.00	20.00	7.00	15.00	40.00	5.00	11.40	43.00	12.00	22.70	86.00
Sheeting	1.00	13.00	50.00	5.00	19.00	140.00	1.00	13.00	50.00	5.00	19.00	170.00
Dewatering	0.00	1.00	20.00	0.00	2.00	20.00	0.00	1.00	20.00	0.00	2.00	20.00
Pipe and Appurt.	11.80	14.10	17.00	16.90	19.00	21.90	45.80	50.40	78.80	54.60	59.50	88.50
Bedding and Backfill	3.50	4.40	9.00	6.00	6.90	17.40	6.70	8.20	13.80	10.50	12.00	27.20
Restoration and Disruption	4.00	6.00	14.00	4.00	6.00	14.00	6.00	8.00	17.00	6.00	8.00	17.00
TOTAL	23.30	46.50	130.00	38.90	67.90	253.30	64.50	92.00	222.60	88.10	123.20	408.70

TABLE 10. COST DISTRIBUTION
SEWERS IN VARYING GROUND CONDITIONS*

Pipe Diameter	305 mm (12 inch)						915 mm (36 inch)					
Depth to Invert	2.7 m (9 ft)			5.5 m (18 ft)			2.7 m (9 ft)			5.5 m (18 ft)		
Ground Conditions	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum
1. Excavation	13	17	15	18	22	16	8	12	19	14	18	21
2. Sheeting	4	28	39	13	28	55	2	14	23	5	15	41
3. Dewatering	0	2	15	0	3	8	0	1	9	0	2	5
4. Pipe and Appurt.	51	30	13	43	28	9	71	55	35	62	48	22
5. Bedding and Backfill	15	10	7	16	10	7	10	9	6	12	10	7
6. Restoration and Disruption	17	13	11	10	9	5	9	9	8	7	7	4
TOTAL OF 1-3	17	47	69	31	50	71	10	27	51	19	35	67
TOTAL OF 4-6	83	53	31	69	47	21	90	73	49	81	65	33

* Costs are expressed as a percentage of total costs.

Pipeline Cost Centers

Inspection of Tables 9-A, 9-B and 10 leads to several conclusions. Under normal and minimum cost conditions, pipe and appurtenances costs represent the major cost of construction. For average conditions, sheeting costs become a major cost item. For maximum cost conditions, sheeting becomes the single, most costly item, with excavation and dewatering of major importance and pipe and appurtenances remaining important.

Excavation as a percentage of total cost remains approximately constant and averages 17 percent of total costs. Costs for trench support increase dramatically according to the degree of difficulty of construction. The percent of total cost for minimum conditions -- trench jacks or battered trench -- is a nominal 6 percent average, while for maximum conditions up to 55 percent of total cost may be allocated to trench supporting systems. Under average degree of difficulty conditions, using a travelling shield, approximately 30 percent of total cost for 305 mm (12 inch) diameter pipe and 15 percent for 915 mm (36 inch) was identified against this item.

Dewatering is not as high a cost center as had been anticipated. Only a maximum of 15 percent was identified against this item, and normal costs are minimal. In our judgement, the reason the maximum figure is proportionally low is because once a water problem is acknowledged, a definable amount of equipment can be purchased or rented to cope with the problem. The cost of this equipment will not increase substantially above this definable base amount.

Piping and appurtenances exhibit an interesting trend. Under minimum cost conditions, this item represented some 57 percent of total costs. This percentage falls to 40 percent for average conditions and to 20 percent for maximum cost conditions. The reason for the declining percentage is that, although pipe and appurtenance costs are sensitive to type of material, trench conditions and size, the rate of increase is a great deal less than those associated with risk elements such as excavation and dewatering.

Neither bedding and backfill, with weighted averages of ten and nine percent respectively, nor restoration and disruption represent a major impact on total costs. These are substantial but are not considered major cost centers.

Table 11 shows the cost distribution for the cost centers examined in the study items for 305 mm (12 inch) and 915 mm (36 inch) diameter sewers. Inspection shows that pipe and

TABLE 11. COST CENTER DISTRIBUTION*

	305 mm (12 inch)		915 mm (36 inch)	
Cost center	Excluding maximum cost example	All examples	Excluding maximum cost example	All examples
Excavation	19	18	15	17
Sheeting	25	37	13	23
Dewatering	2	6	1	3
Pipe and appurtenances	32	21	54	42
Bedding and backfill	11	9	10	8
Restoration and disruption	11	9	7	7

* Expressed an average of total cost.

appurtenances has the greatest impact on construction cost, followed by excavation and sheeting costs.

WASTEWATER TREATMENT PLANTS

Analysis of cost centers on a plant-by-plant basis for the EPA construction grant program would provide a wealth of nearly meaningless data because of the range of sizes and types of facilities involved. Thus it was first necessary to examine the scope of the program, select representative sizes of facilities which would provide the most direct impact in terms of cost saving, then identify, for those representative sizes, those unit processes most commonly employed. These representative samples were then analyzed for cost center identification. Data for 157 plants were analyzed and two representative plant sizes selected for detailed analysis. Results are summarized according to common construction shapes and types and compared to total cost. These cost analyses also provide baseline data for novel method development cost comparisons.

Data Sources

Basic treatment plant costs were derived from the most up-to-date national data rather than data available on a regional or company basis. This approach was adopted to avoid a bias to the developed cost centers favoring regional requirements or individual company design approaches.

Two sources of national cost data were adopted. The EPA Areawide Assessment Manual, Appendix H data was used for overall treatment plant costs and for costs of process units not analyzed in depth. Data from an analysis of Construction Cost Experience for Wastewater Treatment Plants, EPA 430/9-76-002 was used to determine the frequency of occurrence of treatment plant size and process. Typical plant sizes and process streams for analysis were determined from these data.

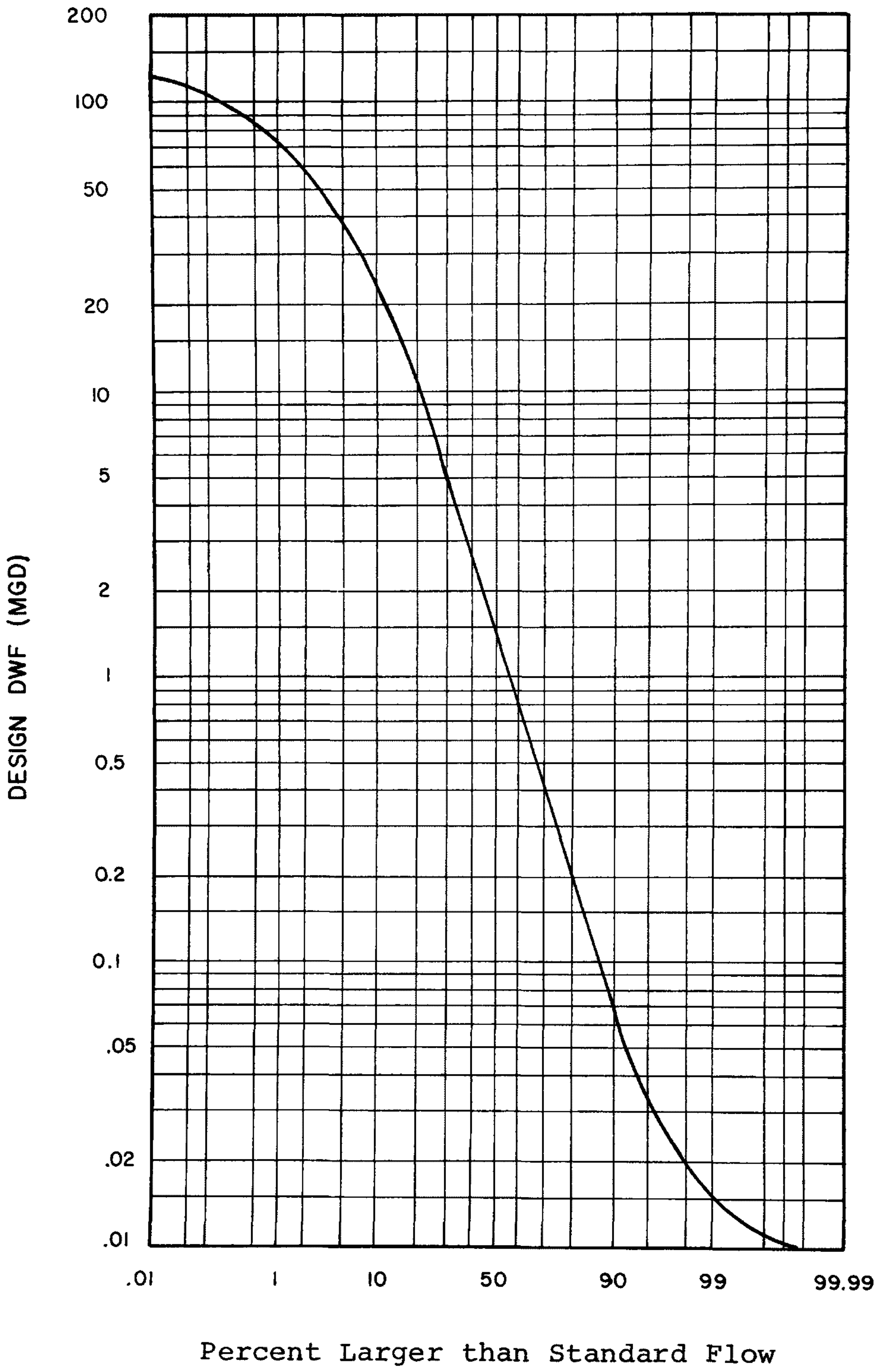
Data for detailed cost breakdowns were obtained using actual information from job cost breakdowns or obtained from Richardons' Estimating Manual 1977. In some instances, costs of materials and equipment were obtained directly from suppliers or manufacturers.

Selection of Typical Plants

The initial requirement was to determine representative treatment plant sizes for analysis. Data from the EPA Construction Cost Experience reference covered 157 treatment plant projects. Of these, 99 were new facilities and 58 projects involved modification and upgrading of installations. Figure 4 presents a distribution of these projects by design flow. The list of projects was then screened to classify them by size, cost and type. Thirty-seven of the treatment facilities (24 percent of the projects considered) have a capacity of 11 l/s (0.25 mgd) or less. This group, which represented an expenditure of $14,000,000, or less than one percent of the total, was comprised mostly of either package treatment plants or relatively simple facilities such as oxidation ditches and lagoons. Since the group has only a small impact on the grant program, it was not given further consideration in the cost center analysis.

Fifteen wastewater treatment plants larger than 880 l/s (20 mgd), or 10 percent of the total represented a cost of $774,000,000, nearly half of the total expenditure for the projects examined. This group included both biological and physical-chemical secondary plants as well as tertiary processes. Solids stabilization and disposal processes included watering and thickening, digestion and incineration. A summary of these projects by type is presented in Table 12.

Typically, unit processes for large plants are constructed as a number of modules of smaller units. This statement is true of nearly all processes and most process elements. The more complex mechanical items such as incinerators and oxygen generation plants may be provided singly, but in the largest plants even these are duplicated for reliability. Thus, analyses of smaller plants will give similar cost centers to those in larger plants constructed from smaller modules. A decision was therefore made to analyze a moderately sized plant rather than a large plant.



Based on data in Construction Cost Experience for Wastewater Treatment Plants. EPA 430/7-76-002.

FIGURE 4. TREATMENT PLANT SIZE DISTRIBUTION

TABLE 12. WASTEWATER TREATMENT,
PLANTS OVER 888 l/s (20 mgd)

Unit process	No. of plants
Treatment	
Activated sludge	10
Oxygen-activated sludge	3
Step aeration	1
Physical/chemical	1
Solids disposal	
Dewatering	10
Thickening	10
Anaerobic digestion	7
Incineration	4
Heat treatment	1
(two plants did not report)	

Of the plants investigated, 108 or 69 percent lie within the range of 11-1/2 to 880 l/s (0.25 to 20 mgd). This group accounted for over half of the total cost of all projects. Further, if a reasonably large plant within this range is evaluated, identified cost centers will be similar to those for larger plants. Since two plant sizes, 44 l/s (1 mgd) and 440 l/s (10 mgd), were selected for analysis it was felt these capacities seemed to nearly represent the extremes of the group. The 44 l/s plant is judged representative of plants with capacities between 11 l/s and 175 l/s (0.25 to 4 mgd) and the 440 l/s plant is considered typical of plants in the range of 175 l/s to 880 l/s (4 mgd to 20 mgd).

Selection of unit processes for the typical plants was based upon an analysis of those typically employed in the respective groups. Table 13 presents a summary of this analysis.

A review of Table 13 reveals that over 70 percent of all plants used the activated sludge process or a variation thereof. The activated sludge process was therefore selected for the 440 l/s (10 mgd) plant. The activated sludge process or one of its variations was employed with similar frequency in plants with capacities in the 11 l/s to 175 l/s range; however, to analyze an activated sludge process again would be repetitive. Accordingly, the trickling filter, or biofilter, was selected for analysis to obtain some diversity in the study results. Solids stabilization was also to be evaluated. Well over half of the plants in the 44 l/s (1 mgd) size range used aerobic digestion, while anaerobic digestion was employed in more than half of the plants 175 l/s or larger. These unit processes were therefore selected for the two typical plants studied under this investigation.

TABLE 13. TYPICAL UNIT PROCESSES
WASTEWATER TREATMENT PLANTS

Unit processes	11 to 175 l/s	11 to 175 l/s
Treatment		
Activated sludge*	27	18
Contact stabilization	12	1
Extended activated sludge	12	3
Step aeration	1	-
Oxygen activated sludge	-	3
Roughing filter/activated sludge†	3	4
Physical/chemical	-	2
Standard rate trickling filter	1	-
High rate trickling filter	5	2
Aerated lagoons	6	2
Bio-disc	1	-
Oxidation ditch	3	-
Secondary process not stated	-	2
Total	71	37
Solids Disposal		
Liquid, thickened, or dewatered sludge to disposal	23	4
Anaerobic digestion	12	14
Aerobic digestion	22	4
Incineration and/or heat treatment	1	9
Other methodΦ	-	3Φ
Solids process not stated	13	3
Total	71	37

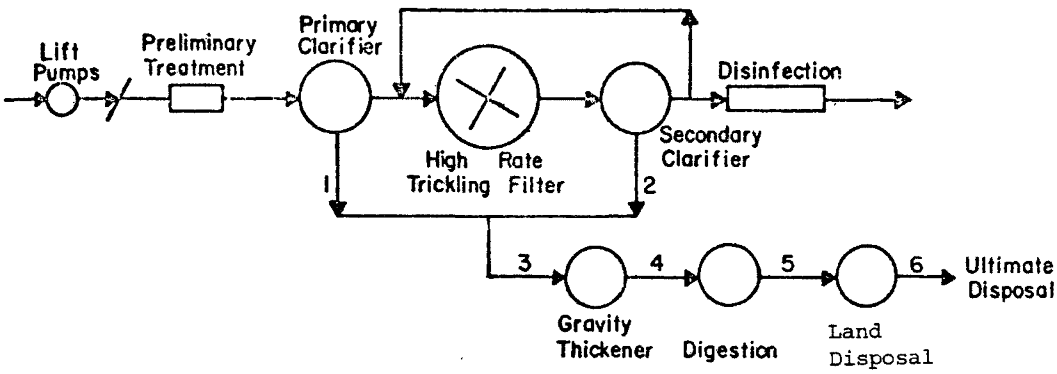
* Includes 2 plants rated "primary chemical, activated sludge".
† Includes 1 plant rated "trickling filter (high rate), step aeration".
Φ Two plants reported with both aerobic and anaerobic digestion.
One plant reported with aerobic and anaerobic digestion and heat treatment.

Unit Sizing for Typical Plants

Areawide Assessment Procedures Manual Appendix H was used as a source for design data and costs of unit processes. In general, these design data were followed closely in order to be consistent with the manual's cost data. An exception was made in the case of gravity sludge thickeners to reflect an arrangement where both primary and secondary sludges are routed via the thickener. In the manual, unit cost data provides only for secondary sludges; so an adjustment was made to the unit cost data in this case.

Process schematics, wastewater characteristics and design assumptions for the typical plants are shown in Figures 5 and 6. Unit loadings, process unit sizing and additional items included within the scope of the unit process are indicated in Tables 14 and 15. The process arrays selected represent those most commonly employed, as described previously. No implication is intended or inferred that these represent recommended arrangements

Process Schematic



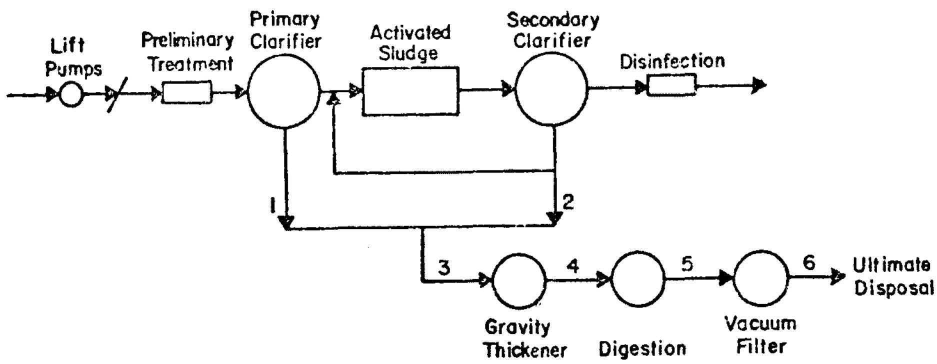
Wastewater Characteristics:	Influent	Effluent
BOD_5, mg/l	210	45
COD, mg/l	400	90
TSS, mg/l	230	60
Total-P, mg/l	11	8
NH_3-N, mg/l	20	18
NO_3-N, mg/l	0	0
UOD, mg/l	406	150

Sludge Audit:

Point No.	Sludge Quantity lbs/mg	Concentration %
1	1,080	4
2	450	3
3	1,530	4
4	1,530	5
5	765	3
6	765	20

FIGURE 5. PROCESS SCHEMATIC AND DESIGN ASSUMPTIONS, 44 l/s (1 mgd) WASTEWATER TREATMENT PLANT

Process Schematic



Wastewater Characteristics:	Influent	Effluent
BOD_5, mg/l	210	20
COD, mg/l	400	45
TSS, mg/l	230	20
Total-P, mg/l	11	7
NH_3-N, mg/l	20	17
NO_3-N, mg/l	0	0
UOD, mg/l	406	107

Sludge Audit:

Point No.	Sludge Quantity kg	Concentration %
1	4,900	4
2	3,700	0.8
3	1,900	2.6
4	8,600	8
5	4,300	5
6	4,300	20

FIGURE 6. PROCESS SCHEMATIC AND DESIGN ASSUMPTIONS, 440 l/s (10 mgd) WASTEWATER TREATMENT PLANT

TABLE 14. DESIGN DETAILS AND DATA, 44 l/s (1 mgd) PLANT

Process Step	Description and design parameter*	Design criteria Metric	English
Influent pumping	Lift, mechanically cleaned screens	6 m	20 ft
Preliminary treatment	Gravity grit channels, Parshall flume		
Primary sedimentation	Overflow rate,		800 gpd/ft^2
	Rectangular, number	2	2
	length		62 ft 6 in
	width		10 ft
	Sludge pumping head	3 m	10 ft
Trickling filters	High rate, loading,		45 lb BOD/1000 ft^3/day
	number	2	2
	diameter		50 ft
	depth		6 ft
	Recirculation rate 3:1 (pump cost in clarifier)		
Secondary sedimentation	Overflow rate,		800 gpd/ft^2
	Circular, number	2	2
	diameter		30 ft
Disinfection	Contact time,		30 min
	Rectangular, number	2	2
	length		50 ft
	width		6 ft
	depth		4 ft 6 in
Gravity thickening	Solids loading rate,		10 lb/ft^2/day
	Rectangular, number	1	1
	length		16 ft
	width		12 ft
	Adjustment factor for cost† curve = $1.0 \times \frac{6}{10} \times \frac{1900}{820}$ = 1.4 mgd		
Aerobic digestion	Detention time,	20 days	20 days
	Rectangular, length		50 ft
	width		25 ft
	depth		12 ft
	Floating mechanical aerators		
Land application of sludge	Lagoon, storage time	30 days	30 days
	surface dimensions		80 ft x 80 ft
	depth		8 ft
	side slope		3:1
	Land preparation, monitoring wells and access roads		

* Data in this table is for cost centers development and is not necessarily representative of an actual facility.
† Refer Appendix H, p. H-156, cost curves are for secondary sludge, typical plant utilizes thickener for both primary and secondary sludges.

TABLE 15. DESIGN DETAILS AND DATA, 440 l/s (10 mgd) PLANTS

Process Step	Description and design parameter*	Design criteria Metric	English
Influent pumping	Lift, mechanically cleaned screens	6 m	20 ft
Preliminary treatment	Gravity grit channels, Parshall flume		
Primary sedimentation	Overflow rate		800 gpd/ft^2
	Circular tanks, number	2	2
	diameter		90 ft
	depth		8 ft
	Rectangular tanks, number	2	2
	dimensions		167.5 x 37.5 x 8 ft
	Sludge pumping, head	3 m	10 ft
Activated sludge	Detention time	6 hr	6 hr
	Number of tanks	3	3
	Length		250 ft
	Width		30 ft
	Depth		15 ft
	Diffused aeration		
	RAS rate assumed 25-100%		
Secondary sedimentation	Overflow rate		600 gpd/ft^2
	Number of tanks	3	3
	Diameter		85 ft
Disinfection	Contact time, adwf	30 min	30 min
	Number of tanks	2	2
	Length		110 ft
	Width		15 ft
	Depth		8 ft
Gravity thickening	Solids loading rate		12 $lb/ft^2/day$
	Circular, number	1	1
	diameter	15 m	50 ft
	Adjustment factor for cost† curve = 10 x 6/12 $\times \frac{19,000}{8,200}$ = 11.6 mgd		
Anaerobic digestion	Two stage, loading		0.16 $lb/ft^3/day$
	number	2	2
	diameter		55 ft
	sidewall depth		28 ft
	Floating cover		
	Gas utilized for heating		
Vacuum filtration	Surface loading rate		5 $lb/ft^2/hr$
	Number		1
	Diameter		8
	Length		8 ft 6 in
	Assumes 12 hr day, 5 day week		

* Data in this table is for cost centers development and is not necessarily representative of an actual facility.

† Refer Appendix H, p. H-156, cost curves are for secondary sludge, typical plant utilizes thickener for both primary and secondary sludges.

or practices. For further details of work included in the process steps, the reader is directed to the relevant pages of Appendix H of the EPA Areawide Assessment Procedures Manual.

In establishing the unit sizes, attention was given to directions within Appendix H, i.e., "Secondary clarifiers" provides that units of less than 46 m^2 (500 sq. ft.) be rectangular while units of greater size be circular. Wherever feasible, more than one unit is provided. This is a requirement of actual plants, to permit maintenance while maintaining plant flows.

Overall Cost of Typical Plants

Table 16 presents an estimate of total costs of the typical plants on a unit process basis. The data are derived from costs for typical units, with additional costs for site work, miscellaneous structures, interconnecting piping, electrical and instrumentation. These total costs were used as the basis of comparison for costs within this study. As shown in the table, two additional factors must be added to the subtotaled construction cost figures to provide for contingencies and engineering.

TABLE 16. ESTIMATED CONSTRUCTION COSTS

Stage	Estimated cost*	
	44 l/s plant	440 l/s plant
Influent pumping	160,000	700,000
Preliminary treatment	38,000	150,000
Primary sedimentation	105,000	420,000
Trickling filters	160,000	-
Activated sludge	-	1,040,000
Secondary sedimentation	200,000	800,000
Disinfection	50,000	190,000
Gravity thickening (adjusted)	36,000	120,000
Aerobic digestion	115,000	-
Anaerobic digestion	-	600,000
Sludge pumping	-	37,000
Land application of digested sludge	25,000	-
Vacuum filter dewatering	-	470,000
Miscellaneous structures	70,000	250,000
Subtotal	968,000	4,777,000
Piping (10%)	97,000	478,000
Electrical (8%)	77,000	382,000
Instrumentation (5%)	48,000	239,000
Site preparation (5%)	48,000	239,000
Subtotal	1,238,000	6,115,000
Construction contingencies (15%)	186,000	917,000
Engineering (15%)	186,000	917,000
Total, estimated construction cost	1,610,000	7,949,000

* Costs per Areawide Procedures Manual Appendix H (ENR 2475, September 1976).

These factors have not been applied to individual costs because, while they are applied as a percentage (15 percent) to the construction cost subtotal for a given facility, in actual practice it is not the case. Contingencies are used as an allowance for unforeseen construction difficulties and engineering costs do not, in actuality, apply uniformly to a facility on a unit-by-unit basis. The construction cost of the two plants, allowing 15 percent each for contingencies and engineering, is $1,610,000 and $7,940,000 for the 44 l/s (1 mgd) and 440 l/s (10 mgd) plants, respectively. The reader is cautioned that the data are valid only for comparative purposes. There may, and indeed will, be considerable cost differences between the cost estimates herein and the actual construction costs of facilities.

Cost Center Development

Once the basic cost data for the two representative plans were developed, cost centers for the unit processes could be identified and analyzed. The remainder of this chapter describes the development of individual cost centers for unit processes, and the summation of costs of individual elements to determine their impact on overall treatment plant costs. These latter analyses were carried out for the 440 l/s (10 mgd) plant. Two process units were analyzed for the 44 l/s (1 mgd) plant.

Unit Process Cost Breakdowns

Tables in this section are for treatment plant units representative of the common construction shapes. Details of the cost breakdowns are given in Appendix A. All processes were analyzed for the 440 l/s (10 mgd) plant where as only trickling filters and aerobic digesters were analyzed for the smaller plant.

The analysis was conducted by selecting representative examples from actual projects, developing unit quantities, and pricing the quantities. The cost of each major work item for each major construction element was developed in terms of dollar figures. These data are included as Appendix A. It should be noted that although the unit totals are of the same order as in Table 16, they inevitably differ to some degree. To avoid the need to introduce cost indices into these calculations, all costs in the main text are adjusted to the Appendix H cost base date of September, 1976, or they are represented as percentages. The percentage figures in Table 22 are based on a plant subtotal cost and exclude piping, electrical, instrumentation and site preparation costs, in accordance with the established format of Appendix H of the Areawide Procedures Manual.

For five units, selected to be representative of each common construction shape, the cost data have been translated to Appendix H totals by multiplying all figures by the ratio of

Appendix H cost to calculated cost. These cost data are represented in Tables 17 through 21. The totals for each construction element and for each work item are shown as percentages, with two percentages (structural cost = 100 percent, total cost = 100 percent) developed. A relevant commentary on the unit cost centers is included in the form of footnotes to many of the tables in Appendix H.

The information within Tables 17 through 21 and the 13 tables in Appendix A is presented in condensed form. Nevertheless, it is still cumbersome when comparative overall treatment plant costs are desired. Table 22 for structural costs reduces the data to a simple 6x6 matrix.

Several facts should be noted regarding the cost tables. The design of individual treatment units varies widely from project to project and from designer to designer. For example, in Table 21, the cost of the "Y-wall" item for forming effluent launders in concrete is significant, yet in many installations effluent launders are inboard steel channels, in which case "Y-wall" cost would be zero and structural steel costs would be higher. (Note that the "Y-wall" cost item represents an increase over base vertical wall cost.)

"Other structural" and "Other mechanical" items as shown on Table 22 include a variety of items. Many of the constituent items of "Other structural" are shown on the individual unit cost breakdowns (Tables 17 through 23 and Appendix A). The "Miscellaneous structural" item on the detail sheets includes such items as metal and concrete stairways and ladders, painting and other waterproofing, interior drywalls, gratings and frames, supports, anchors and other attachments, handrails (a larger cost item in many instances), and miscellaneous architectural items such as doors, windows, etc.

In a similar fashion, many of the items included in "Other mechanical" can be identified on the detail sheets. Generally, only the main process equipment is included under the heading "Mechanical equipment". For example, in Table 21, the vacuum filter, vacuum pump, filtrate receiver, filtrate pump and sludge cake conveyor are included in the "Mechanical equipment" item, but feed pumps, chemical mixing and feeding systems, building ventilation and similar equipment are either identified separately or included in the "Miscellaneous mechanical" item. Examples of other items typically included under miscellaneous mechanical are heating, ventilation and air conditioning equipment, ducting, louvers, cranes, sump pumps, plant air and water service systems, control gates, weir plates, etc.

TABLE 17. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY
440 l/s (10 mgd) INFLUENT PUMP STATION
TYPICAL OF DEEP STRUCTURES

Item	Cost*						Cost as percent	
	Formwork		Concrete		Rebar steel	Total	Structural	Total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	57,157	-	8.2
Foundation base slab	763	6,407	21,022	1,635	4,859	34,686	13.0	5.0
Ground floor and roof slab	2,429	4,999	5,606	7,008	14,294	34,336	12.9	4.9
Discharge structure	769	6,472	21,234	1,651	4,908	35,034	13.2	5.0
Vertical walls	10,042	30,636	21,153	16,112	21,611	99,554	37.4	14.2
Precast architectural face panels	-	-	20,260	3,576	-	23,836	9.0	3.4
Miscellaneous structural	-	-	13,552	25,167	-	38,719	14.5	5.5
Variable speed pumps	-	-	-	-	-	119,249	-	17.0
Other mechanical equipment	-	-	-	-	-	257,259	-	36.8
						699,830	100.0	100.0
Total	14,003	48,514	102,827	55,149	45,672	266,165		
Cost - Percent of structural concrete	5.3	18.2	38.6	20.7	17.2	100		
- Percent of total	2.0	6.9	14.7	7.9	6.5	38		

*September, 1976 cost levels.

TABLE 18. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY 440 l/s (10 mgd) RECTANGULAR PRIMARY SEDIMENTATION TANKS TYPICAL OF BURIED RECTANGULAR TANKAGE

Item	Cost*						Cost as percent	
	Formwork		Concrete		Rebar steel	Total	Structural	Total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	15,678	-	3.7
Tank floor slabs	358	2,214	21,548	19,817	24,292	68,229	33.6	16.1
Tank solids hoppers	3,018	8,170	2,978	2,623	4,385	21,174	10.4	5.0
Vertical walls	11,249	33,222	9,920	16,303	15,237	85,931	42.3	20.2
Tank piers	283	1,667	149	769	3,976	6,844	3.4	1.6
Ground level cross beams	580	2,014	1,464	3,470	4,973	12,501	6.1	2.9
Ground level flat slabs	668	1,455	1,537	1,223	884	5,767	2.8	1.4
Miscellaneous structural	245	716	1,024	942	-	2,927	1.4	.7
Pumping equipment	-	-	-	-	-	23,914	-	5.6
Sludge collection equipment	-	-	-	-	-	125,222	-	29.5
Miscellaneous mechanical	-	-	-	-	-	56,672	-	13.3
						424,859	100.0	100.0
Total	16,401	49,458	38,620	45,147	53,747	203,373		
Cost - Percent of structural concrete	8.1	24.3	19.0	22.2	26.4	100		
- Percent of total	3.9	11.6	9.1	10.6	12.7	47.9		

* September, 1976 cost levels.

TABLE 19. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY
440 l/s (10 mgd) CIRCULAR SECONDARY CLARIFIERS
TYPICAL OF BURIED CIRCULAR TANKAGE

Item	Cost *						Cost as percent	
	Formwork		Concrete		Rebar steel	Total	Structural	Total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	40,735	-	5.0
Total base slab	852	4,239	28,688	31,473	29,997	95,249	30.2	11.9
Vertical wall sections	13,558	43,302	14,034	15,835	20,756	107,485	34.1	13.4
Y-walls	12,115	20,463	4,477	9,084	15,104	61,243	19.4	7.7
Tank top beams and ground slabs	1,640	3,581	3,782	4,652	2,248	15,903	5.0	2.0
Influent and effluent encasement	1,249	2,465	6,827	2,588	3,425	16,554	5.2	2.1
Sludge collection box	1,651	4,470	1,629	1,063	2,400	11,213	3.6	1.4
Miscelaneous structural	-	-	6,626	1,342	-	7,968	2.5	1.0
Tank hydraulic distribution equipment	-	-	-	-	-	286,322	-	35.8
Pumping equipment	-	-	-	-	-	62,136	-	7.8
Other mechanical equipment	-	-	-	-	-	95,193	-	11.9
						800,100	100.0	100.0
Total	31,065	78,520	66,063	66,037	78,930	315,615		
Cost - Percent of structural concrete	10.0	24.8	20.9	20.9	23.4	100		
- Percent of total	3.9	9.8	8.3	8.3	9.2	39.5		

*September, 1976 cost levels.

TABLE 20. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY 440 l/s (10 mgd) TWIN PRIMARY DIGESTERS AND SLUDGE CONTROL BUILDING TYPICAL OF ABOVEGROUND CIRCULAR TANKAGE

Item	Cost *						Cost as percent	
	Formwork		Concrete		Rebar steel	Total	Structural	Total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	25,758	-	4.3
Tank floor slabs	497	3,110	6,987	1,874	4,573	17,041	8.6	2.8
Tank vertical walls	13,029	43,459	12,599	2,688	24,198	95,973	48.3	16.0
Control building base slab	120	595	2,142	497	3,060	6,414	3.2	1.1
Control building floors and roof	455	948	922	241	1,691	4,257	2.1	.7
Control building vertical walls	4,075	11,338	5,696	8,991	6,103	36,203	18.2	6.0
Architectural - tank and building	589	1,716	15,100	16,771	2,647	36,823	18.5	6.1
Miscellaneous structural	-	1,443	777	-	-	2,220	1.1	.4
Floating gas holder covers	-	-	-	-	-	187,859	-	31.3
Heat exchangers	-	-	-	-	-	92,222	-	15.4
Gas mixing equipment	-	-	-	-	-	46,110	-	7.7
Sludge circulation equipment	-	-	-	-	-	39,279	-	6.6
Miscellaneous mechanical	-	-	-	-	-	9,819	-	1.6
						599,978	100.0	100.0
Total	18,765	62,609	44,223	31,062	42,272	198,931		
Cost - Percent of structural concrete	9.4	31.5	22.2	15.6	21.3	100		
- Percent of total	3.1	10.4	7.4	5.2	7.1	33.2		

*September, 1976 cost levels.

TABLE 21. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY
440 l/s (10 mgd) VACUUM FILTRATION FACILITY
TYPICAL OF ABOVEGROUND PRECAST STRUCTURES

Item	Cost *						Cost as percent	
	Formwork		Concrete		Rebar steel	Total	Structural	Total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	3,919	-	.8
Floor and foundation slab	4,493	12,406	14,933	3,162	14,924	49,918	37.5	10.6
Precast concrete wall panels	-	-	40,732	7,188	-	47,920	36.0	10.2
Roof deck	865	1,584	3,843	1,140	431	7,863	5.9	1.7
Interior drywalls	928	1,855	-	-	-	2,783	2.1	.6
Equipment mezzanine	336	1,041	1,041	258	1,095	3,775	2.8	.8
Miscellaneous structural	1,964	6,584	4,640	3,261	4,453	20,902	15.7	4.5
Steel frame of building	-	-	-	-	-	13,728	-	2.9
Grating	-	-	-	-	-	5,369	-	1.1
Painting	-	-	-	-	-	24,959	-	5.3
Cranes	-	-	-	-	-	9,360	-	2.0
Louvers	-	-	-	-	-	4,991	-	1.1
Vacuum filter and ancillary equipment	-	-	-	-	-	227,126	-	48.3
Pumps and metering equipment	-	-	-	-	-	13,728	-	2.9
Holding tanks	-	-	-	-	-	18,719	-	4.0
Miscellaneous	-	-	-	-	-	14,975	-	3.2
						470,005	100.0	100.0
Total	8,586	23,443	65,189	15,010	20,903	133,131		
Cost - Percent of structural concrete	6.4	17.6	49.0	11.3	15.7	100		
- Percent of total	1.8	5.0	13.9	3.2	4.4	28.3		

*September, 1978 cost levels.

TABLE 22. SUMMARY OF 440 l/s (10 mgd) TYPICAL PLANT COSTS, (Thousand Dollars)

Structure	Structural											Mechanical		Total[b]
	Earthwork	Base slabs	Suspended slabs	Poured vertical	Y-walls	Precast vertical	Hoppers	Piers	Cross beams	Covers	Other	Major	Other	
Buried rectangular structures														
Preliminary treatment	14	10		23	-						5	81	18	151
Primary sedimentation	16	74		86			21	7	13	-	3	149	57	426
Activated sludge	123	126	13	238	86			4	24		101	286	31	1,032
Disinfection	23	17	6	30	-	27			-	-	6	55	27	191
Subtotal	176	227	19	377	86	27	21	11	37	-	115	571	133	1,800
Item cost as percent of plant subtotal	3.7	4.7	.4	7.9	1.8	.6	.4	.2	.8		2.4	12.0	2.8	37.7
Item cost as percent of plant structural	-	10.1	.8	16.8	3.8	1.2	.9	.5	1.7		5.2			
Buried circular structures														
Secondary sedimentation	41	95		107	61		11		16		25	348	95	799
Item cost as percent of plant subtotal	.9	2.0		2.2	1.3		.2		.3		.5	7.3	2.0	16.7
Item cost as percent of plant structural		4.2		5.8	2.7		.5	-	.7		1.1		-	
Aboveground circular structures														
Gravity thickening	11	11		11	11		1	2	-	16		48	9	120
Anaerobic digestion	26	23	4	132						188	39	178	10	600
Subtotal	37	34	4	143	11		1	2		204	39	226	19	720
Item cost as percent of plant subtotal	.8	.7	.1	3.0	.2		.1	.1		4.3	.8	4.7	.4	15.1
Item cost as percent of plant structural		1.5	.2	6.4	.5		.1	.1		9.1	1.7			
Buried deep structures														
Influent pumping station	57	35	35	100		24					74	119	257	701
Item cost as percent of plant subtotal	1.2	.7	.7	2.1		.5		-			1.6	2.5	5.4	14.7
Item cost as percent of plant structural		1.6	1.6	4.4		1.1		-			3.3			
Precast concrete structures														
Sludge pumping												37		37
Vacuum filter facilities	4	50	12			62					59	227	57	471
Miscellaneous structures	3	19	19			58					21	-	130	250
Subtotal	7	69	31		-	120	-			-	80	264	187	758
Item cost as percent of plant subtotal	.2	1.4	.7	-		2.5					1.7	5.5	3.9	15.9
Item cost as percent of plant structural		3.1	1.4			5.3	-				3.6			-
All structural types														
Subtotal	318	460	89	727	158	171	33	13	53	204	333	1,528	691	4,778[a]
Item cost as percent of plant subtotal	6.6	9.6	1.9	15.2	3.3	3.6	.7	.3	1.1	4.3	7.0	32.0	14.5	100.0
Item cost as percent of plant structural	-	20.5	4.0	32.4	7.0	7.6	.6	2.4	9.1	14.9	-			100.0

[a] Plant total cost = Plant subtotal + Piping, 10% + Electrical, 8% + Instrumentation, 5% + Site preparation, 5%
= 4,778 + 478 + 382 + 239 + 239 = $6,116

[b] Differences in item costs exist between this table and tables 17 through 21 due to rounding.

TABLE 23. CONDENSED SUMMARY, TYPICAL PLANT STRUCTURAL COSTS AS A PERCENT OF TOTAL PLANT STRUCTURAL COST, 440 l/s (10 mgd)

	Earthwork	Base and suspended slabs	Vertical walls: poured, Y and precast	Hoppers, piers and cross beams	Covers	Structural
Buried rectangular structures	6.9	9.6	19.2	2.7	-	4.5
Buried circular structures	1.6	3.7	6.6	1.0	-	1.0
Above ground circular structures	1.6	3.7	6.6	1.0	-	1.5
Buried deep structures	2.2	2.7	4.9	-	-	2.9
Precast concrete structures	0.3	3.9	4.7	-	-	3.1
Combined costs for all structural types	12.4	21.4	41.4	3.8	8.0	13.0

COST CENTERS

From Table 23, it is evident that vertical wall construction of various types accounts for some 40 percent of total treatment plant structural cost. Vertical walls for buried rectangular/circular structures alone account for almost 20 percent of total costs. Various slabs account for 20 percent of total cost, with buried rectangular/circular types again representing nearly half. Other notable values from this table are 9.0 percent of total cost for digester covers and some 8.5 percent for excavation and earthwork costs for buried rectangular/circular structures.

Table 22 gives similar conclusions to Table 23, in more detail, and unit-by-unit. The relative costs of mechanical equipment to total plant costs can be seen here. Thirty-two percent of total costs relates to major mechanical equipment, 14.5 percent relates to other items of mechanical equipment. The total cost of these two items approaches 50 percent of total plant cost. Based on an assumption that potential cost savings are proportional to present cost, it is apparent that mechanical equipment offers a promising area for potential cost savings. A discussion of factors impacting the cost of mechanical equipment may be found in Section 4 of this report.

The remaining tables (17 through 23 and Appendix A) show interesting detail trends. The lower relative cost of formwork to concrete for below ground versus above ground structures is apparent if Tables 17 (influent pump station) and 20 (anaerobic digesters) are compared. This represents the difference between the more massive underground structure where finish is relatively unimportant and the thin walled abovegrade structures where finish for visual appearance is of prime concern. Table 21 (vacuum filter facility) indicates a similar aboveground structure trend except that the concrete item is high. Inspection of the table reveals that over 60 percent of the concrete item relates to off-site fabricated precast panels for which no on-site forming and little concrete labor is required.

Similar trend information anomalies, and the reasons for them, can be developed by reviewing and comparing the tables. The data, in its present form, provides a useful guide to designers by providing a means of altering the Engineer to the impact of design decisions. However, since each wastewater treatment project is unique because of various site, environmental and process considerations, we do not believe firm conclusions or recommendations can be drawn from the data. We do believe, however, that the data, in reduced form should be made generally available for use as an aid to designers.

The cost center analysis proved useful in identifying areas having potential for cost savings using unconventional or novel methods or materials of construction; the analysis pointed to some non-structural elements as well, particularly as related to procedures used in specifying mechanical equipment.

REFERENCES

9. 1976 Dodge Guide to Public Works and Heavy Construction Costs.

10. Technical Report MCD-38 "Construction Costs for Municipal Wastewater Conveyance Systems, 1973-1977".

SECTION 6

UNCONVENTIONAL METHODS AND MATERIALS OF CONSTRUCTION

UNCONVENTIONAL METHODS AND MATERIALS

For the purposes of this report, unconventional methods and materials of construction are those which, though not routinely employed, have been proven or at least demonstrated in actual installations. In contrast, novel methods and materials are those which represent promising new approaches to reducing the cost of wastewater conveyance and treatment facility construction.

This section describes the results of the search to identify unconventional methods and materials of construction. A selection of unconventional methods and materials are described in the latter part of the section. The format selected for these individual reports is intended to make them useful as a reference section. Areas of application are highlighted so that a reviewer may easily determine whether or not an idea might apply to a particular situation.

RESEARCH

Computer Searches

Research into unconventional methods and materials of construction was initiated using computer search assistance. EPA, in formulating the scope of the project, undertook several computer searches. This research path was continued, developing a search program, which is included as Appendix C. Authors of articles which deal with novel and unconventional methods and materials of construction do not necessarily term them as such. Key words used in searches for these items were therefore developed to try to identify novel and unconventional items directly. Pairing key words to link, for example, treatment process units with such terms as "economic analysis", "value engineering" and "efficiency" was attempted.

The computer printouts generated by these searches were subjected to careful scrutiny. The first review was always undertaken by an experienced engineer, who eliminated unrelated references. Potential references were then located by staff members, copied and reviewed again by experienced engineers. The process was extremely barren; of over a thousand items reviewed, less than ten provided useful study input.

Contractor Contacts

During contacts with construction contractors to develop input for the nonstructural phase of this study reported in previous sections, questions were raised concerning novel and unconventional methods and materials. The general response was that novel and unconventional ideas were rapidly applied by contractors to improve the inventor's bidding position. No novel ideas were suggested, but several unconventional ideas were identified.

Other Contacts

Various other contacts were made. Industrial associations, mechanical equipment suppliers, engineers, treatment plant operators and others were solicited for ideas. Several more useful ideas were gained from these efforts.

Results

A number of unconventional ideas suggested were not considered since they related to equipment or process ideas. Many ideas showed promise in the area of process improvement or operational cost reductions, but were considered outside the terms of this study. Finally, a selection of unconventional ideas was agreed upon as appropriate to the study theme. Each of these ideas were then examined in more depth. Some were subsequently rejected because they were not effective in reducing capital cost; these are listed in Appendix B.

The remaining unconventional methods are included in this section. Each is described in terms of concept, application, description, advantages, and disadvantages and costs. In some instances, for example, "sewer-within-sewer", no comparative data were available, but potential cost savings are apparent.

Nine potentially cost-effective unconventional methods are identified and are described in following paragraphs:

- Insituform pipe liners

- Trenchless sewer pipe installation

- Sewer-within sewer

- FRP piping

- FRP bridges
- Plastic fluid control equipment
- Miscellaneous FRP items
- FRP digester covers
- Unconventional covers and enclosures.

Ideas delegated to Appendix B by virtue of their inability to pass the capital cost reduction test were:

- Ozone generation
- Shotcrete
- Concrete dome covers
- On-site wound FRP tanks.

POTENTIALLY COST-EFFECTIVE UNCONVENTIONAL METHODS

Insituform Pipe Liners

A new approach to sewer pipe relining is a flexible polyethylene liner that is cured insitu. It supports deteriorated sewer lines and seals against infiltration of groundwater. The process was developed in England where several installations exist.

Applications--

Generally, the insituform pipe lining method may be used to achieve the following:

- Reduce infiltration
- Repair weak or structurally unsound sewers
- Reline brick sewers to improve capacity.

Description--

Two different techniques are used to install insituform pipe liners, depending on whether sewage diversion or overpumping is possible (inversion technique) or not (flow through technique).

The flow through process of insituform lining involves inserting a tube of terylene felt into a sewer pipe of slightly larger diameter. The liner is inflated with low pressure air, followed by steam. The liquid polyester resin that totally impregnates the felt cures because of the increased temperature in four hours. The resultant shell is 3-19 mm (1/8 - 3/4 in) thick with properties similar to glass reinforced plastic.

Flow is maintained through the curing process by the use of an inflation bag. This is a double skinned reinforced polyvinylchloride tube which is placed inside the impregnated felt tube. Air is blown between the PVC skins, collapsing the inner layer, expanding the outer layer and pushing the impregnated felt against the sewer wall until the water forces its way through the middle of the bag.

Cement grout can be injected behind the liner to fill in the voids and consolidate the sewer. The flow from lateral sewers is intercepted and pumped to the next manhole until the inflation bag can be withdrawn and the laterals cut out. In smaller diameter sewers, the laterals are located by television camera and cut out with a remotely controlled drogue.

The terylene felt is relatively inexpensive as it is made up by a needling process from waste fiber. Impregnation is carried out at the factory by enclosing the felt in an inner and outer polyethene skin and applying catalyzed resin under vacuum. The linings are transported under refrigeration.

It is possible to line pipes from 102 mm (4 in) up to 1,220 mm (48 in) diameter. The work is usually carried out through normal manhole openings using lengths of up to 122 m (400 ft).

The inversion technique is used when flows can be overpumped or diverted. This process is also appropriate for sewers that are too small for access. A resin impregnated felt tube is enclosed in a sheath of polyurethane film and fed through a vertical inversion pipe with a 90-degree bend at the bottom. The tube is turned inside out over the ends of a horizontal spout and clamped to the end of the inversion pipe. Water is then pumped into this pipe. As heat builds up the lining turns inside out. Hot water (75 C) is circulated to cure the resin; a process which requires about two hours.

Advantages--

The insituform technique provides the following benefits:

- Increases flow coefficient
- Chemically resistant to most chemicals found in wastewaters
- Abrasion resistant
- Maintenance free

- Conforms to contours of distorted sewer line
- Supports old sewers from collapse and prevents scouring of mortar jointing
- Rapid and simple installation, no excavation
- Small reduction in cross-sectional area of pipe.

Research is currently being carried out on a system for inverting resin felt lining into a new sewer with a reusable polyurethane tube. The concrete sewer is sprayed with a non-catalyzed resin which bonds to the catalyst contained in the felt.

Disadvantages--

Only sparse data have been collected on the performance of this system in the variety of environmental conditions which commonly prevail in wastewater collection systems. The material is not adequately resistant to plating wastes, for example. Hence, this technique may not be suitable for use in industrial sewers. In our judgement, careful attention to detail is required during application, or the possibility exists that the curing process may not be accomplished properly.

Cost Data--

The insituform technique is appropriate for repair of existing sewers, where it may be used to correct excessive infiltration or strengthen failing pipe. Comparative cost data, based upon hypothetical situations, therefore, are meaningless. The cost of repair or replacement or remedial measures, such as soil grouting for control of infiltration, must be compared directly against the cost of the insituform method on a site specific basis because of the many variables to be encountered. With due consideration of the disadvantages noted above, it would appear that insituform pipe liners may offer promising economic advantages.

Trenchless Sewer Pipe Installation

A recent EPA demonstration grant project has successfully shown that installation of sewer pipe to accurate grade and alignment is possible with trenchless pipelaying equipment. European engineers have considerable experience with installation of drainage pipes, pressure pipes and conduit.

Applications--

Possible uses in the EPA grant program include:

- Installation of small diameter sewer pipelines and house connections

- Installation of conduit and small pressure pipelines in rural areas of treatment plant projects.

Description--

A vertically fixed, modified plough blade cuts the ground to the required depth. The sewer pipe is connected to the blade's toe and pulled through the cavity generated by the plough. A pointed steel shield protects the leading end of the pipe. Capabilities exist for installing pipe up to 22 inches in diameter to a depth of 9 feet, assuming relatively consistent soil conditions.

Vibratory plowing equipment, a somewhat different design from that used in the EPA demonstration, is available in the United States for trenchless underground pipe installation. A plow blade with a vibrating compactor tip is used to pull continuous lengths of pipe into place. Pipe up to 4 inches in diameter may be placed 36 inches underground with this equipment. Vehicles equipped with vibratory plowing equipment can lay pipe in highly manicured areas, such as golf courses, without having unsightly trench or wheel scars.

Advantages--

- Surface disturbance is less than by conventional construction, hence restoration costs will be less,

- Installation speeds can be greater than by conventional construction, hence cost savings.

Disadvantages--

At present, the following are the major disadvantages of trenchless sewer construction:

- Machinery is currently available only in England and Germany, and is expensive to build and ship,

- Limiting pipe size and ground conditions,

- Limited availability of specialized pipe laying equipment,

- Soil conditions will dictate results: Well consolidated soils, boulders, high ground water table, etc., will cause problems.

Cost Data--

Potential cost savings are discernible in favorable soil conditions, and where small diameter pipe can be laid accurately and rapidly with the right machinery. In the only known U.S. demonstration project, sponsored by EPA, the trenchless sewer method proved more cost-effective than conventional methods. On the basis of the actual bid price, for 20.3 cm (8 in) polyvinylchloride (PVC) gravity sewer mains, installed cost using conventional methods was $49.21 per lineal meter ($15 per lineal foot), while installed cost for trenchless areas was $29.33 per lineal meter ($9 per lineal foot). On the basis of computed costs for complete PVC sewer installation, including wyes, manholes and laterals, the costs per lineal meter for conventional and trenchless systems were $75.90 and $63.57 ($23.15 and $19.39) respectively. Concerning labor only, the computed cost differential was $2.76 per lineal meter ($.84 per lineal foot) in favor of the trenchless method.[11]

<u>Sewer-Within-Sewer</u>

Many of the nation's metropolitan areas are served by combined sewers. While the need for separation of these systems is obvious, progress has been slow because of the enormous costs associated with sewer construction in congested areas. The sewer-within-a-sewer technique, where the sanitary sewer is installed within the existing storm sewer promises to be an economical solution in at least some areas.

Applications--

In the case history described below, a gravity sewer was installed within an existing large diameter combined sewer, realizing large savings over more traditional approaches to the sewer separation problem. The technique could be applied as well to pressure sewer systems, if that type of installation was found to be more cost effective, as indicated in EPA-R2-72-091 and <u>Status of Pressure Sewer Technology</u> by James F. Kreissl.

Description--

In a previous application of this technique,[12] a 14 inch diameter, asbestos-cement, sanitary sewer was laid in the invert of an existing combined sewer; a 60 inches high by 40 inches wide, elliptical, cast-in-place, concrete pipe. Total length involved was approximately 1,800 feet. The sanitary sewer pipe was placed into position (one 8 foot section at a time), working manhole to manhole along the length of the combined sewer. Pipe sections were connected with pressure joints.

Sanitary leads from buildings along the route were tapped into the new sewer using 6 inch diameter asbestos-cement pipe and fittings. The new leads were routed along the interior wall contour of the old pipe, and were fastened to the pipe wall using stainless steel straps and anchors. The sanitary leads were then covered with gunite to provide protection and to keep turbulence to a minimum. A quick-set mortar sealant prevented leakage of sanitary sewage into the storm sewer during construction.

Each 400 foot section of sanitary sewer pipe installed in the manner described was then concreted over to a depth of two inches with 3,500 psi concrete. In this particular installation, the invert of the new storm sewer formed by this process was considerably flatter than that of the original combined sewer. A wooden screed cut to ride the pipe walls at the designed depth kept the covering uniform. Cleanouts were installed through the concrete invert at each deep manhole to allow for flushing by high pressure water.

Entrance to the combined sewer was made via shafts sunk at street intersections: the shafts were located at the sites where sanitary laterals emptied into the old combined sewer manholes. These laterals were dead-ended into their own manholes, and the manholes then sewered into the new sanitary sewer.

Advantages--

The following advantages were cited for the referenced installation:[13]

- Substantial savings in cost (a reduction from $600,000 to $200,000) over traditional methods of sewer installation involving open-cut or tunneling techniques,

- Reduced inconvenience to downtown traffic, businesses and shoppers,

- Reduced sanitary sewer maintenance problems because the sewer pipe is not subjected to the loads, etc., experienced by a conventional sewer line,

- Construction produces minimum disruption to the existing sanitary system and the utilities.

Disadvantages--

The installation of the sewer within an existing storm sewer will reduce the storm sewer's cross-sectional area and, thus, its capacity. In the instance cited, the sewer was installed in the invert of the existing sewer and a new invert was formed with concrete, possibly causing future maintenance problems because of reduced velocities at low flow. Some of these drawbacks could potentially be avoided by installing the new sewer in the crown of the storm sewer; where the elevations of existing sanitary sewer laterals permit, interception system can be justified.

The technique is limited to instances where a relatively large diameter (60 inches or larger) existing sewer is available, and only modest quantities of sanitary wastewater must be accommodated.

Fiberglass Reinforced Polyester Applications

Fiberglass reinforced polyester (FRP) piping systems are becoming more prevalent and quality control is improving. Properly engineered, FRP systems can be used to overcome problems caused both by corrosive soils and corrosive liquids in wastewater systems.

Applications--

Specific applications for FRP piping systems include:

- Sewerage systems carrying high-temperature, acidic, alkaline wastewaters, or corrosive gases,
- Sewerage systems in corrosive soils,
- Process piping systems for corrosive chemicals or gases,
- Sewerage systems where pipe flexibility and reduced installation time is important,
- Sewerage systems in cold climates.

Description--

Fabrication of FRP pipe system materials consists of forming a laminate by combining controlled amounts of epoxy or polyester resin and catalyst with fiberglass mat, cloth, woven roving, filaments or synthetic fibrous material. Successful use of FRP depends upon proper selection of materials (resin in particular), particular attention to details of construction, and proper methods of fabrication, Typically, care must be exercised to insure that proper protection is provided for the reinforcing filaments through selection of protective veils and resins. Veils should be included in any laminate subject to immersion in liquids, or used for the conveyance of liquids, to protect against migration of liquid along the reinforcing filaments, and destruction of the bond between the filaments and resin. FRP laminates can be constructed by either hand layup, contact molding or filament winding techniques. Of those three methods, filament winding, which is limited to circular or elliptical sections, provides the strongest construction and the advantages of quality control measures which can be more rapidly applied to machine-made products. The precision filament-winding process integrates the lightweight materials into one unitized high-strength piping structure. FRP is assembled and installed using flanges or a chemical-resistant adhesive for joining. Joints may be rapidly installed and are as strong as the original pipe. No costly pipe threading or welding is involved.

In Hillsborough County, Florida, FRP manholes and pump station wet wells are being used to combat severe hydrogen-sulfide corrosion in a municipal sewerage system. One 13 ton FRP wet well 2,340 mm (92 in) in diameter and 7.5 m (25 ft) in length was lifted whole and set on a concrete base at ground level. Laterals and cover were added after installation. At another site, a 1,020 mm (42 in) ID section of FRP pipe was used as a manhole liner to repair deteriorated brick manholes.[14]

At a wastewater treatment plant in California, a 1,220 mm (48 in) diameter pipe was selected by the contractor for use on a buried foul air duct because its overall cost was less than plastic lined concrete pipe.

Advantages--

Corrosion control is excellent due to resistance to both chemical and biological attack. FRP offers flexibility and toughness and is easily cut to size. Except for stiffness, FRP strength characteristics compare favorably to carbon steel or aluminum. Most of this comparable strength can be provided at weights which are only a fraction of that necessary using steel or concrete. Time and cost of pipe installation are reduced substantially due to the light weight, ease of handling and installation, longer pipe lengths (fewer joints), lower labor and construction costs. FRP exhibits low thermal conductivity, is nonconductive, and will not collect stray ground currents which may corrode other equipment. Total energy requirements to produce a ton of FRP are less than that required to produce a ton of steel.[15] Manufacturers claim that FRP life-cycle cost is approximately equal to that of mild steel with some form of coating for protection, and is about one-half the cost of stainless steel and one-fifth the cost of rubberlined steel.

Disadvantages--

FRP may often have a higher price or first cost than competitive materials. These differences are usually offset, however, by savings in support structures, installation costs, etc. Laboratory or field tests may be necessary to determine the correct resin and veiling system for each application. Without specific protection, FRP can be subject to degradation under strong ultraviolet light from sunlight or fluorescent lighting. When immersed in liquids, the material may delaminate if all exposed edges are not completely sealed with resin. Since fabrication often requires hand processing, allow for the possibility of human error. At some stress below its ultimate burst strength, FRP piping can "weep" or transmit fluid through the pipe wall without showing visible cracks. Reinforced plastics do not have definite temperature and pressure limits. Care must be used to adequately compensate for thermal expansion and contraction.

Care must be used in the selection and specification of FRP pipe for buried applications. Poorly designed or installed applications can result in cracking of the protective resin from both ring and beam tension. These cracks can lead to exposure of the reinforcing filaments to hostile environments and ultimate failure of the pipe. Several failures of reinforced plastic mortar (RPM) pipe, a variation of FRP construction, have been attributed to this cause.

Cost Data--

It is reported that two wastewater treatment plants claim 50 percent cost savings in labor and material of fiberglass reinforced plastic pipe in lieu of glass lined cast iron for sludge, sludge gas and scum systems.[16] It is also reported that another wastewater treatment project claimed 35 percent savings by using FRP suspended piping in lieu of conventional materials, such as cast iron and steel.[17]

Fiberglass Reinforced Polyester Bridges

A box type design walkway bridge of fiberglass reinforced polyester (FRP) material is claimed by manufacturers to be cheaper than steel installed costs as well as substantially cheaper in life cycle costs.

Applications--

Specific applications for this type of bridge at a wastewater treatment plants include:

- Walkways on circular clarifiers and gravity thickeners,
- Access bridges between adjacent structures,
- Access bridges for surface and turbine aerators in aeration basins and oxidation ponds.

Description--

The bridge is constructed of a high-strength continuous-fiberglass reinforced laminate which is 1/3 as dense as steel. It is pre-engineered in one piece according to specifications and is designed to be bolted in place. Generally custom fabricated, these structures can be equipped with a variety of appurtenances for various needs. Manufacturers claim that the bridge can meet OSHA requirements at all times without periodic checks for safety hazards.

Advantages--

The main advantage of FRP bridges is its low capital and operating costs. In addition, the following benefits may be realized with FRP construction:

- Lower installation costs, because of its lighter weight,

- Color is impregnated into the laminate, maintenance painting is not required,

- Non-corrosive construction,

- Non-sparking construction, suitable for hazardous environments.

Disadvantages--

As with all FRP construction, care should be exercised in the selection of resins and other construction details. Mechanical damage to the laminate could expose the reinforcing filaments to the elements and corrosive chemicals. Repairs and/or modifications to the structure must be made with care by technicians skilled in this type of construction. Since the material is relatively new, there is uncertainty with respect to the effects of ageing (creep, embrittlement, etc.) and its overall impact on useful life.

Cost Data--

A 21 m (70 ft.) FRP bridge is estimated to cost $9,450 in place. A steel bridge of the same length will cost about $17,830. This information is based on November, 1977 prices.

Plastic Fluid Control Equipment

With the advent of modern technology came the development of plastic construction materials and their utilization in fluid control equipment. A variety of plastics have been developed specifically for use in wastewater and water treatment projects. These products have structural and corrosion resistant properties which apparently make them ideally suited for wastewater treatment applications.

Applications--

Applications for advanced technology plastics in wastewater treatment include the following:

- Sluice gates,

- Slide gates,

- Stop gates or stop logs,

- Rigid or flexible non-return flap gates,

- Horizontal or vertical splitter gates,

- Weir plates, scumboards and baffleboards.

Description--

A rigid compressed composite plastic, with ultra-vilolet light inhibitors and extremely high tensile and impact strength, is used as the outer sandwich on sluice gates, stop gates, flap valve discs, weir plates, and scum baffles.

High pressure, wall mounted, watertight sluice gates are available in a range of sizes with upward or downward opening gates and with square, rectangular or circular openings. A flush invert provides for a straight-through self-cleansing flow, eliminating grit pockets and reducing turbulence. The recommended maximum working head is 4 m (12 ft.); however, special units may sustain a higher working head.

Sluice gate frames can be fabricated of stainless steel or mild steel (sandblasted, flame zinc sprayed, etch primed and finished with epoxy paint) to provide corrosion resistant qualities consistent with those of the disc. The stem is a single-start stub-acme thread machine cut from ferrous or non-ferrous materials. The stem nut is machine cut from high molecular weight polyolefin, which has both strength and low coefficient of friction. Sluice gates fitted with a rising stem have the nut housed in the handwheel while those with the non-rising stem have the nut fitted in the disc.

The patented sluice disc sealing arrangement consists of polyolefin sealing faces and side guides with a resilient backing strip of specially expanded neoprene. The discs are factory preadjusted but can be easily readjusted on site at any time. All contact faces are made in materials selected for smooth and easy operation.

Advantages--

Plastic construction, as described above, offers the following advantages:

- Greatly reduced thicknesses and weight results in lower handling, installation and operation costs. Simpler construction and less area requirements also result. (Channel wall thickness may be reduced by 60 percent.)

- Non-toxic, smooth corrosion-free surfaces result in low maintenance and long life equipment which is not affected by and does not affect most chemical processes. Surfaces require no painting and are resistant to fungus, and algal and marine growths.

- Low friction in moving parts results in less physical effort for manual operation, smaller hand wheels, and smaller and less costly electric actuators.

- Low thermal expansion properties result in equipment that will not buckle or warp.

- Material is self-extinguishing, hence resistant to damage by fire.

- Satisfies AWWA specifications for water tightness.

Disadvantages--

Plastic construction could be a disadvantage in systems where high concentrations of solvents may be present in the wastewater.

Cost Data--

According to information furnished by the manufacturer, lower capital and installation costs for plastic fluid control equipment will result in savings of up to 20 percent over cast iron equivalents. While operating costs may be reduced somewhat, because of smaller operators, this impact will be minimal. Maintenance costs may be expected to be equal to or less than those associated with conventional sluice gate construction.

Miscellaneous FRP Uses for Wastewater Treatment Plants

Fiberglass reinforced polyester (FRP) construction for various elements commonly found in many waste treatment facilities may offer substantial benefits in both installed and overall costs. Although it is an emerging engineering material, FRP is worthy of serious consideration in a variety of applications.

Applications--

FRP could be used for the fabrication of various items typically found in wastewater treatment applications, including:

- Weir plates, effluent launders, and scum baffles,

- Metering flume liners,

- Cabinets and shelters,

- Walkway grating,

- Supports for biofilter media,

- Chain and flight sludge scrapers for rectangular sedimentation tanks.

Description--

Laminates of resin and fiberglass reinforcing material can be made in any shape desired and to fit most chemical and temperature environments. Given sufficient knowledge of expected service conditions, resins and reinforcing materials may be selected to tailor a laminate to specific needs. Production may be of special fabrications or standard products; again depending upon specific service requirements. Standard products enjoy the greatest cost saving potential.

Depending upon the nature of the corrosion protection system specified for fabricated steel, weir plates, effluent launders, and scum baffles, these items, manufactured in FRP, can be equal or marginally cheaper in cost. A major advantage of FRP elements, however, lies in lower maintenance costs when compared to steel. Assuming proper attention to details, such as structural loads, corrosion resistance and proper protective systems for the reinforcing filaments, FRP laminates may be expected to be virtually trouble free.

FRP laminates are used increasingly to provide permanent formwork for complex shapes, such as metering flumes. Cost savings of zero to 25 percent is possible over similar wood formed shapes. A more important consideration is the increased degree of precision obtained by using a correctly reinforced permanent form. This latter factor is of particular significance because of the requirements necessary to insure accurate metering facilities.

Free-standing, weatherproof cabinets and shelters constructed of FRP are becoming more readily available for the enclosure of electrical equipment,emergency generators, pumping station superstructures and substructures, and fuel tanks, etc. First cost savings over mild steel enclosures are possible provided standard sizes are adopted to permit permanent molds to be used, and provided that the mild steel is coated with a high quality corrosion protection system, and miscellaneous hardware are of non-corrosive metals. FRP enclosures can be substantially cheaper than permanent construction in these areas.

FRP grating, offering superior corrosion resistance, is available in a variety of off-the-shelf shapes and load carrying capacities. In addition, FRP grating has been used as a support system for synthetic media in biofilters. The grating is placed on a concrete subframe, forming a load-carrying platform for the media. Ease of installation plus no requirement for corrosion protection make FRP more economical under these conditions than comparable materials such as steel or concrete.

Fiberglass flights and thermoplastic chains are claimed to be lower in cost, and offer superior resistance to severely corrosive operating conditions of sludge collection service. The weight savings over the conventional metal chain and redwood flights could result in lower operating and maintenance costs through reductions in energy consumption and wear.

Advantages--

In addition to those qualities indicated above, the non-corroding, non-conducting and thermal insulating characteristics are three of FRP's foremost advantages. Its light weight frequently permits relatively convenient installation, which in turn results in lower costs. Assuming proper design and fabrication, the structures require no painting and minimal maintenance.

Disadvantages--

Since relatively little capital investment and only a modest degree of training are required for an individual to enter the FRP fabrication business, quality control can be a substantial problem. At present, only a few standards, such as National Bureau of Standards' Voluntary Product Standard PS-15, are available for the use of the specifier. The industry lacks any recognized standards setting organization, such as the National Electrical Manufacturer's Association in the electrical industry. FRP has consequently gained a relatively poor reputation in some circles. Until such time as specific standards are published and some type of effective quality regulation system is placed into effect, utilization of FRP laminates in the public works industry must be done cautiously, with rigid, owner-established and enforced quality control programs. This type of control will inevitably increase costs and reduce the attractiveness of the material.

Cost Data--

Comparative cost data are not generally applicable. An extreme variability of application and specification requirements between individual projects exists. As standards are established, and standard products developed, costs should become more competitive with conventional engineering materials. At present, FRP products tend to be cost-effective where specialized specific applications occur.

Fiberglass Reinforced Polyester Digester Covers

Fiberglass reinforced polyester (FRP) tank covers, either floating or fixed, are now available at a lower installed cost than conventional steel covers used with digesters.

Applications--

FRP covers are manufactured in four styles. Analagous to their steel counterparts are the FRP fixed, floating and floating gas holder (FGH) styles. The fixed FRP cover is a ribbed dome rigidly attached to the top of the digester tank walls. Floating FRP covers have a ballasted perimeter collar which floats on the tank contents and moves in well slides. A submerged ceiling plate mounted in a dome attached to the ballast collar helps control scum accumulations. The floating gas holder is of similar construction, except that it does not have a ceiling plate. Recently, a new type of cover was developed called the constant pressure (CP) cover. This unit, shown in Figure 7, consists of the domed (fixed or floating) cover, with an internal ballasted neoprene membrane designed to maintain a constant gas pressure. The design allows more usable gas to be stored within the digester.

Advantages--

FRP covers offer the following principal benefits:

- Lower installed costs. See Table 24.
- Greater volume of gas at usable pressure (FRP-CP type). See Table 24. This could eliminate gas storage and compression equipment at some plants.
- Better insulation properties.
- Less maintenance, corrosion free.

Disadvantages--

Presently, the specifier has only a few standards available to him, such as National Bureau of Standards Voluntary Product Standard PS-15. This is a consequence of the industry's lack of any recognized standards setting organization; such as the National Electrical Manufacturer's Association in the electrical

TABLE 24. COMPARISONS OF DIGESTER COVER COSTS AND USABLE GAS VOLUMES

Type	Installed cost*†	Usable gas - percent
40'ϕ FRP-CP	41,000	100
40'ϕ FRP-FGH	63,000	75
40'ϕ Steel-floating	58,000	3
40'ϕ Steel-FGH	63,000	33
90'ϕ FRP-CP	165,000	100
90'ϕ FRP-FGH	214,000	75
90'ϕ Steel-floating	241,000	2
90'ϕ Steel-FGH	250,000	21

* Does not include mixing equipment.

† Based on November 1977 prices.

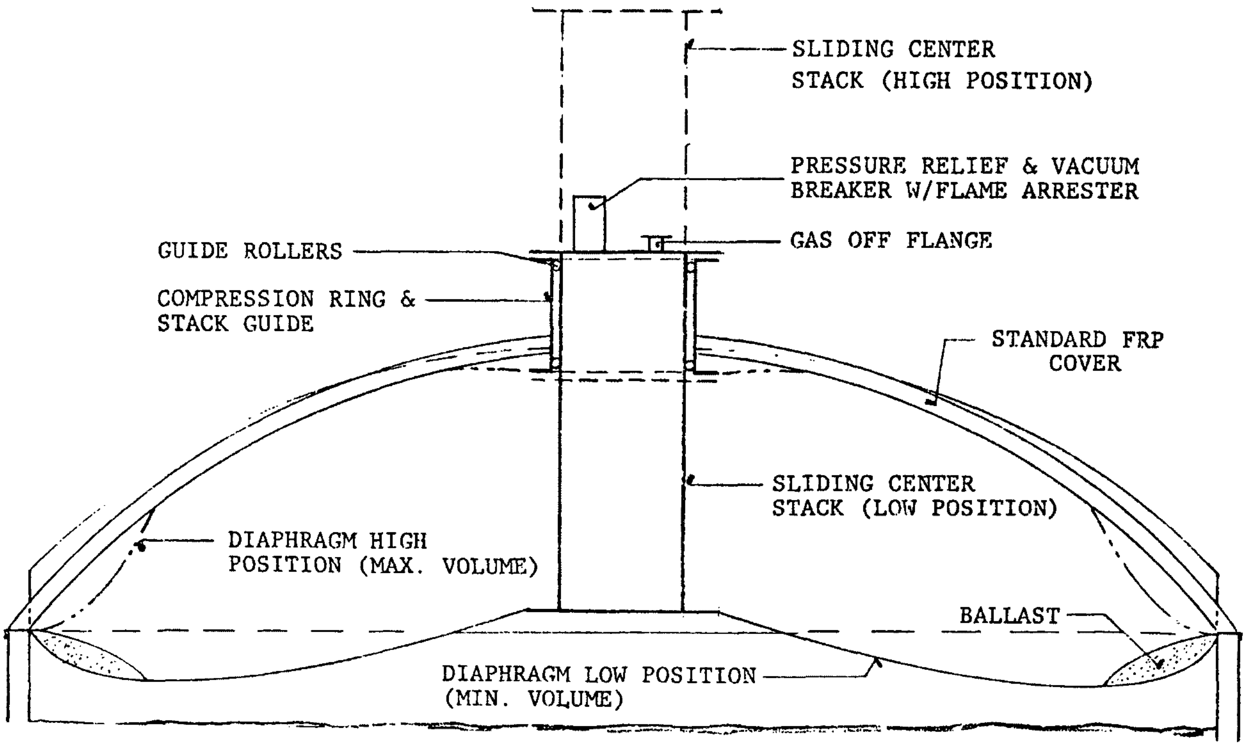


FIGURE 7. CONSTANT PRESSURE DIGESTER COVER

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industry. By virtue of the relatively low capital investment, and modest degree of training required of an individual to enter the FRP fabrication business, quality control is a problem. As a result, FRP has obtained a poor reputation in some circles. It seems apparent that until specific standards are published. and an effective quality regulation system put into working order, utilization of FRP laminates by the public works industry must be done with caution by rigid, owner-established and enforced quality control programs. Unfortunately, this kind of control will have the inevitable result of increasing the cost, while at the same time reducing the attractiveness of the material. Since the environment in and around anaerobic digesters presents some unique problems, special care must be employed when selecting resins, veils and construction details.

Cost Data--

Cost data for 40 foot and 90 foot diameter examples are provided in Table 24.

Unconventional Covers and Enclosures

Rising community expectations and regulated standards for WWTP design in some areas have necessitated that many process units be covered or totally enclosed. Several varieties of covers and enclosures are more economical than conventional concrete or steel truss units.

Applications--

Applications include the following:

- Odor containment over any size process tankage,
- Containment and recycle of generated process oxygen or ozone,
- Drying bed covers,
- Equipment covers,
- Architectural treatment.

Description--

FRP circular covers are domed structures ribbed with structural reinforcement. The covers are fabricated with the exterior surface against the mold to provide a smooth, dimensionally stable finish. A protective gelcoat resin prevents ultraviolet deterioration. Windows, entry doors, fan housings, equipment pads, etc. are integrally molded into the dome in such a manner that the structural integrity of the cover is not compromised. Resins may be tinted to provide full depth color. Gasketed panel sections can be gas tight.

Aluminum circular covers are geodesic domes, consisting of structural frames and skins. A wide variety of architectural finishes are available. They are attractive and extremely lightweight. Aluminum frames may be provided with either external permanent skins, or form a space frame around a fabric cover which can be opened when desired. FRP covers for rectangular openings come in many varieties. FRP covers are available in flat, ribbed-flat, ribbed-arch, arch and half-barrel configurations, as illustrated in Figure 8. These shapes accommodate different loadings and transmit different forces to the foundations. For all span widths, rounded or arched covers can have thinner cross sections than flat covers and hence are more economical. Openings and holes of any shape can be provided with custom FRP covers. In short spans, concrete lift slabs may be as economical as FRP covers, but the FRP covers have the advantages that they are light, and easily removable; repetitive machinery units can have integrally molded enclosures made as part of the cover. Moreover, FRP covers, properly designed and fabricated, can provide superior resistance to attack by sulfuric acid.

Aluminum covers for rectangular openings may be custom fabricated from corrugated sheet aluminum mounted on frames, forming an arch, thereby permitting access to the space below through ports at the ends. Alternatively, specially formed interlocking aluminum sheets may be used to provide a reasonably airtight flat cover. In this form, the sheets are held in place at the ends with a gasketed, two piece frame. The cover can be removed for access to the tank by one man simply by removing the top half of the frames and rolling the cover up as one would roll up a rug.

Fabric structures or membrane structures are a relatively recent development. They offer a means to enclose large amounts of space (possibly entire treatment plants) with minimal internal supports. There are basically three types: (1) "single dome" covers supported by air pressure maintained in the enclosed space; (2) "double dome" configurations where the structural members are made of fabric and gain their strength from air within the member itself; and (3) networks of tension members (cables) covered by attached membranes. Classroom buildings, convention halls, pavilions, stadiums and recreational centers have chosen fabric covers because they become increasingly cost effective as a real requirements increase. The fabric is composed of teflon coated fiberglass with a tensile strength of up to 1,000 pounds per inch of width. Pressure regulation of the building, either above or below atmospheric, is necessary for proper roof shaping, but loss of pressure is not catastrophic. A fabric roof which utilizes a three-layer cell with a movable inner,half reflective, half translucent, membrane has been developed which is capable of minimizing

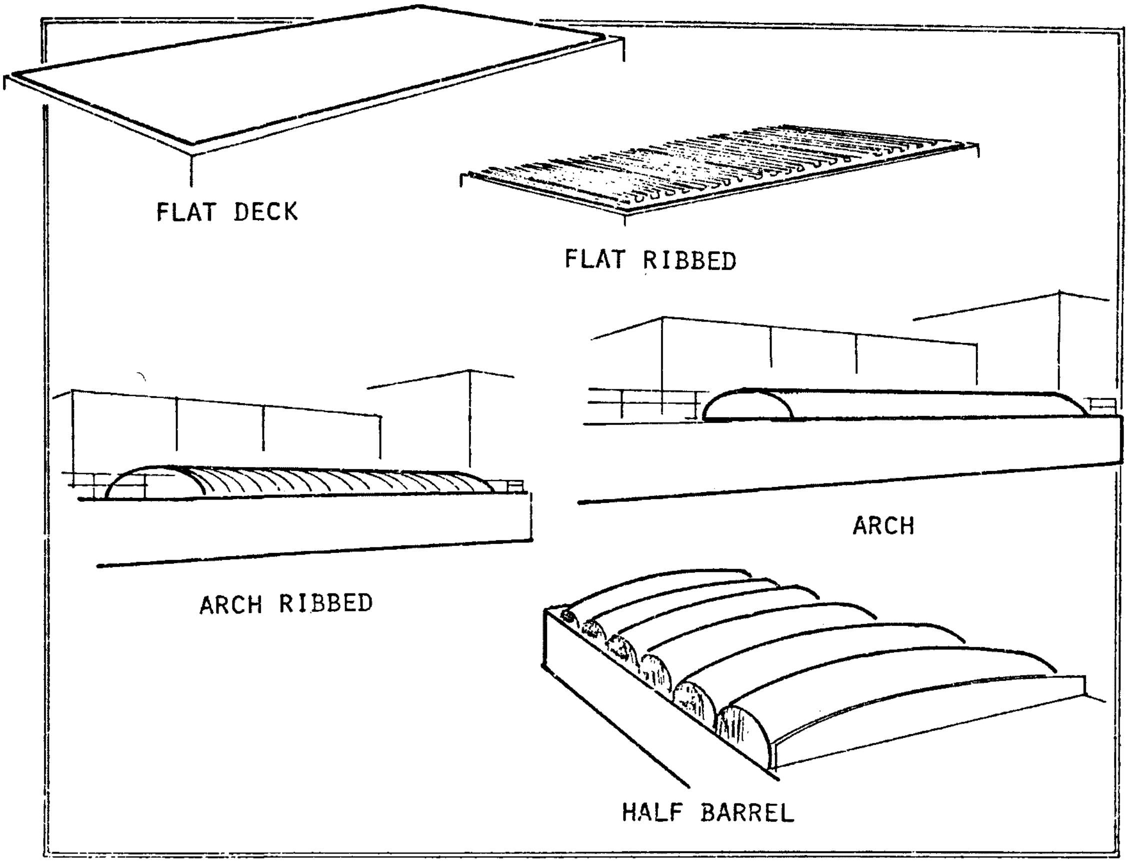

FIGURE 8. FRP COVER FOR RECTANGULAR OPENINGS

seasonal heating and cooling loads of the enclosed space even in severe climatic regions.

Advantages--

General advantages of these unconventional covers and enclosures over more conventional materials are as follows:

- Lower installed cost than concrete or steel, in most sizes,
- Extra savings from reduced wall loads,
- Lightweight. Some can be installed in a single ground-assembled piece by crane or helicopter - general ease and speed of erection,
- Self-supporting,
- Minimum maintenance.

Special advantages identified for FRP are as follows:

- Good light transmission,
- Non-conductive,
- Thermally insulating,
- Formable to any specialty shape; i.e., outline of specific place of equipment.

Advantages unique to the aluminum frame covers include:

- Can be assembled by unskilled labor,
- Easily modified when penetration or additional equipment mounting is required.

Teflon-fiberglass fabric covers have the following unique advantages:

- Lightest weight roof - 1/3 weight of conventional truss,
- Rain will clean teflon fabric,
- Good light transmission,
- Can be high or low profile,
- Variety of construction techniques offers wide choice in methods used to regulate enclosure temperatures.

Disadvantages--

Generally, these unconventional covers are:

- More vulnerable to vandalism,

- Load limitations of these materials may limit use of cover-mounted equipment.

Cost Data--

An installation cost comparison for basic covers based upon manufacturers information is shown in Table 25. Appurtenances and specialty requirements for prefabricated covers greatly influence their cost and each project must be examined individually. Covers which enclose process units on all sides, have high thermal insulation values, and transmit some light to the interior are marketed as "enclosures" and can replace a much more costly conventional building with its ancillary HVAC and lighting.

TABLE 25. UNIT COSTS FOR UNCONVENTIONAL COVER MATERIALS

Type	Cost, dollars/sf*	Type	Cost, dollars/sf*
Circular		Rectangular	
50'ϕ FRP	11-13	10' span FRP	6-11
Aluminum	12-14	Concrete	10-11
Concrete	14-16		
Fabric†	16-18	10' span FRP	7-11
100'ϕ FRP	9-11	Concrete	11-12
Aluminum	9-11	40' span FRP	8-12
Concrete	10-12	Concrete	-
Fabric	10-12		
		60' span FRP	8-12
150'ϕ FRP	9-11	Concrete	-
Aluminum	8-10		
Concrete	10-12	Aluminum spans to 60'	5-10
Fabric	9-11		
200'ϕ Fabric	8-10		

* Projected area.

† Teflon-fiberglass air supported.

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SECTION 7

NOVEL METHODS AND MATERIALS OF CONSTRUCTION

NOVEL METHODS AND MATERIALS

Novel methods and materials are those which represent new approaches to the task of wastewater conveyance and treatment facilitation. In this chapter, the methodology for the development of novel methods and materials of construction is explained, as is the rationale behind the areas of concentration of idea development. Finally, those ideas which were considered to have potential for cost savings are outlined.

IDEA GENERATION

At the outset of the study it was anticipated that novel methods and materials would be generated in two principal fashions: external to our company, and internally within the company. The methods employed and the results of those efforts are described in succeeding paragraphs. Generally, the objective was to develop as many external ideas as possible, compare these to the identified cost centers in Section 5, and generate ideas internally to resolve any apparent problems with implementation.

External Idea Development

Contacts were established with representatives of mechanical equipment suppliers, research associations, and wastewater treatment plant owners and operators. These contacts were then questioned in regard to novel methods they might have a knowledge of. In addition, computer assisted literature search methods were employed to seek out documented, new approaches. While many ideas were suggested for the study, the great majority did not fall into the categories of construction cost reductive novel methods and materials. The topics most frequently suggested were:

1. Process improvement ideas,

2. New process ideas,

3. Ideas which would reduce O&M costs,

4. Mechanical equipment ideas.

Some of these categories (1, 2 and 4) produce indirect capital cost savings. For example, a process improvement idea leads to smaller treatment units than would previously have been required for the same degree of treatment. Some preliminary development of ideas within categories 1, 2 and 4 was undertaken, along with the instigation of programs for obtaining further ideas within these categories. The principal thrust of the study effort was to produce new and more cost-effective methods of wastewater facility construction. We believe these areas of investigation should be pursued in the future studies of a similar nature. We therefore offer the following observations of our sources:

Industry--

We know that many industrial processes involve construction of facilities that are similar to those used in wastewater systems, and that industry strives to minimize its construction costs. Therefore, it follows that an in-depth review of methods and materials of industrial construction should uncover ideas which could be effectively applied to wastewater facility construction, thereby reducing costs.

Our efforts to uncover ideas from the industrial sector were directed toward three principal areas: National associations of representative wet and liquid processing industries, industries within the Central California area, and contractors involved in the construction of both industrial and wastewater facilities. In general, the associations were of little help (no replies were received from more than 80 percent of those contacted). Notable exceptions were the Asphalt Institute, the Sulfur Institute, and the National Canners Association; all of whom provided useful input. Contractors indicated that in construction they were not hesitant to cross such technical boundaries as exist between wastewater and industrial process technology; contractors frequently undertake construction in both fields, and, indeed, in many other construction fields.

Mechanical Equipment Suppliers--

Much of the information offered by mechanical equipment suppliers centered around mechanical equipment, process improvements and cost reduction. Some ideas were suitable for increased use of state-of-the-art materials and for unconventional methods, but no truly novel ideas were suggested.

Patent Information--

Preliminary investigations were made to establish the degree of effort necessary to obtain potential ideas from patent sources. Two volumes of Patent Abstracts for Solid Waste Management were reviewed; this information yielded no ideas insofar as novel methods and materials of construction are concerned. It was concluded that only patents relating directly to construction would be valid. A patent search of the size necessary to ensure full subject coverage is greatly beyond the scope of this project and would, in fact, be best undertaken as a separate major study.

Foreign Research Associations--

Foreign construction and wastewater treatment associations were contacted. No information was obtained from the construction associations. Some of the wastewater treatment associations offered general information concerning their research programs (the United Kingdom associations especially), but such ideas fell inevitably into new process or process improvement categories, and were dropped from further consideration.

Wastewater Treatment Plant Personnel--

Four wastewater treatment plant managerial and operations personnel were selected for a telephone survey. It was postulated that their close contact with wastewater treatment plant construction projects might have led them to develop innovative ideas. Unfortunately, this was not the case.

Computer Literature Searches--

The lack of success achieved with this method was documented previously in Section 6.

To summarize, very little in the way of cost reductive novel methods and materials ideas were developed from outside sources.

Internal Idea Development

Since efforts to develop suitable ideas from various external sources were not successful, the study team decided to generate ideas from within our own organization. Early attempts to do so resulted in failure. Most engineers' minds are constrained by a myriad of rules, regulations and conventions which inhibit original thought. When engineers are hired for their conceptual abilities they are most frequently used in process development areas, not in design and construction. This does not imply that design and construction engineers are limited in conceptual ability; rather, such an engineer's free conceptual thought is alienated by requirements. This problem has been identified by others in the past.

It was necessary to develop procedures whereby the constraints on the engineering mind could be relaxed, temporarily at least. The developed solution was to isolate one or two engineers from outside influences, to take an identified cost center (such as excavation or vertical wall construction) and to work from concept through to detailed methods and materials of construction. As soon as any constraint on an engineer's thought became apparent, the interviewer(s) redirected thought. All ideas were noted and no judgement on ideas was permitted. The engineer's train of thought was allowed to flow for both the individual and group. After development of all trains of thought, each idea was reviewed in detail and impracticable ideas were eliminated. The maximum period measured where useful ideas were generated through free thought was between two and four hours.

Idea Treatment

Novel ideas were developed through two stages. For each idea, the methodology of the idea conception and idea development was set down, and sufficient work was carried out to establish that the idea was suitable for potential engineering applications. Secondly, for a selection of the best ideas, detailed cost analyses were made, where possible, to establish that the idea passed the test of capital cost reduction. Advantages and disadvantages were established, and in one or two cases the ideas's potential for implementation was discussed with manufacturers and/or contractors. In some cases, cost data were not available or special cost studies beyond the scope of this work would have been necessary; several ideas are identified where the cost analysis was not performed but which may be cost-effective in certain applications.

Several of the ideas developed beyond the first stage failed to meet the criterion of capital cost reduction. These were rejected, and are listed in Appendix B along with unconventional ideas rejected on similar grounds. Cost information was not uniformly available for all ideas; in some cases, only limited cost data were available covering a narrow range of construction conditions. Accordingly, selection of ideas required engineering judgement which recognized the cost data limitations. Ideas found suitable for inclusion as novel methods and materials of construction include:

- Drilled vertical shaft construction
- Reinforced earth tank
- Precast concrete tanks
- Reinforced asphalt pond liner

Other novel ideas which were not tested from a cost standpoint but which may be worth further study include:

- Shipboard treatment
- Deodorizing foul air with botanical systems

These two ideas are described in this section with the understanding that added work would be needed to determine their suitability on novel methods as defined

NOVEL IDEAS

Drilled Vertical Shafts

The use of vertical shafts 50 to several hundred meters deep in the earth for certain wastewater management and treatment applications has been proposed. Economic justification of the method(s) will rest on costs of constructing shafts of requisite depth and diameter, and comparison with more conventional construction on a site-specific basis. The technology of shaft drilling in rock has advanced significantly over the past decade; much of the impetus toward improved methods has come from the mining industries and construction associated with major water resource development projects. Shaft construction technology is still developing.

Drilling in unconsolidated overburden is likely to be more difficult and costly than shafts in rock, especially where the ground is wet and unstable. Methods described here apply to rock which is essentially self-supporting. Excessive depths of overburden will adversely affect the economics of waste treatment systems that utilize vertical shafts.

Use of deep shafts is proposed as an alternative to conventional shallow surface tankage for:

- Wastewater aeration-biological treatment
- Chlorine contact chambers
- Sludge thickening (dissolved air flotation)
- Solids separation (dissolved air flotation)
- Attached growth reactors

Implementation--

A discussion of some of these applications and developments in deep shaft treatment technology may be found in Appendix B. Raise drilling is the most economical method for shaft construction in rock for situations where access required at a given site is sufficient to offset mobilization and other fixed costs. In raise drilling, the rotary cutter head is placed at the bottom of the shaft site for starting the bore, and drills upward, pulled from the surface by the drill pipe which passes through a small pilot hole. Except for the cutter head, all machinery (derrick, motor, controls, etc.) are located on top of the ground. Cuttings fall to the bottom of the hole and are removed by a normal mucking method.

Raise drills, teamed with domed reamers, have excavated shafts up to 6 meters (20 feet) in diameter and up to 600 meters (2,000 feet) in depth. Boring rates are highly variable, but one to five meters per hour may be attained.

Since raise drilling requires access to the bottom of the shaft before drilling, it is practical only for situations where rather intensive development of underground facilities is planned. This could occur, for example, where a number of shafts are needed at one site, justifying driving of a horizontal drift to connect the bottoms of all shafts. In any event, the first shaft at a site will have to be drilled blind from the top down. Where deep tunnels are used for sewage conveyance, the necessary drop shafts can be raise drilled.

Blind drilling of large diameter (e.g., 1 meter (40 inches) to 2.5 meters (8.3 feet)) holes is similar to the rotary well drilling process using reverse circulation. Air or water can be used as the medium for bringing cuttings to the ground surface. The cuttings flow upward through the double-wall drill pipe. No slurry or drilling mud is used. The size of the diameter that can be blind-drilled is limited by the ability to force cuttings to flow from the perimeter of the hole to the center where they enter the upward flow within the drill pipe. Without further technical advances, the maximum feasible diameter will remain at about 2.5 meters (8.3 feet).

The blind-shaft borer is a new concept currently being developed by the Bureau of Mines (Department of Interior) for boring extremely large and deep holes from the top down. A machine, now being built for testing early in 1978, is designed to bore holes up to 7.5 meters (25 feet) in diameter. It is expected to be economical only where shafts of 300 meters (1,000 feet) depth or greater are required. The blind-shaft borer functions essentially the same as a tunnel boring machine placed vertically, and totally different than the drill techniques previously described. The machine itself, including operator, sits in the bottom of the shaft and has a mechanical system for removing cuttings. There are no elements at ground surface, except for muck handling. The mucking system includes scrapers at the bottom of the hole, conveyors, and bucket elevators to the top of the machine, where cuttings are dumped into skips that haul them to the surface.

Cost Considerations--

The cost of deep shaft construction depends on several factors, and can be expected to vary considerably. The following assumptions were employed for the purpose of developing the costs presented in Table 26.

TABLE 26. GENERAL COST RANGES FOR DEEP SHAFTS*

Average depth		Cost range	
Meters	Feet	$ per meter	$ per foot
2.5 m (8.2 feet) diameter drilled shaft			
60	200	910-6,700	260-2,040
120	400	860-5,900	245-1,800
200	650	840-5,500	235-1,680
1 m (3.3 feet) diameter drilled shaft			
110	350	405-1,150	115-350
240	800	375-870	105-265
400	1,300	365-800	105-240

* Costs in 1978 dollars.

- Holes are drilled in competent rock of medium strength (10 to 25 ksi compressive strength).
- Each shaft is lined with a steel casing, grouted in place.
- Drill is fully utilized on a two-shifts per day annual basis (95 percent or greater utilization).
- Site preparation for drilling is included, but disposal of spoil material is not.

The cost of raise-drilling is estimated to be in the range of 60 to 75 percent of the cost of blind down-drilling for comparable shaft diameters and depths. Raise-drilling can provide much larger holes than blind-drilling, up to 6 meters or more in diameter. However, because of the required underground access, raise-drilling is likely to be feasible only on larger projects which require tunnels for other purposes that could incidentally provide access for the raise drill.

In order to fully utilize a drill, and thus minimize fixed charges and amortization on a unit meter basis, it may be cost-effective for EPA to own the equipment and lease it to contractors. Full utilization of a blind drill capable of making 2.5 meters (8.3 feet) diameter holes would produce a total of about 1,200 meters (4,000 feet) of vertical shaft per year in average strength rock. This figure includes allowances for short moves within a site, and non-productive time allowances. Long moves would have to be made on weekends or would result in curtailed annual production totals.

Reinforced Earth Tank

This concept was developed as a possible solution to the high cost of conventional vertical wall construction for sedimentation, equalization, aeration, and similar excavated tanks. Functionally such walls were determined to be watertight and to resist internal and external liquid pressures, and external earth loadings.

Consideration centered on how to eliminate the external forces. Groundwater pressure could be eliminated by drainage. Earth forces could be eliminated if the earth itself is reinforced. The use of a "reinforced earth" method was indicated, which, if used in conjunction with a waterproofing agent, would provide a vertical, waterproof wall capable of resisting internal water pressure.

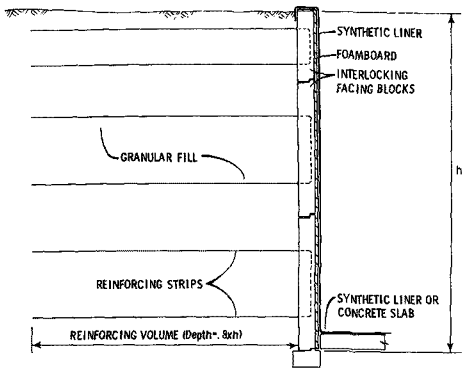
Implementation--

Reinforced earth is a patented construction method in this country; as such items used in this type of construction are obtained through a sole source, the Reinforced Earth Company. This method has been used by the Highway Department in the State of Washington. Reinforced earth is a composite material formed by the association of non-cohesive soil and reinforcements tied together by facing plates, which form the visible wall. The basic mechanism of reinforced earth is the action of friction between the soil and reinforcements; the active horizontal component of soil pressure being absorbed by the reinforcements.

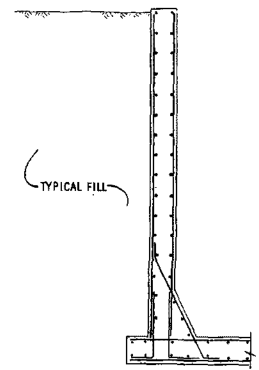
Reinforcements are normally thin strips of galvanized steel or aluminum. These strips are fastened to interlocking precast panels or semi-elliptical steel skin facing panels. The soil should have a minimum angle of friction of 25 degrees, with not more than 15 percent passing a 200 sieve.

The first step in construction is to install an underdrainage system. The reinforced earth wall is constructed by setting lifts of facing panels on an unreinforced concrete footing. Non-cohesive soil is spread and compacted and the rows of reinforcements are laid horizontally and bolted to the facing panels. This process is then repeated until the structure is complete. The structure is stable at all times during construction.

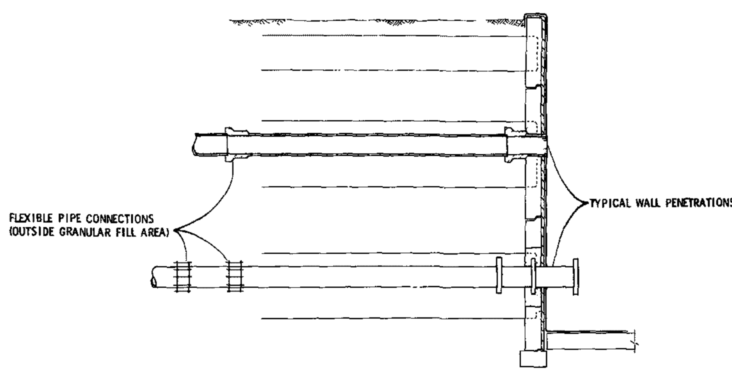
A section of the wall proposed for use in vertical wall construction and a typical reinforced concrete tank wall section are shown in Figure 9. Regular details for pipe penetrations, machinery fixings and sludge hoppers are also shown.



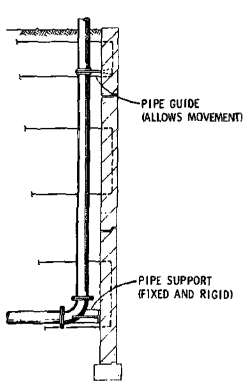
REINFORCED EARTH VERTICAL WALL



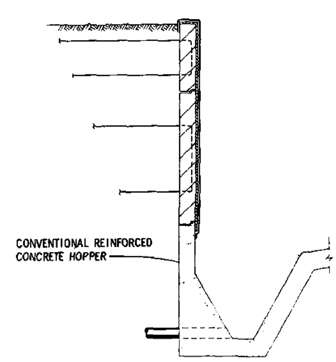
CONVENTIONAL VERTICAL WALL



TYPICAL PIPE PENETRATIONS



TYPICAL EQUIPMENT ATTACHMENT



SLUDGE HOPPER

FIGURE 9. REINFORCED EARTH TANK DETAILS

Cost Considerations--

Where suitable native soil material is available and where groundwater can be maintained at a level below the reinforced earth mass, the cost of reinforced earth walls for process units is estimated to range from $130/m^2$ ($12/ft^2) for a 3m (10 foot) high wall to $170/m^2$ ($16/ft^2) for a 12m (40 foot) high wall. This cost includes foam board facing and a hypalon liner. Credit is given to the reinforced earth design for a simpler base slab construction. Analysis indicated reinforced concrete construction to be approximately 25 percent cheaper using a 3m (10 ft) high wall. For a 12m (40 ft) high wall, reinforced earth was approximately 30 percent cheaper than reinforced concrete. Reinforced earth becomes more economical than reinforced concrete at about the 6m (20 ft) wall height. If soil must be imported in order to be suitable for the reinforced earth design, then only walls 8m (26 ft) and above are more economical in reinforced earth.

Advantages--

An advantage of reinforced earth over conventional reinforced concrete is its lower capital cost for walls greater than 6m (20 ft) high at locations where non-cohesive material is available, and groundwater levels can be maintained naturally, or artificially, below reinforced earth massformation. Also, where tankage is to be constructed on unstable soils of considerable depth, the reinforced earth concept is lower in cost than pile supported structures for all wall heights.

Disadvantages--

The major disadvantage is the loss of the reinforced earth area around the tank for future use, unless the reinforced earth wall is removed. For a 12m (40 ft) deep tank this would involve a strip 9.5m (32 ft) wide. This disadvantage is partially compensated for by the fact that the reinforced earth materials can be reclaimed and reused. Thus, during an in-plant expansion project this would mean that an existing tank would be out of service during construction of a new or larger tank.

A second limitation is the requirement that groundwater levels be maintained below the reinforced earth structure foundation.

Precast Concrete Tanks

The economics and quality of factory precast concrete elements is known to be superior to cast-in-place concrete work. Trickling filter structures have been constructed using precast panel and post-tensioning construction techniques.
Sludge digestion tanks are frequently post-tensioned after erection of the concrete shell. It would appear that there should be no reason why all treatment units should not be constructed from precast panels.

Potential cost savings resulting from precast versus cast-in-place construction increase with tank height. Cost savings are in the 0 to 5 percent range for relatively low tanks (up to 5 meters or 17 feet high), 5 to 15 percent for medium height tanks (5m-19m or 17-30 feet)and 15 to 25 percent for higher tanks. Tanks higher than 9 meters (30 feet) would normally employ post-tensioning in either construction approach. Potential savings for higher tanks reflect the difference between casting a high wall versus erection of precast tilt up panels.

Implementation--

Circular tanks can be constructed using a series of straight wall segments. Each segment is poured with curved post-tensioning conduits cast-in-place. Following completion of a cast-in-place slab, each segment is erected, the spaces between units grouted, and post-tensioning tendons are pulled through the conduits. Each tendon is then post-tensioned to the required force and the conduit grouted under pressure.

Rectangular tanks would be constructed with both vertical and horizontal conduits. The cast-in-place base is poured with threaded sockets into which high tensile bars are later threaded. The precast units are threaded into the bars, the spaces between units grouted, and horizontal tendons installed. Post-tensioning of both horizontal and vertical steel is then carried out.

Reinforced Asphalt Pond Liner

Where potential for leakage from an earthen basin used for sewage or sludge exists, providing an impervious layer over the basin area would be a high cost. Where the use of a soil additive (e.g., betonite) is not considered adequate, or suitable, the use of sprayed liquid asphalt is recommended as being economical. Unfortunately, the resulting layer has disadvantages: it is brittle, subject to fracture under thermal variations, and easily damaged by maintenance operations. Typically it has, therefore, been covered with a 300 mm (12 inches) layer of soil. In considering this cost center and evaluating alternatives to asphalt, the investigation also centered on methods whereby asphalt might be reinforced cheaply to form a suitable coating. Discussion with the Asphalt Institute revealed the fact that porous concrete bridge decks are waterproofed utilizing asphalt reinforced by "Petromat"; a random, non-woven polypropylene fabric. Use of this fabric, together with asphalt, as a pond liner was judged potentially cost-effective. Further thought led to the concept of using a liquid asphalt/chopped glass fiber matrix sprayed simultaneously onto a prepared (sand) surface to produce a similar reinforced asphalt matrix. The basis for such a system comes from the "Monoform" roofing system owned by Flintkote.

Implementation--

Construction of the reinforced asphalt pond liner would involve subgrade preparation, installation of a granular base course and application of two coats of reinforced asphalt liner.

Subgrade preparation includes necessary pond excavation and embankment fill adequately compacted. Large rocks would be removed from the surface layer. 100 to 150 mm (4 to 6 inches) of sand material would be laid and compacted as a base for the liner. The line installation would require a liquid asphalt tank truck, and a second vehicle to carry the chopped glass fiber and spray arm. The two vehicles would work in tandem. The spray arm would probably have a number of spray guns similar to those in present day use for roofing application. These guns have an individual capacity of 2,300 m^2 (25,000 ft^2 or approximately 0.6 acre). Ten would be required to cover six acres. If controlled feed to so many guns became difficult, a larger gun could, no doubt, be developed.

Application rates to achieve 3 mm (1/8 inch) layers, with a total of 6 mm (1/4 inch) are attainable. This thickness of coating on the granular base course should provide a waterproof coating, with good resistance to routine maintenance and long life.

Cost Considerations--

Costs of equivalent conventional methods of pond waterproofing liners range from \$5.00 to \$8.50 per m^2 (\$4-7/yd^2). The cost of the proposed method is estimated by Flintkote to be within the range \$1.70 to \$2.40/m^2 (\$1.42 to \$2.0/yd^2). This assumes the use of tankers and manually operated guns. Allowing the cost of granular bedding, the total cost for this construction is in the range of \$3 to \$3.60/m^2 (\$2.50 to \$3.00/yd^2).

Advantages--

The advantages of a reinforced asphalt pond liner lie beyond the low first cost. Repair and patching of the membrane is extremely simple. The asphalt emulsion and glass cloth are the only materials needed. Resistance to domestic wastewater is excellent, and resistance to foot and even some vehicular traffic is achieved.

Disadvantages--

The material would only be capable of absorbing limited differential settlement, and will become increasingly less flexible with time. This particular disadvantage is offset to some degree by the fact that most differential settlement will occur during the early life of the pond. The poor resistance of reinforced asphalt to localized or point loading is also a disadvantage. In common with most liners, weed inhibitors and rodent control precautions must be taken.

Recommendations--

In view of the limited potential market and the uncertainty of whether or not this method of pond lining would be accepted by engineers and regulatory agencies, it is possible that no manufacturer would be interested in developing the equipment necessary for full scale application. It is recommended, therefore, that a demonstration project using existing roof coating methods and equipment be undertaken on a 1-2 ha (2.5 to 5 acre) lagoon. Application techniques, application costs and performance should be closely monitored, and, if the project is successful, manufacturers should be made aware of it so the potential market can be developed.

OTHER NOVEL IDEAS FOR FURTHER STUDY

Two novel ideas have been identified which require additional information to determine their potential as cost-effective solutions. These include shipboard treatment and deodorization of foul air with botanical systems. Potential application of these approaches are considered limited but worth mentioning here.

Shipboard Treatment

In seacoast cities and cities located near major waterways, existing separate and combined wastewater interception systems and storm sewers follow the contour of the land to discharge points, which are near to or in deep water. As a rule, the task of accommodating increased wastewater flow involves construction of new interceptor systems through already congested urban areas to locations where suitable treatment works can be constructed. In order to expedite dry weather flow and supplement storm season flow provisions, a possible alternative is modifying obsolete or surplus marine vessels into wastewater treatment facilities.

The vessels could be stripped of the equipment required for going to sea, and re-equipped in drydock where skills required for construction of wastewater treatment systems are readily available. The vessels could then be towed to their final position for connection to shore-bound collection systems or combined sewer overflows. The on-board treatment systems could be arranged for treatment of overflow volumes to remove pollutants and provide necessary disinfection. Solids removed from the wastewater would be stored until storm flows subside, then returned to the on-shore interceptor for conveyance to shore-based treatment facilities.

A similar concept could be employed where a vessel is used as a treatment system for an overloaded collection system. This approach would eliminate the need for providing solids stabilization processes on the vessel, and reduce overall costs of operation.

Implementation--

Existing vessels held in reserve, or for salvage, would be required in order to implement this idea. For example, Liberty ships in Navy mothball fleets could be used for this purpose. However, a survey of this potential source showed that as of the end of March 1978, only seven Liberty ships remained in the reserve fleet. Of this number, four are located on the James River (Virginia) and three are berthed in Suisun Bay,California. Four were scheduled to be scrapped, one is to be used as a museum and two were reserved for use for classified Navy projects. Thus, it would appear that this particular source could not be tapped for this purpose. The approach could be employed, however, using other types of marine vessels; such as smaller tankers made obsolete by the super tankers now favored by shipping companies. Vessels of this type, because of their large holds, would make ideal platforms for construction of process tankage. In large cities where treatment sites are a premium the use of such floating platforms could be cost-effective and less of an aesthetic intrusion to the waterfront if the treatment facility was disguised within the interior of the vessel.

Existing vessels would require modification to provide the required treatment capacity. Scrap value would have to be low relative to alternative site costs. Maximum utilization of existing equipment and space would have to be made to further reduce costs. Examples of modifications and use of existing features include:

- Existing equipment (such as hydraulic and electric systems) could be integrated into the plant design.
- Large holds could be converted into process tanks.
- Existing boiler water laboratories could be refitted as water quality laboratories.
- Crew living and messing quarters could be refurbished for plant operators.

In the case of ships of a single design, a single treatment plant design could be developed and used for several plants; the plants could then be produced at shipyards similar to the concept employed for construction of a class of ships. Other advantages to this arrangement would be centralized testing and quality assurance, enabling a completed plant to be delivered to the user.

A pier would have to be provided by the user for docking the floating plant. Shore supporting connections, such as electric power and water, would be required. Additionally, connection to the sewerage system,and pumping and sludge removal would be required.

No known changes to regulations, codes, etc. would be required to implement this idea. However, some institutional barriers may be encountered in obtaining existing vessels. For example, at the time of writing (prior to issuance of 95-217) it is unlikely that EPA regulations would permit the adoption of such a project.

Cost Considerations--

Cost savings would be dependent on initial cost for the vessels and the extensiveness of the modifications required, as well as site specific conditions for land construction. Although building floating plants from the platform up would probably not be competitive, this technique has been used by Ishikawajima-Harima Heavy Industries Co. (IHI) of Tokyo to manufacture a 750 metric ton/day pulp plant for a remote location in Brazil. IHI claims that construction costs were 15 to 30 percent less than for field fabrication.

Advantages--

Shipboard treatment plants could be located in protected areas along seacoasts or same inland waterways. They would be particularly attractive in areas where poor soil conditions would make conventional construction difficult and expensive.

Advantages derived from shipboard treatment works include:

- Potential significant reduction or elimination of land requirements.
- Enhanced salvage value and resale possibilities.
- Flexibility through modular construction.
- Potential use as interim measure or for facilities expansion.
- Protection from vandalism.
- Built-in flood protection.
- Potential for multipurpose use of shipboard facilities not required for treatment capacity.

Disadvantages--

Floating wastewater treatment plants could not be located in landlocked areas or on non-navigable streams. In addition, certain conditions along seacoasts or inland waterways may preclude implementation of this idea. These include areas where breakwaters are required to provide reasonable quiescence, where extreme tidal variations occur, and where sufficiently acceptable, inexpensive land is available. There would also be plant size limitations; the number of modular units required could make this concept realistic. Influent pumping stations would be required.

Deodorizing Foul Air with Botanical Systems

Objectionable odors from wastewater interceptors and wastewater pumping and treatment facilities are sometimes removed by mechanical or biological scrubbing systems. These systems are ordinarily constructed using conventional materials of construction (e.g., plastic media and steel tanks). A simpler system might provide cost savings. Because foul air frequently contains carbon dioxide at concentrations greatly in excess of the atmosphere, the use of botanical systems (i.e., growing plants in greenhouses) is an attractive concept which might reduce construction costs as well as put the foul air to a beneficial use.

Greenhouse structures are sometimes used to protect sludge drying beds from rain. It is possible that foul air might be routed to such areas and use be made of drying sludge for growing botanical systems.

A botanical deodorizing system would consist of a greenhouse containing appropriately selected plants. Foul air would be delivered to the greenhouse to provide a carbon dioxide enriched atmosphere for accelerated plant growth. Potential odor reduction mechanisms include absorption on leave surfaces and oxidation of odor producing compounds in the oxygen rich atmosphere surrounding continuously lighted vegetation. Plant growth accelerated by the unique greenhouse conditions with its carbon dioxide source and sludge fertilized soil could produce soluble plants or cuttings. An experimental system of this kind near Willitts,California,produced grape cuttings as a by-product. Off gases from a small trickling filter were captured and vented into a small greenhouse in this particular case. Oxygen enrichment of the atmosphere and the masking effect of pleasant plant odors would also help to decrease the offensiveness of the gas released from the greenhouse.

Implementation--

In order to implement this idea, design criteria would need to be established and appropriate plants would need to be selected. Determination of such things as growth-limiting factors, growth rates, supplemental lighting requirements, oxygen production rates, and areal requirements must be established to determine actual feasibility. Design and construction of greenhouses is ordinarily carried out according to well-established principles, and only minor design changes would be required to efficiently distribute the foul air and to collect the deodorized air for release. Consideration should be given to a cascade arrangement of greenhouses to reduce the potential for inadvertent release of odors due to incomplete reaction. The system for delivering the foul air from its source to the greenhouse would be the same as for any other deodorizing system.

Because the plants grown in the greenhouses potentially have a marketable value, consideration should be given to harvesting and marketing requirements. This effort may be important in offsetting the total costs of the botanical system. There are no known regulations or codes which would require change to implement this concept.

Cost Considerations--

Information on the potential savings in using botanical deodorizing systems are not available. Greenhouse construction would be cheaper than scrubbing systems due to its simplicity and lower use of steel. Economics would depend heavily upon the areal requirements for the greenhouses. It is possible that this concept would be appropriate only at locations where greenhouses already exist.

Advantages--

Botanical systems could be used in areas where the climate is relatively mild and solar radiation is reasonably consistent throughout the year. The major advantage of botanical deodorizing systems would be the potential reduction in material and construction costs due to its simplicity. An additional benefit would be harvesting of a marketable by-product which would put the foul air to a beneficial use and would reduce overall costs. Public relations aspects of such a "natural" system are probably quite positive since the idea is in harmony with many of the views expressed by ecologists and other concerned citizens.

Disadvantages--

Botanical systems would be inappropriate in areas where climatological conditions are unsuitable or would be expensive to overcome; e.g., where excessive insulation and supplemental light would be required. Also, the distance of the foul air source to the greenhouse site, and the availability and cost of land would be factors affecting the economics of botanical systems.

APPENDIX A

CONSTRUCTION COST SUMMARIES

The following cost breakdowns were developed to help locate high cost centers in terms of labor, material, or area of the completed unit process.

The breakdowns were derived by taking examples from real projects, breaking them down to unit quantities, and pricing the quantities. The mechanical equipment, structural style, site conditions, and labor market are among factors which will vary project costs from one project to the next. However, costs for each construction category are expected to represent approximately the same percentage of the total cost.

TABLE A-1. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY
440 l/s (10 mgd) Influent Pump Station

Item	Formwork		Concrete		Rebar steel	Cost dollars	Cost % of structural concrete	Cost % of total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	35,948	-	8.3
Foundation base slab	480	4,032	13,230	1,029	3,058	21,829	13.0	4.9
Ground floor and roof slab	1,529	3,146	3,528	4,410	8,996	21,609	12.9	4.9
Discharge structure	484	4,073	13,363	1,039	3,089	22,050	13.2	5.0
Vertical walls	6,320	19,280	13,312	10,140	13,600	62,652	37.4	14.3
Precast architectural face panels	-	-	12,750	2,250	-	15,000	9.0	3.4
Misc. structural	-	-	8,528	15,839	-	24,367	14.5	5.5
Variable speed pumps	-	-	-	-	-	75,000	-	17.0
Other mechanical equipment	-	-	-	-	-	161,800	-	36.7
						440,255	100	100
Cost - dollars	8,813	30,531	64,711	34,707	28,743	Σ167,507		
Cost - % of structural concrete	5.3	18.3	38.6	20.7	17.1	100		
Cost - % of total	2.0	6.9	14.7	7.9	6.5	38.0		

ADDENDUM - TABLE A-1

1. Deep structures require the extra weight of additional structural concrete to overcome bouyance forces, therefore, floor and wall costs per square foot are higher than for other structural types.

2. Mechanical equipment comprises 53.7 percent of the pump station cost. The "typical" real station examined had twelve separate mechanical systems.

TABLE A-2. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY
440 l/s (10 mgd) Preliminary Treatment

Item	Formwork		Concrete		Rebar steel	Cost dollars	Cost % of structural concrete	Cost % of total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	11,008	-	9.2
Horizontal slabs	292	1,452	2,309	536	2,639	7,228	24.1	6.1
Vertical surfaces	2,528	7,200	2,336	3,680	2,688	18,432	61.5	15.5
Misc. structural	175	954	1,442	824	605	4,000	13.4	3.4
Grit collection equipment	-	-	-	-	-	42,500	-	35.6
Grit washers	-	-	-	-	-	22,000	-	18.4
Flume + recorder + housing	-	-	-	-	-	10,200	-	8.6
Gates	-	-	-	-	-	2,000	-	1.7
Misc. mechanical	-	-	-	-	-	1,500	-	1.3
						119,268	100	100
Cost - dollars	2,995	9,606	6,087	5,040	5,932	Σ 29,660		
Cost - % of structural concrete	10.0	32.1	20.3	16.8	19.8	100		
Cost - % of total	2.5	7.3	5.1	4.2	5.0	24.9		

TABLE A-3. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY 440 l/s (10 mgd) Rectangular Primary Sedimentation Tanks

Item	Formwork		Concrete		Rebar steel	Cost dollars	Cost % of structural concrete	Cost % of total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	21,910	-	3.7
Tank floor slabs	500	3,094	30,114	27,696	33,948	95,352	34.5	16.2
Tank solids hoppers	4,218	11,418	4,162	3,666	6,128	29,592	10.7	5.0
Vertical walls	15,720	46,428	13,864	22,784	21,294	120,090	43.5	20.5
Tank piers	396	2,330	208	1,075	5,556	9,565	3.5	1.6
Ground level cross beams	810	2,814	2,046	4,850	6,958	17,478	6.3	3.0
Ground level flat slabs	934	2,034	2,148	1,709	1,236	8,061	2.9	1.4
Misc. structural	342	1,000	1,431	1,317	-	4,090	1.5	.7
Pumping equipment	-	-	-	-	-	33,420	-	5.7
Sludge collection equipment	-	-	-	-	-	175,000	-	29.8
Misc. mechanical	-	-	-	-	-	79,200	-	13.5
						586,958	100	100
Cost - dollars	22,578	68,118	52,542	57,820	75,120	Σ276,178		
Cost - % of structural concrete	8.2	24.7	19.0	20.9	27.2	100		
Cost - % of total	3.8	11.6	9.0	9.9	12.8	47.1		

ADDENDUM - TABLE A-3

1. Concrete finishing of vertical surfaces comprises 80 percent of the vertical concrete labor costs if "whip" sand blasting, fin grinding and sack finishing of tank interiors is specified.

2. Equipment and piping costs are about equal to the tank structural construction costs.

3. The sludge and scum collection systems comprise 60 percent of the total installed equipment cost, the effluent launders account for 10 percent, the gallery piping 8 percent, and the scum pumps and sludge pumps each account for 5.5 percent

of the total. The sludge and scum collection systems carry both a high initial cost and a fairly labor intensive installation sequence, which presupposes difficult alignment problems associated with a great number of preplaced concrete anchor bolts. Flight storage and preservation is difficult, and wastage and rejection of untrue flights is often high.

4. In the lower or base structural slabs the material costs, concrete and reinforcing steel, exceed the formwork and concrete placing labor costs. Good vibratory concrete placement and trowel finishing minimize subsequent need for concrete surface finishing; and formwork is a minimum on flat surfaces. Fully engineered slab design using minimal material is required to achieve cost reductions in flat slabs.

5. The total installed cost for the base structural slab of the rectangular tanks is nearly double the cost of equal capacity circular tank base slabs. This is because base thickness and reinforcing steel must be designed to take cantilever loads from the walls. This loading may be taken in either direction in a tank system when adjacent tanks may be alternately dewatered.

6. Central tank piers (necessary for solids collection equipment) require additional slab strengthening. These piers in turn are often complex in shape, in that they have fillet bases and "T" tops with the tank cross beams.

7. Sloping wells (sludge collection, grit collection) are expensive to form because window or shutter top forms are necessary. Form labor is approximately 6 times as great, and concrete placing labor 2.5 times as great as for pouring a comparably reinforced flat structural slab. Precast construction of any slab over 20 degrees inclination is worth examining as well as minimizing area of tank used for deep sloping hoppers.

TABLE A-4. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY 440 l/s (10 mgd) Activated Sludge with Blower Building

Item	Formwork		Concrete		Rebar steel	Cost dollars	Cost % of structural concrete	Cost % of total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	118,384	-	11.8
Tank base slab	1,924	12,033	39,690	7,088	41,580	102,315	20.0	10.2
Channel horizontal slabs	854	4,620	5,280	825	5,280	16,859	3.3	1.7
Vertical tank walls	22,066	61,389	36,211	34,231	41,021	194,918	38.2	19.4
Y-walls	18,957	40,379	7,163	3,338	8,114	82,951	16.3	8.3
Circular piers	869	1,206	527	783	945	4,330	.8	.4
Cross beams	4,050	7,200	2,970	4,293	4,307	22,820	4.5	2.3
Blower bldg. footing	96	280	960	200	520	2,056	.4	.2
Blower bldg. floor and pipe chase slabs	954	1,988	2,067	504	2,544	8,057	1.6	.8
Blower bldg. vertical walls	4,868	13,865	4,498	6,157	5,176	34,564	6.8	3.4
Blower bldg. roof	1,365	2,520	5,865	1,659	1,092	12,501	2.4	1.2
Misc. structural and architectural	-	-	19,760	9,280	-	29,040	5.7	2.9
Handrails and misc. metal	-	-	-	-	-	68,058	13.3	6.8
Blowers	-	-	-	-	-	171,000	-	17.0
Air diffusion hardware	-	-	-	-	-	105,000	-	10.5
Misc. mechanical	-	-	-	-	-	30,400	-	3.0
						1,004,253	100	100
Cost - dollars	56,003	145,480	124,991	73,358	110,579	Σ510,411		
Cost - % of structural concrete	11.0	28.5	24.5	14.4	21.7	100		
Cost - % of total	5.6	14.5	12.4	7.3	11.0	50.8		

ADDENDUM - TABLE A-4

1. Concrete finishing of vertical surfaces comprises 60 percent of concrete labor costs for the activated sludge structures.

2. On the examined "typical" activated sludge unit the by-pass, influent and effluent channels, were cast integral to the wall sections, cantilevered out from the wall. This required additional wall thickness.

3. Vertical walls and walls with Y-wall top sections are the highest cost center. Where feasible, tilt-up construction should be employed for activated sludge tank construction.

TABLE A-5. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY 440 l/s (10 mgd) Circular Secondary Clarifiers

Item	Formwork		Concrete		Rebar steel	Cost dollars	Cost % of structural concrete	Cost % of total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	21,910	-	5.0
Tank base slab	458	2,280	15,430	16,928	16,134	51,230	30.2	11.9
Vertical wall section	7,292	23,290	7,548	8,517	11,164	57,811	34.1	13.4
Y-walls	6,516	11,006	2,408	4,886	8,124	32,940	19.4	7.7
Tank top beams and ground slabs	882	1,926	2,034	2,502	1,209	8,553	5.0	2.0
Influent and effluent encasement	672	1,326	3,672	1,392	1,842	8,904	5.2	2.1
Sludge collection box	888	2,404	876	572	1,291	6,031	3.6	1.4
Misc. structural	-	-	3,546	722	-	4,286	2.5	1.0
Tank hydraulic distribution equipment	-	-	-	-	-	154,000	-	35.8
Pumping equipment	-	-	-	-	-	33,420	-	7.8
Other mechanical equipment	-	-	-	-	-	51,200	-	11.9
						430,285	100	100
Cost - dollars	16,708	42,232	35,532	35,519	39,764	Σ 169,755		
Cost - % of structural concrete	9.8	24.9	20.9	20.9	23.4	100		
Cost - % of total	3.9	9.8	8.3	8.3	9.2	39.5		

ADDENDUM - TABLE A-5

1. For a circular sedimentation tank, equipment costs are approximately 10 percent greater than structural construction costs.

2. Center pier influent well, sludge collection drive, access bridges, and effluent rim weirs all purchased from a common supplier account for 65 percent of installed equipment cost on a circular clarifier. Since items are factory built, field savings possible are quite minimal.

TABLE A-6. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY
440 l/s (10 mgd) Chlorine Disinfection Including Chlorination Building

Item	Formwork		Concrete		Rebar steel	Cost dollars	Cost % of structural concrete	Cost % of total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	18,964	-	11.9
Tank base slab	321	1,597	3,696	858	3,828	10,300	16.6	6.5
Tank walls	3,089	8,593	4,316	4,673	4,435	25,106	40.6	15.8
Chlorine building base slab	28	28	648	1,848	324	2,876	4.6	1.8
Chlorine building walls precast	-	-	13,875	1,688	-	15,563	25.1	9.8
Chlorine building wall footings	77	210	356	151	75	869	1.4	.5
Concrete fill metal roof with waterproofing	1,200	1,080	1,776	840	108	5,004	8.1	3.1
Chlorine channel influent, effluent structures	816	868	436	100	448	2,168	3.5	1.4
Steel frame of building	-	-	-	-	-	6,600	-	4.1
Architectural hardware	-	-	-	-	-	3,200	-	2.0
Chlorinators, evaporators, injectors	-	-	-	-	-	31,600	-	19.5
HVAC	-	-	-	-	-	15,000	-	9.4
Other mechanical	-	-	-	-	-	22,300	-	14.0
						159,010	100	100
Cost - dollars	5,031	12,376	25,103	10,158	9,218	Σ 61,886		
Cost - % of structural concrete	8.1	20.0	40.6	16.4	14.9	100		
Cost - % of total	3.1	7.8	15.8	6.4	5.8	38.9		

TABLE A-7. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY
440 l/s (10 mgd) Gravity Thickener

Item	Formwork		Concrete		Rebar steel	Cost dollars	Cost % of structural concrete	Cost % of total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	16,627	-	9.5
Tank floor slab-sloped	182	1,093	2,926	926	3,800	8,927	16.8	5.1
Horizontal slabs surface level	138	686	2,218	515	3,168	6,725	12.7	3.8
Vertical tank walls	2,481	7,924	2,568	589	3,299	16,861	31.8	9.6
Y-walls	2,365	9,550	1,878	822	2,140	16,755	31.6	9.5
Center influent pier and influent/effluent encasement	820	474	385	275	403	2,857	5.4	1.6
Sludge collection well	167	451	164	71	120	973	1.8	.6
FRP cover	-	-	-	-	-	23,561	-	13.4
Foul air ducting	-	-	-	-	-	8,800	-	5.0
Tank mixer	-	-	-	-	-	61,000	-	34.7
Misc. mechanical	-	-	-	-	-	12,535	-	7.1
						175,621	100	100
Cost - dollars	6,153	20,178	10,639	3,198	12,930	Σ 53,098		
Cost - % of structural concrete	11.6	38.0	20.0	6.0	24.4	100		
Cost - % of total	3.5	11.5	6.1	1.8	7.4	30.2		

ADDENDUM - TABLE A-7

1. Conical sloped floor slabs require 35 percent more concrete labor manhours, and 50 percent more edge forming materials and labor manhours than flat structural slabs.

2. Vertical and Y-walls costs comprise 63 percent of the concrete construction cost.

TABLE A-8. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY 440 l/s (10 mgd) Sludge Pumping Equipment

Item	Formwork		Concrete		Rebar steel	Cost dollars	Cost % of structural concrete	Cost % of total
	Material	Labor	Material	Labor				
Sludge pumping equipment	-	-	-	-	-	37,000	-	100

TABLE A-9. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY
440 l/s (10 mgd) Twin Primary Digesters and Sludge Control Building

Item	Formwork		Concrete		Rebar steel	Cost dollars	Cost % of structural concrete	Cost % of total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	30,165	-	3.5
Tank floor slabs	582	3,642	8,183	2,195	5,355	19,957	8.6	2.3
Tank vertical walls	15,258	50,894	14,754	3,148	28,338	112,392	48.2	13.2
Control building base slab	141	697	2,509	582	3,584	7,513	3.2	.9
Control building floors and roof	533	1,110	1,080	282	1,980	4,985	2.1	.6
Control building vertical walls	4,772	13,278	6,670	10,530	7,147	42,397	18.2	5.0
Architectural-tank and building	690	2,010	17,683	19,640	3,100	43,123	18.5	5.1
Misc. structural	-	1,690	910	-	-	2,600	1.1	.3
Floor gas holder covers	-	-	-	-	-	220,000	-	25.8
Heat exchangers	-	-	-	-	-	108,000	-	12.7
Gas mixing equipment	-	-	-	-	-	54,000	-	6.3
Sludge circulation equipment	-	-	-	-	-	46,000	-	5.4
Control building piping	-	-	-	-	-	151,000	-	17.7
Misc. mechanical	-	-	-	-	-	11,500	-	1.3
						853,632	100	100
Cost - dollars	21,976	73,321	51,789	36,377	49,504	Σ 232,967		
Cost - % of structural concrete	9.4	31.5	22.2	15.6	21.2	100		
Cost - % of total	2.6	8.6	6.1	4.3	5.8	27.3		

ADDENDUM - TABLE A-9

1. Of the total construction plus equipment cost, the largest individual cost items are floating covers - 31.3 percent, digester wall construction - 16.0 percent, and heat exchangers - 15.4 percent.

2. Of the total construction plus equipment cost, looking at types of labor, material or equipment, we see that mechanical equipment with its associated controls contributes 63 percent of the total cost, and the next highest being construction formwork labor contributing 10 percent.

3. Construction formwork related costs exceed construction material related costs for these circular structures.

4. For mechancial equipment the following cost order exists: Floating covers, heat exchangers, gas compression and mixing and flaring equipment, sludge circulation pumps, etc.

TABLE A-10. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY 440 l/s (10 mgd) Vacuum Filtration Facility

Item	Formwork		Concrete		Rebar steel	Cost dollars	Cost % of structural concrete	Cost % of total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	3,873	-	-
Floor and foundation slab	4,440	12,261	14,758	3,125	14,749	49,333	37.5	10.6
Precast concrete wall panels	-	-	40,256	7,104	-	47,360	36.0	10.2
Roof deck	855	1,566	3,798	1,127	426	7,770	5.9	1.7
Interior drywalls	917	1,833	-	-	-	2,750	2.1	.6
Equipment mezzanine	332	1,002	1,028	256	1,082	3,700	2.8	.8
Misc. structural	1,941	6,507	4,586	3,223	4,401	20,658	15.7	4.4
Steel frame of building	-	-	-	-	-	13,567	-	2.9
Grating	-	-	-	-	-	5,303	-	1.1
Painting	-	-	-	-	-	24,667	-	5.3
Cranes	-	-	-	-	-	9,250	-	2.0
Louvers	-	-	-	-	-	4,933	-	1.0
Vacuum filter and ancillary equipment	-	-	-	-	-	224,467	-	48.3
Pumps and metering equipment	-	-	-	-	-	13,567	-	2.9
Holding tanks	-	-	-	-	-	18,500	-	4.0
Misc. mechanical	-	-	-	-	-	14,800	-	3.2
						464,498	100	100
Cost - dollars	8,485	23,169	64,426	14,835	20,658	Σ 131,573		
Cost - % of structural concrete	6.4	17.6	49.0	11.3	15.7	100		
Cost - % of total	1.8	5.0	13.9	3.2	4.4	28.3		

TABLE A-11. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY 440 l/s (10 mgd) Miscellaneous Structures Consisting of Internal Maintenance, Laboratory and Garage Facilities

Item	Formwork		Concrete		Rebar steel	Cost dollars	Cost % of structural concrete	Cost % of total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	2,600	-	1.0
Foundations and floor slab	2,137	4,738	5,234	1,412	5,749	19,300	19.8	7.7
Vertical precast walls	-	-	40,290	7,110	-	47,400	48.7	23.0
Roof and coverings	2,101	3,438	8,640	3,546	1,375	19,100	19.6	7.6
Misc. architectural and structural	304	3,480	2,900	2,752	2,164	11,600	11.9	4.6
Steel frame of building	-	-	-	-	-	10,200	10.5	-
Miscellaneous metal	-	-	-	-	-	9,800	10.1	3.9
Laboratory equipment	-	-	-	-	-	30,000	30.8	12.0
Garage and maintenance equipment	-	-	-	-	-	55,000	56.5	22.0
Office furniture and kitchen equipment	-	-	-	-	-	45,000	46.2	18.0
						250,000	100	100
Cost - dollars	4,542	11,656	57,064	14,820	9,288	Σ97,400		
Cost - % of structural concrete	4.7	12.0	58.6	15.2	9.5	100		
Cost - % of total	1.9	4.6	22.8	5.9	3.8	39		

ADDENDUM - TABLE A-11

1. Building structural cost is only 40 percent of the total cost.

TABLE A-12. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY 44 l/s (1 mgd) Trickling Filter

Item	Formwork		Concrete		Rebar steel	Cost dollars	Cost % of structural concrete	Cost % of total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	11,427	-	8.9
Tank floor slab	396	2,262	4,568	1,608	4,304	13,138	16.5	10.3
Ventilation wall	1,672	5,234	884	1,930	580	10,300	12.9	8.1
Collection trough floor	274	3,654	-	-	-	3,928	4.9	3.1
Influent center pier	78	100	130	18	256	582	.7	.5
Perimeter wall	2,352	7,608	1,244	1,361	816	13,381	16.8	10.5
Precast floor beams	-	-	11,468	900	-	12,368	15.5	9.7
Underdrain blocks	-	-	7,916	3,392	-	11,308	14.2	8.9
Rock fill	-	-	8,430	3,140	-	11,620	14.6	9.1
Misc. structural	270	810	725	475	720	3,000	3.8	2.4
Distributor arm assembly	-	-	-	-	-	36,000	-	28.3
						127,052	100	100
Cost - dollars	5,042	19,668	35,415	12,824	6,676	Σ 79,625		
Cost - % of structural concrete	6.3	24.7	44.4	16.1	8.4	100		
Cost - % of total	4.0	15.5	27.9	10.1	5.2	62.7		

ADDENDUM - TABLE A-12

1. Low overall height makes reinforcing minimal in base structural slab; costs are very low compared to base slabs for sedimentation tanks, digesters, etc.

2. Main cost centers are for materials - rock fill media, block underdrain system, and precast underdrain block supports. Labor is minimal with a rock trickling filter. Cost reductions would be possible using underdrain block and precast block support systems.

3. If an outer upturned ventilation wall is employed, the inner wall containing the rock media must be open underneath, requiring a suspended circular wall - a formwork cost center.

TABLE A-13. CONSTRUCTION AND EQUIPMENT INSTALLATION COST SUMMARY
44 l/s (1 mgd) Aerobic Digester

Item	Formwork		Concrete		Rebar steel	Cost dollars	Cost % of structural concrete	Cost % of total
	Material	Labor	Material	Labor				
Earthwork	-	-	-	-	-	18,801	-	16.2
Floor slab	179	1,117	3,360	600	3,200	8,456	18.0	7.3
Vertical walls	1,638	3,555	4,550	1,247	3,045	14,062	29.9	12.2
Vertical concrete baffles	748	2,083	2,667	269	1,392	7,159	15.2	6.2
Tank cross beams	1,000	1,600	660	396	320	3,976	8.5	3.4
Misc. structural (influent and effluent)	284	1,772	5,330	952	5,056	13,394	28.5	11.6
Mechanical aerators and ancillary equipment	-	-	-	-	-	42,400	-	36.7
Misc. mechanical	-	-	-	-	-	7,452	-	6.4
						115,700	100	100
Cost - dollars	3,849	10,127	16,567	3,491	13,013	Σ47,047	100	100
Cost - % of structural concrete	8.2	21.5	35.2	7.4	27.7	100		
Cost - % of total	3.3	8.8	14.3	3.0	11.2	40.7		

APPENDIX B

OTHER IDEAS CONSIDERED IN THIS STUDY

A number of other novel and unconventional ideas were considered during the study. Most of these novel and unconventional ideas were not able to satisfy cost reduction requirements or engineering integrity considerations. Other ideas are included for completions. One, deep shaft treatment, is a process development extension of a novel or unconventional construction method; process development was specifically excluded from in this work. However, an exception was made in the case of the deep shaft case because process considerations were evaluated in the course of study on this unconventional construction approach. Another, septic tanks upstream of sewers is also mentioned; this approach is not universally cost-effective but has application in certain areas. These other ideas are included in this appendix, as follows:

1. Electron beam ozone generation
2. Shotcrete
3. Concrete dome covers
4. Foam formwork
5. Sheet piled vertical walled tank
6. Mass site excavation
7. Oversize trenching plough
8. On-site wound FRP tanks
9. Deep shaft wastewater treatment
10. Septic tanks upstream of sewers

As indicated in 9 above, deep shaft wastewater treatment is process related and is discussed in greater detail at the end of this appendix. Ten above, septic tanks upstream of sewers, is identified at the end of this Appendix since this approach is used and was also considered in the study.

Electron Beam Ozone Generation

While evaluating the comparative costs of disinfection processes, it was noted that most of the cost of chlorine contact tankage and all of the cost of dechlorination facilities could be saved if one of the alternative methods of disinfection could be more fully developed. The savings represented would be significant to the overall construction grant program. A brief novel method analysis was carried out based around an idea for ozone generation using an electron beam accelerator to determine the impact on construction cost of the adoption of such a method.

Development testing with lasers used routinely in the electronics industry showed great potential for energy savings in comparison to existing ozone generation techniques. Unfortunately, the manufacturer of the laser test unit has not been successful in scaling up the equipment for prototype testing. Claims of economy in capital and operating/maintenance cost cannot therefore be accepted at present.

Any potential breakthrough in disinfection should be actively pursued, as substantial operational expenditure is necessary to cover the costs of the commonly used chlorination method.

Shotcrete

Shotcrete has several potential uses in wastewater collection and treatment. In tunneling, shotcreting has been used in Japan to line tunnels without provision of intermediate support. In tank construction, hoppers have been identified as very high unit cost items; these have been constructed more cheaply using shotcreting methods. Consideration has been given to constructing vertically walled tanks using shotcrete. However, this has at present been rejected, because the necessary wall thickness cannot be built up in a single application.

No particular uses for shotcreting were established during the study other than a specialized application for tunneling. Future development of the material in conjunction with other modern materials might open up new uses.

Concrete Dome Covers

Concrete domes have been constructed by pouring concrete flat between two membranes and inflating the completed slab to form a dome. When the concrete has set, doors and windows are sawn into the green concrete. Reinforcing steel is threaded through wire spirals to enable it to expand when the structure is inflated.

Covers of aluminum, fabric and fiber reinforced plastic are considered elsewhere in this report. The potential of concrete domes of this type is not considered to be of sufficient value to warrant further discussion.

Foam Formwork

Methodology--

The forming of complex concrete shapes is very costly using conventional steel and timber forming materials. The concept of using a single master form to create a complex shape, and then to mold multiple forms from the prototype was suggested. Rigid foamed plastic was recommended as a suitable material for making the master form out of. Prior to setting, it is fluid and can be easily shaped. After setting it is rigid, has a smooth surface, and possesses considerable compressive strength.

Development--

Research uncovered two manufacturers who have experimented with foam formwork. Both indicated that composite or laminated foam form structures are necessary for strength and dimensional stability. The making of these forms is a high technology process. One company indicated that foam forms are cheaper than steel where 40 or more uses can be achieved. The foam forms have been used for slab construction, vertical walls, and for complex curved shapes. Neither manufacturer seemed strongly interested in the potential applications to the construction of wastewater treatment plants. They felt that the reuse factor was too low in this application. It was felt that no benefit would be realized in following this idea further at the present time.

Sheet Piled Vertical Walled Tank

Methodology--

Conventional methods and materials of construction for vertical walls in sedimentation/aeration tanks, and similar shallow excavated tanks, have been identified as high cost centers. The function of such walls is to resist internal and external forces, and to retain water.

A variety of ideas were suggested. The idea which was potentially most economical -- diaphragm walls -- was eliminated since no suitable method for maintaining long term integrity was developed. Sheet piling, which is frequently used for temporary excavation support, was suggested to be used in conjunction with a waterproofing of some type.

Development--

Extending beyond the steel sheet piling concept, the use of interlocking concrete piles is also possible. Three structural types are presently available; free cantilever, top restrained (propped) cantilever, and intermediate tied back cantilever. The tied back cantilever was rejected, because the tie back anchors nullify the tank's earth's potential for other uses.

The concept was developed and analyzed for one primary tank 76.2 m (250 ft) long by 7.6 m (25 ft) wide by 4.6 m (15 ft) deep. A 300 x 300 mm (12 x 12 in) concrete beam was used outside of the tank at the surface to cap the piles and anchor the liner. A 600 mm (24 in) high by 300 mm (12 in) wide splay was used around the interior base to anchor the liner and provide machinery fixing points.

Costs were developed for the sheet pile tank and for a concrete tank of the same overall dimensions. Temporary sheet piling was allowed for in the cost of the concrete tank (two reuses of the piles assumed). The cost of the sheetpile wall was approximately 1.5 times the cost of the conventional wall.

It was concluded that there would be no further benefit from this investigation.

Mass Site Excavation

Methodology--

The excavation of several individual process unit areas was identified as one construction task that might be improved upon. The mass site method of excavation was examined as part of the construction of a minimum size plant. On a conventional plant, units are more widely spaced. The most cost-effective method of excavating for the plant is to strip the site to a general minimum formation level. The equipment best designed to handle such excavation is used for strip mining overburden removal.

Development--

The use of strip mining style of equipment would require a contractor or plant to hire a strip mining company or purchase such equipment for use on a contract or in an area. It is unlikely that the use of such equipment on so small a scale would be cost-effective. To be an economical alternative it would be necessary for some regional or federal agency to purchase the equipment, and make it available for rental use by contractors.

The cost of transportation of such equipment was considered potentially prohibitive. The initial analysis was therefore centered on determining likely first cost and transportation costs, a unit cost for excavation using such machinery, and comparing these costs with the cost of conventional treatment plant excavation.

It was determined that even if the equipment capital cost could be offset against many projects, the overall cost of excavation of medium and larger plants using this technique is higher than conventional methods. No benefits are possible, therefore, and no further action was taken.

Oversize Trenching Plough

Trench excavation for sewers is a high cost center. One of the basic limitations with the present backhoe excavation technique is that it is a two-step process. Soil is cut from a trench face into a bucket, the bucket then moves to a conveyor or truck to discharge the material. Dynamic one-step excavation, such as is achieved using a plough, could be more cost-effective if the required energy input could be developed. A plough has been developed which excavated a trench for a 900 mm (3 ft) diameter undersea oil pipeline.[1]

The plough, developed by R. J. Brown and Associates, cut 2.2 km (1.4 mile) through hard clay to allow positioning of the oil pipeline. The trench was excavated in just 30 miniutes. No cost data, nor information concerning maximum depth was available. It is anticipated that such a device would have limited value in view of its inability to cross utilities. There is little likelihood that deep excavations are possible in other than perfect ground conditions.

On-Site Wound Fiberglass Reinforced Polyester (FRP) Tanks

FRP Tank manufacturers suggested on-site winding of large diameter tanks. This technique has been used in industry. Presently only small diameter FRP structures are used at wastewater treatment plants and these structures are generally prefabricated at the shop and shipped to the site in completed form.

FRP wall thickness can be of any dimension, and this thickness can be varied from the top to the bottom of the walls. Polyurethane foam in 1 inch thick sheets can be added between the structural FRP wall and a final FRP protective coating to provide an insulated tank. Diameters of over 100 feet are possible,as well as sidewalls up to 50 feet high.

Cost evaluation was carried out for a 30 m (100 ft) diameter tank with a 4.6 m (15 ft) high sidewall. Concrete wall thickness was assumed to be 350 mm (14 in). The cost of FRP tankage was based on 7¢/litre (28¢/gallon). The ratio of cost of FRP wall vs. cost of concrete walls was 4.4 to 1. Therefore, the proposed FRP method has no advantages over conventional methods for use in municipal wastewater treatment.

Deodorizing Foul Air with Botanical Systems

Objectionable odors from wastewater interceptors and wastewater pumping and treatment facilities are sometimes removed by mechanical or biological scrubbing systems. These systems are ordinarily constructed using conventional materials of construction (e.g., plastic media and steel tanks). A simpler system might provide cost savings. Because foul air frequently contains carbon dioxide at concentrations greatly in excess of that atmosphere, the use of botanical systems (i.e., growing plants in greenhouses) is an attractive concept which might reduce construction costs, as well as put the foul air to a beneficial use.

Greenhouse structures are sometimes used to protect sludge drying beds from rain. It is possible that foul air might be routed to such areas and use be made of drying sludge for growing botanical systems.

A botanical deodorizing system would consist of a greenhouse containing appropriately selected plants. Foul air would be delivered to the greenhouse to provide a carbon dioxide enriched atmosphere for accelerated plant growth. Odor reduction would be primarily from biological oxidation by bacteria on the plant surface area. Oxygen enrichment of the atmosphere and the masking effect of pleasant plant odors would also help to decrease the offensiveness of the gas released from the greenhouse.

Implementation--

In order to implement this idea, design criteria would need to be established and appropriate plants would need to be selected. Determination of such things as growth-limiting factors, growth rates, supplemental lighting requirements, oxygen production rates, and areal requirements must be established to determine the idea's potential. Design and construction of greenhouses is ordinarily carried out according to well-established principles, and only minor design changes would be required to efficiently distribute the foul air and to collect the deodorized air for release. Consideration should be given to a cascade arrangement of greenhouses to reduce the potential for inadvertent release of odors due to incomplete reaction. The system for delivering the foul air from its source to the greenhouse would be the same as for any other deodorizing system.

Because the plants grown in the greenhouses potentially have a marketable value, consideration should be given to harvesting and marketing requirements. This effort will be critical in offsetting the total costs of the botanical system, since other deodorization methods are relatively cheap. There are no known regulations or codes which would require change to implement this concept.

Cost Considerations--

Information on the potential savings in using botanical deodorizing systems are not available. Greenhouse construction would be cheaper than scrubbing systems due to its simplicity and less use of steel. Economics would depend heavily upon the areal requirements for the greenhouses. It is possible that this concept would be appropriate only at locations where greenhouses already exist.

Advantages--

Botanical systems could be used in areas where the climate is relatively mild and solar radiation is reasonably consistent throughout the year. The major advantage of botanical deodorizing systems would be the potential reduction in material and construction costs due to its simplicity. An additional benefit would be harvesting of a marketable by-product, which would put the foul air to a beneficial use and would reduce overall costs.

Disadvantages--

Botanical systems would be inappropriate in areas where climatic conditions are unsuitable or would be expensive to overcome; e.g., where excessive insulation and supplemental heat and light would be required. Also, the distance of the foul air source to the greenhouse site, and the availability and cost of land would be factors affecting the economics of botanical systems.

WASTE TREATMENT PROCESSES UTILIZING DEEP SHAFTS

Section 7 discussed the most economical construction method for drilling deep, large and small diameter shafts. The use of deep shafts for something more than a conduit or reservoir was pioneered by Imperial Chemicals Industries Ltd., Billingham, U.K. They developed a treatment process appropriately labeled "The Deep Shaft Wastewater Treatment Process". Several other treatment processes are clearly adaptable to deep shaft technology. Deep shaft applications include those listed below, each of which will be described briefly.

- Deep Shaft Concept
- Dissolved Air Flotation
- Solids Contact Bed
- Microflotation
- Chlorine Contact

Several of these process units can be paired in combinations to further increase plant economy.

Deep Shaft Concept

This is a deep shaft, of 0.3 to 10 m (1 to 33 ft) in diameter and from about 100 to 300 m (320 to 1,000 ft) deep, in which waste is biologically oxidized (see Figure B-1). ICI claims that this process can replace aerobic activated sludge tanks and anaerobic sludge digestion units. After screening and degritting, wastewater is fed to a concentric pipe (downcomer) in the deep shaft. Recycled sludge is also fed at this point. Compressed air or oxygen added in the descending leg provides oxygen to the system. Essentially, all of the air or oxygen is dissolved before the stream rises up the outside shaft. Carbon dioxide, nitrogen, and unused oxygen come out of solution in the form of microscopic bubbles as hydrostatic pressure decreases. Solids are separated from the main stream by clarification or flotation and either returned to the shaft influent as sludge recycle or wasted.

Optimal shaft depth and diameter vary with both hydraulic and organic loading characteristics and with soils and geology of the site as they affect the costs of shaft construction. Typically, optimal shaft depth will be in the range of 50 to 150 (english equivalent) meters (150 to 500 feet), but in some cases depth may be as much as 200 to 250 meters (600 to 800 feet). At a given treatment site, two or more shafts could be used instead of only one if such configurations result in overall economy in shaft construction, taking into account the specific geologic conditions present. The changes in pressure that take place in the liquid as it travels from the top of the shaft to the bottom, and again to the top aids the oxygen transfer process. Power consumption is claimed to be modest; solids separation methods are evidently in the research and investigative stages to determine the most satisfactory approach. Flotation is held as a promising way to accomplish economical and good quality separation by the system developers.

Only limited experience with full scale deep shaft systems has been reported to date. Several applications for industrial waste treatment are now operating in Europe and in U.K. In Canada, a municipal plant employing deep shafts is now operating at Virden, Manitoba. This installation consists of a shaft 150 meters (500 feet) deep and one meter (3 feet) in diameter designed for a flow of about 25 l/s (0.6 mgd).

The deep shaft treatment system has excellent potential for being the most economical system for meeting secondary effluent quality requirements under certain conditions, including:

- Favorable geologic conditions for economical shaft construction; including shallow, though stable, overburden and completed rock of medium strength.

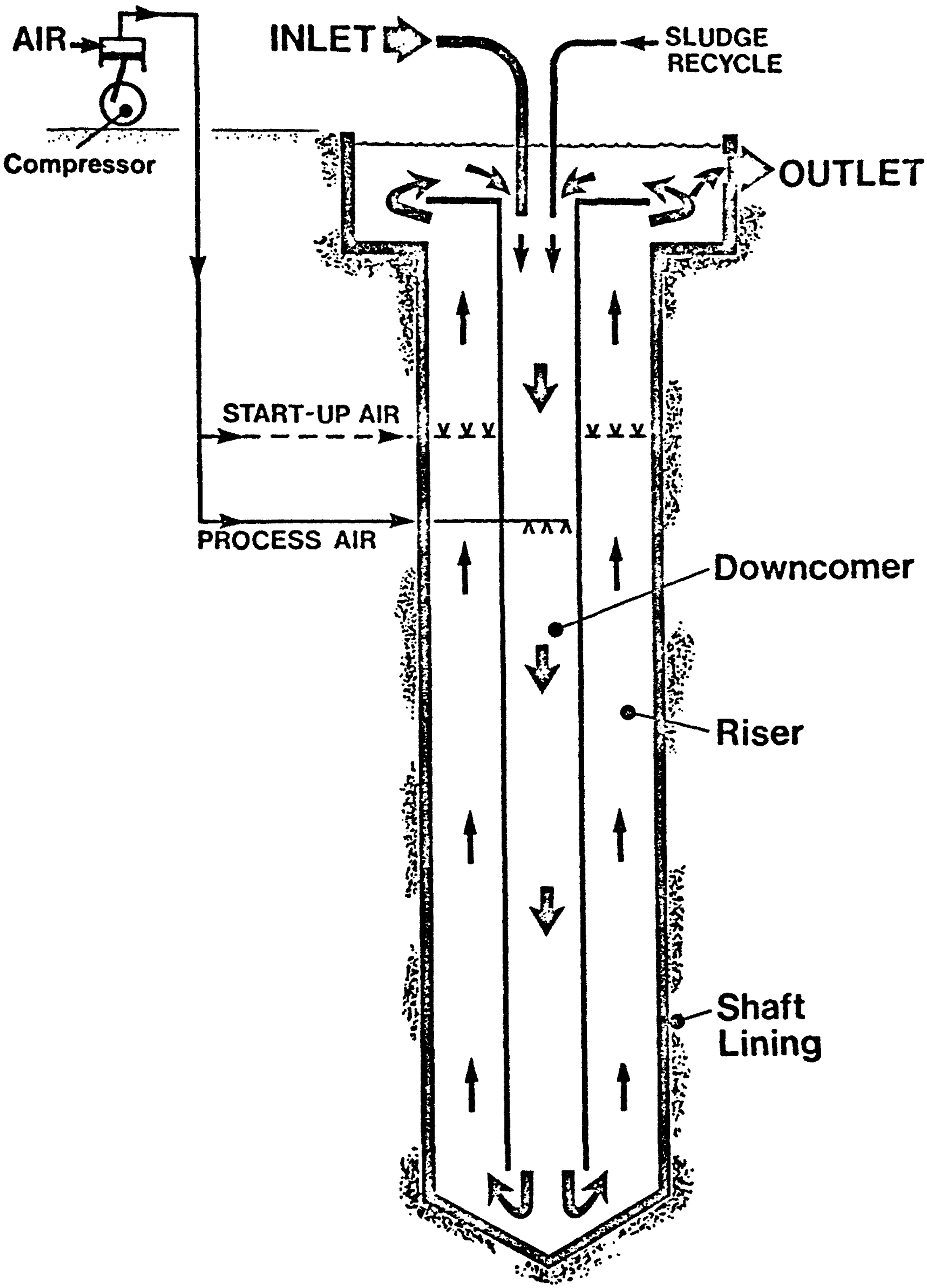


FIGURE B-1. ICI DEEP SHAFT UNIT

- Relatively high land cost, because the shaft system uses little land.

- Severe northern and extremely hot climates which adversely affect conventional treatment.

Under the above conditions, potential advantages compared to conventional activated sludge treatment are:

- Lower power consumption.

- Lower sludge production.

- No primary settling needed with deep shaft.

- Reduced odor potential.

- Overall lower cost, at least for plants serving populations in excess of approximately 50,000 people.

Potential disadvantages include:

- A potential risk for groundwater contamination; however, lining or casing of the shaft should preclude this from occurring.

- Uncertainty in cost owing to high dependency on subsurface conditions.

- Current lack of experience with the method; including, the question of interrelation between the deep shaft and the other units of the treatment plant.

Dissolved Air Flotation

This process would employ a concentric pipe in a sealed shaft, approximately 55 m (180 ft) deep, in place of a conventional pressurization system for a dissolved air flotation unit. This application could provide a low cost, energy-efficient system for air saturation in dissolved air flotation of waste activated sludge.

Liquid requiring pressurization and air saturation at elevated pressure would be fed to the pipe. Air bubbles would then be added to the descending leg of the U-tube. Thus, a high degree of air saturation would be achieved by the turbulence and static pressure in the system. Sludge and appropriate chemicals would be added in the upward flow to combine with the air bubbles, which form as pressure is decreased. The concentrated waste activated sludge would be floated in a conventional flotation tank and removed with skimmers.

Solids Contact Bed

This process would present a deep shaft containing a contact bed of high specific surface area media. This configuration offers the promise of eliminating a surface solids separation step, because the contact bed would also act as an upflow filter.

After pretreatment, air or pure oxygen would be added to the wastewater near the bottom of the descending leg of the U-tube. The high specific surface area contact bed, located in the ascending leg, would provide a fixed growth medium for the microbiological culture, as well as a filter to reduce suspended solids. Only a degassification zone would be required at the surface. A further downstream filtration process might be required for further additional solids removal.

The fixed growth contact bed could also be designed as an anaerobic reactor. Air addition high in the ascending leg would control septicity in downstream processes, and still help provide fluid motive force.

Microflotation

This process, which has been pioneered by Environmental Systems Division of AB Electrolux, Stockholm, requires a shaft of about 8 to 10 m (26 to 33 ft) deep, and employs an unconventional and simple method for generating microscopic air bubbles (see Figure B-2). Electrolux claims that the process, used in lieu of a secondary clarifier, can result in a smaller separation unit (40 minute detention time) and eliminate the need for waste activated sludge thickening, because it can concentrate sludge to about 3 percent.

The process is designed for solids separation. After mechanical pretreatment to remove oversized solids, pH is adjusted, flocculant aids are added, and the wastewater is mixed. Then it flows down the descending leg of the divided shaft. Air, injected at the bottom of the shaft, dissolves under hydrostatic pressure. Undissolved air rises in the descending leg and enhances water saturation. The rising stream is then not only saturated with air, but also free of undissolved air bubbles. The dissolved air is released in the form of microscopic bubbles, that attach to solids as the hydrostatic pressure in the rising leg decreases. Polyelectrolytes may be added to improve float density. The float passes into a separation tank where it is removed by skimmers.

Chlorine Contact Chamber

A deep shaft equipped with an inner tube, or straight partition, is conceived as a method for achieving desired chlorine

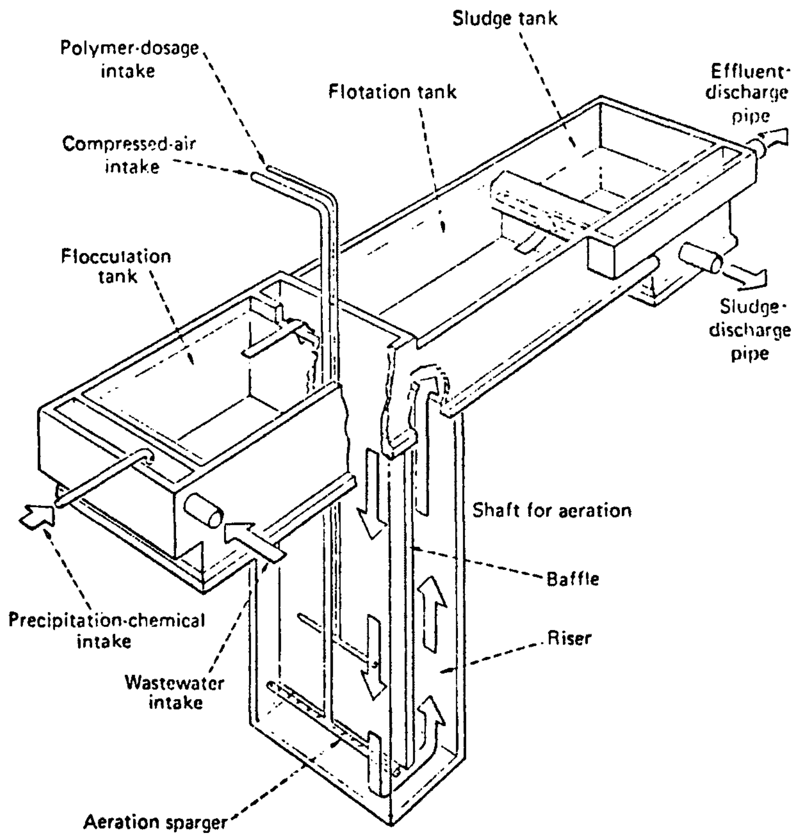


FIGURE B-2. MICROFLOTATION PROCESS

contact time with full assurance that no shortcircuiting can occur. Chlorine would simply be injected at the upper part of the inner conduit, and circulation would be forced by establishing a differential hydraulic head between the downcomer and the riser. Liquid with injected chlorine would flow all the way to the bottom of the shaft, then rise in the outer chamber (annulus) and discharge to the effluent outfall conveyance system.

For 60 minute contact time, the typical combinations of shaft depth and diameter are given in Table B-1 that are required to satisfy volume requirements for various design discharges. Multiple shafts can be employed if found to be more economical for a specific installation; by virtue of the geology and/or other factors.

Uncertainty in construction cost is the major disadvantage. This is coupled with an undemonstrated likelihood of significant cost advantage, particularly for larger size plants. Concern may be expressed over the potential for the contamination of groundwater; care in the design and installation of lining or casing should preclude this possibility, however.

TABLE B-1. SHAFTS FOR CHLORINE CONTACT

Design discharge (l/sec)	Net I.D. of shaft (meters)	Required shaft depth (meters)	Volume (m^3)	Approximate cost range for lined shaft (thousand dollars)
500	2.0	580	1800	--
	2.4	400	1800	310-460
200	2.0	230	720	--
	1.5	395	720	--
	2.4	160	720	125-185
100	2.4	80	360	70-100
	1.5	200	360	--
	1.0	460	360	160-230
	2.0	115	360	--
50	2.4	40	180	40-50
	2.0	58	180	--
	1.5	100	180	--
	1.0	230	180	80-115

Advantages include a relatively long and narrow flow path with a minimal chance of short circuiting, thus assuring achievement of desired contact time. The requirement for land is much less than for surface tankage, and could be a significant advantage where land is scarce. Indications are that, with favorable geology, deep shafts are likely to be cheaper or at least competitive for small-discharge facilities, but conventional surface tankage will be cheaper for medium to large capacity facilities. To be more specific, 50 l/s (1 mgd) and smaller capacities have potential for saving costs with the shaft method, whereas for 200 l/s (5 mgd) and larger flows the shaft does not seem to be competitive under average site conditions.

Septic Tanks Upstream of Sewers

Where rural sewerage systems are to be provided in areas where existing households are connected to septic tanks, continuance of the use of septic tanks provides primary solids removal and enables the use of much smaller shallower gravity piping systems. A disadvantage to be considered is the lifetime cost of removing septage from the septic tanks.

Cost data were not available on this method when these novel ideas were developed; subsequent inquiry has revealed that the University of Wisconsin has implemented a project in Westboro, Wisconsin involving small diameter gravity sewers with community subsurface disposal. Construction was completed during the summer of 1978. Although more information is needed to evaluate costs and performance such systems appear to be a positive solution to cost reduction in rural areas and should be considered along with pressure and vacuum sewer alternatives for these areas.

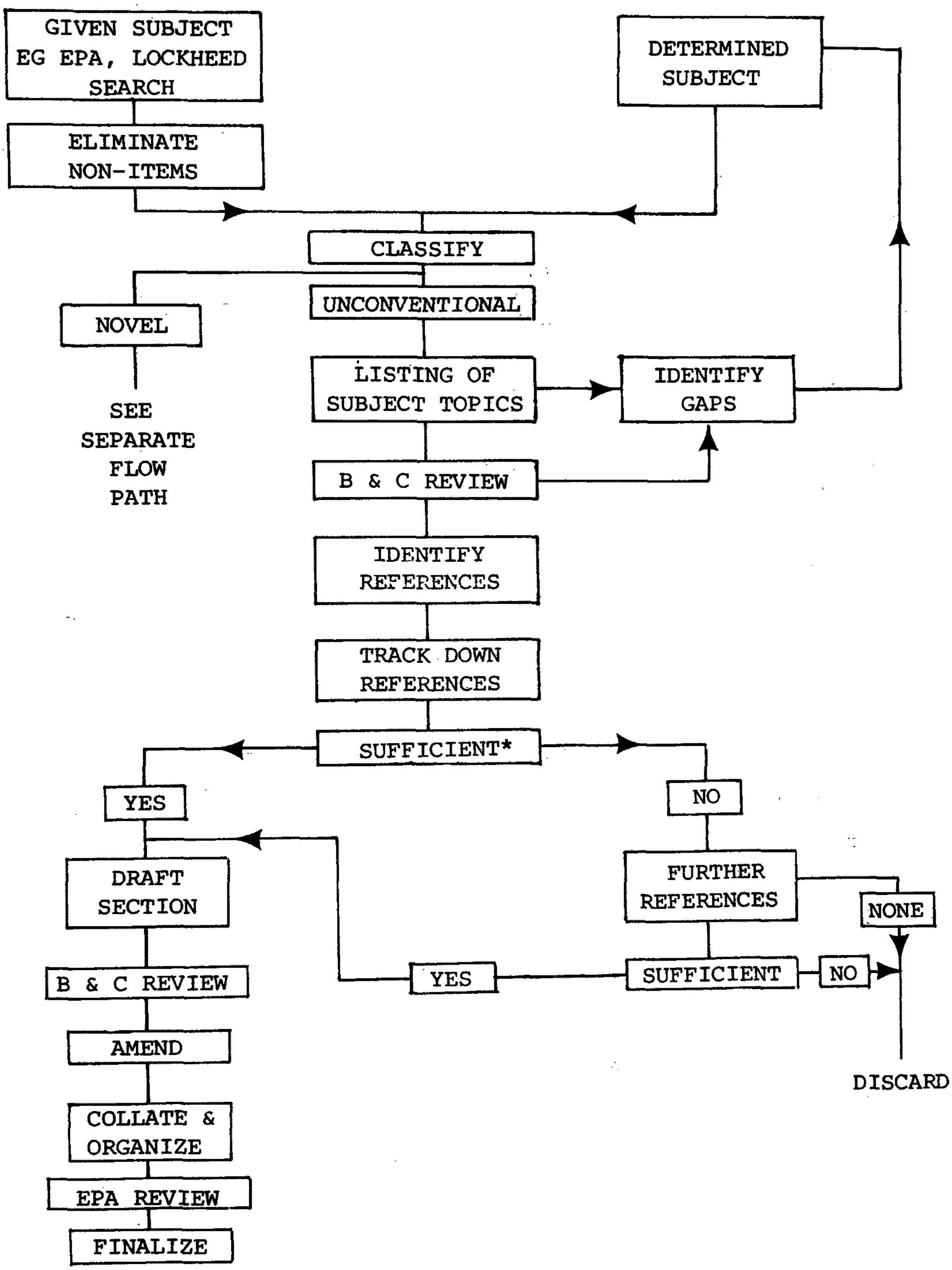
REFERENCES

1. New Civil Engineer, July 7, 1977, p. 3.

APPENDIX C

COMPUTER SEARCHES

The following chart and listing of key words were used during computer searches for references. The chart shows the development path for ideas from the origination of the reference by the computer through to incorporation of the idea in this report or its rejection. The list shows the key words developed for the later computer searches (early searches were by general subject). These key words were paired by the computer, i.e., a "Stage/Process" key word and an "Operation" key word were both required to appear in the key word listing for any citation.



EPA NOVEL METHODS
PHASE 2 TASK 3 - UNCONVENTIONAL METHOD FLOWPATH

Stage/Process	Element	Operation
Activated Sludge	Activated Biofilter	Application Rates
Advanced Wastewater Treatment	Activated Carbon	Benefit Cost Analysis
Aeration	Activated Sludge Process	Capital Costs
Aerobic Digestion	Aerated Grit Chamber	Construction Costs
Anaerobic Digestion	Aerated Lagoons	Cost Comparison
Biodegradability	Aerators	Cost Effectiveness
Biological Processes	Bar Racks	Costs
Biological Treatment	Catch Basins	Design
Biological Waste Treatment	Centrifuges	Economic Analysis
Chemical Treatment	Channels	Economics
Chlorination	Chlorine Contact Tanks	Efficiency
Collection	Clarifiers	Facilities Management
Denitrification	Combined Sewers	Instrumentation
Digester Gas	Diffusers	Loading Rates
Digestion	Digesters	Maintenance Costs
Disinfection	Digestion Tanks	Management
Equalization	Filters	Operating Costs
Extended Aeration	Final Tanks	Operating Results
Filtration	Furnace	Optimization
Flocculation	Heat Treatment	Performance Evaluation
Flotation	Incinerators	Plant Efficiencies
Gas Utilization	Lagoons	Power Costs
Gravity Thickening	Manholes	Process Control
Grit Removal	Mechanical Aerators	Sensitivity Analysis
Hydraulics	Microstrainer	Standards
Land Disposal	Mixed Media Filters	Transfer Efficiency
Methane	Oxidation Ditch	Value Engineering
Nitrification	Oxidation Ponds	
Nitrogen Removal	Ozonators	
Nutrient Addition	Polyelectrolytes	
Ozonation	Polymers	
Phosphorus Removal	Ponds	
Preliminary Treatment	Presses	
Primary Treatment	Pumping Stations	
Screening	Pumps	
Scum Removal	Regulator Stations	
Seasonal Variations	Rotating Biological Surfaces	
Secondary Treatment	Roughing Filter	
Sedimentation	Sanitary Sewers	
Settling	Screens	
Sewage Treatment	Sewage Treatment Plants	
Sludge Dewatering	Sewage Works	
Sludge Disposal	Sludge Drying Beds	
Sludge Treatment	Stabilization Ponds	
Thickening	Storm Sewers	
Wastewater	Thickeners	
Water Pollution Control	Trickling Filters	

EPA NOVEL METHODS - PHASE 2
LOCKHEED COMPUTER SEARCH KEY WORDS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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4. TITLE AND SUBTITLE NOVEL METHODS AND MATERIALS OF CONSTRUCTION		5. REPORT DATE July 1979 (Issuing Date) 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) A. F. Harber and R. C. Bain, Jr.		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Brown and Caldwell, Consulting Engineers 100 W. Harrison Seattle, Washington 98119		10. PROGRAM ELEMENT NO. 1BC611; SOS 2A, Task 25 11. CONTRACT/GRANT NO. 68-03-2512
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15. SUPPLEMENTARY NOTES

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16. ABSTRACT The purpose of this study was to identify the structural and nonstructural factors which influence the cost of construction of municipal wastewater treatment plants and to determine if construction costs could be reduced through the modification of the nonstructural factors or the use of unconventional or novel methods and materials of construction. For nonstructural factors or problems, solutions are posed for some of the identified problems and these are ranked in terms of their potential for implementation and cost savings. Within the top six ranked solutions two involved expansion of the facility planning phase, two involved design criteria while the remaining top ranked solutions involved fast track construction management procedures and adoption of novel ideas.

From the structural aspect, those unconventional materials or methods of construction identified as feasible and cost effective were flexible (in situ formed) pipe liner which enables sewers to be relined using existing access, plastic fluid control equipment, and several fiberglass reinforced plastic (FRP) applications including digester covers, small diameter piping and access bridges for walkways over clarifiers and other process units. The most readily implementable novel concepts identified were vertical shaft construction methods and applications, precast concrete tanks, and reinforced asphalt pond liners. The best ideas identified as requiring further study are shipboard treatment and botanical foul air treatment. Other ideas including those considered non-cost effective are identified.

This report is submitted in fulfillment of Contract No. 68-03-2512 by Brown and Caldwell, Inc., under the sponsorship of the U.S. Environmental Protection Agency. This report was essentially completed during the period March 7, 1977 to November 30, 1977; however, some additional work was conducted during the summer of 1978 which accounts for references to the Clean Water Act Amendments which were passed by Congress in December 1977.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Waste treatment, Expenses, Construction, Construction costs, Construction materials, Building codes, Fabrication, Engineering, Construction equipment	Wastewater treatment, Capital costs, Structural cost centers, Nonstructural cost centers, Design standards, Construction grants eligibility, Construction grants cost savings	13B

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