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Municipal Environmental Research
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Cincinnati OH 45268

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Research and Development

EPA

Estimating Water Treatment Costs

Volume 1
Summary

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ESTIMATING WATER TREATMENT COSTS

Volume 1. Summary

by

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DISCLAIMER

FOREWORD

The U.S. 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 testimonies 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 new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat 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.

The cost of water treatment processes that may be used to remove contaminants included in the National Interim Primary Drinking Water Regulations is of considerable interest to Federal, State, and local agencies, and consulting engineers. This four-volume report presents construction and operation and maintenance cost curves for 99 unit processes that are especially applicable, either individually or in combination, to the removal of contaminants contained in the Regulations.

Francis T. Mayo
Director
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ABSTRACT

This Report discusses unit processes and combinations of unit processes that are capable of removing contaminants included in the National Interim Primary Drinking Water Regulations. Construction and operation and maintenance cost curves are presented for 99 unit processes that are considered to be especially applicable to contaminant removal. The Report is divided into four volumes. Volume 1 is a summary volume. Volume 2 presents cost curves applicable to large water supply systems with treatment capacities between 1 and 200 mgd (3,785 and 757,000 m^3/d), as well as information on virus and asbestos removal. Volume 3 includes cost curves applicable to flows of 2,500 gpd (9.46 m^3/d) to 1 mgd (3,785 m^3/d). And Volume 4 is a computer program user's manual for the curves included in the Report.

For each unit process included in this report, conceptual designs were formulated, and construction costs were then developed using the conceptual designs. The construction costs that were developed are presented in tabular form by eight categories: Excavation and sitework; manufactured equipment; concrete; steel; labor; pipe and valves; electrical and instrumentation; and housing. The construction cost curves were checked for accuracy by a second consulting engineering firm, Zurheide-Herrmann, Inc., using cost-estimating techniques similar to those used by general contractors in preparing their bids. Construction costs are also shown graphically, plotted versus the most appropriate design parameter for the process (such as square feet of surface area for a filter). This type of plot allows the data to be used with varying design criteria and designers' preferences.

Operation and maintenance requirements were determined individually for three categories: Energy, maintenance material, and labor. Energy requirements for the building and the process are presented separately.

All costs are presented in terms of October 1978 dollars, and a discussion is included on cost updating. For construction cost, either of two methods may be used. One is the use of indices that are specific to each of the eight categories used to determine construction cost. The second is use of an all-encompassing index, such as the ENR Construction Cost Index. Operation and maintenance requirements may be readily updated or adjusted to local conditions, since labor requirements are expressed in hours per year, electrical requirements are in kilowatt-hours per year, diesel fuel is in gallons per year, and natural gas is in standard cubic feet per year.

This report was submitted in fulfillment of Contract No. 68-03-2516 by Culp/Wesner/Culp under the sponsorship of the U.S. Environmental Protection Agency. A subcontractor, Zurheide-Herrmann, Inc., Consulting Engineers, checked the validity of all construction cost data which was developed. This report covers the period November 1, 1976 to January 1, 1979, and work was completed as of July 2, 1979.

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ABBREVIATIONS AND SYMBOLS

ft	--	foot
ft^2	--	square foot
ft^3	--	cubic feet
G	--	velocity gradient - feet per second per foot
gal	--	gallon
gpd	--	gallons per day
gpd/ft^2	--	gallons per day per square foot
gpm	--	gallons per minute
hr	--	hours
kg	--	kilogram
kw-hr	--	kilowatt-hour
l	--	liter
lb	--	pound
lpd	--	liters per day
lpd/m^3	--	liters per day per cubic meter
lps	--	liters per second
m	--	meter
m^2	--	square meter
m^3	--	cubic meter
m^3/d	--	cubic meters per day
m^3/s	--	cubic meters per second
mg	--	million gallons
mg/l	--	milligrams per liter
mgd	--	million gallons per day
min	--	minutes
mph	--	miles per hour
psi	--	pounds per square inch
scf	--	standard cubic foot
tdh	--	total dynamic head
tu	--	turbidity unit
yd^3	--	cubic yards
yr	--	year

METRIC CONVERSIONS

English Unit	Multiplier	Metric Unit
cu ft	0.028	m^3
cu yd	0.75	m^3
ft	0.3048	m
gal	3.785	l
gal	0.003785	m^3
gpd	0.003785	m^3/d
gpd/ft^2	40.74	lpd/m^2
gpm	0.0631	l/s
lb	0.454	kg
mgd	3785	m^3/d
mgd	0.0438	m^3/sec
sq ft	0.0929	m^2

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Mr. Ronald M. Dahman of Zurheide-Herrmann, Inc., was responsible for checking all unit costs. Dr. Isadore Nusbaum and Mr. Dean Owens were respective sub-consultants on the reverse osmosis and ion exchange curves.

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Mrs. Anne Hamilton was the technical editor for all four volumes of this Report.

SECTION 1

INTRODUCTION

SCOPE

This four-volume report presents construction and operation and maintenance cost curves for 99 unit processes useful for removing contaminants included in the National Interim Primary Drinking Water Regulations. Volume I, the summary, discusses the cost estimating approaches that were utilized to develop the cost curves, presents the treatment techniques that are applicable to contaminant removal, and gives a series of examples demonstrating the use of the cost curves. Volume 2 presents cost curves applicable to large water supply systems with treatment capacities between 1 and 200 mgd (3,785 and 757,000 m^3/d); it also contains information on virus and asbestos removal. Volume 3 includes cost curves applicable to flows of 2,500 gpd (9.46 m^3/d) to 1 mgd (3,785 m^3/d). Volume 4 is a computer user's manual and contains a computer program that can be used for retrieving and updating all cost data contained in the report.

BACKGROUND

The Safe Drinking Water Act, Public Law 93-523[1] enacted on December 16, 1974, empowered the Administrator of the U.S. Environmental Protection Agency (EPA) to control the quality of the drinking water in public water systems by regulation and other means. The Act specified a three-stage mechanism for the establishment of comprehensive regulations for drinking water quality:

1. Promulgation of National Interim Primary Drinking Water Regulations.
2. A study to be conducted by the National Academy of Sciences (NAS) within 2 years of enactment on the human health effects of exposure to contaminants in drinking water.
3. Promulgation of Revised National Primary Drinking Water Regulations based on the NAS report.

National Interim Primary Drinking Water Regulations

National Interim Primary Drinking Water Regulations were promulgated on December 24, 1975,[2] and July 9, 1976;[3] they became effective on June 24, 1977. These Regulations were based on the Public Health Service Drinking Water Standards of 1962, as revised by the EPA Advisory Committee on the Revisions and Application of the Drinking Water Standards. They are intended to protect health to the maximum extent feasible using treatment methods that are generally available and take cost into consideration. The National Interim Primary Drinking Water Regulations contain maximum contaminant levels (MCL) and monitoring requirements for 10 inorganic chemicals, six organic pesticides, two categories of radionuclides, coliform organisms, and turbidity. An Amendment to the National Interim Primary Drinking Water Regulations was proposed on February 9, 1978.[4] This amendment would establish regulations for total trihalomethanes and establish treatment technique requirements for the control of synthetic organic chemicals for community water systems serving a population of more than 75,000. Secondary Drinking Water Regulations were proposed by EPA on March 31, 1977.[5]

A list of contaminants presently included in the National Interim Primary Drinking Water Regulations, is shown in Tables 1 and 2, along with the MCL for each contaminant except coliform organisms. The MCL for coliform organisms depends on whether the membrane filter technique or the fermentation tube technique is utilized, and on the sample size if the latter is used. Table 3 presents the MCL for coliform organisms.

The Primary Regulations are devoted to contaminants affecting the health of consumers, whereas the secondary regulations include those contaminants that primarily deal with aesthetic qualities of drinking water. The Interim Primary Regulations are applicable to all public water systems and are enforceable by EPA or the States that have accepted primacy. Secondary regulations are not federally enforceable and are intended as guidelines for the States.

NAS Study

The National Academy of Sciences (NAS) Summary Report was delivered to Congress on May 26, 1977, and, the full report, Drinking Water and Health, was delivered on June 20, 1977. The NAS Summary Report was also published in the Federal Register, Monday, July 11, 1977.[6] Based on the completed National Academy of Sciences Report and the findings of the Administrator, EPA will publish:

1. Recommended MCL's (health goals) for substances in drinking water that may have adverse effects on humans. These recommended levels will be selected so that no known or anticipated adverse effects will occur, allowing an adequate margin of safety. A list of contaminants that may have adverse effects but that cannot be accurately measured in water will also be published.
2. Revised National Primary Drinking Water Regulations. These will specify MCL's or require the use of treatment techniques. MCL's will be as close to the recommended levels for each contaminant as feasible. Required treatment techniques for those substances that cannot be measured will reduce their concentrations to a level as close to the recommended level as feasible. Feasibility is defined in the Act as use of the best technology, treatment techniques, and other means that the Administrator finds to be generally available (taking costs into consideration).

Table 1

Contaminants and Maximum Contaminant Levels in the National Interim Primary Drinking Water Regulations

Contaminant	MCL
Arsenic	0.05 mg/1
Barium	1.0 mg/1
Cadmium	0.01 mg/1
Chromium	0.05 mg/1
Lead	0.05 mg/1
Mercury	0.002 mg/1
Nitrate (as N)	10.0 mg/1
Selenium	0.01 mg/1
Silver	0.05 mg/1
Endrin	0.002 mg/1
Lindane	0.004 mg/1
Toxaphene	0.005 mg/1
2, 4-D	0.1 mg/1
2, 4, 5 - TP (Silvex)	0.01 mg/1
Methoxychlor	0.1 mg/1
Alpha Emitters:	
Radium - 226	5 pCi/1
Radium - 228	5 pCi/1
Gross Alpha Activity (Excluding radon and uranium)	15 pCi/1
Beta and Photon Emitters: *	
Tritium	20 pCi/1
Strontium	8 pCi/1
Turbidity	1 turbidity unit+

*Based on a water intake of 2 liters/day. If gross beta particle activity exceeds 50 pCi/1, other nuclides should be identified and quantified on the basis of a 2-liter/day intake.

+One turbidity unit based on a monthly average. Up to 5 turbidity units may be allowed for the monthly average it if can be demonstrated that no interference occurs with disinfection or microbiological determinations.

Table 2

Maximum Contaminant Levels for Fluoride

Average Annual Maximum Daily Air Temperature		
°F	°C	MCL, mg/1
53.7 and below	12.0 and below	2.4
53.8 to 58.3	12.1 to 14.6	2.2
58.4 to 63.8	14.7 to 17.6	2.0
63.9 to 70.6	17.7 to 21.4	1.8
70.7 to 79.2	21.5 to 26.2	1.6
79.3 to 90.5	26.3 to 32.5	1.4

Table 3

Maximum Contaminant Levels for Coliform Organisms

Detection Technique Used	Number of Samples Examined per Month	Maximum Number of Coliform Bacteria
Membrane Filter	---	1/100 ml as arithmetic mean of all samples examined each month
	Fewer than 20	4/100 ml in no more than one sample
	20 or more	4/100 ml in no more than 5 percent of all samples examined each month
Fermentation Tube, 10-ml Standard Portions	---	Coliforms shall not be present in more than 10 percent of the portions in any month
	Fewer than 20	Coliforms shall not be present in three or more portions in more than one sample
	20 or more	Coliforms shall not be present in three or more portions in more than 5 percent of the samples
Fermentation Tube, 100-ml Standard Portions	---	Coliforms shall not be present in more than 60 percent of the portions in any month
	Fewer than 5	Coliforms shall not be present in five portions in more than one sample
	5 or more	Coliforms shall not be present in five portions in more than 20 percent of the samples

Proposed Revisions of the Interim Regulations

On February 9, 1978, the EPA proposed to amend the National Interim Primary Drinking Water Regulations by adding regulations for organic chemical contaminants in drinking water. The proposed amendment[4] consisted of two parts:

1. An MCL of 0.10 mg/l (100 parts per billion) for total trihalomethanes (TTHM), including chloroform.
2. A treatment technique requiring the use of granular activated carbon for the control of synthetic organic chemicals. Three criteria that the granular activated carbon must achieve are: an effluent limitation of 0.5 μg/l for low molecular weight halogenated organics (excluding trihalomethanes); a limit of 0.5 mg/l for effluent total organic carbon concentration when fresh activated carbon is used; and the removal of at least 50 percent of influent total organic carbon when fresh activated carbon is used.

These proposed amendments are initially applicable to community water systems serving a population of more than 75,000. Considerable comment has been received by EPA on the relatively limited use of activated carbon in water treatment to date and the subsequent lack of cost and design data. Activated carbon has however, been utilized, in many wastewater treatment applications, and a considerable amount of cost and design data have resulted. Appendix A presents a summary of information on wastewater applications using granular activated carbon.

PURPOSE AND OBJECTIVES

The principal purpose of this project is to delineate water treatment processes or process combinations that can remove one or more of the contaminants included in the Interim Regulations, and then to develop construction and operation and maintenance cost curves for the required unit processes. To facilitate the usefulness of the curves, separate curves were developed for flows ranging between 1 and 200 mgd (3,785 and 757,000 m^3/d) (Volume 2) and between 2,500 gpd (9.46 m^3/d) and 1 mgd (3,785 m^3/d) (Volume 3). This separation was made because many processes applicable to one range are not applicable to the other, and often when a process is applicable to both ranges, the conceptual design of the components varies significantly. In addition, the economy of scale inherent to treatment of larger flows often causes a dramatic change in the slope of cost curves, commonly in the 1 to 5 mgd (3,785 to 18,925 m^3/d) range.

Other objectives of the project include a literature search on the effectiveness of modifying standard treatment processes to enhance the removal of virus and asbestos, and the development of cost curves for the required modifications (Volume 2). The project also developed a computer program that can be used to retrieve and update costs and to determine the cost of various combinations of unit processes (Volume 4).

This volume includes a detailed discussion of treatment processes and techniques useful for the removal of each contaminant. Following this is a detailed explanation of how the cost curves were derived, and then 17 examples are presented to illustrate how the cost curves can be used to determine construction and operation and maintenance costs for various treatment flow schematics.

The 72 unit processes that were developed for flows of 1 to 200 mgd (3,785 to 18,925 m^3/d) (Volume 2) are:

Chemical Feed Processes

1. Chlorine Storage and Feed Systems
2. Chlorine Dioxide Generating and Feed Systems
3. Ozone Generation Systems and Contact Chambers
4. On-Site Hypochlorite Generation
5. Alum Feed Systems
6. Polymer Feed Systems
7. Lime Feed Systems
8. Potassium Permanganate Feed Systems
9. Sulfuric Acid Feed Facilities
10. Sodium Hydroxide Feed Systems
11. Ferrous Sulfate Feed Systems
12. Ferric Sulfate Feed Systems
13. Ammonia Feed Facilities
14. Powdered Activated Carbon Feed System

Flocculation, Clarification and Filtration Processes

15. Rapid Mix
16. Flocculation
17. Circular Clarifiers
18. Rectangular Clarifiers
19. Upflow Solids Contact Clarifiers
20. Tube Settling Modules
21. Gravity Filtration Structure
22. Filtration Media
23. Backwash Pumping Facilities
24. Hydraulic Surface Water Systems
25. Air-Water Backwash Facilities
26. Wash Water Surge Basin
27. Modification of Rapid Sand Filters to High Rate Filters
28. Continuous Automatic Backwash Filter
29. Recarbonation Basin
30. Recarbonation - Liquid CO_2 as CO_2 Source
31. Recarbonation - Submerged Burners as CO_2 Source
32. Recarbonation - Stack Gas as CO_2 Source
33. Multiple Hearth Recalcination
34. Contact Basin
35. Pressure Diatomite Filters
36. Vacuum Diatomite Filters
37. Pressure Filtration Plants
38. In-Plant Pumping
39. Wash Water Storage Tanks

Reverse Osmosis and Ion Exchange Processes

40. Reverse Osmosis
41. Ion Exchange - Softening
42. Pressure Ion Exchange - Nitrate Removal
43. Activated Alumina for Fluoride Removal

Activated Carbon Processes

44. Gravity Carbon Contactors - Concrete Construction
45. Gravity Carbon Contactors - Steel Construction
46. Pressure Carbon Contactors
47. Conversion of Sand Filter to Carbon Contactor
48. Granular Activated Carbon
49. Capping Sand Filters with Anthracite
50. Regional Off-Site Regeneration - Handling and Transportation
51. Multiple Hearth Granular Carbon Regeneration
52. Infrared Carbon Regeneration Furnace
53. Granular Carbon Regeneration - Fluid Bed Process
54. Powdered Carbon Regeneration - Fluidized Bed Process
55. Powdered Carbon Regeneration - Atomized Suspension Process

Sludge Pumping, Dewatering, and Disposal Costs

56. Chemical Sludge Pumping - Unthickened Sludge
57. Chemical Sludge Pumping - Thickened Sludge
58. Gravity Sludge Thickeners
59. Vacuum Filters
60. Belt Filter Press
61. Filter Press
62. Decanter Centrifuges
63. Basket Centrifuges
64. Sand Drying Beds
65. Sludge Dewatering Lagoons
66. Sludge Disposal - Sanitary Sewer
67. Sludge Hauling to Landfill

Miscellaneous Processes

68. Raw Water Pumping Facilities
69. Finished Water Pumping Facilities
70. Clearwell Storage
71. Aeration
72. Administration, Laboratory, and Maintenance Building

The 27 unit processes that were developed for flows between 2,500 gpd (9.46 m^3/d) and 1 mgd (3,785 m^3/d) (Volume 3) are:

1. Package Complete Treatment Plants
2. Package Gravity Filter Plants
3. Package Pressure Filtration Plants
4. Filter Media

5. Package Pressure Diatomite Filters
6. Package Vacuum Diatomite Filters
7. Package Ultrafiltration Systems
8. Package Granular Activated Carbon Columns
9. Potassium Permanganate Feed Systems
10. Polymer Feed Systems
11. Powdered Activated Carbon Feed Systems
12. Chlorine Feed Systems
13. Ozone Generation Systems and Contact Chamber
14. Chlorine Dioxide Generating and Feed Systems
15. Ultraviolet Light Disinfection
16. Reverse Osmosis
17. Pressure Ion Exchange Softening
18. Pressure Ion Exchange Nitrate Removal
19. Activated Alumina Fluoride Removal
20. Bone Char Fluoride Removal
21. Package Raw Water Pumping Facilities
22. Package High Service Pumping Stations
23. Steel Backwash/Clearwell Tanks
24. Sludge Hauling to Landfill
25. Sludge Disposal - Sanitary Sewer
26. Sludge Dewatering Lagoons
27. Sand Drying Beds

STUDY APPROACH

The information presented in Volumes 1, 2, 3, and 4 has been developed and presented in a manner that will allow maximum flexibility in its use. Construction costs are presented in terms of eight key components, and an appropriate index is recommended for updating each of the eight components. Therefore, if the construction cost components escalate at different rates, which is more likely than not, the variations in escalation can readily be taken into account by using the index specific to each component. If the user prefers to use one composite index to update the total construction cost, a method is presented for use of the Engineering News Record Construction Cost Index.

The construction cost curve plots for the unit processes are presented with construction cost plotted versus the design parameter, which will allow the maximum degree of flexibility in the use of the curve. Although some construction costs are shown plotted versus flow, most are shown plotted versus another design parameter, such as pounds per day for chemical feed systems, cubic feet of volume for rapid mix and flocculation, square feet of surface area for clarifiers and filters, and cubic feet of press volume for sludge filter presses. Use of these design parameters allows designer's preferences and regulatory agency requirements on loading rates to be incorporated into the cost estimating procedure. This approach gives the cost curves for many unit processes a much higher degree of flexibility than if all curves were shown plotted versus flow.

The operation and maintenance requirements were also developed and are presented in a manner that allows maximum flexibility in their use. The component categories that were used to develop the operation and maintenance categories and the units assigned to each are:

Energy

Electrical, kw-hr/year

Building related
Process related

Natural gas, scf/year

Diesel fuel, gal/year

Maintenance material (excludes chemicals), $/year

Labor, hr/year

Separation of electrical energy into building and process-related requirements allows geographical variations in building heating, lighting, air conditioning and ventilation requirements to be taken into account. Appendix B of this volume presents estimated building energy requirements for 21 cities. Process energy requirements do not vary from location to location, and are therefore presented as a separate category. Local variations in the unit cost of electrical energy, natural gas, diesel fuel, and labor can be readily incorporated into the cost calculations, since all tables and plots of operation and maintenance requirements show these components in terms of kw-hr/year, scf/year, gal/year, and hr/year, respectively. The maintenance material requirements, which are for all repair and maintenance items, were calculated using nationwide averages and are presented in dollars/year. Updating of the maintenance material costs is best accomplished using the Producer Price Index for Finished Goods. Note that the maintenance material costs exclude chemical costs, which must be added separately. Chemical costs are added separately because of the wide variation they exhibit in different areas of the country.

Since water treatment plants seldom operate at full capacity, the curves are presented to allow operation and maintenance requirements (except building energy) for less than full capacity operation to be taken into account. If for example, the appropriate design parameter for a unit process is 1.3 mgd, and the process is operating at 0.6 mgd, the operation and maintenance requirements for process energy, natural gas, diesel fuel, maintenance material, and labor can be determined by entering the curve at 0.6 mgd. This approach allows variations in percent utilization of the facilities to be taken into account.

For a unit process in which operation and maintenance requirements are shown plotted versus a parameter that is independent of flow, such as cubic feet of basin volume or square feet of basin area, the requirements are independent of flow, and the design parameter must be used to estimate both construction cost and operation and maintenance requirements.

SECTION 2

TREATMENT TECHNIQUES FOR CONTAMINANT REMOVAL

BASIC WATER TREATMENT TECHNIQUES

A number of conventional water treatment techniques may be utilized for the removal of contaminants considered in this report. These conventional techniques as well as a variety of other new techniques have been researched in considerable detail by EPA in recent years, and the results of the research are contained in numerous publications.[7-11] Information contained in these publications has been used as the basis for the information presented in Tables 4 to 7, as well as the discussion on treatment techniques and percentage removals which is included in this section.

The techniques most applicable to the removal of the various contaminants are listed in Table 4. A detailed listing of unit processes which make up each of these techniques, is shown in Table 5. Also shown in Table 5 are the MCL's for each contaminant as well as the highest initial concentration (Ci) of the contaminant that can be reduced to the MCL by a single pass through the particular treatment technique. If a single pass will not reduce the contaminant concentration to less than the MCL, then multiple steps of the same process or two or more different processes in series may be utilized. The techniques were selected based upon their ability to reduce the initial contaminant concentration from a minimum of 10 times the MCL to less than the MCL. As an example in the use of Table 5, consider the contaminant cadmium. A conventional lime softening plant, when operating in the pH range 8.5 to 11, could reduce concentrations of cadmium from 0.5 mg/l to the 0.01 mg/l MCL. If alum or ferric sulfate are used as the coagulant in a conventional filtration plant, at pH of 9 and 8 respectively, an initial cadmium concentration of 0.1 mg/l could be reduced to the 0.01 mg/l MCL.

As may be observed in Tables 4 and 5, most of the slightly soluble inorganic constituents may be removed by conventional coagulation, whereas highly soluble inorganics are generally removed by reverse osmosis or ion exchange, and soluble organics are generally removed by adsorptive interaction with activated carbon. Although these are generalizations, it is important to recognize that there is a great degree of commonality among many contaminants, and that most treatment techniques are applicable to the removal of more than one contaminant. Many contaminants can be removed by ion exchange or reverse osmosis. Tables 6 and 7 are presented to illustrate the upper limiting raw water concentrations that can be treated by ion exchange and reverse osmosis without exceeding the MCL. The upper limiting raw water concentrations shown in Tables 6 and 7 are based on information presented in reference 7.

Table 4

Most Effective Treatment Methods for Contaminant Removal

Contaminant	Most Effective Treatment Methods
Arsenic	As^{+5} - ferric sulfate coagulation, pH 6 to 8; alum coagulation, pH 6 to 7; excess lime softening As^{+3} - ferric sulfate coagulation, pH 6 to 8; alum coagulation, pH 6 to 7; excess lime softening. NOTE: Oxidation required before treatment for As^{+3}.
Barium	Lime softening, pH 10 to 11; ion exchange softening.
Cadmium	Ferric sulfate coagulation, pH 8; alum coagulation, pH 9; lime softening; excess lime softening.
Chromium	Cr^{+3} - ferric sulfate coagulation, pH 6 to 9; alum coagulation, pH 7 to 9; excess lime softening. Cr^{+6} - ferrous sulfate coagulation, pH 7 to 9.5.
Coliform Organisms . .	Disinfection; coagulation plus disinfection.
Fluoride	Ion exchange with activated alumina; lime softening.
Lead	Ferric sulfate coagulation, pH 6 to 9; alum coagulation, pH 6 to 9; lime softening; excess lime softening.
Manganese	Inorganic - oxidation/sedimentation/filtration. Organic - lime softening.
Mercury	Inorganic - ferric sulfate coagulation, pH 7 to 8. Organic - ion exchange.
Nitrate	Ion exchange.
Organic Contaminants .	Powdered activated carbon; granular activated carbon.
Radium	Lime softening; reverse osmosis.
Selenium	Se^{+4} - ferric sulfate coagulation, pH 6 to 7; ion exchange; reverse osmosis. Se^{+6} - ion exchange; reverse osmosis.
Silver	Ferric sulfate coagulation, pH 6 to 8; alum coagulation, pH 6 to 8; lime softening; excess lime softening.
Sodium	Ion exchange; reverse osmosis.
Sulfate	Ion exchange; reverse osmosis.
Turbidity	Alum coagulation, filtration.

Table 5

Matrix of Water Treatment Processes Useful in Meeting the National Interim Primary Drinking Water Regulation Maximum Contaminant Levels, with Maximum Raw Water Concentrations (C_i) Shown).

CONTAMINANT	MCL	C_i* FOR TREATMENT SHOWN	PRE-DISIN-FECTION	PRE-SEDIMEN-TATION	LIME SOFTENING	COAGULATION			MIXING & FLOCCU-LATION	SEDIMEN-TATION	FILTRA-TION	POST DISINFECTION	OXIDATION			REVERSE OSMOSIS	ION EXCHANGE	ACTIVATED CARBON	
						ALUM	FERRIC SULFATE	FERROUS SULFATE					Cl_2	O_3	$KMnO_4$			POWDERED	GRANULAR
ARSENIC – TRIVALENT	0.05 MG/L	1.0 MG/L											X OR	X	OR X –	THEN SAME AS ARSENIC – PENTAVALENT			
		0.33 MG/L														X			
		—														ACT. ALUMINA OR ANION EXCHANGE			
ARSENIC – PENTA-VALENT	0.05 MG/L	1.0 MG/L			pH>10.8				X	X	X								
		1.0 MG/L				pH 6–7	OR pH 6–8		X	X	X								
BARIUM	1.0 MG/L	10.0 MG/L			pH 10–11				X	X	X								
		45.0 MG/L														X			
		—															SOFTENING		
CADMIUM	0.01 MG/L	0.5 MG/L			pH 8.5–11				X	X	X								
		0.1 MG/L				pH 9			X	X	X								
		0.1 MG/L					pH 8		X	X	X								
CHROMIUM – TRI-VALENT	0.05 MG/L	2.5 MG/L			pH >10.6				X	X	X								
		0.5 MG/L				pH 6.7 –8.5	OR pH 6.5 –9.3		X	X	X								
		0.4 MG/L														X			
CHROMIUM – HEXA-VALENT	0.05 MG/L	5.0 MG/L						pH 6.5–9.3	X	X	X								
		0.4 MG/L														X			

C_i = HIGHEST INITIAL CONCENTRATION OF THE CONTAMINANT THAT COULD BE REDUCED TO THE MCL BY A SINGLE PASS THROUGH THE PARTICULAR TREATMENT TECHNIQUE

** SECONDARY DRINKING WATER REGULATION

*** NO PRIMARY OR SECONDARY REGULATION ESTABLISHED

Table 5. (Continued)

CONTAMINANT	MCL	C_i–* FOR TREATMENT SHOWN	PRE-DISIN-FECTION	PRE-SEDIMEN-TATION	LIME SOFTENING	COAGULATION			MIXING & FLOCCU-LATION	SEDIMEN-TATION	FILTRA-TION	POST DISINFECTION	OXIDATION			REVERSE OSMOSIS	ION EXCHANGE	ACTIVATED CARBON	
						ALUM	FERRIC SULFATE	FERROUS SULFATE					Cl_2	O_3	$KMnO_4$			POWDERED	GRANULAR
COLIFORM ORGANISMS	1/100 ML	100/100 ML										X							
		<5000/100 ML	X			X					X	X							
		<20,000/100 ML	X			X				X	X	X							
		>20,000/100 ML				SPECIAL TREATMENT METHODS AS APPROVED BY STATE LAW													
FLUORIDE	VARIES WITH	—	HARD	WATER	pH 10.6				X	X	X								
	AIR TEMP.	—	SOFT	WATER	ONLY	200–500 MG/L			X	X	X								
	1.4 TO 2.4 MG/L	—															ACTIVATED ALUMINA OR BONE CHAR		
LEAD	0.05 MG/L	1.7 MG/L			pH 8.5–11.3	pH 6–9	pH 6–9		X	X	X								
		0.4 MG/L														X			
MANGANESE – INORGANIC	0.05 MG/L**	—								X	X		X		X				
		—														X			
ORGANIC		—			pH 9.0–9.5				X	X	X		X		X				
		—				X			X	X	X		X		X				
MERCURY – INORGANIC	0.002 MG/L	0.007 MG/L			pH 10.7–11.4				X	X	X								
		0.006 MG/L				pH 7			X	X	X							X	
		0.07 MG/L					pH 8		X	X	X							X	
		0.01 MG/L																	X
		0.1 MG/L															CATION-ANION IN SERIES		
– ORGANIC		—				X			X	X	X							X	
		0.1 MG/L															CATION-ANION IN SERIES		
		0.01 MG/L																	X

C_i = HIGHEST INITIAL CONCENTRATION OF THE CONTAMINANT THAT COULD BE REDUCED TO THE MCL BY A SINGLE PASS THROUGHT THE PARTICULAR TREATMENT TECHNIQUE

** SECONDARY DRINKING WATER REGULATION

*** NO PRIMARY OR SECONDARY REGULATION ESTABLISHED

Table 5. (Continued)

CONTAMINANT	MCL	C_i* FOR TREATMENT SHOWN	PRE-DISIN-FECTION	PRE-SEDIMEN-TATION	LIME SOFTENING	COAGULATION: ALUM	COAGULATION: FERRIC SULFATE	COAGULATION: FERROUS SULFATE	MIXING & FLOCCU-LATION	SEDIMEN-TATION	FILTRA-TION	POST DISINFECTION	OXIDATION: Cl_2	OXIDATION: O_3	OXIDATION: $KMnO_4$	REVERSE OSMOSIS	ION EXCHANGE	ACTIVATED CARBON: POWDERED	ACTIVATED CARBON: GRANULAR
NITRATE - AS N	10 MG/L	67 MG/L														X			
		50 MG/L															ANION		
ORGANIC CHEMICALS	—	—																X	OR X
RADIUM	5 pCi/L	30 pCi/L	LOW HARDNESS WATER		X				X	X	X								
		70 pCi/L	MEDIUM HARDNESS WATER		X				X	X	X								
		165 pCi/L	HIGH HARDNESS WATER		X				X	X	X								
		100 pCi/L														X	OR X		
SELENIUM - QUADRAVALENT	0.01 MG/L	0.05 MG/L					pH 6.0		X	X	X								
		0.33 MG/L														X	OR X		
SELENIUM - HEXAVALENT	0.01 MG/L	0.33 MG/L														X	OR X		
SILVER	0.05 MG/L	0.17 MG/L			pH 9				X	X	X								
		0.5 MG/L			pH 11.5				X	X	X								
		0.17 MG/L				X pH 6–8	OR X		X	X	X								
		0.83 MG/L														X			
SODIUM	***	285 MG/L														X			
		133 MG/L															X		
SULFATE	250 MG/L**	3570 MG/L														X			
		8330 MG/L															X		
TURBIDITY	1 T.U.	25 TU				X					X	X							
		1000 TU				X			X	X	X	X							
		> 1000 TU	X			X			X	X	X	X							

C_i = HIGHEST INITIAL CONCENTRATION OF THE CONTAMINANT THAT COULD BE REDUCED TO THE MCL BY A SINGLE PASS THROUGH THE PARTICULAR TREATMENT TECHNIQUE

** SECONDARY DRINKING WATER REGULATION

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Table 6

Upper Limiting Raw Water Concentrations of Various Contaminants That Can Be Treated by Ion Exchange Without Exceeding the MCL

Contaminant to be Removed	Upper Limiting Raw Water Concentration	MCL	Remarks
Arsenic, Trivalent	Unknown	0.05 mg/l	Activated alumina or bone char
Barium	45 mg/l. Generally by blending of raw & finished water for corrosion & hardness control	1.0 mg/l	Softening resins
Fluoride	pH dependent (best @ pH = 5.5 to 7).	1.4 to 2.4 mg/l	Activated alumina or bone char
Manganese	Unknown	0.5 mg/l	Secondary MCL
Inorganic Mercury	0.1 mg/l	0.002 mg/l	Cation and anion resins
Organic Mercury	0.1 mg/l	0.002 mg/l	Cation and anion resins
Nitrate - as N	50 mg/l	10.0 mg/l	NO_3 selective resin
Radium	100.0 pCi/l	5.0 pCi/l	Softening resins
Selenium, Quadrivalent	0.33 mg/l	0.01 mg/l	--
Selenium, Hexavalent	0.33 mg/l	0.01 mg/l	--
Sodium	133.0 mg/l	20.0 mg/l	No MCL set
Sulfate	8,300 mg/l	250.0 mg/l	Secondary MCL

Table 7

Upper Limiting Raw Water Concentrations of Various Contaminants That Can Be Treated by Reverse Osmosis Without Exceeding the MCL

Contaminant to be Removed	Upper Limiting Raw Water Concentration	MCL	Remarks
Arsenic, Trivalent	0.33 mg/1	0.05 mg/1	--
Barium	45.0 mg/1	1.0 mg/1	--
Chromium, Hexavalent	0.4 mg/1	0.05 mg/1	--
Lead	0.4 mg/1	0.05 mg/1	--
Nitrate - as N	67 mg/1	10 mg/1	--
Radium	100.0 pCi/1	5.0 pCi/1	--
Selenium, Quadrivalent or Hexavalent	0.33 mg/1	0.05 mg/1	--
Silver	0.83 mg/1	0.05 mg/1	--
Sodium	285.0 mg/1	20.0 mg/1	No MCL set
Sulfate	3,570.0 mg/1	250.0 mg/1	Secondary MCL

The following sections present detailed discussions, by contaminant, of the treatment techniques and process combinations listed in Tables 4 through 7. These detailed discussions also give the assumptions which were used in calculating the upper limiting raw water concentrations shown in Tables 5 to 7.

ARSENIC (MCL = 0.05 mg/1)

Arsenic in water may be either the trivalent (+3) form known as arsenite (AsO_2^-) or the pentavalent (+5) form known as arsenate (AsO_4^{-3}). Conversion of the trivalent form to the pentavalent form may be by biological or chemical oxidation. Reduction of the oxidized form generally occurs by anaerobic biological action. The trivalent form is more toxic than the pentavalent form. Elemental arsenic is essentially insoluble in water, and organic arsenic forms are rarely found. Arsenic contributions from natural sources, generally found only in certain portions of the western United States, are due to leaching of native arsenic from rock formations and leaching of mine tailings from copper, gold, and lead refining operations. Industry related contributors are from the aforementioned refining operations, pesticides, herbicides, insecticides, and fossil fuel combustion.

Pentavalent (+5) Arsenic

Pentavalent arsenic can be treated by pH adjustment (if required) to pH 6 to 7 or pH 6 to 8 for alum or ferric sulfate addition, respectively. To meet the MCL of 0.05 mg/1, coagulant dosages up to 20 to 30 mg/1 may be required, followed by rapid mixing, 30 min of flocculation, settling at a basin overflow rate of 24,450 lpd/m^2 (600 gpd/ft^2) and filtration at 81.4 to 203.4 lpd/m^2 (2 to 5 gpm/ft^2).

Pentavalent arsenic may also be removed coincidently by chemical clarification during the treatment of moderate to high coliform concentrations or high turbidity, provided that proper attention is given to pH and alum or ferric sulfate dosage (20 to 30 mg/1).

Pentavalent arsenic can also be removed by lime softening at a pH above 10.8. Treatment would consist of lime addition and mixing, 30 min of flocculation, settling at a basic overflow rate of 24,450 lpd/m^2 (600 gpd/ft^2) with 2 hr detention, pH adjustment, and filtration at 81.4 to 203.4 lpd/m^2 (2 to 5 gpm/ft^2).

Trivalent (+3) Arsenic

Trivalent arsenic can be oxidized to the pentavalent form by the use of chlorine, ozone, or potassium permanganate and then removed by the treatment processes previously described for the pentavalent form.

Pentavalent (+5) and Trivalent Arsenic

Both valences of arsenic may be removed by ion exchange using activated alumina or commercial anion resins. Insufficient data are available at present to determine the maximum concentration that can be reduced to the

0.05 mg/l MCL. Arsenic may also be reduced by about 85 percent using reverse osmosis, making such treatment applicable to raw waters containing up to 0.33 mg/l of arsenic.

BARIUM (MCL = 1.0 mg/l)

Barium is only present in trace amounts in most surface water and ground water supplies. The most commonly occurring natural form of barium is barite (barium sulfate), which has a low solubility, especially in waters containing sulfate. Soluble forms of barium are very toxic, whereas insoluble forms are considered nontoxic. Barite is used principally as a drilling mud in oil and gas well drilling, whereas other barium compounds are used in the production of glass, paint, rubber, ceramics, and the chemical industry

Lime softening in the pH range of 10 to 11 may be used to treat waters containing 1.0 to 10.9 mg/l of barium. Treatment consists of lime addition and mixing, 30 min of flocculation, settling at a basin overflow rate of 24,450 lpd/m^2 (600 gpd/ft^2) with 2 hr detention, pH adjustment, and filtration at 81.4 to 203.4 lpd/m^2 (2 to 5 gpm/ft^2).

Ion exchange systems similar to those used for softening (calcium and magnesium removal) may be used for barium concentrations exceeding the 1.0 mg/l MCL. The maximum concentration of barium in the raw water is limited if the usual method of blending raw and treated water is to be practiced for hardness concentration control and stabilization of the treated water. The amount of raw water used for blending must be controlled to insure that the 1.0 mg/l MCL for barium is not exceeded in the blended mixture.

Barium concentrations up to 45 mg/l may be reduced below the 1.0 mg/l MCL using reverse osmosis operating at about 98 percent removal. Depending on water composition, however, there may be difficulties with membrane fouling in treatment of high-barium waters.

CADMIUM (MCL = 0.01 mg/l)

Cadmium generally does not present a water quality problem from naturally occurring sources, although it may occur in leachates from iron and other ore mining and smelting operations. Carbonate and hydroxide forms found at higher pH are relatively insoluble, whereas other forms are soluble. Water supply contamination from industries may occur from electroplating industry wastes, sludges resulting from paint manufacture, battery manufacturing, metallurgical alloying, ceramic manufacturing, and textile printing.

Lime softening in the pH range of 8.5 to 11.3 may be used to treat waters containing 0.010 to 0.50 mg/l of cadmium. The amount of lime that must be added increases with increasing concentrations of cadmium in the raw water. Treatment would consist of lime addition and mixing, 30 min of flocculation, settling at a basin overflow rate of 24,450 lpd/m^2 (600 gpd/ft^2) with 2 hr detention, pH adjustment, and filtration at 81.4 to 203.4 lpd/m^2 (2 to 5 gpm/ft^2).

Raw water containing 0.010 to 0.10 mg/1 of cadmium can be treated by pH adjustment to 8.0 for ferric sulfate coagulation and 9.0 for alum coagulation at dosages of 30 mg/1, followed by mixing, 30 min of flocculation, settling at basin overflow rate of 24,450 lpd/m^2 (600 gpd/ft^2), and filtration at 81.4 to 203.4 lpd/m^2 (2 to 5 gpm/ft^2).

Cadmium at initial concentrations of 0.010 to 0.10 mg/1 is removed coincidentally in the treatment of high coliform waters and moderate or high turbidity waters, provided proper pH conditions are maintained (8.0 for ferric sulfate and 9.0 for alum) and sufficient coagulant is used.

CHROMIUM (MCL = 0.05 mg/1)

Chromium in water supplies may be present in either the trivalent ($^+3$) or the hexavalent ($^+6$) form. Unless pH is very low, the hexavalent form predominates. The hexavalent form is the more toxic and is also the more difficult to remove. Most forms of hexavalent chromium treatment incorporate reduction of hexavalent chromium to the trivalent form before removal.

Chromium occurs naturally as chromite (CrO_3) or chrome iron ore ($FeO \cdot Cr_2O_3$). The major source of chromium in water supplies is not from natural sources, but rather from industrial operations. Operations involving metal plating, alloy preparation, tanning, wood preservation, corrosion inhibition, and pigments for inks, dyes, and paints are all potential sources.

Trivalent ($^+3$) Chromium

Trivalent chromium can be reduced to the MCL of 0.05 mg/1 by coagulation: (a) with 30 mg/1 ferric sulfate in the pH range of 6.5 to 9.3 and raw water concentrations up to 2.5 mg/1, or (b) with 30 mg/1 of alum in the pH range of 6.7 to 8.5 and raw water concentrations up to 0.5 mg/1. The chemical treatment should be followed by mixing, 30 min flocculation, settling at basin overflow rates of 24,450 lpd/m^2 (600 gpd/ft^2), and filtration at 81.4 to 203.4 lpd/m^2 (2 to 5 gpm/ft^2). This type of treatment is similar to the treqtment required for high coliform and moderate or high turbidity, and trivalent chromium is removed along with these contaminants, provided proper attention is given to pH and coagulant dose.

Waters containing up to 2.5 mg/1 of trivalent chromium can be treated by lime softening at pH >10.6. Treatment would include lime addition and mixing, 30 min of flocculation, settling at a basin overflow rate of 24,450 lpd/m^2 with 2 hr detention, pH adjustment, and filtration at 81.4 to 203.4 lpd/m^2 (2 to 5 gpm/ft^2).

Pre-oxidation of raw water containing trivalent chromium is normally not practiced, since the trivalent form would be converted to hexavalent chromium, making removal more difficult.

Hexavalent (+6) Chromium

Raw water concentrations up to 5.0 mg/l of hexavalent chromium can be treated using a special ferrous sulfate coagulation process in which pH adjustment to the 6.5 to 9.3 range is made several minutes after coagulation. Chemical treatment should be followed by mixing, 30 min flocculation, settling at basin overflow rates of 24,450 lpd/m^2 (600 gpd/ft^2), and filtration at 81.4 to 203.4 lpd/m^2 (2 to 5 gpm/ft^2). Prechlorination will interfere with this process, as the ferrous ion is oxidized by chlorine and is then unavailable for reduction of hexavalent chromium. Prechlorination would necessitate a higher ferrous sulfate dose.

Trivalent (+3) and Hexavalent (+6) Chromium

Chromium concentrations, trivalent or hexavalent, up to 0.4 mg/l can be reduced to the 0.05 mg/l MCL by reverse osmosis.

COLIFORM BACTERIA

Coliform bacteria are not pathogens, but indicators of the presence of contamination from the intestinal tract of humans and warm-blooded animals. The advantage of measuring for coliform organisms is that the testing procedures are much simpler and more sensitive than those for pathogenic bacteria and virus. The disadvantages of using coliform organisms as an indicator is that they may survive for longer periods than some pathogenic organisms and for shorter times than others.

Low-Coliform Waters

Underground waters (only) containing more than one but less than 100 coliform bacteria (MPN)/100 ml (as measured by the monthly arithmetic mean) and having a standard plate count limit of 500 organisms/ml, and a fecal coliform density of less than 20/100 ml (as measured by a monthly arithmetic mean) can be treated using only continuous disinfection. Thirty minutes of contact should be used before discharge of the water into the distribution system.

Moderate-Coliform Waters

Water containing not more than 5,000 coliform bacteria (MPN)/100 ml should be treated by predisinfection with 30 min of contact, coagulation (with or without settling), filtration at 41.4 to 203.5 lpm/m^2 (2 to 5 gpm/ft^2), and continuous postdisinfection with 30 min or more contact before use.

Excessively High-Coliform Waters

Water containing more than 20,000 coliform bacteria/100 ml or having a fecal coliform count exceeding 2,000/100 ml monthly geometric mean are considered undesirable as a source of supply. In the absence of an adequate supply of better bacteriological quality, special methods of treatment may be considered. Proposed special methods of treatment for highly polluted waters should be approved by the State before the preparation of plans.

FLUORIDE (MCL = 1.4 to 2.4, depending on average annual air temperature)

Fluoride can be contributed to water from fluoride-bearing materials, although most naturally occurring fluoride compounds are only moderately soluble. Generally, natural sources do not cause excessively high concentrations, although well water supplies in several States do have naturally high concentrations. There are also soluble fluorides from industrial wastewaters in some supply sources. Industries that may discharge significant amounts of fluoride include glass production, fertilizer manufacturing, and aluminum processing.

Water containing excessive fluoride ion may be treated by ion exchange methods using either activated alumina or bone char. Removals by both are pH dependent, with the best removals occurring between pH 5.5 and 7.0. Exchange capacity varies widely among water supplies, and laboratory testing should be utilized to develop design criteria.

Fluoride may also be removed from hard waters with lime softening followed by filtration. The amount of the fluoride reduction accomplished by lime softening depends on both the initial fluoride concentration and the amount of magnesium removed in the softening process. The fluoride reduction is generally proportional to the square root of the magnesium removed.

For very soft waters (only), flocculation with massive alum dosages of 200 to 500 mg/l is an effective means of fluoride reduction when followed by clarification and filtration as described for moderate-turbidity waters.

LEAD (MCL = 0.05 mg/l)

Lead in water supplies may result from naturally occurring lead sulfide and lead oxide mineral compounds. The lead solubility may approach 0.4 to 0.8 mg/l, although the solubility limit is lower for alkaline and mineralized sources. Major industrial sources of lead include storage battery manufacture and gasoline additives, although photographic materials, explosives, and lead mining and smelting may also contribute significant amounts.

Naturally occurring carbonates and hydroxides of lead are very insoluble, and treatment of a somewhat turbid surface water by plain sedimentation will reduce 0.5 mg/l of lead to below the 0.05 mg/l MCL.

Coincidental reduction of 2.5 mg/l to the MCL will also occur during lime soda softening in the pH range of 8.5 to 11.3. Also, initial concentrations up to 1.7 mg/l are reduced to the MCL coincidentally during the treatment of high-coliform waters and moderate or high-turbidity waters with alum and ferric sulfate.

Reverse osmosis may be used to remove soluble lead concentrations up to 0.4 mg/l. Precautions are necessary, however, to prevent membrane fouling by insoluble lead carbonates and lead hydroxides.

MANGANESE (Secondary Drinking Water Regulation MCL = 0.05 mg/l)

Manganese solution from mineral forms is primarily the result of bacterial action or complexation by organic material. Reduced forms of manganese (+2) in water are soluble, while oxidized forms (+4) are insoluble. Acid mine drainage is a principal natural source of manganese in water supplies. Industrial contributions of manganese generally are not significant.

Manganese is included in the Secondary Drinking Water Regulations and not the Interim Primary Drinking Water Regulations. There is no presently known health danger from manganese in the oxidized, unoxidized, or organic states in water supplies. The principal problems with manganese are the brown-black stains it may deposit on laundered goods and the taste it may impart to drinking water.

Unoxidized and Oxidized Inorganic Manganese

Manganese in the absence of iron and organic matter can be oxidized at low pH (7.2 to 8.0) values with chlorine, potassium, permanganate, or previously precipitated manganese. An alternative approach would be aeration at pH 9.4 to 9.6 to oxidize all manganese. The insoluble oxidized form may then be removed by settling and filtration.

Organic Manganese

Manganese present in water as a complex of organic matter or iron must be treated with lime to pH values of 9.0 to 9.6 before oxidation of manganese will occur. Ferric sulfate coagulation is also especially suitable for waters containing organic manganese.

With these modifications and with oxidation by chlorine or potassium permanganate, manganese complexed with organic matter or iron can be removed by the conventional treatment processes of mixing, flocculation, settling, and filtration.

MERCURY (MCL = 0.002 mg/l)

Organic forms of mercury are significantly more toxic than inorganic forms and can result from utilization of inorganic forms by bacteria and higher level organisms. Elemental mercury is soluble in aerobic situations and may form mercuric oxide salts. Generally, such salts adsorb on sediment and are naturally removed by sedimentation. Mercury in water supplies from natural sources is rare. Industrial sources or mercury include electrical and electronics industries, pulp and paper production, pharmaceuticals, paint manufacture, and agricultural herbicides and fungicides.

Inorganic Mercury

Chemical coagulation, at pH 8 with ferric sulfate will treat raw waters containing up to 0.07 mg/l inorganic mercury; at pH 7, alum will treat raw waters containing up to 0.006 mg/l inorganic mercury when followed by the clarification treatment described for moderate-turbidity waters. Powdered activated carbon may be used in conjunction with coagulation to increase removals above those obtained by coagulation alone, although dosages significantly above those used for taste and odor control are necessary to provide increased removal.

Lime softening in the pH range of 10.7 to 11.4, followed by filtration, can reduce concentrations up to 0.007 mg/l to the MCL.

Cation and anion exchange resins operated in series can reduce inorganic mercury from concentrations up to 0.1 mg/l to the MCL of 0.002 mg/l. Experiments on such removal are only preliminary, and the removal mechanism is uncertain.

Granular activated carbon at a contact time of only 3.5 min can remove 80 percent of the applied inorganic mercury, making this process applicable for treatment of raw water concentrations up to 0.01 mg/l.

Organic Mercury

Powdered activated carbon can be used in the clarification process described for moderate-turbidity waters to remove organic mercury. About 1 mg/l of powdered activated carbon is needed for each 0.1 μg/l of organic mercury to be removed down to the MCL of 0.002 mg/l.

As with inorganic mercury, granular activated carbon at a contact time of only 3.5 min can be used to remove 80 percent of the organic mercury applied, making this process applicable for raw water concentrations up to 0.01 mg/l.

Cation and anion exchange resins operated in series can reduce organic mercury from concentrations up to 0.1 mg/l to the 0.002 mg/l MCL.

NITRATE (MCL = 10 mg/l as N)

Naturally occurring high nitrate concentrations are very rare. High nitrate concentrations in ground or surface water are generally the result of direct or indirect contamination by wastewater, animal excrement, or agricultural fertilization. Industrial discharges from fertilizer manufacturing also represent a potential source of contamination. Nitrate is a relatively stable form of nitrogen, but nitrate may be produced by the biological oxidation of ammonia.

Anion ion exchange resins can be used to reduce nitrates from as high as 50 mg/l to as low as 0.5 mg/l (as N). Since the MCL is 10 mg/l (as N), the use of blending can result in a considerable savings in capacity and operational cost.

Reverse osmosis can achieve up to 85 percent removal of nitrate. Thus, concentrations as high as 67 mg/l (as N) could be reduced to the MCL, or concentrations of less than 67 mg/l could be treated to below the MCL and utilized for blending purposes.

ORGANIC CONTAMINANTS

The six organic pesticides presently included in the Interim Primary Drinking Water Standards are not naturally occurring. Four of these organics (endrin, lindane, toxaphene and methoxychlor) are chlorinated hydrocarbon insecticides. These synthetic organic insecticides may be contributed to water supplies by industrial discharge during manufacture or runoff following use. The remaining two organics (2,4-D and 2,4,5-TP, or Silvex) are chlorophenoxy herbicides, which are generally used for the control of aquatic vegetation. Contamination of water supplies may occur by manufacturing operation and/or use.

Proposed as an amendment to the Primary Standards is the regulation of total trihalomethanes (TTHM's). Trihalomethanes (chloroform, bromodichloromethane, dibromochloromethane, and tribromomethane) are not naturally occurring they are reaction by-products resulting from chlorination of water containing naturally occurring humic and fulvic compounds. Bromide and iodide ions may also be reactants in the process. The criteria for volatile halogenated compounds in the proposed amendment was established as a measure of analysis for a broad range of organic chemicals that are difficult to measure individually and/or are unknown.

For the six organic pesticides of concern, information on removal is available for only four: endrin (MCL = 0.0002 mg/l), lindane (MCL = 0.004 mg/l), toxaphene (MCL = 0.005 mg/l), and 2,4-D (MCL = 0.1 mg/l). No information is available for methoxychlor (MCL = 0.1 mg/l), or 2,4,5-TP (Silvex) (MCL = 0.01 mg/l). In general, granular activated carbon or powdered activated carbon used in conjunction with coagulation and filtration are the only treatment methods capable of significant removals. Other treatment methods such as coagulation/filtration, chlorination, ozonation, and addition of potassium permanganate generally remove less than 10 percent of the organics. The percent removals that various treatment methods achieve, are shown in Table 8. Where blanks occur in this table, information is not presently available.

For TTHM's, removal of the precursor organic compounds by use of granular activated carbon has been determined to be the best treatment technique. Other techniques that will partially remove some of the naturally occurring precursors are precipitation, oxidation, aeration, and adsorption on synthetic resins.

RADIUM (MCL = 5 pCi/l)

Radium may occur naturally in water either as radium 226 or radium 228, and is generally found in ground water rather than surface water. Radium

Table 8

Percent Removals of Pesticides*

by Various Water Treatment Processes

Treatment Method	Endrin	Lindane	Toxaphene	2,4-D Sodium Salt	2,4-D Isopropyl Ester	2,4-D Butyl Ester	2,4-D Isooctyl Ester
Coagulation, Filtration	35	<10	<10	<10	<10	<10	<10
Coagulation, Filtration and Adsorption with:							
Powdered Activated Carbon:							
5-9 mg/1	85	30	93	--	--	--	--
10-19 mg/1	80	55	--	--	90	90	90
20-29 mg/1	94	80-90	--	--	--	--	--
30-39 mg/1	--	--	--	90	--	--	--
40-49 mg/1	--	--	--	--	97	97	--
50-59/mg/1	98	--	--	--	--	--	97
70-79 mg/1	--	99	--	--	98	--	--
Granular Activated Carbon, 5 to 7 min Full Bed Contact Time	>99	>99	--	--	--	--	--
Oxidation:							
Chlorine:							
5 mg/1	<10	<10	--	--	--	--	--
8 mg/1	--	<10	--	--	--	--	--
50 mg/1	--	<10	--	--	--	--	--
100 mg/1	--	--	<10	<10	<10	<10	<10
Ozone:							
11 mg/1	--	<10	--	--	--	--	--
38 mg/1	--	55	--	--	--	--	--
Potassium Permanganate:							
10 mg/1	--	<10	--	<10	<10	<10	<10
40 mg/1	--	<10	--	--	--	--	--

*Treatment information not available for methoxychlor and 2,4,5-TP (Silvex).

exists in radium-bearing rock strata, particularly in Iowa and Illinois, and in phosphate rock deposits found in parts of Florida. Leaching from such deposits has resulted in high ground water concentrations.

The lime-soda softening process removes radium as well as hardness. Operationally, the total hardness removal necessary is equal to the fraction of radium removed, raised to the 2.86 power. In equation form:

$$\text{Hardness Removal Fraction} = (\text{Radium Removal Fraction})^{2.86}$$

or

$$\text{Radium Removal Fraction} = \sqrt[2.86]{\text{Hardness Removal Fraction}}$$

Therefore, to reduce 25 pCi/l to the 5 pCi/l MCL requires a radium removal fraction of $0.8^{2.86} = 0.528$, meaning that 52.8 percent of the hardness must be removed. If desired hardness levels are met by blending, consideration must also be given to the influence of this blending on the radium concentration in the final blend. In situations with a relatively low hardness and high radium concentration, radium may control the blending ratio. Radium removal increases as pH increases.

Ion exchange and reverse osmosis are each capable of removing up to 95 percent of the input radium. Therefore the limiting concentration that can be treated to meet the MCL is 100 pCi/l.

SELENIUM (MCL = 0.01 mg/l)

Selenium is chemically similar to sulfur and commonly occurs with sulfur in mineral veins. Selenium in water may be in either the quadrivalent (+4) form known as selenite (SeO_3^{-2}) or the hexavalent (+6) form known as selenate (SeO_4^{-2}). The quadrivalent form may be found in ground water, and the hexavalent form may occur in either ground water or surface water. Selenium contributions from natural sources are from selenium containing soils and runoff from these soils. Industry-related contributions may result from paint, rubber, dye, insecticide, glass, and electronic manufacturing.

Quadrivalent (+4) Selenium

Adjustment of pH to 6.0 and coagulation with 30 mg/l ferric sulfate will treat raw waters containing up to 0.05 mg/l of Se^{+4} to meet the 0.01 mg/l MCL when followed by the clarification treatment described for moderate-turbidity waters.

Raw waters containing up to 0.33 mg/l of Se^{+4} can be treated by ion exchange or reverse osmosis. Lower concentrations may be treated to less than the MCL and then be utilized for blending purposes.

Hexavalent (+6) Selenium

Raw waters containing up to 0.33 mg/l of Se^{+6} can be treated by ion exchange or reverse osmosis. As for the quadrivalent form, lower concentrations may be reduced to less than the MCL and then be utilized for blending.

SILVER (MCL = 0.05 mg/l)

Silver rarely occurs in water supplies from natural sources, and many silver salts such as the chloride and sulfide forms are relatively insoluble. Generally speaking, silver contamination of water supplies is industrial in origin, from photographic and electroplating industries.

Coagulation in the pH range of 6 of 8 with 30 mg/l of alum or ferric sulfate will treat raw waters containing up to 0.17 mg/l of silver to meet the MCL of 0.05 mg/l, when followed by the clarification treatment described for moderate-turbidity waters.

Coincidental removal occurs during the treatment of high-coliform waters and moderate or high turbidity waters provided that the dosage of ferric chloride or alum is adequate. In the pH range of 6 to 8, concentrations of 0.17 mg/l can be reduced to the MCL.

Lime softening followed by chemical clarification and filtration will also remove silver. Raw water silver concentrations of 0.17 mg/l can be treated at pH 9, and values as high as 0.5 mg/l can be reduced to the MCL of 0.05 at pH 11.5.

Reverse osmosis may be used to remove silver, and concentrations up to 0.83 mg/l can be reduced to the MCL.

SODIUM (No Primary or Secondary Regulation MCL)

Sodium occurs naturally in water supplies as a result of leaching from rock formations or naturally occurring salt deposits. Sea water intrusion may represent a sodium source in coastal areas. Sodium is extremely soluble and rarely forms a precipitate.

Although there is presently no established sodium standard, a concentration of 20 mg/l of sodium in drinking water is considered compatible with a restricted sodium diet of 500 mg/day. Since sodium is a very soluble ion, removal is best accomplished by ion exchange or reverse osmosis. Ion exchange can remove up to 85 percent, restricting use to supplies with an initial sodium concentration of 133 mg/l. Reverse osmosis can offer somewhat larger removals, up to 93 percent, and can thus treat initial sodium concentrations up to 285 mg/l.

SULFATE (Secondary Regulation MCL = 250 mg/l)

Sulfate is an extremely soluble anion that occurs in water supplies from both natural and industrial sources. Sulfate represents the principal form of sulfur in nature. Natural sources include leaching from soils and mineral deposits containing sulfate, and the biological oxidation of sulfides. Rainfall in many areas is a major contributor of sulfate. Key industrial sources include sulfuric acid, sulfate manufacture, and industries using sulfates and sulfuric acid, such as sulfate pulp mills and tanneries.

Research indicates that a limit of 250 mg/l of sulfate in drinking water affords a reasonable factor of safety against water that causes laxative effects. As with sodium, ion exchange and reverse osmosis are the only practical treatment methods. Ion exchange can give removals up to 97 percent and is therefore useful for concentrations as high as 8,330 mg/l. Reverse osmosis, however, will only remove 93 percent of the sulfate and is therefore useful only up to 3,570 mg/l of sodium.

TURBIDITY (MCL = 1 to 5 TU, depending on several circumstances)

Turbidity is produced by suspended and colloidal matter in water and is generally only a problem in surface water supplies. The principal importance of turbidity is its possible interference with disinfection because of shielding of microbial contaminants and the inability to maintain a disinfectant residual in the water supply. Aesthetic considerations are also important at high-turbidity levels.

Low-Turbidity Waters

Waters containing more than 1 but less than 25 turbidity units (TU) should be treated by coagulation without settling, filtration at 41.4 to 203.5 lpd/m^2 (2 to 5 gpm/ft^2), and postdisinfection with 30 min of contact before use.

Moderate-Turbidity Waters

Water containing more than 25 but less than 1,000 TU should be treated by chemical addition, mixing, coagulation, 30 min of flocculation, settling at basin overflow rates of 24,450 lpd/m^2 (600 gpd/ft^2), filtration at 81.4 to 203.4 lpd/m^2 (2 to 5 gpm/ft^2), and post chlorination with 3 min of contact before use.

High-Turbidity Waters

Waters containing more than 1,000 TU and meeting the Interim Regulations in other respects should be subjected to 2 hr of presedimentation at basin overflow rates of 142,600 lpd/m^2 (3,500 gpd/ft^2), followed by the treatment provided for moderate-turbidity waters (above).

SECTION 3

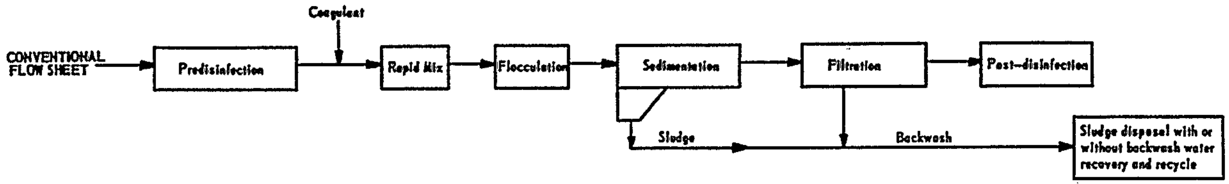
EXAMPLE PROCESS FLOW DIAGRAMS

As can be seen in Tables 4 and 5, filtration and softening are two treatment techniques that are particularly well suited to the removal of many of the contaminants listed in the Interim Regulations. Figure 1 presents a schematic flow diagram of the unit processes in a conventional water filtration plant, as well as the upper limiting raw water concentration of contaminants that can be removed by conventional water filtration plants. Also shown in Figure 1 are modifications that can be made to conventional water filtration plants, and the contaminants and the upper limiting raw water concentrations that can be treated by the various modifications.

The schematic flow diagram of a conventional lime-softening plant is shown in Figure 2. The contaminants that may be removed by lime softening and the pH range required for their removal are also shown.

A wide variety of unit processes and techniques are available for the treatment and disposal of water treatment plant sludges. Figure 3 illustrates schematically various options for treatment and disposal of water treatment plant sludges. As shown, the ultimate disposal may be either to a sewer, land, landfill, a lagoon, or the sea. Lime sludges may also be dewatered and recalcined for reuse. Figure 4 presents possible options for the recalcination of lime.

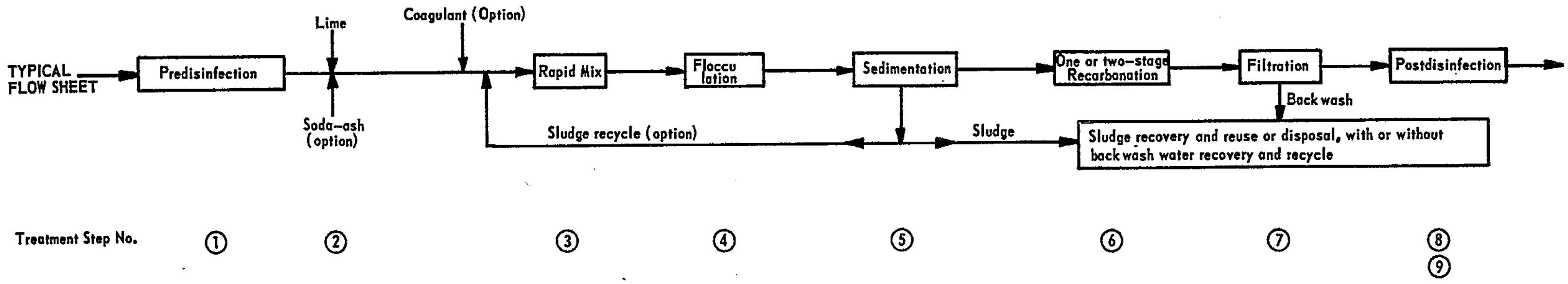
Many other sludge treatment concepts are in the development stage or in limited application, but a complete discussion of these processes and their cost is not within the scope of this project. A number of references that provide in-depth detail on both new and established sludge treatment concepts are available, however, and these references should be consulted for more detail on techniques and design parameters.[12-18]



Treatment Step No. ① ② ③ ④ ⑤ ⑥ ⑦ ⑧

SUBSTANCE TO BE REMOVED	UPPER LIMITING RAW WATER CONCENTRATION	MAXIMUM CONTAMINANT LIMIT	COAGULANT TYPE	COAGULANT DOSAGE	MODIFICATION
Coliform Bacteria	20,000 MPN/100 ml	1 per 100 ml	Usually alum	5 to 140 mg/L	None
Turbidity	1,000 TU	1 TU	Usually alum	5 to 140 mg/L	None
Virus	1,000 pfu/gallon	None established (Turbidity 1 TU)	Usually alum	5 to 140 mgl	None
Silver	0.17 mg/L	0.05 mg/L	Alum	30 mg/L @ pH=6 to 8	None
			'MODIFIED' CONVENTIONAL WATER FILTRATION PLANTS		
Coliform Bacteria	Over 20,000 MPN/100 ml	1 per 100 ml	Usually alum	20 to 140 mg/L	Presedimentation, plus double coagulation, floc. & settling.
Turbidity	Over 1,000 TU	1 TU	Usually alum	20 to 140 mg/L	Presedimentation and/or double coagulation, floc. & settling.
Virus	Over 1,000 pfu/gallon	None established	Usually alum	20 to 140 mg/L	Add: Cl_2 to 1.0 mg/L free residual at point ⑦, polymer at points ②&⑥, add pilot filter at point ②, add turbidity monitors to each filter effluent and point ⑦, use dual or mixed media rather than single media.
Arsenic, Pentavalent or Trivalent	1.0 mg/L	0.05 mg/L	Alum or $Fe_2(SO_4)_3$ @ pH < 7.5	20 to 30 mg/L	Add: facilities for pH adjustment and for feeding ferric sulfate. Preoxidation required for trivalent form.
Asbestos		None established	Alum	5 to 140 mg/L	Add: 2 stages to rapid mix, polymer feed, pilot filter, mixed media in filters, cont. turbidity recorders, adequate backwash, washwater recovery proper sludge disposal, and lab equipment for asbestos analysis.
Chromium, Hexavalent	5.0 mg/L	0.05 mg/L	Ferrous sulfate	5 to 140 mg/L	No predisinfection; add $FeSO_4$ feeder and equipment for pH adjustment to 6.5 to 9.3 at point ④.
Cadmium	0.1 mg/L	0.010 mg/L	Alum or ferric sulfate	Varies	Add facilities for pH adjustment at point ②, pH = 9 for alum, pH = 8 for $Fe_2(S)_4)_3$.
Fluoride (Soft Waters)	4 to 6 mg/L	1.4 to 2.4 mg/L	Alum	200 to 500 mg/L	High capacity alum feed plus lime or caustic feed for final pH adjustment, provision for alum sludge disposal.
Lead	1.7 mg/L	0.5 mg/L	Alum & $Fe_2(SO_4)_3$	Varies	Add ferric sulfate feeder at Point ②
Manganese, Inorganic	None	0.05 mg/L (Sec.std)	Alum & $KMnO_4$	5 to 140 mg/L 0.3 to 2.0 mg/L	Add $KMnO_4$ feeder at Point ②
Mercury, Inorganic	0.006 mg/L	0.002 mg/L	Alum @ pH = 7 or $Fe_2(SO_4)_3$ @ pH 8 + powdered act. carbon (PAC)	Varies Varies 5 to 20 mg/L	Add feeders for ferric sulfate and PAC and provide for pH adjustment at Point ②
Mercury, Organic	0.02 mg/L	0.002 mg/L	Alum & PAC	1 mg/L PAC for each microgram Hg removed	Add PAC feeder at Point ②
Selenium, Quadrivalent	0.05 mg/L	0.01 mg/L	Ferric sulfate	30 mg/L @ pH = 6.0	Add ferric sulfate feeder and provide for pH adjustment at Point ②
Silver	0.17 mg/L	0.05 mg/L	Ferric sulfate	30 mg/L @ pH=6 to 8	Add ferric sulfate feeder at Point ②

Figure 1. Capabilities of Conventional Water Filtration Plants to Meet Maximum Contaminant Levels of the National Interim Primary Drinking Water Regulations.



SUBSTANCE TO BE REMOVED	UPPER LIMITING RAW WATER CONCENTRATION	MAXIMUM CONTAMINANT LIMIT	LIME REQUIRED - PH RANGE FOR TREATMENT	REMARKS
Arsenic, Pentavalent	1.0 mg/L	0.05 mg/L	Above 10.8	—
Barium	10.0 mg/L	1.0 mg/L	10 to 11	—
Cadmium	0.5 mg/L	0.010 mg/L	8.5 to 11	—
Chromium, Trivalent	2.5 mg/L	0.05 mg/L	Above 10.6	—
Fluoride (Hard Waters)	4 to 6 mg/L	1.4 to 2.4 mg/L	Above 10.6	Low magnesium may require addition of Mg for maximum removal.
Lead	1.7 mg/L	0.05 mg/L	8.5 to 11.3	—
Manganese, Organic	None	0.05 mg/L (sec. std.)	Above 9.6	Feed 0.3 to 2.0 mg/L potassium permanganate.
Mercury, Inorganic	0.007 mg/L	0.002 mg/L	Above 10.7	—
Radium:				
Low Hardness	30 pCl/L	5 pCl/L	Above 10.6	—
Medium Hardness	70 pCl/L	5 pCl/L	Above 10.6	—
High Hardness	165 pCl/L	5 pCl/L	Above 10.6	—
Silver	0.17 mg/L	0.05 mg/L	Above 9	—
Silver	0.50 mg/L	0.05 mg/L	Above 11.5	—

Figure 2. Capabilities of Conventional Lime Softening Plants to Meet Maximum Contaminant Levels of the National Interim Primary Drinking Water Regulations.

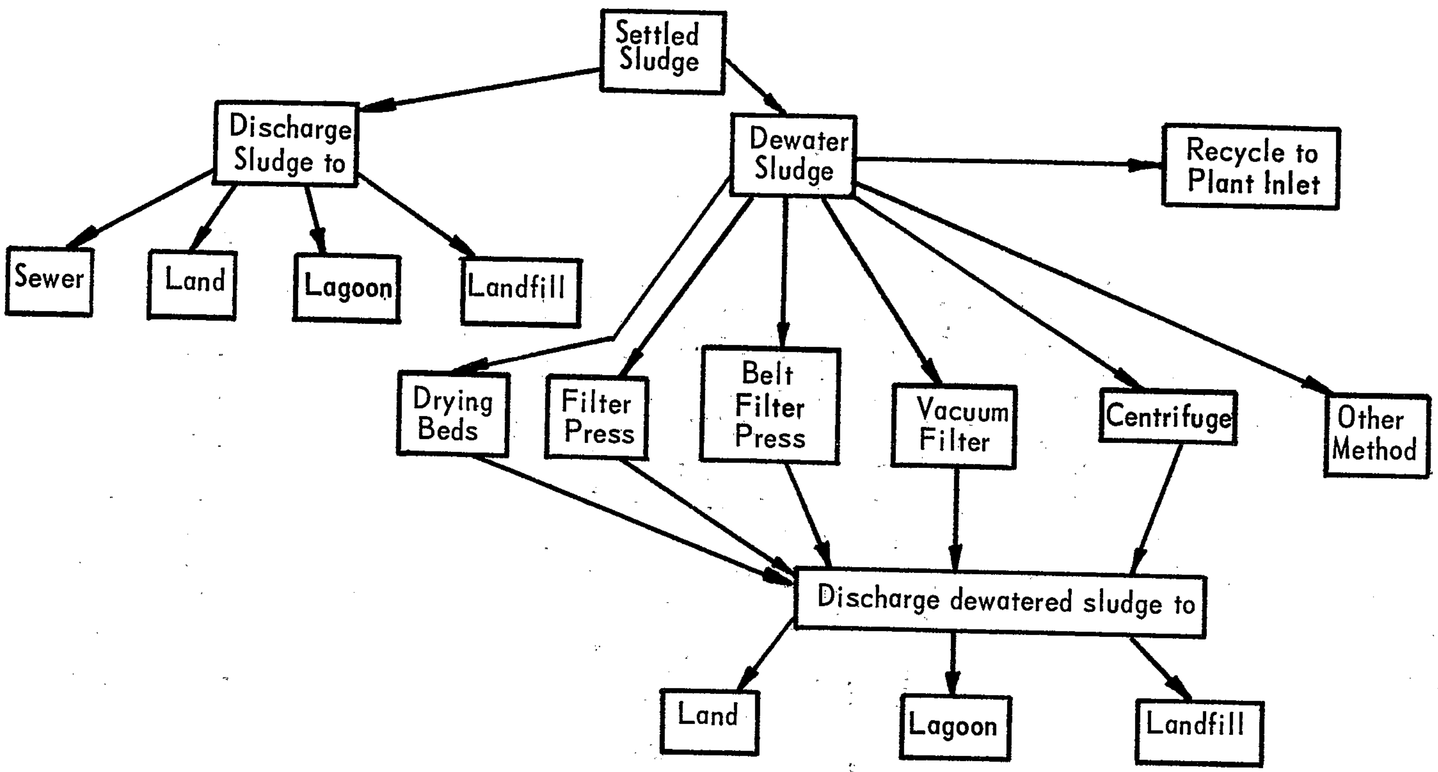


Figure 3. Treatment and disposal options for water treatment plant sludges.

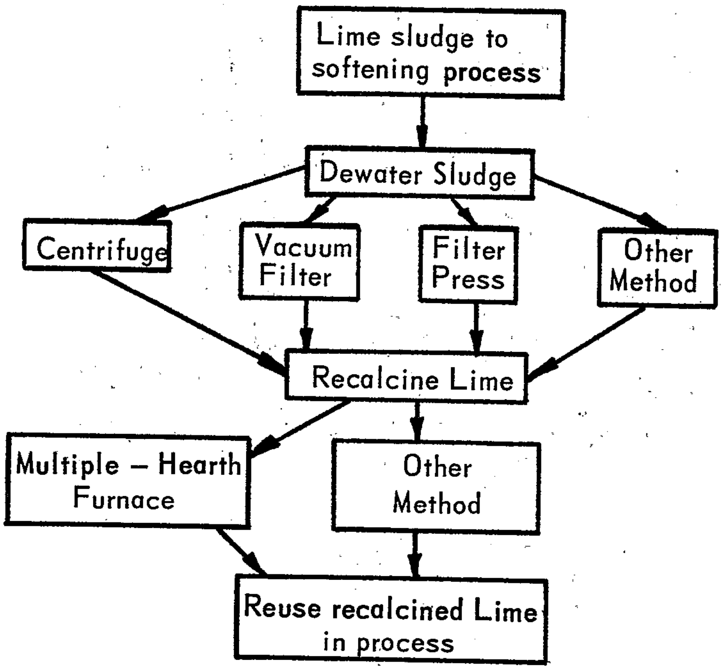


Figure 4. Treatment options for reuse of lime sludge from lime-softening plants.

SECTION 4

COST CURVES

CONSTRUCTION COST CURVES

The construction cost curves were developed using equipment cost data supplied by manufacturers, cost data from actual plant construction, unit takeoffs from actual and conceptual designs, and published data. When unit cost takeoffs were used to determine costs from actual and conceptual designs, estimating techniques from Richardson Engineering Services Process Plant Construction Estimating Standards,[19] Mean's Building Construction Cost Data,[20] and the Dodge Guide for Estimating Public Works Construction Costs[21] were often utilized. An example illustrating how costs were determined using unit cost takeoffs from an actual design for a reinforced concrete wall (similar to a wall for a clarifier or a filter structure) is presented in Appendix C. The cost curves that were developed were then checked and verified by a second engineering consulting firm, Zurheide-Herrmann, Inc., using an approach similar to that a general contractor would utilize in determining his construction bid. Every attempt has been made to present the conceptual designs and assumptions that were incorporated into the curves. Adjustment of the curves may be necessary to reflect site-specific conditions, geographic or local conditions, or the need for standby power. The curves should be particularly useful for estimating the relative economics of alternative treatment systems and in the preliminary evaluation of general cost level to be expected for a proposed project. The curves contained in this report are based on October 1978 costs.

The construction cost was developed by determining and then aggregating the cost of the following eight principal components: (1) Excavation and site work; (2) manufactured equipment; (3) concrete; (4) steel, (5) labor; (6) pipe and valves; (7) electrical equipment and instrumentation; and (8) housing. These eight categories were utilized primarily to facilitate accurate cost updating, which is discussed in a subsequent section of this chapter. The division will also be helpful where costs are being adjusted for site-specific, geographic and other special conditions. The eight categories include the following general items:

Excavation and Site Work. This category includes work related only to the applicable process and does not include any general site work such as sidewalks, roads, driveways, or landscaping.

Manufactured Equipment. This category includes estimated purchase cost of pumps, drives, process equipment, specific purpose controls, and other items that are factory made and sold with equipment.

Concrete. This category includes the delivered cost of ready mix concrete and concrete-forming materials.

Steel. This category includes reinforced steel for concrete and miscellaneous steel not included under manufactured equipment.

Labor. The labor associated with installing manufactured equipment, and piping and valves, constructing concrete forms, and placing concrete and reinforcing steel are included here.

Pipe and Valves. Cast iron pipe, steel pipe, valves, and fittings have been combined into a single category. The purchase price of pipe, valves, fittings, and associated support devices are included within this category.

Electrical Equipment and Instrumentation. The cost of process electrical equipment, wiring, and general instrumentation associated with the process equipment is included in this category.

Housing. In lieu of segregating building costs into several components, this category represents all material and labor costs associated with the building, including heating, ventilating, air conditioning, lighting, normal convenience outlets, and the slab and foundation.

The subtotal of the costs of these eight categories includes the cost of material and equipment purchase and installation, and subcontractor's overhead and profit. To this subtotal, a 15-percent allowance has been added to cover miscellaneous items not included in the cost takeoff as well as contingency items. Experience at many water treatment facilities has indicated that this 15-percent allowance is reasonable. Although blanket application of this 15-percent allowance may result in some minor inequity between processes, these are generally balanced out during the combination of costs for individual processes into a treatment system.

The construction cost for each unit process is presented as a function of the most applicable design parameter for the process. For example, construction costs for package gravity filter plants are plotted versus capacity in gallons per minute, whereas ozone generation system costs are presented versus pounds per day of feed capacity. Use of such key design parameters allows the curves to be utilized with greater flexibility than if all costs were plotted versus flow.

The construction costs shown in the curves are not the final capital cost for the unit process. The construction cost curves do not include costs for special site work, general contractor overhead and profit, engineering, or land, legal, fiscal, and administrative work and interest during construction. These cost items are all more directly related to the total cost of a project rather than the cost of the individual unit processes. They are therefore most appropriately added following cost summation of the individual unit processes, if more than one unit process is required. The examples presented in a subsequent section of this volume illustrate the recommended method for the addition of these costs to the construction cost.

OPERATION AND MAINTENANCE COST CURVES

Operation and maintenance curves were developed for: (1) energy requirements, (2) maintenance material requirements, (3) labor requirements, and (4) total operation and maintenance cost. The energy categories included are: process energy, building energy, diesel fuel, and natural gas. The operation and maintenance requirements were determined from operating data at existing plants, at least to the extent possible. Where such information was not available, assumptions were made based on the experience of both the author and the equipment manufacturer. Such assumptions are stated in the description of the cost curve.

Electrical energy requirements were developed for both process energy and building-related energy, and they are presented in terms of kilowatt-hours per year. This approach was used to allow adjustment for geographical influence on building related energy. For example, though lighting requirements average about 17.5 kw-hr/ft^2 per year throughout the United States, heating, cooling, and ventilating requirements vary from a low of about 8 kw-hr/ft^2 per year in Miami, Florida, to a high of about 202 kw-hr/ft^2 per year in Minneapolis, Minnesota. The building energy requirements presented for each process are in terms of kilowatt-hours per year, and they were calculated using an average building-related demand of 102.6 kw-hr/ft^2 per year. This is an average for the 21 cities included in the Engineering News Record Index. An explanation of the derivation of this number is included in Appendix B. The computer program developed as a portion of this project will allow use of other building related energy demands than 102.6 kw-hr/ft^2 per year. Process electrical energy is also included in the electrical energy curve and was calculated using manufacturer's data for required components. Where required, separate energy curves for natural gas and diesel fuel are also presented. When using the curves to determine energy requirements, the design flow or parameter should be utilized to determine building energy, and the operating flow or parameter should be used to determine process energy, diesel fuel, and natural gas.

Maintenance material costs include the cost of periodic replacement of component parts necessary to keep the process operable and functioning. Examples of maintenance material items included are valves, motors, instrumentation, and other process items of similar nature. The maintenance material requirements <u>do not include the cost of chemicals</u> required for process operation. <u>Chemical costs must be added separately</u>, as will be shown in the subsequent examples. The operating parameter or flow should be used to determine maintenance material requirements.

The labor requirement curve includes both operation and maintenance labor and is presented in terms of hours per year. The operating parameter or flow should be used to determine the labor requirement.

The total operation and maintenance cost curve is a composite of the energy, maintenance material, and labor curves. To determine annual energy costs, unit costs of \$0.03/kw-hr of electricity, \$0.0013/ft^3 of natural gas, and $0.45/gal of diesel fuel were utilized. The labor requirements were converted to an annual cost using an hourly labor rate of $10.00/hr, which includes salary and fringe benefits. The computer program that was developed as a portion of this project (Volume 4) will allow utilization of other unit costs for energy and labor.

UPDATING COSTS TO TIME OF CONSTRUCTION

Continued usefulness of the curves developed as a portion of the project depends on the ability of the curves to be updated to reflect inflationary increases in the prices of the various components. Most engineers and planners are accustomed to updating costs using one all-encompassing index, which is developed by tracking the cost of specific items and then proportioning the costs according to a predetermined ratio. They key advantage of a single index is the simplicity with which it can be applied. Although use of a single index is an uncomplicated approach, there is much evidence to indicate that these time-honored indices are not understood by many users and/or are inadequate for application to water works construction.

The most frequently utilized single indicies in the construction industry are the Engineering News Record (ENR) Construction Cost Indexes (CCI) and Building Cost Index (BCI). These ENR indices were started in 1921 and were intended for general construction cost monitoring. The CCI consists of 200 hours of common labor, 2,500 lb of structural steel shapes, 1.128 tons of Portland cement and 1,008 board feet of 2 x 4 lumber. The BCI consists of 68.38 hr of skilled labor plus the same materials included in the CCI. The large amount of labor included in the CCI was appropriate before World War II; however, on most contemporary construction, the index labor component is far in excess of actual labor used.

To update the construction cost using the CCI, which was 265.38 in October 1978, the following formula may be utilized:

$$\text{Updated Cost} = \text{Total Construction Cost from Curve} \left(\frac{\text{Current ENR CCI}}{265.38}\right)$$

This approach may also be utilized in the computer program developed for this report.

Although key advantages of the ENR indices include their availability, their simplicity, and their geographical specificity, many engineers and planners believe that these indices are not applicable to water treatment plant construction. The rationale for this belief is that the index does not include mechanical equipment or pipes and valves that are normally associated with such construction, and the proportional mix of materials and labor is not specific to water treatment plant construction.

An approach that may be utilized to overcome the shortcomings of the ENR indices relative to water works construction is to apply specific indices to the major cost components of the construction cost curves. This approach allows the curve to be updated using indices specific to each category and weighted according to the dollar significance of the category.

For the eight major categories of construction cost, the Bureau of Labor Statistics (BLS)[22] and ENR indices shown in Table 9 were utilized as a basis for the cost curves included in this report.

Table 9

BLS and ENR Indices Used as Bases for the Construction Cost Curves

Cost Component	Index	October 1978 Value of Index
Excavation and Sitework	ENR Skilled Labor Wage Index (1967)	247
Manufactured Equipment	BLS General Purpose Machinery and Equipment - Code 114	221.3
Concrete	BLS Concrete Ingredients Code 132	221.1
Steel	BLS Steel Mill Products Code 1013	262.1
Labor	ENR Skilled Labor Wage Index (1967 Base)	247
Pipe and Valves	BLS Valves and Fittings Code 114901	236.4
Electrical Equipment and Instrumentation	BLS Electrical Machinery and Equipment - Code 117	167.5
Housing	ENR Building Cost Index (1967 Base)	254.76

The principal disadvantages of this approach are the lack of geographical specificity of the BLS indices and the use of seven indices rather than a single index.

To update the construction costs using the above two ENR and five BLS indices, the construction cost from the construction cost curve or the construction cost table must first be broken down into the eight component categories. One acceptable method of accomplishing this breakdown is to utilize all the detailed cost estimates included in the construction cost table to determine the average percent of the subtotal construction cost for each of the eight (or less) construction cost components. The appropriate index for each component can then be used to update the component cost. For example, if the sum of all of the manufactured equipment costs in the construction cost table for a particular unit process is $1 million, and the subtotal of all construction costs is $3 million, the manufactured equipment represents, on the average, 33.3 percent of the subtotal construction costs. Therefore, if the construction cost curve for a particular size of the unit process gives a construction cost of $500,000, the the BLS General Purpose Machinery and Equipment Index is 260, the manufactured equipment cost for this particular size would be:

$$\text{Manufactured Equipment Cost} = 0.3333\ (\$500{,}000)\ \left(\frac{260}{221.3}\right) = \$195{,}790$$

When this approach is used with each of the components of construction cost, the updated sum gives the subtotal of construction cost, and the updated total construction cost is obtained by adding 15 percent to this updated subtotal cost. Either this approach or the previously described approach using the CCI may be used with the computer program contained in Volume 4.

Updating of total operation and maintenance costs may be accomplished by updating the three individual components: Energy, labor, and maintenance material. Energy and labor are updated by applying the current unit costs to the kilowatt-hour and labor requirements obtained from the energy and labor curves. Maintenance material costs, which are presented in terms of dollars per year, can be updated using the Producer Price Index for Finished Goods. The maintenance material costs in this report are based on an October 1978 Producer Price Index for Finished Goods of 199.7

FIRMS THAT SUPPLIED COST AND TECHNICAL INFORMATION

During the development of both construction and operation and maintenance cost curves, a large number of equipment manufacturers and other firms were contacted to determine cost and technical information. The help provided by those firms that did respond is sincerely appreciated, for the information furnished was instrumental in assuring a high level of accuracy for the curves. The manufacturers and other firms that provided input to this study were:

- Acrison, Inc.
- Advance Chlorination Equipment
- Aqua-Aerobic Systems, Inc.
- Aquafine Corporation
- BIF, a Division of General Signal Corporation
- Bird Centrifuge
- Capital Control Company
- Ralph B. Carter Company
- Chemical Separations Corporation
- Chicago Bridge and Iron Company
- Chicago, Rock Island and Pacific Railroad Company
- Chromalloy, L.A. Water Treatment Division
- Clarkson Industries, Inc., Hoffman Air & Filtration Division
- Colt Industries, Inc., Fairbanks Morse Pump Division
- Continental Water Conditioning
- Copeland Systems
- Crane Company, Cochrane Environmental Systems
- Curtiss-Wright Corporation
- DeLaval Turbine, Inc.
- Dorr-Oliver, Inc.
- Dravo Corporation
- The Duriron Company, Inc., Filtration Systems Division
- E.I. Dupont De Nemours & Company, Inc.
- The Eimco Corporation

Electrode Corporation, Subsidiary of Diamond Shamrock Corporation
Englehard Industries
Envirex, Inc. - A Rexnord Company
Environmental Conditioners
Environmental Elements Corp., Subsidiary of Koppers Co., Inc.
Envirotech Corporation
Fischer and Porter Company
FMC Corporation
General Filter Company
Infilco Degremont, Inc.,
Ionics, Inc.
Johns-Manville
Kaiser Chemicals
Keystone Engineering
Komline-Sanderson Engineering Corporation
Merck & Co., Inc., Calgon Company
Mixing Equipment Company, Inc.
Morton-Norwick Products, Inc., Morton Salt Company
Muscatine Sand and Gravel
Nash Engineering Company
Neptune Micro Floc, Inc.
Nichols Engineering & Research Corp., Neptune International Corp.
Northern Gravel Company
Ozark-Mahoning Company
Pacific Engineering & Production Company of Nevada
PACO
R.H. Palmer Coal Company
Passavant Corporation
PCI Ozone Corp., A Subsidiary of Pollution Control Industries, Inc.
Peabody Welles, Inc.
Peerless Pump
Pennwalt Corporation
The Permutit Company, Inc., Division of Sybron Corporation
Reading Anthracite Company
Robbins & Meyers, Inc., Moyno Pump Division
Rohm and Haas Company, Fluid Process Chemicals Department
Shirco, Inc.
D.R. Sperry & Company
Sybron Corporation, R.B. Leopold Co. Division
TOMOCO2 Equipment Company
Union Carbide Corporation - Linde Division
Universal Oil Products Company, Fluid Systems Division
U.S. Filter Co., Inc., Calfilco Division
Westvaco Corporation, Chemical Division
Western States Machine Company
Worthington Pump, Inc.
Zimpro, Inc.

SECTION 5

EXAMPLE CALCULATIONS

INTRODUCTION

To demonstrate the use of the construction and operation and maintenance cost curves included in Volume 2 and 3, a series of examples has been prepared. These examples, which are for a variety of different treatment schemes at various capacities, are:

1. 70 gpm Package Complete Treatment Plant
2. 350 gpm Package Complete Treatment Plant
3. 700 gpm Package Complete Treatment Plant
4. 5 mgd Conventional Treatment Plant
5. 40 mgd Conventional Treatment Plant
6. 130 mgd Conventional Treatment Plant
7. 1 mgd Direct Filtration Plant
8. 10 mgd Direct Filtration Plant
9. 100 mgd Direct Filtration Plant
10. 5 mgd Reverse Osmosis Plan
11. 5 mgd Ion Exchange Plant
12. 25 mgd Lime Softening Plant
13. 10 mgd Pressure Filtration Plant
14. 5 mgd Corrosion Control Facility
15. 2 mgd Pressure Granular Activated Carbon Plant
16. 20 mgd Pressure Granular Activated Carbon Plant
17. 110 mgd Gravity, Steel Granular Activated Carbon Plant

These examples are only for hypothetical situations, however, and the design criteria and costs presented should be considered as general in nature and not necessarily applicable to all plants having the same capacities as the examples.

The examples illustrate the method of adding a number of special costs to the subtotal obtained from the construction cost curves to arrive at the total capital cost for a project. These special costs are added to the subtotal of the construction cost for all of the unit processes in the plant, since they are more appropriately related to the subtotal of construction cost than to the construction cost of each individual unit process. These special costs include: (1) special site work, landscaping, roads, and interface piping between processes; (2) special subsurface considerations; and (3) standby power. The special costs will vary widely depending on the site, the design engineer's preference, and regulatory agency requirements. Addition of these special costs to the subtotal cost of the unit processes gives the total construction cost.

To arrive at the total capital cost, the following costs must then be added to the total construction cost: (1) general contractor's overhead and profit, (2) engineering costs, (3) land costs, (4) legal, fiscal, and administrative costs, and (5) interest during construction. Curves for these costs, with the exception of engineering and land, are presented in Figures 5 through 9. A curve for engineering cost is not included, as the cost will vary widely, depending on the need for preliminary studies, time delays, the size and complexity of the project, and any construction-related inspection and engineering design activities.

PACKAGE COMPLETE TREATMENT PLANT EXAMPLES

Package complete treatment plants include coagulation, flocculation, sedimentation, and filtration, all included in factory preassembled units or field-assembled modules. Their relatively low initial cost, as well as the low operation and maintenance cost that results from automatic control features, makes package complete treatment facilities popular for small installations.

Examples are presented for three capacities of package complete treatment plants: 70 gpm, 350 gpm, and 700 gpm. All examples are for complete and operable facilities, including raw water pumping, clearwell storage, high service pumping, an enclosure for all facilities, and chemical requirements. All plants in the examples were assumed to be operating at 70 percent of full capacity. Other than the capacity variation, the only other key difference is the method of sludge disposal utilized. The 70 gpm plant utilizes sand drying beds, the 350 gpm uses sludge lagoons, and the 700 gpm uses a sanitary sewer for sludge disposal.

The design criteria utilized, as well as the capital and annual cost calculations, are presented in Tables 10 and 11 for the 70 gpm plant, in Tables 12 and 13 for the 350 gpm plant, and in Tables 14 and 15 for the 700 gpm plant. The annual cost analysis indicates that economy of scale has a substantial effect. Whereas the unit cost of water produced is 158.41 ¢/1,000 gal for the 70 gpm plant, it decreases to 64.76 ¢/1,000 gal for the 350 gpm plant and to 47.27 ¢/1,000 gal for the 700 gpm plant. Note that each of these plants was assumed to be operating at 70 percent of capacity, and other percentages of full capacity utilization would affect the unit cost of water produced.

CONVENTIONAL TREATMENT PLANT EXAMPLES

Conventional treatment plants are made principally of reinforced concrete, cast-in-place structures. They consist of chemical feed systems, rapid mix, flocculation, clarification, filtration, and sludge disposal facilities.

Examples are presented for 5, 40 and 130 mgd plants. Various methods of sludge disposal are utilized in each of the three examples. The 5 mgd plant uses sand drying beds with on-site sludge disposal; the 40 mgd plant uses gravity thickening, basket centrifugation, and sludge hauling to landfill; and the 100 mgd plant uses gravity thickening, a filter press, and sludge hauling to landfill. All plants were assumed to be operating at 70 percent of full capacity.

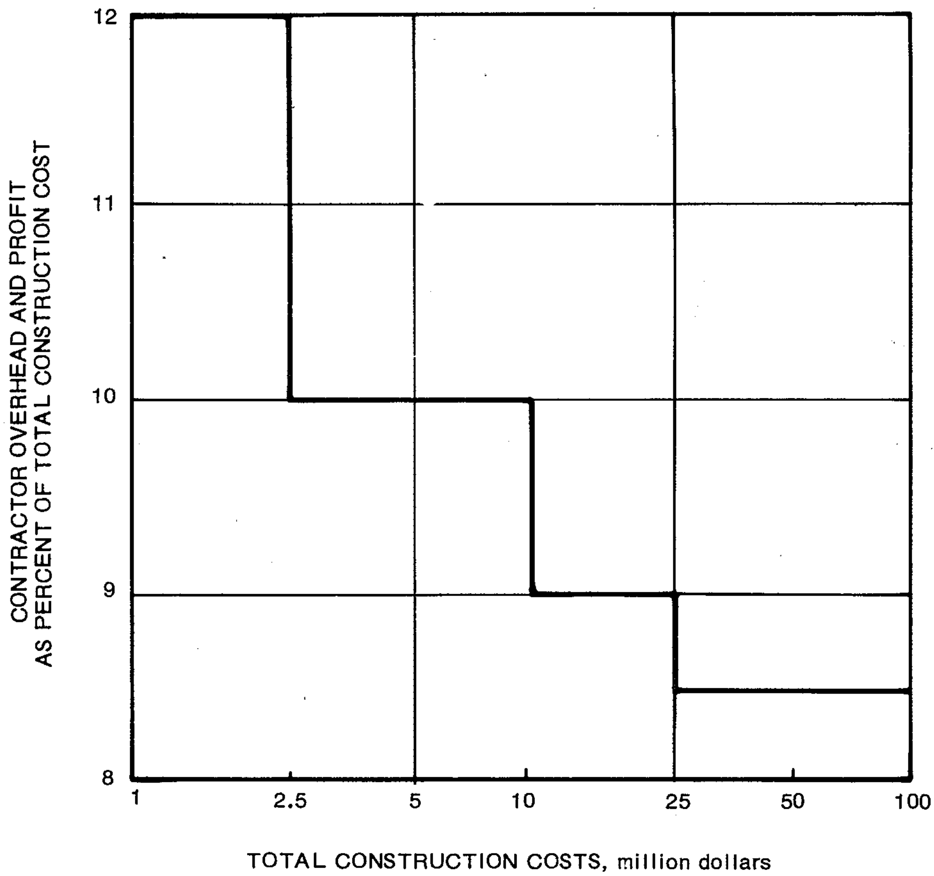


Figure 5. General Contractor Overhead and Profit as Percent of Total Construction Cost.

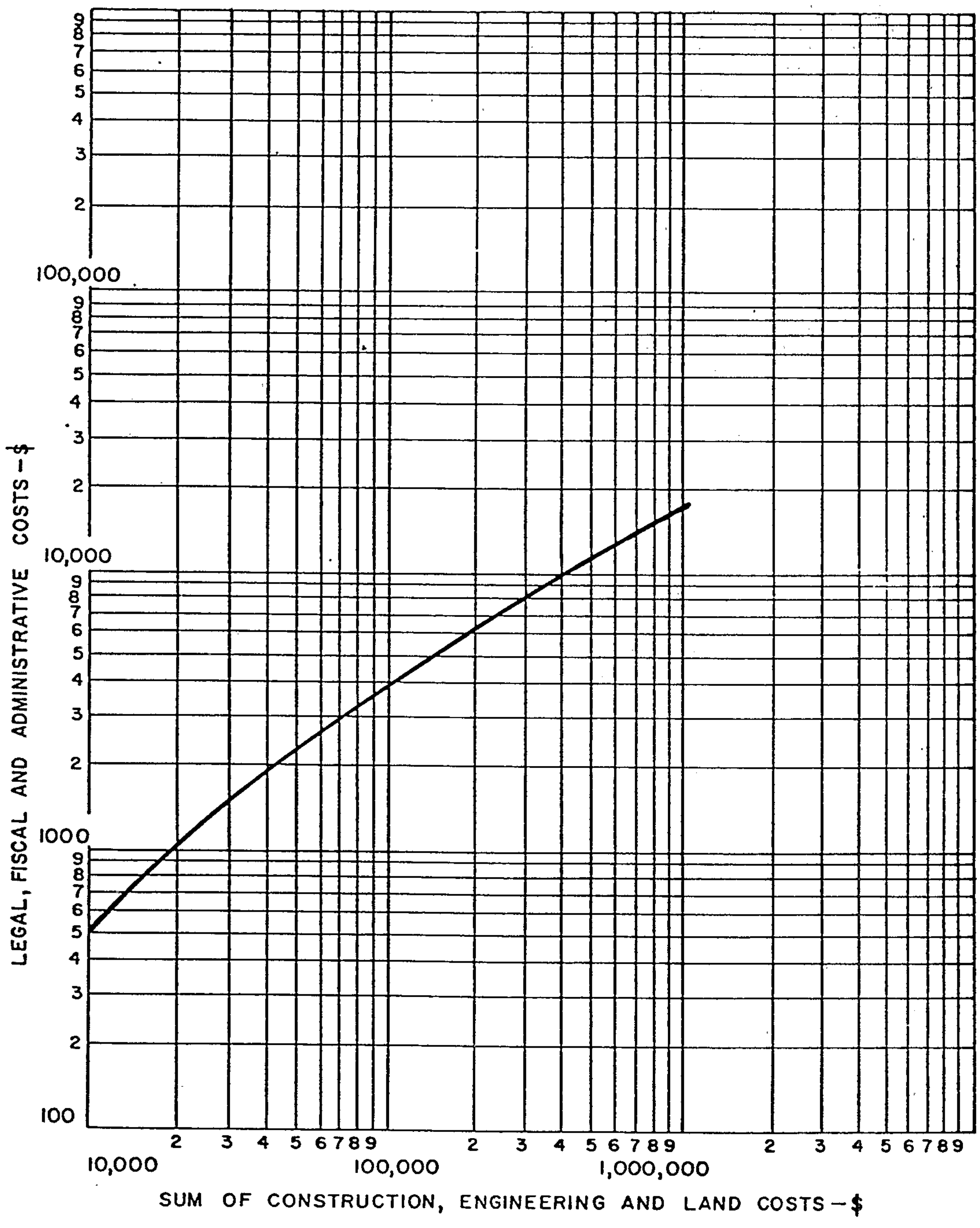


Figure 6. Legal, fiscal and administrative costs for projects less than $1 million.

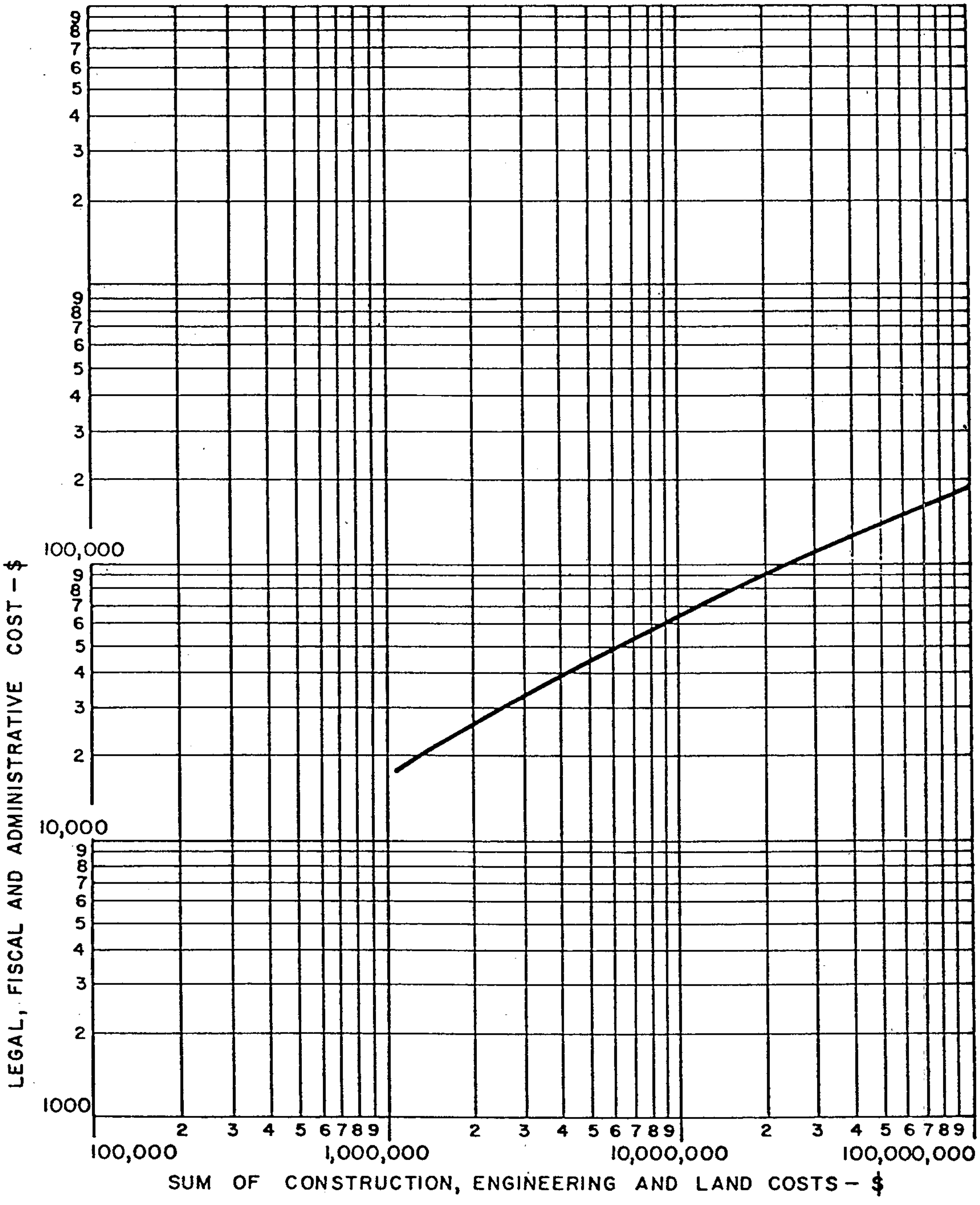


Figure 7. Legal, fiscal and administrative costs for projects greater than $1 million.

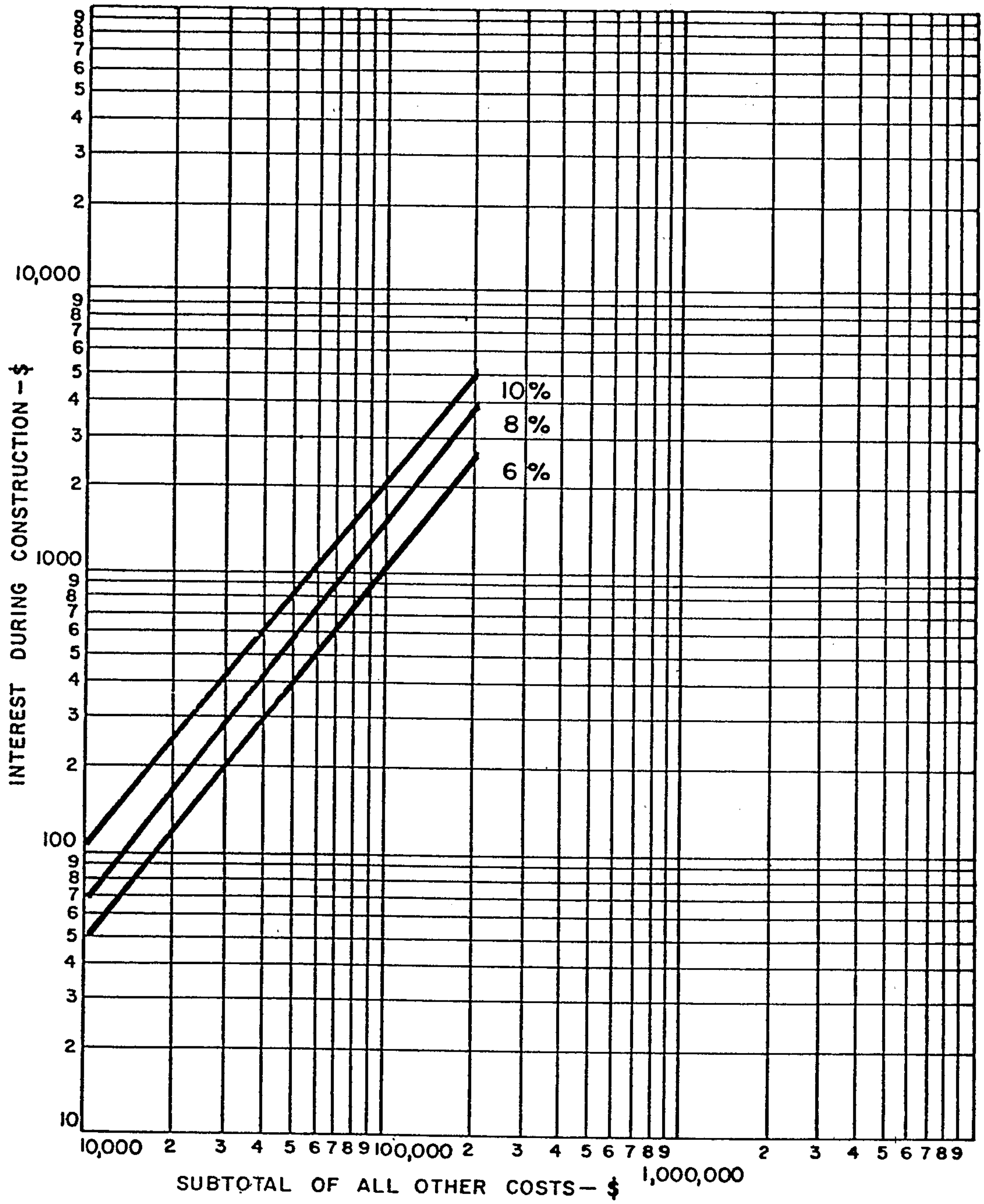


Figure 8. Interest during construction for projects less than $200,000.

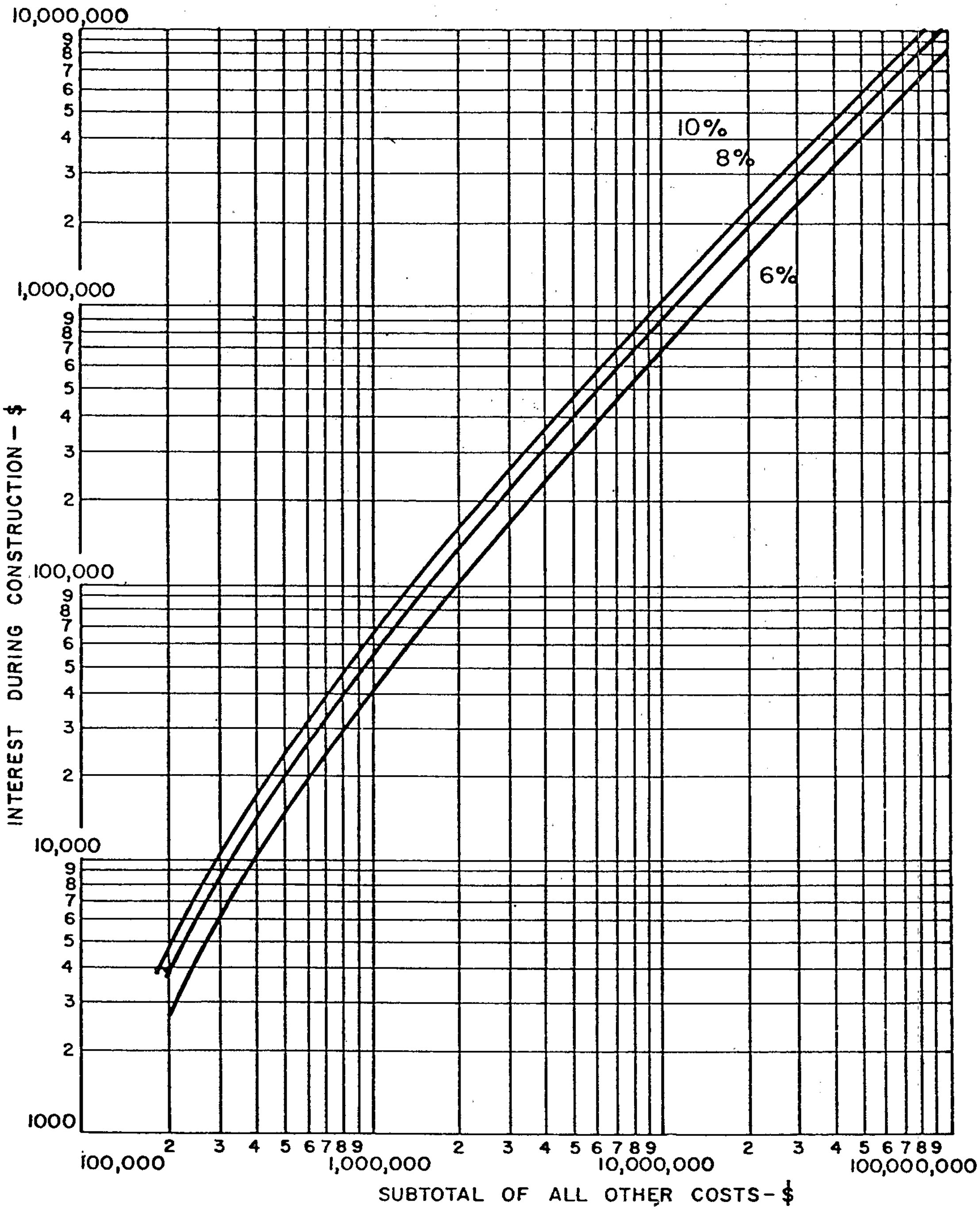


Figure 9. Interest during construction for projects greater than $200,000.

Table 10

Design Criteria and Cost Calculation

70 gpm Package Complete Treatment Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy (kw-hr/yr)	Diesel Fuel (gal/yr)	Maintenance Material ($/yr)	Labor (hr/yr)
Package Raw Water Pumping Facilities	50, 51, 52	105 gpm	$ 15,650	50 gpm	5,800	0	60	54
Package Complete Treatment Plant, 5 gpm/ft^2	2, 3, 4	70 gpm	87,290	50 gpm	58,140	0	640	1,705
Steel Backwash/Clearwell Tank	56	15,000 gal	14,900	--	0	0	0	0
Package High Service Pumping Station	53, 54, 55	105 gpm	11,870	50 gpm	7,170	0	30	104
Sand Drying Beds	66, 67, 68	500 ft^2	3,760	500 ft^2	0	40	20	255
Subtotal	--	--	133,470	--	71,110	40	750	2,118
Sitework, Interface Piping, Roads @ 5%	--	--	6,670	--	--	--	--	--
Subsurface Considerations	--	--	0	--	--	--	--	--
Standby Power	--	--	0	--	--	--	--	--
Total Construction Cost	--	--	140,140	--	--	--	--	--
General Contractor's Overhead and Profit	--	--	16,820	--	--	--	--	--
Subtotal	--	--	156,960	--	--	--	--	--
Engineering @ 10%	--	--	15,700	--	--	--	--	--
Subtotal	--	--	172,660	--	--	--	--	--
Land, 0.25 acres @ $2,000/acre	--	--	500	--	--	--	--	--
Legal, Fiscal, and Administrative	--	--	6,060	--	--	--	--	--
Interest during Construction - 7%	--	--	2,780	--	--	--	--	--
Total Capital Cost	--	--	$182,000	--	--	--	--	--

*Note. Figure numbers refer to Volume 3 of this report.

Table 11

Annual Cost for a 70 gpm

Package Complete Treatment Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$17,180
Labor, 2,118 hr @ $10/hr (Total Labor Costs Including Fringes and Benefits).	21,180
Electricity, 71,110 kw-hr @ $0.03	2,130
Fuel, 40 gal @ $0.65	30
Maintenance Material	750
Chemicals, Alum, 2.2 tons/yr @ $70/ton; Polymer, 55 lb/yr @ $2/lb; Chlorine, 0.33 tons/yr @ $300/ton	360
Total Annual Cost*	41,630

$$\text{*Cents per 1,000 gal treated} = \frac{\$41,630\ (100)}{72\ (365)}$$

= 158.41¢/1,000 gal treated

Table 12

Design Criteria and Cost Calculation for a
350 gpm Package Complete Treatment Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy kw-hr/yr	Fuel gal/yr	Maintenance Material ($/yr)	Labor (hr/yr)
Package Raw Water Pumping Facilities	50, 51, 52	500 gpm	$ 23,280	245 gpm	28,460	0	110	73
Package Complete Treatment Plant - 5 gpm/ft^2	2, 3, 4	350 gpm	183,690	245 gpm	160,230	0	1,630	2,940
Steel Backwash/Clearwell Tank	56	100,000 gal	84,430	-	0	0	0	0
Package High Service Pumping Station	53, 54, 55	500 gpm	16,570	245 gpm	44,330	0	40	123
Sludge Dewatering Lagoon	63, 64, 65	15,000 ft^3	3,720	12,000 ft^3/yr	0	155	70	118
Subtotal	--	--	311,690	--	233,020	155	1,850	3,254
Sitework, Interface Piping, Roads @ 5%	--	--	15,590	--	--	--	--	--
Surface Considerations	--	--	0	--	--	--	--	--
Standby Power	--	--	0	--	--	--	--	--
Total Construction Cost	--	--	327,280	--	--	--	--	--
General Contractors Overhead and Profit	--	--	39,270	--	--	--	--	--
Subtotal	--	--	366,550	--	--	--	--	--
Engineering @ 10%	--	--	36,660	--	--	--	--	--
Subtotal	--	--	403,210	--	--	--	--	--
Land, 0.45 acres @ $2,000/acre	--	--	900	--	--	--	--	--
Legal, Fiscal and Administrative	--	--	10,080	--	--	--	--	--
Interest during Construction - 7%	--	--	10,680	--	--	--	--	--
Total Capital Cost	--	--	$424,870	--	--	--	--	--

*Note - Figure numbers refer to Volume 3 of this report.

Table 13

Annual Cost for a 350 gpm

Package Complete Treatment Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 40,100
Labor, 3,254 hr @ $10/hr (Total Labor Costs Including Fringes and Benefits)	32,540
Electricity, 233,017 kw-hr @ $0.03	6,990
Fuel, 155 gal @ $0.65	100
Maintenance Material	1,850
Chemicals, Alum, 11 tons/yr @ $70/ton; . . . . . . Polymer, 264 lb/yr @ $2/lb; Chlorine, 1.6 tons/yr @ $300/gon	1,810
Total Annual Cost*	83,390

$$\text{*Cents per 1,000 gal treated} = \frac{\$83{,}390/\text{yr } (100)}{352.8 \times 365}$$

$$= 64.76¢/1{,}000 \text{ gal treated}$$

Table 14

Design Criteria and Cost Calculation for a
700 gpm Package Complete Treatment Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy kw/hr/yr	Maintenance Material ($/yr)	Labor (hr/yr)
Package Raw Water Pumping Facilities	50, 51, 52	1000 gpm	$ 33,340	500 gpm	58,100	120	97
Package Complete Treatment Plant - 5 gpm/ft^2	2, 3, 4	700 gpm	270,800	500 gpm	261,630	2,230	3,593
Steel Backwash/Clearwell Tank	56,	250,000 gal	195,490	-	0	0	0
Package High Service Pumping Station	53, 54, 55	1000 gpm	21,170	500 gpm	102,140	50	134
Sludge Disposal - Sanitary Sewer	--	1000 gpd	0	700 gpd	0	0	0
Subtotal	--	--	520,800	--	421,870	2,400	3,824
Sitework, Interface Piping, Roads @ 5%	--	--	26,040	--	--	--	--
Subsurface Considerations	--	--	0	--	--	--	--
Standby Power	--	--	0	--	--	--	--
Total Construction Cost	--	--	546,840	--	--	--	--
General Contractors Overhead and Profit	--	--	65,620	--	--	--	--
Subtotal	--	--	612,460	--	--	--	--
Engineering @ 10%	--	--	61,250	--	--	--	--
Subtotal	--	--	673,710	--	--	--	--
Land, 0.6 acres @ $2,000/acre	--	--	1,200	--	--	--	--
Legal, Fiscal and Administrative	--	--	12,330	--	--	--	--
Interest during Construction - 7%	--	--	23,440	--	--	--	--
Total Capital Cost	--	--	$710,680	--	--	--	--

*Note - Figure numbers refer to Volume 3 of this report.

Table 15

Annual Cost for a 700 gpm

Package Complete Treatment Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 67,080
Labor, 3,824 hr @ $10/hr (Total Labor Costs Including Fringes & Benefits)	38,240
Electricity, 421,870 kw-hr @ $0.03	12,660
Maintenance Material	2,400
Sludge Disposal	240
Chemicals, Alum, 22 tons/yr @ $70/ton; Polymer, 548 lb/yr @ $2/lb; Chlorine, 3.3 tons/yr @ $300/ton	3,610
Total Annual Cost*	124,230

*Cents per 1,000 gal treated = $\frac{\$124,230\ (100)}{720\ (365)}$

= 47.27¢/1,000 gal treated

The design capacity utilized and the capital and annual cost calculations are presented in Tables 16 and 17 for the 5 mgd plant, in Tables 18 and 19 for the 40 mgd plant, and in Tables 20 and 21 for the 130 mgd plant. The unit cost of water produced drops as the size of the plant increases, but the drop is not as dramatic as in the previous examples for package complete treatment plants. For the three conventional plants, the unit cost decreased from 31.05 ¢/1,000 gal for the 5 mgd plant, to 18.12 ¢/1,000 gal for the 40 mgd plant, to 13.39 ¢/1,000 gal for the 130 mgd plant. It should be recognized that these unit costs are based upon a 70 percent utilization of plant capacity.

DIRECT FILTRATION PLANTS

For water supplies with a low turbidity and a low suspended solids concentration, direct filtration may be utilized at a resultant cost savings over a typical conventional filtration plant. Because the settling basin and its associated sludge collection apparatus are eliminated, a substantial initial capital cost savings results. Operation and maintenance costs are also reduced because there is less equipment to maintain.

Examples are presented for direct filtration plants of three capacities: 1 mgd, 10 mgd, and 100 mgd. Other than the capacity variations, the only other major difference is the method of sludge handling. The 1 mgd plant uses a sanitary sewer for sludge disposal; the 10 mgd plant uses a sludge storage lagoon; and the 100 mgd plant uses gravity thickening, a filter press, and sludge disposal by hauling to landfill. Each example is for a complete and operable plant, including raw water pumping, clearwell storage, and finished water pumping. All plants were assumed to be operating at 70 percent of design capacity.

The design criteria utilized and the capital and annual cost calculations are shown in Tables 22 and 23 for the 1 mgd plant, in Tables 24 and 25 for the 10 mgd plant, and in Tables 26 and 27 for the 100 mgd plant. A substantial decrease in annual cost occurs between 1 and 10 mgd, decreasing from 63.04 to 18.87 ¢/1,000 gal. The annual cost variation between the 10 and 100 mgd plants is substantially less, decreasing from 18.87 to 12.20 ¢/1,000 gal. These cost calculations are based on operation at 70 percent of design capacity.

REVERSE OSMOSIS EXAMPLE

As shown in Tables 4, 5, and 7, reverse osmosis can remove a substantial number of the contaminants included in the National Interim Primary Drinking Water Regulations. This example is for a complete, 5 mgd reverse osmosis plant, including clearwell storage, chlorination disinfection, and finished water pumping.

The design criteria and the capital and annual cost calculations are shown in Tables 28 and 29. The estimated annual cost for a 5 mgd plant operating at 70 percent of capacity is 78.68 ¢/1,000 gal treated.

Table 16

Design Criteria and Cost Calculation for a

5 mgd Conventional Treatment Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy (kw-hr/yr)	Diesel Fuel (gal/yr)	Maintenance Material ($/yr)	Labor (hr/yr)
Alum Feed System - 50 mg/1	16, 19, 20	87 lb/hr	$ 28,730	50 lb/hr	15,790	0	80	60
Sodium Hydroxide Feed System - 20 mg/1	33, 34, 35	830 lb/day	20,680	550 lb/day	15,610	0	160	128
Polymer Feed System - 0.2 mg/1	21, 22, 23	8.3 lb/day	20,170	5.0 lb/day	25,470	0	270	198
Rapid Mix - 1 min., G=600	50, 51, 52	464 ft^3	19,000	464 ft^3	47,350	0	30	453
Flocculation - 30 min., G=50	53, 55, 56	13,930 ft^3	84,840	13,930 ft^3	16,500	0	880	166
Rectangular Clarifiers - 1,000 gpd/ft^2	60, 61, 62	5000 ft^2	380,570	5000 ft^2	10,380	0	1,250	689
Gravity Filtration - 5 gpm/ft^2	67, 68, 69	700 ft^2	329,610	700 ft^2	150,320	0	2,310	1,390
Filter Media - Mixed Media	70	700 ft^2	24,720	--	0	0	0	0
Surface Wash	74, 75, 76	700 ft^2	45,870	700 ft^2	10,120	0	240	115
Backwash Pumping - 18 gpm/ft^2	71, 72, 73	3150 gpm	61,610	700 ft^2	16,730	0	990	199
Wash Water Surge Basin	80	60,000 gal	183,560	-	0	0	0	0
Chlorine Feed System - 2 mg/1	1, 2, 3	84 lb/day	19,820	50 lb/day	18,190	0	1,650	441
Clearwell - Below Ground	207	400,000 gal	195,350	-	0	0	0	0
Finished Water Pumping - 100' tdh	204, 205, 206	7.5 mgd	59,480	3.5 mgd	281,170	0	700	581
Sand Drying Beds	188, 189, 190	50,000 ft^2	156,370	50,000 ft^2	0	3,000	1,550	2,143
Dewatered Sludge Hauling - 20 miles	196, 199, 200	850 yd^3/yr	47,460	850 yd^3/yr	0	810	800	226
Administration, Laboratory & Maintenance Building	214, 215, 216	5 mgd	51,700	5 mgd	117,900	0	3,020	2,560
Subtotal	--	--	1,713,200	--	725,530	3,810	13,930	9,350
Sitework, Interface Piping, Roads @ 5%	--	--	85,660	--	--	--	--	--
Subsurface Considerations	--	--	0	--	--	--	--	--
Standby Power	--	--	0	--	--	--	--	--
Total Construction Cost	--	--	1,798,860	--	--	--	--	--
General Contractors Overhead and Profit	--	--	215,860	--	--	--	--	--
Subtotal	--	--	2,014,720	--	--	--	--	--
Engineering at 10%	--	--	201,470	--	--	--	--	--
Subtotal	--	--	2,216,190	--	--	--	--	--
Land, 2 acres @ $2,000/acre	--	--	4,000	--	--	--	--	--
Legal, Fiscal, and Administrative	--	--	25,940	--	--	--	--	--
Interest during Construction - 7%	--	--	117,850	--	--	--	--	--
Total Capital Cost	--	--	$2,364,000	--	--	--	--	--

*Note - Figure numbers refer to Volume 2 of this report.

Table 17

Annual Cost for a 5 mgd

Conventional Treatment Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 223,140
Labor, 9,350 hr @ $10/hr (Total Labor Costs Including Fringes & Benefits)	93,500
Electricity, 725,530 kw-hr @ $0.03	21,770
Fuel, 3,810 gal @ $0.65/gal	2,480
Maintenance Material	13,930
Chemicals, Alum, 219 tons/yr @ $70/ton; Polymer, 1,825 lb/yr @ $2/lb; Sodium Hydroxide, 100 tons/yr @ $200/ton; Chlorine, 9 tons/yr @ $300/ton	41,790
Total Annual Cost	396,610

$$\text{*Cents per 1,000 gal treated} = \frac{\$396{,}610\ (100)}{3{,}500\ (365)}$$

$$= 31.05¢/1{,}000 \text{ gal treated}$$

Table 18

Design Criteria and Cost Calculation for a

40 mgd Conventional Treatment Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy (kw-hr/yr)	Diesel Fuel (gal/yr)	Maintenance Material-($/yr)	Labor (hr/yr)
Alum Feed System - 40 mg/1	16, 19, 20	556 lb/hr	$ 71,440	350 lb/hr	46,260	0	100	65
Sodium Hydroxide Feed System - 15 mg/1	33, 34, 35	5000 lb/day	47,300	3300 lb/day	46,860	0	250	150
Polymer Feed System - 0.2 mg/1	21, 22, 23	67 lb/day	22,400	45 lb/day	26,280	0	300	207
Rapid Mix - 45 sec., G=600	50, 51, 52	2785 ft^3	44,210	2785 ft^3	284,180	0	60	499
Flocculation - 35 min., G=50	53, 55, 56	130,000 ft^3	447,070	130,000 ft^3	154,370	0	4,770	394
Rectangular Clarifiers - 1,000 gpd/ft^2	60, 61, 62	40,000 ft^3	2,247,330	40,000 ft^3	70,560	0	10,050	4,344
Gravity Filtration - 5 gpm/ft^2	67, 68, 69	5560 ft^2	1,747,730	5560 ft^2	978,200	0	12, 170	4,464
Filter Media - Mixed Media	70	5560 ft^2	148,200	-	0	0	0	0
Surface Wash	74, 75, 76	5560 ft^2	160,850	5560 ft^2	76,960	0	400	310
Backwash Pumping - 18 gpm/ft^2	71, 72, 73	10,010 gpm	122,530	5560 ft^2	132,840	0	3,170	294
Wash Water Surge Basin	80	200,000 gal	357,600	-	0	0	0	0
Chlorine Feed System - 2 mg/1	1, 2, 3	670 lb/day	68,980	450 lb/day	79,800	0	2,520	747
Clearwell Storage - Below Ground	207	2,500,000 gal	912,030	-	0	0	0	0
Finished Water Pumping	204, 205, 206	55 mgd	415,030	28 mgd	4,689,640	0	4,200	1,107
Gravity Thickener	166, 167, 168	850 ft^2	73,520	850 ft^2	4,140	0	230	145
Basket Centrifuge	185, 186, 187	115,000 gpd	334,810	70,000 gpd	476,760	0	3,000	8,300
Dewatered Sludge Hauling - 20 miles	196, 199, 200	20,000 yd^3/yr	81,510	12,000 yd^3/yr	0	4,820	5,250	914
Administrative, Laboratory & Maintenance Building	214, 215, 216	40 mgd	216,200	40 mgd	493,660	0	9,430	8,596
Subtotal	--	--	7,518,740	--	7,560,510	4,820	55,900	30,534
Sitework, Interface Piping, Roads, @ 5%	--	--	375,940	--	--	--	--	--
Subsurface Considerations	--	--	0	--	--	--	--	--
Standby Power	--	--	0	--	--	--	--	--
Total Construction Cost	--	--	7,894,680	--	--	--	--	--
General Contractor's Overhead and Profit	--	--	789,470	--	--	--	--	--
Subtotal	--	--	8,684,150	--	--	--	--	--
Engineering @ 10%	--	--	868,420	--	--	--	--	--
Subtotal	--	--	9,552,570	--	--	--	--	--
Land, 13 acres @ $26,000/acre	--	--	26,000	--	--	--	--	--
Legal, Fiscal, and Administrative	--	--	67,030	--	--	--	--	--
Interest during Construction - 7%	--	--	688,790	--	--	--	--	--
Total Capital Cost	--	--	$10,334,390	--	--	--	--	--

*Note - Figure numbers refer to Volume 2 of this report.

Table 19

Annual Cost for a 40 mgd

Conventional Treatment Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 975,460
Labor, 30,534 hr $ $10/hr, (Total Labor Costs Including Fringes & Benefits)	305,340
Electricity, 7,560,510 kw-hr @ $0.03	226,820
Fuel, 4,820 gal @ $0.65/gal	3,130
Maintenance Material	55,900
Chemical, Alum, 1,533 tons/yr @ $70/ton; Polymer, 16,425 lb/yr @ $2/lb; Sodium Hydroxide, 602 tons/yr @ $200/ton; Chlorine, 82 tons/yr @ $300/ton	285,250
Total Annual Cost*	1,851,900

$$\text{*Cents per 1,000 gal treated} = \frac{\$1{,}851{,}900\ (100)}{28{,}000\ (365)}$$

$$= 18.12¢/1{,}000 \text{ gal treated}$$

Table 20

Design Criteria and Cost Calculation for a

130 mgd Conventional Treatment Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy (kw-hr/yr)	Diesel Fuel (gal/yr)	Maintenance Material ($/yr)	Labor (hr/yr)
Alum Feed System - 30 mg/l	16, 19, 20	1355 lb/hr	$ 115,540	900 lb/hr	71,950	0	130	75
Polymer Feed System - 0.2 mg/l	21, 22, 23	217 lb/day	30,440	140 lb/day	27,730	0	340	220
Rapid Mix - 60 min., G=900 mg/l	50, 51, 52	12,070 ft^3	261,220	12,070 ft^3	4,098,030	0	170	1,177
Flocculation - 25 min., G=80	53, 55, 56	301,730 ft^3	785,300	301,730 ft^3	1,013,610	0	9,640	540
Rectangular Clarifiers - 900 gpm/ft^2	60, 61, 62	144,450 ft^2	8,081,080	144,450 ft^2	255,990	0	37,320	15,274
Gravity Filtration - 5 gpm/ft^2	67, 68, 69	18,060 ft^2	3,381,010	18,060 ft^2	2,675,310	0	23,800	10,199
Filter Media - Mixed Media	70	18,060 ft^2	403,800	-	0	0	0	0
Surface Wash	74, 75, 76	18,060 ft^2	398,160	18,060 ft^2	249,110	0	490	397
Backwash Pumping - 18 gpm/ft^2	71, 72, 73	23,000 gpm	209,790	18,060 ft^2	431,840	0	4,160	348
Wash Water Surge Basin	80	200,000 gal	357,600	-	0	0	0	0
Chlorine Feed System - 2 mg/l	1, 2, 3	2170 lb/day	157,700	1300 lb/day	207,100	0	3,960	1,343
Clearwell - Below Ground	207	7,500,000 gal	1,626,390	-	0	0	0	0
Finished Water Pumping - 220' tdh	204, 205, 206	200 mgd	1,226,940	90 mgd	13,020,260	0	12,460	2,474
Gravity Thickener	166, 167, 168	1750 ft^2	101,480	1750 ft^2	5,480	0	380	171
Filter Press	177, 178, 179	510 cu ft	1,151,190	510 ft^3	1,082,150	0	7,570	20,427
Dewatered Sludge Hauling - 20 miles	196, 199, 200	23,000 yd^3/yr	86,830	14,000 yd^3/yr	0	5,540	6,060	1,042
Administration, Laboratory, and Maintenance Building	214, 215, 216	130 mgd	324,000	130 mgd	737,670	0	15,590	11,282
Subtotal	--	--	18,698,470	--	23,876,230	5,540	122,070	64,969
Sitework, Interface Piping, Roads @ 5%	--	--	934,920	--	--	--	--	--
Subsurface Considerations	--	--	0	--	--	--	--	--
Standby Power	--	--	0	--	--	--	--	--
Total Construction Cost	--	--	19,633,390	--	--	--	--	--
General Contractor's Overhead and Profit	--	--	1,767,000	--	--	--	--	--
Subtotal	--		21,400,390	--	--	--	--	--
Engineering at 10%	--	--	2,140,040	--	--	--	--	--
Subtotal	--	--	23,540,430	--	--	--	--	--
Land, 33 acres @ $2,000/acre	--	--	66,000	--	--	--	--	--
Legal, Fiscal, and Administrative	--	--	113,590	--	--	--	--	--
Interest during Construction - 7%	--	--	2,330,340	--	--	--	--	--
Total Capital Cost	--	--	$26,050,360	--	--	--	--	--

*Note - Figure numbers refer to Volume 2 of this report.

Table 21

Annual Cost for a 130 mgd

Conventional Treatment Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 2,458,890
Labor, 64,969 hr @ $10/hr (Total Labor Costs Including Fringes & Benefits)	649,690
Electricity, 23,876,230 kw-hr @ $0.03	716,290
Fuel, 5,540 gal @ $0.65/gal	3,600
Maintenance Material	122,070
Chemicals, Alum, 3,942 tons/yr @ $70/ton; Polymer, 51,100 lb/yr @ $2/lb; Chlorine, 237 tons/yr @ $300/ton	499,320
Total Annual Cost	4,399,890

*Centers per 1,000 gal treated = $\frac{\$4,399,890\ (100)}{90,000\ (365)}$

= 13.39¢/1,000 gal treated

Table 22

Design Criteria and Cost Calculation for a

1 mgd Direct Filtration Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)
Raw Water Pumping - 100' tdh	201, 202, 203	1.5 mgd	$ 27,270	0.7 mgd	195,670	300	511
Alum Feed System - 20 mg/l	16, 19, 20	7 lb/hr	19,900	5.0 lb/hr	9,260	70	62
Polymer Feed System - 0.1 mg/l	21, 22, 23	0.83 lb/day	20,010	0.5 lb/day	25,310	260	196
Chlorine Feed System - 2 mg/l	1, 2, 3	17 lb/day	13,600	10 lb/day	10,660	1,550	409
Rapid Mix - 1 min., G=600	50, 51, 52	92 ft^3	15,030	92 ft^3	9,400	20	453
Flocculation - 20 min., G=80	53, 55, 56	1857 ft^3	38,470	1857 ft^3	6,290	440	135
Gravity Filtration - 5 gpm/ft^2	67, 68, 69	140 ft^2	170,480	140 ft^2	44,140	820	958
Filter Media - Mixed Media	70	140 ft^2	8,740	-	0	0	0
Surface Wash	74, 75, 76	140 ft^2	30,050	140 ft^2	2,300	210	80
Backwash Pumping - 18 gpm/ft^2	71, 72, 73	1250 gpm	42,700	140 ft^2	3,350	400	150
Wash Water Surge Basin	80	20,000 gal	81,330	-	0	0	0
In-Plant Pumping - 35' tdh	108, 109, 110	1.5 mgd	30,470	0.7 mgd	67,280	290	520
Clearwell - Ground Level	207	100,000 gal	47,600	-	0	0	0
Finished Water Pumping - 100' tdh	204, 205, 206	1.5 mgd	41,760	0.7 mgd	88,970	260	505
Sludge Disposal - Sanitary Sewer 1,000 mg/l	--	10 gpm	0	10 gpm	0	0	0
Administration, Laboratory, and Maintenance Building	214, 215, 216	1 mgd	25,200	1 mgd	57,370	2,050	1,546
Subtotal	--	--	612,620	--	520,000	6,670	5,524
Sitework, Interface Piping, Roads @ 5%	--	--	30,630	--	--	--	--
Subsurface Considerations	--	--	0	--	--	--	--
Standby Power	--	--	0	--	--	--	--
Total Construction Cost	--	--	643,250	--	--	--	--
General Contractor's Overhead and Profit	--	--	77,190	--	--	--	--
Subtotal	--	--	720,440	--	--	--	--
Engineering at 10%	--	--	72,040	--	--	--	--
Subtotal	--	--	792,480	--	--	--	--
Land, 1 acre @ $2,000/acre	--	--	2,000	--	--	--	--
Legal, Fiscal, and Administrative	--	--	13,530	--	--	--	--
Interest during Construction - 7%	--	--	30,020	--	--	--	--
Total Capital Cost	--	--	$838,030	--	--	--	--

*Note - Figure numbers refer to Volume 2 of this report.

Table 23

Annual Cost for a 1 mgd

Direct Filtration Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 79,100
Labor, 5,524 hr @ $10/hr (Total Labor Costs Including Fringes & Benefits)	55,240
Electricity, 520,000 kw-hr @ $0.03	15,600
Maintenance Material	6,670
Sludge Disposal	2,000
Chemicals, Alum, 21.9 tons/yr @ $70/ton; Polymer, 182.5 lb/yr @ $2/lb; Chlorine, 1.8 tons/yr @ $300/ton	2,450
Total Annual Cost*	161,060

$$\text{*Cents per 1,000 gal treated} = \frac{\$161{,}060\ (100)}{700\ (365)}$$

$$= 63.04¢/1{,}000 \text{ gal treated}$$

Table 24

Design Criteria and Cost Calculation for a

10 mgd Direct Filtration Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy (kw-hr/yr)	Diesel Fuel (gal/yr)	Maintenance Material($/yr)	Labor (hr/yr)
Raw Water Pumping - 100' tdh	201, 202, 203	15 mgd	$ 93,860	7 mgd	1,360,540	0	1,160	663
Alum Feed System - 20 mg/1	16, 19, 20	70 lb/hr	26,890	50 lb/hr	14,480	0	80	62
Polymer Feed System - 0.1 mg/1	21, 22, 23	8.3 lb/day	20,170	5 lb/day	25,470	0	270	198
Chlorine Feed System - 2 mg/1	1, 2, 3	167 lb/day	27,350	100 lb/day	27,380	0	1,770	480
Rapid Mix - 1 min., G=600	50, 51, 52	928 ft^3	23,940	928 ft^3	94,680	0	30	455
Flocculation - 20 min., G=80	53, 55, 56	18,570 ft^3	126,660	18,570 ft^3	63,050	0	1,050	178
Gravity Filtration - 5 gpm/ft^2	67, 68, 69	1400 ft^2	626,140	1400 ft^2	279,580	0	4,060	1,910
Filter Media - Mixed Media	70	1400 ft^2	44,130	-	0	0	0	0
Surface Wash	74, 75, 76	1400 ft^2	64,770	1400 ft^2	19,850	0	270	155
Backwash Pumping - 18 gpm/ft^2	71, 72, 73	6260 gpm	90,610	1400 ft^2	33,460	0	1,470	224
Wash Water Surge Basin	80	100,000 gal	258,900	-	0	0	0	0
In-Plant Pumping - 35' tdh	108, 109, 110	15 mgd	101,130	7 mgd	468,150	0	1,160	662
Clearwell - Ground Level	207	1,000,000 gal	224,240	-	0	0	0	0
Finished Water Pumping - 180' tdh	204, 205, 206	15 mgd	83,070	7 mgd	519,470	0	1,210	655
Sludge Storage Lagoon	173, 174, 175	140,000 ft^3	18,130	60,000 ft^3	0	560	100	479
Administration, Laboratory and Maintenance Building	214, 215, 216	10 mgd	82,380	10 mgd	187,980	0	4,150	3,725
Subtotal	--	--	1,912,370	--	3,094,090	560	16,780	9,847
Sitework, Interface Piping, Roads @ 5%	--	--	95,620	--	--	--	--	--
Subsurface Considerations	--	--	0	--	--	--	--	--
Standby Power	--	--	0	--	--	--	--	--
Total Construction Cost	--		2,007,990	--	--	--	--	--
General Contractor's Overhead and Profit	--	--	240,960	--	--	--	--	--
Subtotal	--	--	2,248,950	--	--	--	--	--
Engineering @ 10%	--	--	224,890	--	--	--	--	--
Subtotal	--	--	2,473,840	--	--	--	--	--
Land, 2.2 acres @ $2,000/acre	--	--	4,400	--	--	--	--	--
Legal, Fiscal, and Administrative	--	--	27,670	--	--	--	--	--
Interest during Construction - 7%	--	--	133,350	--	--	--	--	--
Total Capital Cost	--	--	$2,639,260	--	--	--	--	--

*Note - Figure numbers refer to Volume 2 of this report.

Table 25

Annual Cost for a 10 mgd

Direct Filtration Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 249,120
Labor, 9,847 hr @ $10/hr (Total Labor Costs Including Fringes & Benefits)	98,470
Electricity, 3,094,090 kw-hr @ $0.03	92,820
Fuel, 560 gal @ $0.65/gal	360
Maintenance Material	16,780
Chemicals, Alum, 219 tons/yr @ $70/ton; Polymer, 1,825 lb/yr @ $2/lb; Chlorine, 18.25 tons/yr @ $300/ton	24,460
Total Annual Cost*	482,010

$$\text{*Cents per 1,000 gal treated} = \frac{\$482{,}010\ (100)}{7{,}000\ (365)}$$

$$= 18.87¢/1{,}000 \text{ gal treated}$$

Table 26

Design Criteria and Cost Calculation

for a 100 mgd Direct Filtration Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy kw-hr/yr	Diesel Fuel (gal/yr)	Maintenance Material ($/yr)	Labor (hr/yr)
Raw Water Pumping - 100' tdh	201, 202, 203	150 mgd	$ 711,540	70 mgd	12,848,460	0	10,340	2,040
Alum Feed System - 20 mg/1	16, 19, 20	700 lb/hr	81,760	500 lb/hr	53,380	0	100	67
Polymer Feed System - 0.1 mg/1	21, 22, 23	83 lb/day	23,250	50 lb/day	26,410	0	310	208
Chlorine Feed System - 2 mg/1	1, 2, 3	1670 lb/day	133,370	1100 lb/day	169,060	0	3,670	1,209
Rapid Mix - 1 min., G=600	50, 51, 52	9280 ft^3	120,700	9280 ft^3	947,480	0	130	937
Flocculation - 20 min., G=80	53, 55, 56	278,520 ft^3	751,910	278,520 ft^3	935,720	0	9,030	530
Gravity Filtration - 5 gpm/ft^2	67, 68, 69	13,900 ft^2	2,917,780	13,900 ft^2	2,139,720	0	20,740	8,206
Filter Media - Mixed Media	70	13,900 ft^2	321,180	13,900 ft^2	0	0	0	0
Surface Wash	74, 75, 76	13,900 ft^2	313,830	13,900 ft^2	190,790	0	490	375
Backwash Pumping	71, 72, 73	22,950 gpm	209,520	13,900 ft^2	332,190	0	4,130	345
Clearwell Storage - Below Ground	207	8,300,000 gal	1,695,770	-	0	0	0	0
Finished Water Pumping - 300' tdh	204, 205, 206	150 mgd	1,089,310	70 mgd	13,767,940	0	9,880	2,027
Wash Water Surge Basin	80	300,000 gal	381,500	300,000 gal	0	0	0	0
Gravity Sludge Thickener - 1 unit	166, 167, 168	4700 ft^2	160,890	4700 ft^2	9,250	0	850	234
Filter Press	177, 178, 179	378 ft^3	1,070,120	378 ft^3	943,200	0	6,720	15,661
Dewatered Sludge Hauling - 20 miles	196, 199, 200	14,000 yd^3/yr	81,290	14,000 yd^3/yr	0	5,540	6,060	1,042
Administrative, Laboratory and Maintenance Building	214, 215, 216	100 mgd	310,300	100 mgd	707,600	0	14,420	11,190
Subtotal	--	--	10,374,020	--	33,071,200	5,540	86,870	44,072
Sitework, Interface Piping, Road @ 5%	--	--	518,700	--	--	--	--	--
Subsurface Considerations	--	--	0	--	--	--	--	--
Standby Power	--	--	0	--	--	--	--	--
Total Construction Cost	--	--	10,892,720	--	--	--	--	--
General Contractor's Overhead and Profit	--	--	980,340	--	--	--	--	--
Subtotal	--	--	11,873,060	--	--	--	--	--
Engineering @ 10%	--	--	1,187,300	--	--	--	--	--
Subtotal	--	--	13,060,360	--	--	--	--	--
Land, 24.5 acres @ $2,000/acre	--	--	49,000	--	--	--	--	--
Legal, Fiscal, and Administrative	--	--	81,800	--	--	--	--	--
Interest during Construction - 7%	--	--	1,044,030	--	--	--	--	--
Total Capital Cost	--	--	$14,235,190	--	--	--	--	--

*Note - Figure numbers refer to Volume 2 of this report.

Table 27

Annual Cost for a 100 mgd

Direct Filtration Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 1,343,660
Labor, 44,072 @ $10/hr (Total Labor Costs Including Fringes & Benefits)	440,720
Electricity, 33,071,200 kw-hr @ $0.03	992,140
Fuel, 5,540 gal @ $0.65/gal	3,600
Maintenance Material	86,870
Chemicals, Alum, 2,190 tons/yr @ $70/ton; Polymer, 18,250 lb/yr @ $2/lb; Chlorine, 200.8 tons/yr @ $300/ton	250,030
Total Annual Cost*	3,117,020

$$\text{*Cents per 1,000 gal treated} = \frac{\$3,117,020\ (100)}{70,000\ (365)}$$

$$= 12.20¢/1,000 \text{ gal treated}$$

Table 28

Design Criteria and Cost Calculation
for a 5-mgd Reverse Osmosis Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)
Reverse Osmosis	113, 114, 115	5 mgd	$2,869,040	3.5 mgd	8,323,980	261,480	2,121
Clearwell Storage - Below Ground Level	207	300,000 gal	155,100	-	0	0	0
Chlorine Feed System - 1.5 mg/l	1, 2, 3	63 lb/day	17,880	44 lb/day	15,850	1,630	436
Finished Water Pumping - 200' tdh	204, 205, 206	8 mgd	85,730	3.5 mgd	570,910	700	581
Subtotal	---	---	$3,127,750	---	8,915,740	263,810	3,138
Sitework, Interface Piping, Roads @ 5%	---	---	156,390	---	---	---	---
Subsurface Considerations	---	---	0	---	---	---	---
Standby Power	---	---	0	---	---	---	---
Total Construction Cost	---	---	3,284,140	---	---	---	---
General Contractors Overhead and Profit	---	---	328,410	---	---	---	---
Subtotal	---	---	3,612,550	---	---	---	---
Engineering at 10%	---	---	361,260	---	---	---	---
Subtotal	---	---	3,973,810	---	---	---	---
Land, 1.5 acres @ $2,000/acre	---	---	3,000	---	---	---	---
Legal, Fiscal, and Adminstrative	---	---	37,290	---	---	---	---
Interest during Construction - 7%	---	---	230,620	---	---	---	---
Total Capital Cost	---	---	4,244,720	---	---	---	---

*Note - Figure numbers refer to Volume 2 of this report.

Table 29

Annual Cost for a 5 mgd

Reverse Osmosis Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 400,670
Labor, 3,138 hr @ $10/hr (Total Labor Costs Including Fringes & Benefits)	31,380
Electricity, 8,915,740 kw-hr @ $0.03	267,470
Maintenance Material	263,810
Chemicals, Sulfuric Acid, 190 tons/yr @ $65/ton; . Sodium Hexameta Phos., 38 tons/yr @ $650/ton; Chlorine, 19 tons/yr @ $300/ton	41,800
Total Annual Cost*	1,005,130

$$\text{*Cents per 1,000 gal treated} = \frac{\$1,005,130\ (100)}{3,500\ (365)}$$

$$= 78.68¢/1,000 \text{ gal treated}$$

PRESSURE ION EXCHANGE SOFTENING PLANT

Like reverse osmosis, ion exchange softening can be used to remove many of the contaminants included in the Interim Regulations, as shown in Tables 4, 5, and 6. This example is for a 5 mgd plant using pressure ion exchange softening. The plant is complete and operable, including chlorination, clearwell storage, and finished water pumping.

The design criteria and the capital and annual cost calculations are shown in Tables 30 and 31. The estimated annual cost for the 5 mgd plant operating at 70 percent of capacity is 24.82 ¢/1,000 gal. This unit cost is substantially less than that for water produced by a reverse osmosis plant of equal size, indicating that if both processes remove the contaminant or contaminants of concern, pressure ion exchange softening would normally be the process selected.

LIME SOFTENING PLANT EXAMPLE

Tables 4 and 5 illustrate that lime softening may be used to remove many of the contaminants included in the Interim Regulations. This example is for a typical 25 mgd lime-softening plant operating at 70 percent of capacity, or 17.5 mgd. The plant includes chemical feed systems, upflow solids contact clarification, and recarbonation using stack gas, filtration, clearwell storage, and finished water pumping. Lime was assumed to be dewatered using a basket centrifuge and then recalcined for reuse. Waste sludge was hauled to landfill.

The design criteria and the capital and annual cost calculations are shown in Tables 32 and 33. The estimated annual cost for this 25-mgd plant operating at 17.5 mgd is 24.57 ¢/1,000 gal.

PRESSURE FILTRATION PLANT EXAMPLE

Pressure filters often show an economic advantage in small and medium sized plants, especially when the suspended solids concentration is relatively high. When the filter is followed by another process that operates under pressure, such as pressure ion exchange or pressure granular carbon adsorption, pressure filtration may also be economically advantageous. This example is for a 10 mgd pressure filtration plant operating at 7 mgd. The plant includes chemical feed systems, filter supply pumping, pressure filters, clearwell storage, finished water pumping, and sludge storage lagoons.

The design criteria and the capital and annual cost calculations are presented in Tables 34 and 35. The estimated capital cost for this 10 mgd plant operating at 7 mgd is $1.8 million, and the estimated annual cost is 16.34 ¢/1,000 gal treated.

CORROSION CONTROL EXAMPLE

Although a wide variety of chemicals may be used for corrosion control, one of the more common methods of preventing corrosion is to elevate pH.

Table 30

Design Criteria and Cost Calculation
for a 5-mgd Ion Exchange Softening Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)
In-Plant pumping - 75' tdh	108, 109, 110	7.5 mgd	62,490	3.5 mgd	527,260	680	586
Pressure Ion Exchange Softening	116, 117, 118	5 mgd	485,650	3.5 mgd	176,600	15,390	2,548
Sodium Hydroxide Feed System - 15 mg/l	33, 34, 35	625 lb/day	19,180	438 lb/day	13,060	150	126
Chlorine Feed System - 1.5 mg/l	1, 2, 3	63 lb/day	17,880	44 lb/day	15,850	1,630	436
Clearwell Storage - Ground Level	207	500,000 gal	128,070	-	0	0	0
Finished Water Pumping - 200' tdh	204, 205, 206	8 mgd	85,730	3.5 mgd	570,910	700	581
Subtotal	--	--	799,000	--	1,303,680	18,550	4,276
Sitework, Interface Piping, Roads @ 5%	--	--	39,950	--	--	--	--
Subsurface Considerations	--	--	0	--	--	--	--
Standby Power	--	--	0	--	--	--	--
Total Construction Cost	--	--	838,950	--	--	--	--
General Contractor's Overhead and Profit	--	--	100,670	--	--	--	--
Subtotal	--	--	939,620	--	--	--	--
Engineering at 10%	--	--	93,960	--	--	--	--
Subtotal	--	--	1,033,580	--	--	--	--
Land, 1.5 acres @ $2,000/acre	--	--	3,000	--	--	--	--
Legal, Fiscal, and Administrative	--	--	17,680	--	--	--	--
Interest during Construction - 7%	--	--	51,460	--	--	--	--
Total Capital Cost	--	--	1,105,720	--	--	--	--

*Note - Figure numbers refer to Volume 2 of this report.

Table 31

Annual Cost for a 5 mgd

Ion Exchange Softening Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 104,370
Labor, 4,276 hr @ $10/hr (Total Labor Costs Including Fringes & Benefits)	42,760
Electricity, 1,303,680 kw-hr @ $0.03	39,110
Maintenance Material	18,550
Chemicals, Salt, 3,130 tons/yr @ $30/ton; Sodium Hydroxide, 80 tons/yr @ $200/ton; Chlorine, 8.03 tons @ $300/ton	112,290
Total Annual Cost*	317,080

*Cents per 1,000 gal treated = $\frac{\$317,080\ (100)}{3,500\ (365)}$

= 24.82¢/1,000 gal treated

Table 32
Design Criteria and Cost Calculation for a 25 mgd Lime Softening Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy (kw-hr/yr)	Diesel Fuel (gal/yr)	Natural Gas (scf/yr)	Maintenance Material ($/yr)	Labor (hr/yr)
Lime Feed System - 300 mg/l	24, 25, 26	2600 lb/hr	$ 99,400	1800 lb/hr	40,320	0	0	1,380	2,827
Chlorine Feed System - 3 mg/l	1, 2, 3	625 lb/day	65,530	365 lb/day	75,250	0	0	2,350	2,827
Rapid Mix - 1 min., G=600	50, 51, 52	2320 ft^3	39,070	2320 ft^3	236,720	0	0	50	483
Upflow Solids Contact Clarifiers - G=110 - 5 Clarifiers	63, 64, 65	4455 ft^2	1,325,150	4455 ft^2	387,560	0	0	7,170	3,131
Recarbonation Basins - 15 min., 5 basins	85	6964 ft^3	137,670	6964 ft^3	0	0	0	0	0
Recarbonation - Stack Gas as CO_2 Source	92, 93, 94	50,000 lb/day	186,340	30,000 lb/day	519,400	0	0	5,960	518
Filtration - 5 gpm/ft^2	67, 68, 69	3470 ft^2	1,250,750	3470 ft^2	641,060	0	0	8,560	3,280
Filter Media - Mixed Media	70	3470 ft^2	98,130	3470 ft^2	0	0	0	0	0
Surface Wash	74, 75, 76	3470 ft^2	115,680	3470 ft^2	48,390	0	0	340	248
Backwash Pumping - 18 gpm/ft^2	71, 72, 73	23,000 gpm	209,790	3470 ft^2	82,910	0	0	2,460	264
Wash Water Surge Basin	80	250,000 gal	374,740	-	0	0	0	0	0
Clearwell - Below Ground	207	2,500,000 gal	912,030	-	0	0	0	0	0
Finished Water Pumping - 260' tdh	204, 205, 206	40 mgd	327,620	17.5 mgd	3,227,830	0	0	2,720	880
Thickened Sludge Pumping	163, 164, 165	70 gpm	19,140	50 gpm	30,920	0	0	2,130	92
Basket Centrifuge	185, 186, 187	100,000 gpd	306,750	100,000 gpd	505,700	0	0	3,760	10,152
Lime Recalcination Furnace - 1 unit	95, 96, 97	280 ft^2	1,061,010	280 ft^2	413,840	0	33,129,320	7,640	4,023
Dewatered Sludge Hauling - 20 miles	196, 198, 199	800 yd^3/yr	46,060	500 yd^3/yr	0	630	0	610	191
Administration, Laboratory and Maintenance Building	214, 215, 216	25 mgd	159,320	25 mgd	363,730	0	0	7,100	6,582
Subtotal	--	--	6,734,180	--	6,573,630	630	33,129,320	52,230	33,352
Sitework, Interface Piping, Roads @ 5%	--	--	336,710	--	--	--	--	--	--
Subsurface Considerations	--	--	0	--	--	--	--	--	--
Standby Power	--	--	0	--	--	--	--	--	--
Total Construction Cost	--	--	7,070,890	--	--	--	--	--	--
General Contractor's Overhead and Profit	--	--	707,090	--	--	--	--	--	--
Subtotal	--	--	7,777,980	--	--	--	--	--	--
Engineering @ 10%	--	--	777,790	--	--	--	--	--	--
Subtotal	--	--	8,555,770	--	--	--	--	--	--
Land, 9 acres @ $2,000/acre	--	--	18,000	--	--	--	--	--	--
Legal, Fiscal, and Administrative	--	--	62,330	--	--	--	--	--	--
Interest during Construction - 7%	--	--	596,670	--	--	--	--	--	--
Total Capital Cost	--	--	9,232,770	--	--	--	--	--	--

*Note - Figure numbers refer to Volume 2 of this report.

Table 33

Annual Cost for a 25 mgd

Lime Softening Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 871,480
Labor, 33,352 hr @ $10/hr (Total Labor Costs Including Fringes & Benefits)	333,520
Electricity, 6,573,630 kw-hr @ $0.03	197,210
Fuel, 630 gal @ $0.65/gal	410
Natural Gas, 33,129,320 scf @ $0.0013/scf	43,070
Maintenance Material	52,230
Chemicals, Lime, 788.4 tons/yr @ $65/ton; Chlorine, 66.6 tons/yr @ $300/ton	71,230
Total Annual Cost	1,569,150

$$\text{*Cents per 1,000 gal treated} = \frac{\$1,569.150\ (100)}{17,500\ (365)}$$

$$= 24.57¢/1,000 \text{ gal treated}$$

Table 34

Design Criteria and Cost Calculation for a 10 mgd Pressure Filtration Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy (kw-hr/yr)	Diesel Fuel (gal/yr)	Maintenance Material ($/yr)	Labor (hr/yr)
In-Plant Pumping 75' tdh	108, 109, 110	15 mgd	$ 101,130	7 mgd	1,003,170	0	1,160	662
Chlorine Feed System - 2.3 mg/l	1, 2, 3	190 lb/day	29,400	120 lb/day	29,900	0	1,810	495
Polymer Feed System - 0.15 mg/l	21, 22, 23	13 lb/day	20,280	8 lb/day	25,560	0	270	199
Sodium Hydroxide Feed System - 15 mg/l	33, 34, 35	1250 lb/day	23,650	880 lb/day	20,470	0	170	132
Pressure Filtration Plant	105, 106, 107	1390 ft^2	550,250	1390 ft^2	575,710	0	7,030	3,039
Filter Media - Mixed Media	70	1390 ft^2	43,860	1390 ft^2	0	0	0	0
Backwash Pumping - 18 gpm/ft^2	71, 72, 73	5210 gpm/ft^2	81,080	1390 ft^2	33,220	0	1,460	224
Wash Water Surge Basin	80	50,000 gal	160,690	-	0	0	0	0
Clearwell Storage - Ground Level	207	800,000 gal	186,360	-	0	0	0	0
Finished Water Pumping - 150' tdh	204, 205, 206	15 mgd	104,670	7 mgd	779,200	0	1,210	655
Sludge Storage Lagoon	173, 174, 175	40,000 ft^2	10,040	35,000	0	330	70	287
Administration, Laboratory, and Maintenance Building	214, 215, 216	10 mgd	82,380	10 mgd	187,980	0	4,150	3,725
Subtotal	--	--	1,393,790	--	2,655,210	330	17,330	9,419
Sitework, Interface Piping, Roads @ 5%	--	--	69,690	--	--	--	--	--
Subsurface Considerations	--	--	0	--	--	--	--	--
Standby Power	--	--	0	--	--	--	--	--
Total Construction Cost	--	--	1,463,480	--	--	--	--	--
General Contractor's Overhead and Profit	--	--	175,610	--	--	--	--	--
Subtotal	--	--	1,639,090	--	--	--	--	--
Engineering @ 10%	--	--	163,910	--	--	--	--	--
Subtotal	--	--	1,803,000	--	--	--	--	--
Land, 2.2 acres @ $2,000/acre	--	--	4,400	--	--	--	--	--
Legal, Fiscal, and Administrative	--	--	23,110	--	--	--	--	--
Interest during Construction - 7%	--	--	93,770	--	--	--	--	--
Total Capital Cost	--	--	1,924,280	--	--	--	--	--

*Note - Figure numbers refer to Volume 2 of this report.

Table 35

Annual Cost for a 10 mgd

Pressure Filtration Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 181,630
Labor, 9,419 hr @ $10/hr (Total Labor Costs Including Fringes & Benefits)	94, 190
Electricity, 2,655,210 kw-hr @ $0.03	79,660
Fuel, 330 gal @ $0.65/gal	210
Maintenance Material	17,320
Chemicals, Chlorine 22 tons/yr @ $70/ton; Polymer, 2,920 lb/yr @ $2/lb; Sodium Hydroxide, 161 tons/yr @ $200/ton	44,530
Total Annual Cost*	417,540

$$\text{*Cents per 1,000 gal treated} = \frac{\$417{,}540\ (100)}{7{,}000\ (365)}$$

$$= 16.34¢/1{,}000 \text{ gal treated}$$

This example is for corrosion control by the addition of lime. The facility was assumed to have a 5 mgd capacity and operate at 3.5 mgd. The lime feed rate was 30 mg/1.

The capital and annual cost calculations are shown in Tables 36 and 37. The estimated capital cost is $95,750, and the annual cost would be 2.16 ¢/1,000 gal.

GRANULAR ACTIVATED CARBON PLANT EXAMPLES

Granular activated carbon has great versatility for the removal of organic compounds, including trihalomethanes, from water. Generally, the smaller installations are pressure, and larger installations are gravity flow using large-diameter steel contactors or concrete contactors similar to rapid sand filter structures.

Examples are presented for three different capacity granular activated carbon plants: 2 mgd, 20 mgd, and 110 mgd. The two smaller plants operate using pressure steel contactors, and the 110 mgd plant operates using gravity steel contactors. Another difference is the method of carbon regeneration utilized. The 2 mgd facility uses off-site regional regeneration and assumes that the 2 mgd plant is 5 percent of the amount of carbon regenerated at the regional facility. The 20 mgd plant uses on-site carbon infrared carbon regeneration, and the 110 mgd plant uses on-site, multiple-hearth regeneration. Each example is for a complete and operable plant, including raw water pumping, chlorination, clearwell storage, and finished water pumping.

The design criteria utilized and the capital and annual cost calculations are shown in Tables 38 and 39 for the 2 mgd example, in Tables 40 and 41 for the 20 mgd example, and in Tables 42 and 43 for the 110 mgd example.

Table 36

Design Criteria and Cost Calculation

for a 5 mgd Corrosion Control Facility

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)
Lime Feed System - 30 mg/l	24, 25, 26	50 lb/yr	$ 70,420	35.0 lb/hr	26,770	790	702
Subtotal	--	--	70,420	--	--	--	--
Sitework, Interface Piping, Roads @ 5%	--	--	3,520	--	--	--	--
Subsurface Considerations	--	--	0	--	--	--	--
Standby Power	--	--	0	--	--	--	--
Total Construction Cost	--	--	73,940	--	--	--	--
General Contractor's Overhead and Profit	--	--	8,870	--	--	--	--
Subtotal	--	--	82,810	--	--	--	--
Engineering at 10%	--	--	8,280	--	--	--	--
Subtotal	--	--	91,090	--	--	--	--
Land, 0 acres @ $2,000/acre	--	--	0	--	--	--	--
Legal, Fiscal, and Administrative	--	--	3,630	--	--	--	--
Interest during Construction - 7%	--	--	1,030	--	--	--	--
Total Capital Cost	--	--	$95,750	--	--	--	--

*Note - Figure numbers refer to Volume 2 of this report.

Table 37

Annual Cost for a 5 mgd

Corrosion Control Facility

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 9,040
Labor, 702 hr @ $10/hr, (Total Labor Costs Including Fringes & Benefits)	7,020
Electricity, 26,770 kw-hr @ $0.03	800
Maintenance Material	790
Chemicals, Lime, 153 tons/yr @ $65/ton	9,960
Total Annual Cost*	27,610

$$\text{*Cents per 1,000 gal treated} = \frac{\$27{,}610\ (100)}{3.5\ (365)}$$

$$= 2.16¢/1{,}000 \text{ gal treated}$$

Table 38

Design Criteria and Cost Calculation for a

2 mgd Pressure Granular Activated Carbon Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy kw-hr/yr	Natural Gas (scf/yr)	Diesel Fuel (gal/yr)	Maintenance Material ($/yr)	Labor (hr/yr)
In Plant Pumping - 60' tdh	108, 109, 110	3 mgd	$ 38,570	1.4 mgd	192,130	0	0	400	540
Pressure Carbon Contactors - 20 min. E.B.C.T.	134, 135, 136	1850 ft^3/ Contactor	351,810	5570 ft^3	153,680	0	0	2,080	1,096
Initial Carbon Charge - 26 lb/ft^3	138	145,800 lb	89,380	-	0	0	0	0	0
Backwash Pumping - 10 gpm/ft^2	71, 72, 73	1130 gpm	38,240	-	0	0	0	0	0
Wash Water Surge Basin	80	10,000 gal	51,070	-	0	0	0	0	0
Off-Site Regional Regeneration - Transportation - 20 miles	140, 141, 142		105,480	874,800 lb/yr	0	0	3,380	350	285
Off-Site Regional Regeneration **		800 sq ft	107,550	560 sq ft	38,950	3,973,960	0	540	440
Make-up Carbon - 7%/regen., 6 regen./yr	138	-	0	60,830 lb/yr	0	0	0	37,920	0
Chlorine Feed System - 1.5 mg/l	1, 2, 3	25 lb/day	14,350	15 lb/day	11,570	0	0	1,570	413
Clearwell Storage - Ground Level	207	200,000 gal	68,010	-	0	0	0	0	0
Finished Water Pumping - 150' tdh	204, 205, 206	3 mgd	51,360	1.4 mgd	205,740	0	0	390	535
Administration, Laboratory and Maintenance Building	214, 215, 216	2 mgd	31,990	2 mgd	72,880	0	0	2,300	1,806
Subtotal	--	--	947,810	--	674,950	3,973,960	3,380	45,550	5,116
Sitework, Interface Piping, Roads @ 5%	--	--	47,390	--	--	--	--	--	--
Subsurface Considerations	--	--	0	--	--	--	--	--	--
Standby Power	--	--	0	--	--	--	--	--	--
Total Construction Cost	--	--	995,200	--	--	--	--	--	--
General Contractor's Overhead and Profit	--	--	119,430	--	--	--	--	--	--
Subtotal	--	--	1,114,630	--	--	--	--	--	--
Engineering @ 10%	--	--	111,470	--	--	--	--	--	--
Subtotal	--	--	1,226,100	--	--	--	--	--	--
Land, 2 acres $ 2,000/acre	--	--	4,000	--	--	--	--	--	--
Legal, Fiscal, and Administrative	--	--	19,060	--	--	--	--	--	--
Interest during Construction - 7%	--	--	61,740	--	--	--	--	--	--
Total Capital Cost	--	--	1,310,900	--	--	--	--	--	--

*Note - Figure numbers refer to Volume 2 of this report.

**Assumes this plant uses 5% of the regional regeneration facilities, and that the regional facilities operate at 70 percent of full capacity. No curve is included in Volume 2, but the computer uses the curve for multiple hearth granular carbon regeneration.

Table 39

Annual Cost for a 2 mgd

Pressure Granular Activated Carbon Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 123,740
Labor, 5,116 hr @ $10/hr (Total Labor Costs Including Fringes & Benefits)	51,160
Electricity, 674,950 kw-hr @ $0.03	20,250
Natural Gas, 3,973,960 scf @ $0.0013/scf	5,170
Fuel, 3,380 gal @ $0.65/gal	2,200
Maintenance Material	45,550
Chemicals, Chlorine, 2.7 tons/yr @ $300/ton . . .	820
Total Annual Cost*	248,890

$$\text{*Cents per 1,000 gal treated} = \frac{\$248,890\ (100)}{1,400\ (365)}$$

$$= 48.71¢/1,000\ \text{gal treated}$$

Table 40

Design Criteria and Cost Calculation for a

20 mgd Pressure Granular Activated Carbon Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)
In-Plant Pumping - 70' tdh	108, 109, 110	30 mgd	$ 174,380	14 mgd	1,816,860	2,140	814
Pressure Carbon Contactors - 20 min. E.B.C.T.	134, 135, 136	1160 ft^3/ Contactor	2,370,400	2715 ft^2	850,590	13,640	3,129
Initial Carbon Charge - 26 lb/ft^3	138	724,100 lb	437,100	-	0	0	0
Backwash Pumping - 10 gpm/ft^2	71, 72, 73	1130 gpm	41,530	-	0	0	0
Wash Water Surge Basin	80	12,000 gal	57,280	-	0	0	0
Infrared Carbon Regeneration	146, 147, 148	16,500 lb/day	657,750	11,600 lb/ day	2,370,810	12,480	2,804
Make-up Carbon - 7%/regen., 6 regen/yr	138	250,000 lb/yr	0	175,000 lb/ yr	0	107,040	0
Chlorine Feed System - 1.5 mg/1	1, 2, 3	250 lb/day	34,690	150 lb/day	36,400	1,880	519
Clearwell Storage - Ground Level	207	2,000,000 gal	401,800	-	0	0	0
Finished Water Pumping - 125' tdh	204, 205, 206	30 mgd	154,140	14 mgd	1,237,590	2,220	805
Administration, Laboratory, and Maintenance Building	214, 215, 216	20 mgd	136,090	20 mgd	310,610	6,190	5,730
Subtotal	--	--	4,465,160	--	6,622,860	145,590	13,801
Sitework, Interface Piping, Roads @ 5%	--	--	223,260	--	--	--	--
Subsurface Considerations	--	--	0	--	--	--	--
Standby Power	--	--	0	--	--	--	--
Total Construction Cost	--	--	4,688,420	--	--	--	--
General Contractor's Overhead and Profit	--	--	468,840	--	--	--	--
Subtotal	--	--	5,157,260	--	--	--	--
Engineering @ 10%	--	--	515,720	--	--	--	--
Subtotal	--	--	5,672,980	--	--	--	--
Land, 5 acres @ $2,000/acre	--	--	10,000	--	--	--	--
Legal, Fiscal, and Administration	--	--	47,290	--	--	--	--
Interest during Construction - 7%	--	--	354,760	--	--	--	--
Total Capital Cost	--	--	$6,085,030	--	--	--	--

*Note - Figure numbers refer to Volume 2 of this report.

Table 41

Annual Cost for a 20 mgd Pressure

Granular Activated Carbon Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 574,370
Labor, 13,801 hr @ $10/hr (Total Labor Costs Including Fringes & Benefits)	138,010
Electricity, 6,622,860 kw-hr @ $0.03	198,690
Maintenance Material	145,590
Chemicals, Chlorine, 27.4 tons/yr @ $300/ton . . .	8,210
Total Annual Cost*	1,064,870

*Cents per 1,000 gal treated = $\frac{\$1,064,870\ (100)}{14,000\ (365)}$

= 20.84¢/1,000 gal treated

Table 42

Design Criteria and Cost Calculation for a

110 mgd Gravity, Steel Granular Activated Carbon Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost-$	Operating Parameter	Energy kw-hr/yr	Natural Gas S.C.F/yr	Maintenance Material-$/yr	Labor hr/yr
In-Plant Pumping - 55' tdh	108, 109, 110	150 mgd	$ 717,250	77 mgd	7,479,720	0	11,930	2,147
Gravity, Steel Contactor - 20 min. E.B.C.T., 30' dia.	130, 131, 132	12,765 ft^3/ Contactor	4,922,900	204,250 ft^3	4,104,220	0	23,150	9,268
Initial Carbon Charge - 26 lb/ft^3	138	5,310,500 lb	3,031,660	-	0	0	0	0
Backwash Pumping - 10 gpm/ft^2	71, 72, 73	7070 gpm	97,780	-	0	0	0	0
Wash Water Surge Basin	80	75,000 gal	214,730	-	0	0	0	0
Multiple Hearth Carbon Regeneration Furnace	143, 144, 145	1509 ft^2	2,796,180	1509 ft^2	1,349,760	209,414,200	16,080	17,027
Make-up Carbon, 7%/regen., 6 times/yr	138	-	0	1,858,700 lb/yr	0	0	1,106,300	0
Chlorine Feed System - 2 mg/l	1, 2, 3,	1830 lb/day	141,670	1000 lb/day	181,250	0	3,510	1,141
Clearwell Storage	207	7,000,000 gal	986,170	-	0	0	0	0
Finished Water Pumping - 200' tdh	204, 205, 206	150 mgd	888,480	77 mgd	9,878,630	0	10,790	2,183
Administration, Laboratory, and Maintenance Building	214, 215, 216	110 mgd	315,030	110 mgd	718,060	0	14,850	11,208
Subtotal	--	--	14,111,850	--	23,711,640	209,414,200	1,186,610	42,973
Sitework, Interface Piping, Roads @ 5%	--	--	705,590	--	--	--	--	--
Subsurface Considerations	--	--	0	--	--	--	--	--
Standby Power	--	--	0	--	--	--	--	--
Total Construction Cost	--	--	14,817,440	--	--	--	--	--
General Contractor's Overhead and Profit	--	--	1,333,570	--	--	--	--	--
Subtotal	--	--	16,151,010	--	--	--	--	--
Engineering @ 10%	--	--	1,615,100	--	--	--	--	--
Subtotal	--	--	17,766,110	--	--	--	--	--
Land, 20 acres @ $2,000/acre	--	--	40,000	--	--	--	--	--
Legal, Fiscal, and Administrative	--	--	98,000	--	--	--	--	--
Interest during Construction - 7%	--	--	1,586,100	--	--	--	--	--
Total Capital Cost	--	--	$19,490,210	--	--	--	--	--

*Note - Figure numbers refer to Volume 2 of this report.

Table 43

Annual Cost for a 110 mgd Gravity,

Steel Granular Activated Carbon Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 1,839,680
Labor, 42,973 hr @ $10/hr (Total Labor Costs Including Fringes & Benefits)	429,730
Electricity, 23,711,640 kw-hr @ $0.03	711,350
Natural Gas, 209,414,200 scf @ $0.0013	272,240
Maintenance Material	1,186,610
Chemicals, Chlorine, 182.5 tons/yr @ $300/ton . .	54,750
Total Annual Cost*	4,494,360

$$\text{*Cents per 1,000 gal treated} = \frac{\$4,494,360\ (100)}{77,000\ (365)}$$

$$= 15.99¢/1,000 \text{ gal treated}$$

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APPENDICES

APPENDIX A. ESTIMATING COSTS FOR GRANULAR CARBON SYSTEMS IN WATER PURIFICATION BASED ON EXPERIENCE IN WASTEWATER TREATMENT

Introduction

Because the use of granular activated carbon (GAC) for the purification of potable water in the United States has generally been for controlling taste and odor, there is a rather limited amount of cost data from actual water treatment operations where the GAC is reactivated frequently. However, GAC has been used by United States municipalities since 1965 for the adsorption of organics from pre-treated wastewater. From such applications, complete, detailed, and reliable cost data are available for the construction, operation, and maintenance of complete GAC wastewater treatment systems including carbon contact, reactivation, and transport. These data are available from a number of sources and for a variety of plant capacities up to 20 mgd (million gallons per day).

There are differences in the use of GAC for water purification and for wastewater treatment, and these differences influence cost. Some of the differences are obvious, but others are less apparent. However, a sanitary engineer who is informed and experienced in both fields, as well as in cost estimating, can estimate GAC costs for water purification quite readily, and with the same degree of accuracy (± 15 percent) which is attendant to preliminary estimates for conventional water treatment processes. To do this, the cost experience accumulated from wastewater operations must be combined with the results of water treatment pilot plant task and laboratory tests of carbon reactivation which determine allowable carbon loadings and reactivation requirements.

GAC Systen Components

Systems utilizing granular carbon are rather simple. In general, they provide for: (1) contact between the carbon and the water to be treated for the length of time required to obtain the necessary removal of organics, (2) reactivation or replacement of spent carbon, and (3) transport of makeup or reactivated carbon into the contactors and of spent carbon from the contactors to reactivation or hauling facilities.

Selecting Carbon and Plant Design Criteria

Laboratory and pilot plant tests are a mandatory prelude to carbon selection and plant design for both water and wastewater treatment projects. Pilot column tests make it possible to: (1) select the best carbon for the specific purpose based on performance; (2) determine the required contact time; (3) establish the required carbon dosage, which, together with laboratory tests of reactivation, will determine the capacity of the carbon reactivation furnace or the necessary carbon replacement costs; and (4) determine the effects of influent water quality variations on plant operation.

One of the principal differences in costs for GAC treatment between water and wastewater is the more frequent reactivation required in water purification due to earlier breakthrough of the organics of concern. In wastewater treatment, GAC may be expected to adsorb 0.30 to 0.55 pounds of COD per pound of carbon before the carbon is exhausted. From the limited amount of data available from research studies and pilot plant tests (most of it unpublished), it appears that some organics of concern in water treatment may breakthrough at carbon loadings as low as 0.15 to 0.25 pounds of organic per pound of carbon. The actual allowable carbon loading or carbon dosage for a given case must be determined from pilot plant tests. Costs taken from wastewater cost curves which are plots of flow in mgd versus cost (capital or operation and maintenance costs) cannot be applied directly to water treatment. Allowance must be made in the capital costs for the different reactivation capacity needed, and in the operation and maintenance costs for the actual amount of carbon to be reactivated or replaced.

Because the organics adsorbed from water are generally more volatile than those adsorbed from wastewater, the increased reactivation frequency due to lighter carbon loading may be partially offset, or more than offset, by the reduced reactivation requirements of the more volatile organics. The times and temperatures required for reactivation may be reduced due to both the greater volatility and to the lighter loading of organics in the carbon.

From the limited experimental reactivations to date it appears that reactivation temperatures may be reduced from the 1,650° to 1,750°F required for wastewater carbons to about 1,500°F for water purification carbons. The shorter reactivation times required for water purification carbons may allow the number of hearths in a multiple hearth reactivation furnace to be reduced. Also, less fuel may be required for reactivation. These factors must be determined on a case-by-case basis, as already suggested.

Selection of the general type of carbon contactor to be used for a particular water treatment plant application may be used on several considerations indicating the judgement and experience of the engineering designer. The choice generally would be made from three types of downflow vessels:

1. Deep-bed, factory-fabricated, steel pressure vessels of 12-foot maximum diameter, These vessels might be used over a range of carbon volumes from 2,000 to 50,000 cubic feet.

2. Shallow-bed, reinforced concrete, gravity filter-type boxes may be used for carbon volumes ranging from 1,000 to 200,000 cubic feet. Shallow beds probably will be used only when long service cycles between carbon regenerations can be expected, based on pilot plant test results.

3. Deep-bed, site-fabricated, large (20 to 30 feet) diameter, open steel, gravity tanks may be used for carbon volumes ranging from 6,000 to 200,000 cubic feet, or larger.

These ranges overlap, and the designer may very well make the final selection based on local factors, other than total capacity, which affect efficiency and cost.

GAC Contactors

The advanced wastewater treatment (AWT) experience with GAC contactors may be applied to water purification if some differences in requirements are taken into account. The required contact time must be determined from pilot plant test results. Contactors may be designed for a downflow or upflow mode of operation. Upflow packed beds or expanded beds provide maximum carbon efficiency through the use of countercurrent flow principles. However, upflow beds for water treatment can be used only when followed by filtration due to the leakage of some (1 to 5 mg/l) carbon fines in the upflow carbon column effluent. Downflow carbon beds probably will be used in most municipal water treatment applications.

At the Orange County (California) Water Factory 21, upflow beds were converted to downflow beds which successfully corrected a carbon fines problem. This is one indication at full plant operating scale that carbon fines are not a problem in properly operated downflow contactors.

Single beds or two beds in series may be used. Open gravity beds or closed pressure vessels may be used. Structures may be properly protected steel or reinforced concrete. In general, small plants will use steel, and large plants may use steel or reinforced concrete.

In some instances where GAC has been used in existing water filtration plants, sand in rapid filters has been replaced with GAC. In situations where GAC regeneration or replacement cycles are exceptionally long (several months or years); as may be the case in taste and odor removal, this may be a solution. However, with the short cycles anticipated for most organics, conventional concrete box style filter beds are not well suited to GAC contact. Their principal drawbacks are the shallow bed depths and the difficulty of moving carbon in and out of the beds. Deeper beds, or contactors with greater aspect ratios of depth to area, provide much greater economy in capital costs. The contactor cost for the needed volume of carbon is much less. Carbon can be moved in water slurry from contactors with conical bottoms easily and quickly and with virtually no labor. Flat-bottomed filters which require labor to move the carbon, unnecessarily add to carbon transport costs. For most, if not all, GAC installations for precursor organic removal, or synthetic organic removal, the use of conventional filter boxes will not be a permanent solution and specially designed GAC contactors should be installed. Contactors should be equipped with flow measuring devices. Separate GAC contactors are especially advantageous where GAC treatment is required only part of the time during certain seasons, because they then can be used only when needed and bypassed when not needed, possibly saving unnecessary exhaustion and reactivation of GAC. In summary, tremendous cost savings can be realized in GAC treatment of water through proper selection and design of the carbon contactors. The design of carbon contactor underdrains requires experienced expert attention. Good proven underdrain systems are available, but there have been several underdrain failures due to poor design. Some of these same designs have failed in conventional filter service, but they continue to be misapplied.

GAC Reactivation or Replacement

Spent carbon may be removed from contactors and replaced with virgin carbon, or it may be reactivated either on-site or off-site. The most economical procedure depends on the quantities of GAC involved. For larger volumes, on-site reactivation is the answer. Only for small quantities of carbon will carbon replacement or off-site reactivation be economical.

Carbon may be thermally reactivated to very near virgin activity. However, carbon burning losses may be excessive under these conditions. Experience in industrial and wastewater treatment indicates that carbon losses can be minimized (held to 8 to 10 percent per cycle) if the GAC activity of reactivated carbon as indicated by the Iodine Number, is held at about 90 percent of the virgin activity. For removal of certain organics, there may be no decrease in actual removal of organics despite a 10 percent drop in Iodine Number.

Thermal Reactivation Equipment

GAC may be reactivated in a multiple-hearth furnace, a fluidized bed furnace, a rotary kiln, or an electric infrared furnace. Spent GAC is drained dry in a screen-equipped tank (40 percent moisture content) or in a dewatering screw (40 to 50 percent moisture) before introduction to the reactivated furnace. Dewatered carbon is usually transported by a screw conveyor. Following thermal reactivation, the GAC is cooled in a quench tank. The water-carbon slurry may then be transported by means of diaphragm slurry pumps, eductors, or a blow-tank. The reactivated carbon may contain fines produced during conveyance, and these fines should be removed in a wash tank or in the contactor. Maximum furnace temperatures and time of retention in the furnace are determined by the amount (pounds of organics per pound of carbon) and nature, molecular weight, or volatility, of the organics adsorbed.

Off-gases from carbon reactivation present no air pollution problems provided they are properly scrubbed. In some cases an afterburner may also be required (for odor control).

Required Furnace Capacity

The principal cost differences between GAC treatment of water and wastewater lie in the capital cost of the furnace and in the operation and maintenance costs for carbon reactivation. As already explained, the two principal differences between carbon exhausted in wastewater treatment and carbon exhausted in water purification are that water purification carbons are likely: (1) to be easier to regenerate (less time in furance and lower furnace temperatures), but (2) more lightly loaded (greater volume of carbon to be reactivated per pound of organics removed). Accurate estimates of GAC costs require knowledge and consideration of these two factors. To repeat, it is not possible to use GAC cost curves for AWT based on mgd throughout or plant capacity to obtain costs for water treatment. Differences in reactivation requirements must be taken into account.

Carbon Transport and GAC Process Auxiliaries

There can be large differences in operation and maintenance costs for GAC systems depending on the method selected for carbon transport. Hydraulic transport of GAC in water slurry by gravity or use of water pressure is simple, easy, inexpensive, rapid, and uses very little labor. Moving dry or dewatered carbon manually or with mechanical means involving labor can be very difficult, time consuming, and costly. The proper use of conical bottoms in carbon contactors, dewatering bins, storage bins, wash tanks, and the like can minimize GAC handling costs. Efforts to use flat-bottomed structures requiring operator or other labor to move the carbon can be costly.

SOURCES OF COST AND DESIGN DATA FOR GAC SYSTEMS

General

There are three main sources of cost information and organic adsorption data needed to prepare cost estimates for GAC systems for production of drinking water. These are the: (1) EPA publications, particularly those of recent research at the Cincinnati laboratories, (2) articles concerning the experience with GAC in AWT, and (3) papers concerning the use of GAC in water filtration plants.

EPA Publications

Pertinent publications of interest are:

1. Clark, Robert M., et al., "The Cost of Removing Chloroform and Other Trihalomethanes From Drinking Water Supplies", EPA 600/1-77-008, March, 1977.

2. Symons, James M., "Interim Treatment Guide for Controlling Organic Contaminants in Drinking Water Using Granular Activated Carbon", EPA Water Supply Research Division, Cincinnati, Ohio, January, 1978.

3. "Advanced Wastewater Treatment as Practiced at South Tahoe", EPA 17010ELQ08/71, August, 1971.

Reference No. 2 on page A108 gives an example of the method of converting carbon dosage requirements for water purification into reactivation requirements and costs, using carbon dosage requirements obtained from the results of pilot plant work. This example includes capital and operation and maintenance costs.

AWT Cost Experience

Good cost data is available from operating installations at: (1) The South Tahoe Public Utility District, South Lake Tahoe, California (13 years), (2) the Orange County Water District, Fountain Valley, California (4 years), (3) the Upper Occoquan Sewage Authority, Manassas Park, Virginia (capital cost data only - plant in operation for only a few months).

The South Tahoe data is summarized in two books: (1) Culp, R.L. and Culp, G.L., "Advanced Wastewater Treatment", Van Nostrand Reinhold, New York, 1971, and (2) Culp, Wesner, Culp, "Handbook of Advanced Wastewater Treatment", Van Nostrand Reinhold, New York, 1978.

GAC Experience in Potable Water Treatment

The experience with 12 integrated filtration-adsorption units is summarized on pages 239-247 of "New Concepts in Water Purification", Culp and Culp, Van Nostrand Reinhold, New York 1974 (see Table 1).

Industrial and Miscellaneous Municipal Carbon Regeneration Furance Installations

Some cost data is also available from the following carbon furance installations:

CARBON FURNACE INSTALLATIONS

Installation	Date	Use	
Colorado Springs, CO	1969	Wastewater	Municipal
Rocky River, OH	1972	"	"
Derry Township, PA	1974	"	"
Vallejo, CA	1974	"	"
Santa Clara V.W.D, Palo Alto, CA	1975	"	"
Tahoe-Truckee San. Dist., CA	1976	"	"
No. Towanda, N.Y.	1976	"	"
Nassau Co. P.U.D., CA	1977	"	"

CARBON FURNACE INSTALLATIONS

(Continued)

Installation	Date	Use	
So. Tahoe P.U.D., CA	1965	Wastewater	Municipal
Orange County (CA) Water District	1972	"	"
Fitchburg, Mass.	1972	"	"
Arlington Co., Va	1977	"	"
Niagra Falls, N.Y.	1977	"	"
Lower Potomac Plant, Va.	1977	"	"
St. Charles, MO	1977	"	"
San. Dist. of L.A. County	1975	"	"
Courtland, N.Y.	1975	"	"
Le Roy, N.Y.	1975	"	"
Hollytex Carpet Mills, PA	1969	Dye Wastewater	
BP Oil, N.H.	1971	Wastewater	Industrial
Stepan Chemical Co., N.Y.	1972	"	"
Hercules, Miss.	1972	"	"
Amerada Hess, N.J.	1973	"	"
American Aniline, PA	1973	"	"
American Cyanimid, N.J.	1977	"	"
Esso Research	1973	"	"
Republic Steel Corp.	1974	"	"
Atlantic Richfield, Wilmington, CA	1970	"	"
Washington Suburban San. Comm. Prince Georges Co., MD (test)	1971	"	"
Mobay Chem., New Martinsville, W. VA.	1972	"	"
Mobay Chem., Baytown, TX	1973	"	"
Niagra Falls, N.Y.	1974	"	"
TRA, Irving, TX	1976	"	"

There are another 30-50 carbon furnaces installed for use in connection with refining (decolorizing) of corn syrup and beet sugar.

APPENDIX B. GEOGRAPHICAL INFLUENCE ON BUILDING-RELATED ENERGY

Overall building-related energy requirements are greatly influenced by the geographical location. Those components that show strong geographical influence are heating and cooling. Whole lighting and ventilation are relatively constant in different geographic areas. A lighting requirement of 2 watts/ft^2 is adequate for most enclosed water treatment processes or equipment. This is equivalent to 17.5 kw-hr/ft^2/year. Ventilating requirements are also relatively constant at 2.2 kw-hr/ft^2/year, based on six air changes per hour.

An analysis was conducted of heating and cooling requirements for each of the 21 cities included in the ENR Indices. This analysis was done for a building module of 20' x 40' x 14', an average winter indoor temperature of 68^{o}F, and an average summer indoor temperature of 75^{o}F. Although it

Table 1

Granular Carbon Installations in

Municipal Water Plants in the United States

Water Plant Location	Year Installed	Size of Plant (mgd)	Flow Rate (gpm ft^3)	Carbon Bed Depth
AWWS Co., Hopewell, Virginia	1961	3.0	2.0	24 in.
Nitro, West Virginia	1966	10.0	1.5-2.0	30 in.
Montecito Co. Water District Santa Barbara, California	1963	1.5	6	12 ft.
Del City, Oklahoma	1967	5.25	2	36 in.
Somerset, Massachusetts	1968	4.5	2	11 in.
Pawtucket, Rhode Island	1969	24	2	18 in.
Lawrence, Massachusetts	1969	10	2	24 in. 30 in.
Piqua, Ohio	1969	8	2	18 in.
Bartlesville, Oklahoma	1970	4.5	2	24 in.
Granite City, Illinois	1971	7	1.4	18 in.
Winchester, Kentucky	1970	1.5	2	24 in.
Mt. Clemens, Michigan	1968	7	1.7	24 in.

Supplemental List

Manchester, N.H.

Passaic, N.J. (Pilot)

Cincinnati, Ohio (Pilot)

Queensburg, N.Y.

Amesburg, Mass.

Goleta, CA

certainly would not be true in many situations, electrical energy was assumed for heating in each area. The results, expressed in terms of kw-hr/ft^2/year, are shown in Table B-1, along with the ventilation and lighting requirements.

As can be seen, building-related energy requirements range from a low of 25.8 kw-hr/ft^2 in Miami to a high of 219.8 kw-hr/ft^2 in Minneapolis. The 21-city average was 102.6 kw-hr/ft^2, and this value was used to develop the total operation/maintenance cost curves included in this report.

APPENDIX C. EXAMPLE CALCULATION OF COST ESTIMATING USING UNIT COST TAKEOFFS FROM A CONCEPTUAL DESIGN

For unit processes which include reinforced concrete structures, the structural costs were determined using unit cost takeoffs for actual or conceptual designs. To illustrate the techniques which were utilized in this estimating procedure, this Appendix has been prepared. The example is a 10 inch thick gang formed structural wall, a cross section of which is shown in Figure 1.

The calculations for walls such as this were performed on the basis of one foot of wall length. The wall under consideration is 11.88 feet high (excluding the footing which is not included in this example). Therefore, each foot of wall length is 11.88 square feet.

The unit costs used in the cost calculations were:

Labor - Concrete forming and placement -	\$210.80/100 sq. ft.
Concrete (Including forming materials) -	\$146.30/100 sq. ft
Steel Reinforcing Bars	
#5 bars - Steel	\$ 30.90/100 feet of bar
- Labor	\$ 21.97/100 feet of bar
#6 bars - Steel	\$ 43.04/100 feet of bar
- Labor	\$ 23.12/100 feet of bar

The length of reinforcing bars per foot of wall (excluding the footing) are 28 feet of #5 bar and 6.7 feet of #6 bar.

Applying the unit costs to the wall design the following costs were calculated per foot of wall:

Labor - Concrete forming and placement	\$ 25.04/foot of wall
Concrete	\$ 17.38/foot of wall
Steel	\$ 11.54/foot of wall
Labor - Steel Placement	\$ 7.70/foot of wall

Table B-1

Geographical Influence on

Building-Related Energy

City	Electrical Energy (kw-hr/ft^2/yr)* Lighting	Ventilation	Heating	Cooling	Total
Seattle	17.5	2.2	59.4	0.2	79.3
Salt Lake City	17.5	2.2	144.0	0.8	164.5
Omaha	17.5	2.2	157.3	0.9	177.9
Minneapolis	17.5	2.2	199.4	0.7	219.8
Chicago	17.5	2.2	146.4	0.8	166.9
New York	17.5	2.2	90.3	0.7	110.7
Boston	17.5	2.2	104.4	0.4	124.5
San Francisco	17.5	2.2	40.5	0.5	60.7
Denver	17.5	2.2	149.5	1.6	170.8
St. Louis	17.5	2.2	116.6	2.4	138.7
Las Vegas	17.5	2.2	36.3	2.4	58.4
Richmond, Va.	17.5	2.2	71.6	1.6	92.9
Nashville	17.5	2.2	70.6	2.0	92.3
Washington, D.C.	17.5	2.2	78.3	1.6	99.6
Los Angeles	17.5	2.2	27.7	0.5	47.9
Phoenix	17.5	2.2	23.7	2.4	45.8
Albuquerque	17.5	2.2	80.6	1.2	101.5
Dallas	17.5	2.2	43.8	5.6	69.1
Tampa	17.5	2.2	9.2	3.2	32.1
Atlanta	17.5	2.2	54.9	1.5	76.1
Miami	17.5	2.2	2.9	3.2	25.8
Average	17.5	2.2	81.3	1.6	102.6

*Building module used was 20 x 40 x 14 ft, with a winter inside design temperature of 68°F, a summer inside design temperature of 75°F, and a ventilation rate of 6 changes per hour.

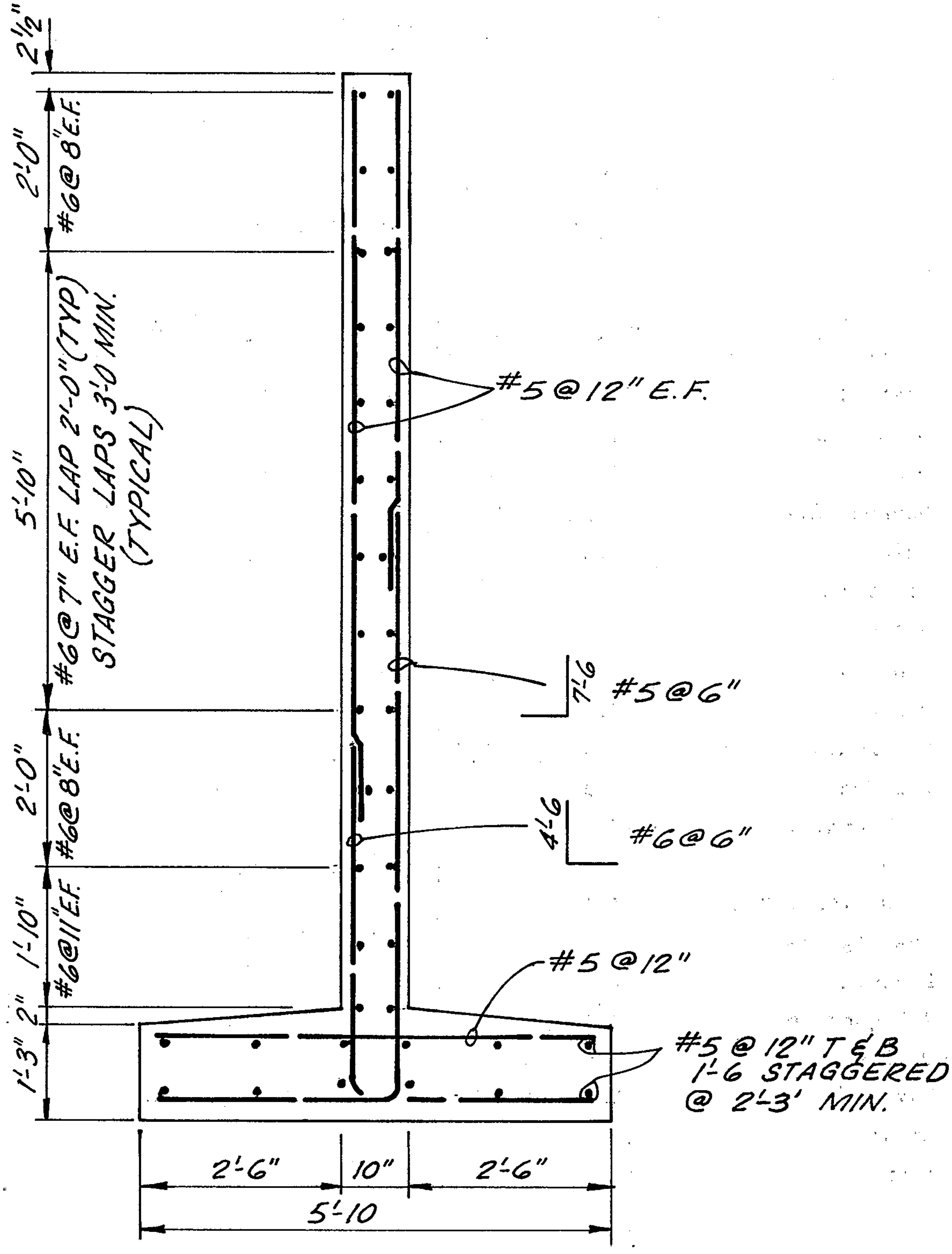

Figure 1. Cross section for outer wall of a typical clarifier structure.

Using these numbers, the cost of an 11.88 foot high wall, fifteen feet long, would be:

Concrete	-	\$260.70
Steel	-	\$173.10
Labor	-	\$491.10

Similar calculations were performed for other portions of reinforced concrete structures, such as slabs, footings, columns, beams, elevated slabs and floors. The additive cost for all portions of the reinforced concrete structure give the cost of the structure itself.

Other costs in the construction cost tables, such as excavation, pipe and valves (installation labor is included in the labor category) were calculated using unit costs, in a manner similar to the above. Electrical and instrumentation and housing costs were estimated from actual bids and cost information from manufacturers. The component for manufactured equipment includes all manufactured equipment except electrical and instrumentation. The manufactured equipment costs, as well as installation labor, were obtained from manufacturers. Labor for manufactured equipment is included within the labor category.

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(Please read Instructions on the reverse before completing)

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16. ABSTRACT

This report discusses unit processes and combinations of unit processes that are capable of removing contaminants included in the National Interim Primary Drinking Water Regulations. Construction and operation and maintenance cost curves are presented for 99 unit processes that are considered to be especially applicable to contaminant removal. The report is divided into four volumes. Volume 1 is a summary volume. Volume 2 presents cost curves applicable to large water supply systems with treatment capacities between 1 and 200 mgd, as well as information on virus and asbestos removal. Volume 3 includes cost curves applicable to flows of 2,500 gpd to 1 mgd. And Volume 4 is a computer program user's manual for the curves included in the report. For each unit process included in this report, conceptual designs were formulated, and construction costs were then developed using the conceptual designs. The construction cost curves were checked for accuracy by a second consulting engineering firm, Zurheide-Herrmann, Inc., using cost-estimating techniques similar to those used by general contractors in preparing their bids. Operation and maintenance requirements were determined individually for three categories: Energy, maintenance material, and labor. Energy requirements for the building and the process are presented separately. Costs are in October 1978 dollars.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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