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1. INTRODUCTION

The U.S. Environmental Protection Agency (EPA), under direction from Congress, is planning to supplement the existing 1989 Surface Water Treatment Rule (SWTR) with three stages of rules to further guard against waterborne disease transmission through water supply systems. These rules are the Interim Enhanced Surface Water Treatment Rule (IESWTR), the Stage 1 Long Term ESWTR (LT1ESWTR) and the Stage 2 Long Term ESWTR (LT2ESWTR). The IESWTR will revise and strengthen the existing SWTR, which presently contains filtration and disinfection requirements for surface water systems and requirements for the removal of and/or inactivation of *Giardia lamblia*, viruses, and bacteria. In advance of comprehensive data collection and analysis efforts necessary to fully evaluate and develop an enhanced regulation, EPA is using currently available information to develop the Interim ESWTR (IESWTR). The IESWTR pertains only to community water systems serving 10,000 or more people, that use either surface water sources or ground water sources under the direct influence of surface water (GWUDI). Subsequent to the IESWTR, EPA will promulgate the LT1ESWTR that will affect community and non-community systems serving less than 10,000 people that use surface water sources or GWUDI. The LT2ESWTR will address some of the key regulatory questions regarding the MCLGs and associated treatment technique requirements for all systems. This document focuses on the technologies and costs associated with the IESWTR.

It is anticipated that compliance with the IESWTR will generally be possible through adjustments to existing treatment processes. However, in some cases, additional treatment processes of other treatment technologies or enhancements (i.e., supervisory control and data acquisition system), may be required. These enhancements may require additional staff to either operator or maintain the new systems. It is not anticipated that systems will need to make major capital improvements. For the purposes of this document, costs and activities associated with meeting the IESWTR were developed for systems using existing facilities with some reconstruction and upgrading, although some new construction options were considered (i.e., new rapid mix basin). Systems considering major capital improvements in order to meet requirements of the IESWTR, should conduct an optimization activity similar to the Composite Correction Program (CCP) in order to assess the real need of construction. The CCP approach is a tool developed by EPA that can be

used to identify and correct factors that limit a plant's performance. The CCP seeks to achieve optimum performance from an existing water treatment facility without major modifications. CCP experience has demonstrated that the proposed turbidity requirements may be produced from systems that are currently meeting the SWTR without major construction (USEPA, 1990).

This document describes treatment technologies, process modifications, and associated costs to improve the removal of microbial pathogens in drinking water systems and to comply with the IESWTR.

1.1. Background

As a means to control pathogens in drinking water, EPA promulgated the SWTR (54 *FR* 27486) on June 29, 1989. The goal of the SWTR is to reduce pathogen risk to less than one infection per year per 10,000 people (10^{-4}). Because many pathogenic microorganisms are particles that can be removed by sedimentation and filtration processes and can be inactivated by disinfection, the SWTR allows the use of filtration and disinfection to achieve target removal or inactivation of *Giardia* cysts and viruses. The SWTR set maximum contaminant level goals of zero for *Giardia lamblia*, viruses, and *Legionella* and promulgated national primary drinking water regulations for public water systems using surface water sources or GWUDI. To protect against health effects from pathogens, the SWTR set criteria under which filtration (including coagulation and sedimentation, as appropriate) is required, outlined procedures for states to determine which systems must install filtration, and set disinfection requirements. The SWTR also includes certain limits on turbidity, specifically:

- Public water systems (PWSs) that use conventional treatment or direct filtration are required to achieve a turbidity performance criterion of 0.5 NTU 95 percent of the time over a 1-month period based on 4-hour sampling intervals.
- Systems may not exceed a maximum turbidity of 5 NTU based on 4-hour sampling intervals.

In 1990, EPA's Science Advisory Board (SAB), an independent panel established by Congress, cited drinking water contamination as one of the highest ranking environmental risks. The

SAB reported that microbiological contaminants (e.g., bacteria, protozoa, and viruses) are likely the greatest remaining health risk management challenge for drinking water suppliers. This view was prompted by the SAB's concern about the number of waterborne disease outbreaks in the United States. Between 1980 and 1994, 378 waterborne disease outbreaks were reported, with over 500,000 cases of disease. Most of the cases (but not outbreaks) were associated with surface water, and specifically to a single outbreak of cryptosporidiosis in Milwaukee in 1993 (over 400,000 cases) (USEPA, 1998a).

Recent investigations have demonstrated small numbers of *Cryptosporidium parvum* oocysts in fully treated (i.e., filtered and disinfected) water from 27 to 54 percent of the municipal treatment plants studied, most of which met these SWTR standards (LeChevallier et al., 1991; 1995). Outbreaks associated with filtered systems illustrate the need for an IESWTR ahead of the LTESWTR.

1.2. Microbial and D/DBP Advisory Committee

To build consensus among stakeholders and to ensure compliance with statutory deadlines for promulgation of the IESWTR and Stage 1 D/DBPR, EPA established the Microbial and D/DBP Advisory Committee (the Committee). The Committee, established under the Federal Advisory Committee Act (FACA) on February 12, 1997, consists of 20 members representing EPA, state and local public health and regulatory agencies, local elected officials, drinking water suppliers, chemical and equipment manufacturers, and public interest groups. This Committee was established as a means to collect, share, and analyze new information and data, as well as to build consensus on the regulatory implications of this new information.

The Committee has reached agreement on several major issues that pertain to the IESWTR as noted below:

- An MCLG for *Cryptosporidium* at zero
- Requirement of a 2-log removal of *Cryptosporidium* for surface water systems serving more than 10,000 people that are required to filter

- Turbidity performance requirements
- Individual filter requirements
- A disinfection profile/microbial benchmarking requirement.

The Committee also recommended treatment process enhancements that may be implemented by systems under this rule. These processes are listed in Section 1.3. The Committee's recommendations are discussed in more detail in the November 3, 1997 National Primary Drinking Water Regulations, Interim Enhanced Surface Water Treatment Rule, Notice of Data Availability (NODA) (*62 FR 59486*).

1.3. Purpose of Document

This document is one of several documents being prepared in support of the IESWTR development and its associated Regulatory Impact Analysis (RIA) for the Interim Enhanced Surface Water Treatment Rule (USEPA, 1998b). This document describes treatment technologies, process and administrative modifications, and associated costs that may be incurred by community water systems to comply with the turbidity requirements of the IESWTR. EPA will use calculated costs to estimate the national treatment costs for compliance with the IESWTR.

Within this document, process enhancements descriptions are divided into the following groups:

- Chemical addition
- Coagulant improvements
- Rapid mixing improvements
- Flocculation improvements
- Settling improvements
- Filtration improvements
- Hydraulic improvements
- Administration culture improvements
- Laboratory modifications

- Process control modifications
- Other modifications.

EPA does not intend for this document to be used as an engineering tool by systems in designing treatment solutions for compliance with the proposed IESWTR. Instead, this document discusses technologies and associated costs only to support regulatory development of the IESWTR. Water suppliers may find this document as a useful reference to supplement more engineering specific guidance and literature.

Certain technologies, especially those involving large financial expenditures, should only be implemented with appropriate engineering guidance, and should consider factors such as:

- Quality and type of raw source water
- Source water turbidity
- Economies of scale and the potential economic impact on the community being served
- Treatment and waste disposal requirements.

An engineering study could be conducted, if needed, to select a technically feasible and cost-effective method to meet the unique needs of each system for improved filter effluent quality to comply with the IESWTR. Depending on the unique circumstances of an individual system, appropriate engineering guidance may take the form of a simple survey of needs and alternative improvements. Some situations may require more extensive water quality analyses or bench and/or pilot scale testing. The engineering study may include preliminary designs and estimated capital, operating and maintenance costs for full-scale treatment.

1.4. Document Organization

This document is organized into four sections and an appendix as follows:

Section 1 – Introduction: This section provides background on the IESWTR, describes the purpose of the document, highlights the recommendations of the Committee regarding the IESWTR, and outlines the document contents.

Section 2 – Overview of Surface Water Treatment Configurations: This section provides a general description of water treatment configurations for surface water systems and ground water systems under the direct influence of surface water. This discussion focuses on existing treatment technologies or unit operations that may be impacted by the IESWTR in addition to supplementary treatment technologies that may be employed by community water systems to meet IESWTR requirements.

Section 3 – Design Criteria and Costs for Treatment Technologies under the IESWTR: This section discusses and provides costs for 10 categories of process enhancements that water treatment plants may have to employ to comply with the IESWTR. Where applicable, the design criteria and assumptions specified in the Watercost model software manual are presented in this section. This design criteria are used to estimate associated design and operation and maintenance (O&M) costs for the impacted treatment technologies for five different population categories. In cases where the process enhancements are not in the Watercost model, current research and best professional judgement is used to provide process descriptions, assumptions and costs. The annualized costs at 3, 7, and 10 percent interest are presented in tables at the end of this chapter, and O&M costs are presented in the text.

Section 4 – References: This section identifies information sources used in the preparation of this document.

Appendix A – Cost Assumptions: Appendix A presents example calculations for the breakdown of costs for one system size as presented in Section 3.

2. OVERVIEW OF SURFACE WATER TREATMENT CONFIGURATIONS

This section provides a general description of the existing treatment systems that may be affected by the IESWTR as identified by the members of the Committee. The discussion includes existing treatment systems or unit operations that may be impacted by the Rule in addition to supplementary treatment systems or units that the Committee believes may have to be added to meet the requirements of the Rule. The systems described include: conventional treatment; direct filtration; slow-sand filtration; package plants; diatomaceous earth filtration; and membrane filtration. Note that for any given treatment configuration, unique site-specific conditions may make design and operation of a treatment system slightly different than another seemingly similar system. That is, for any "typical configuration" or "range of operating parameters," variations of these configurations and operating ranges likely exist. As such, this chapter provides only a basic overview of these systems and does not define design specification or operating ranges. Because the primary goal of the IESWTR is improved public health protection through the removal of pathogens and not pathogen inactivation, chemical disinfection is not discussed in this document. Costs and technologies for disinfection are discussed in the *Technologies and Costs for the Disinfection By-Products Rule* (EPA, 1997).

Filtration of domestic water supplies is the most widely used technique for removing turbidity and microbial contaminants (AWWA/ASCE, 1998). Filtration is defined as passing water through a porous medium, such as a layer of sand, to remove suspended solids and pathogens. Numerous types of filtration systems are used in water treatment plants across the country. The selection of an appropriate system is dependent on several site-specific considerations, most notably water quality and finished water requirements.

Filters are classified in a number of ways. Classification is usually based on loading rate or on type of media. Sand filters are classified as either slow or rapid, based on loading rate. Based on the type of media used, filters may be classified as sand, diatomaceous earth, dual-media (anthracite-sand), or tri-media in which a third finer and heavier sand layer is used (AWWA/ASCE, 1998).

The removal of suspended material from water using filtration occurs via physical, chemical or biological means. Suspended matter is removed by: adsorption of the particles in the water to the filter grains as water passes through the pores in the filter bed, sedimentation of particles while in media pores, and coagulation (floc growth) while traveling through the pores. In the case of slow-sand filters, removal can also occur by biological mechanisms. In membrane filters, particle removal occurs through physical sieving of materials or adsorption of the contaminant onto the membrane. Where rapid rate granular filters are used, coagulation of colloidal material is necessary to retain particulates in the filter bed. Backwashing the filter beds dislodges accumulated material in the filters. The backwash water can then be recycled, treated, and returned to the drinking water treatment train, or sent to a wastewater treatment plant (AWWA/ASCE, 1998).

The IESWTR will require that all surface water systems using filtration that serve more than 10,000 people achieve at least 2-log removal of *Cryptosporidium*. Filtration processes provide various levels of *Cryptosporidium* and *Giardia lamblia* removal. Table 2-1 summarizes current data for the removal of *Cryptosporidium* and *Giardia* for a range of filtration processes. Most of the studies demonstrated at least a 2.0 log removal of *Cryptosporidium* and *Giardia lamblia* for conventional treatment, direction filtration, slow-sand filtration, diatomaceous earth filtration and microfiltration.

2.1. Conventional Treatment

Conventional treatment is the most widely used technology for removing turbidity and microbial contaminants from surface water supplies. Conventional treatment consists of chemical coagulation, rapid mix, flocculation, and sedimentation followed by filtration. Disinfection is provided as necessary. A flow schematic for a conventional water treatment plant is presented as Figure 2-1. Today, many other treatment processes (such as static mixers, upflow solids-contact clarifiers, superpulsators, and dissolved air flotation) may replace or combine a number of the treatment steps shown in the schematic. However, these processes are not being considered in the IESWTR and therefore are not discussed in this document.

Table 2-1. *Cryptosporidium* and *Giardia* Filtration Removal Efficiencies

Type of Treatment	Log Removal	Experimental Design	Researcher
Conventional	*Crypto* 4.2 – 5.2	Pilot plants	Patania et al. 1995
	Giardia 4.1 – 5.1	Pilot plants	Patania et al. 1995
	Crypto 1.9 – 4.0	Pilot-scale plants	Nieminski/Ongerth 1995
	Giardia 2.2 – 3.9	Pilot-scale plants	Nieminski/Ongerth 1995
	Crypto 1.9 – 2.8	Full-scale plants	Nieminski/Ongerth 1995
	Giardia 2.8 – 3.7	Full-scale plants	Nieminski/Ongerth 1995
	Crypto 2.3 – 2.5	Full-scale plants	LeChevallier and Norton 1992
	Giardia 2.2 – 2.8	Full-scale plants	LeChevallier and Norton 1992
	Crypto 2 – 3	Pilot plants	Foundation for Water Research, Britain 1994
	Giardia and *Crypto* 1.5 – 2	Full-scale plant (operation considered not optimized)	Kelley et al. 1995
Direct filtration	*Crypto* 2.7 – 3.1	Pilot plants	Ongerth/Pecaroro 1995
	Giardia 3.1 – 3.5	Pilot plants	Ongerth/Pecaroro 1995
	Crypto 2.7 – 5.9	Pilot plants	Patania et al. 1995
	Giardia 3.4 – 5.0	Pilot plants	Patania et al. 1995
	Crypto 1.3 – 3.8	Pilot plants	Nieminski/Ongerth 1995
	Giardia 2.9 – 4.0	Pilot plants	Nieminski/Ongerth 1995
	Crypto 2 – 3	Pilot plants	West et al. 1994
Slow-sand filtration	*Giardia* and *Crypto* > 3	Pilot plant at 4.5 to 16.5°C.	Shuler and Ghosh 1991
	Crypto 4.5	Full-scale plant	Timms et al. 1995

Upon entering the treatment system, source water is treated with chemical coagulant(s), such

as aluminum sulfate (alum), ferric or ferrous sulfate, ferric chloride, and/or a coagulant aid to destabilize suspended particles and improve sedimentation. Coagulant aids promote adsorption of the colloidal particles to the polymers, and coagulate to form a heavy floc that is easily removed in the settling process. The flow is then subjected to rapid mixing, which blends the coagulant into the raw water. In the flocculation step, coagulated water is gently stirred to allow particles to collide and combine to form larger particles. This produces a dense and readily settleable floc. The flocculated water flows into a sedimentation basin and the dense floc settles thereby clarifying the settled water. Sedimentation should provide a high level of particulate removal, significantly reducing the turbidity level. This clarified water is then filtered to remove particles or turbidity that remains after sedimentation.

To assist with the removal and/or inactivation of pathogens, an oxidant or disinfectant is typically used in the treatment process. Disinfectant may be added at any number of points in the treatment process, depending on the inactivation requirements, and may potentially improve the performance of subsequent treatment processes, including filtration.

2.2. Direct Filtration

In the direct filtration process, suspended solids are removed solely through the filtration process (AWWA/ASCE, 1998). As depicted in Figure 2-2a, direct filtration consists of coagulation followed by rapid mixing and flocculation. Unlike conventional treatment, the chemically conditioned and flocculated water is applied directly to the filters. No separate sedimentation process is used in direct filtration.

In-line filtration is a variation of the direct filtration process. As shown in Figure 2-2b, in-line filtration excludes the flocculation process. Instead of relying on a separate basin, flocculation occurs in the piping or conduit between the rapid mix and filtration processes, in the water volume above the filters, and in the filter media itself.

In both direct and in-line filtration, the filters are responsible for suspended solid, particle, and pathogen removal. Therefore, the type of filter media is very important. Commonly, dual media, tri-media, or deep bed mono-media are used.

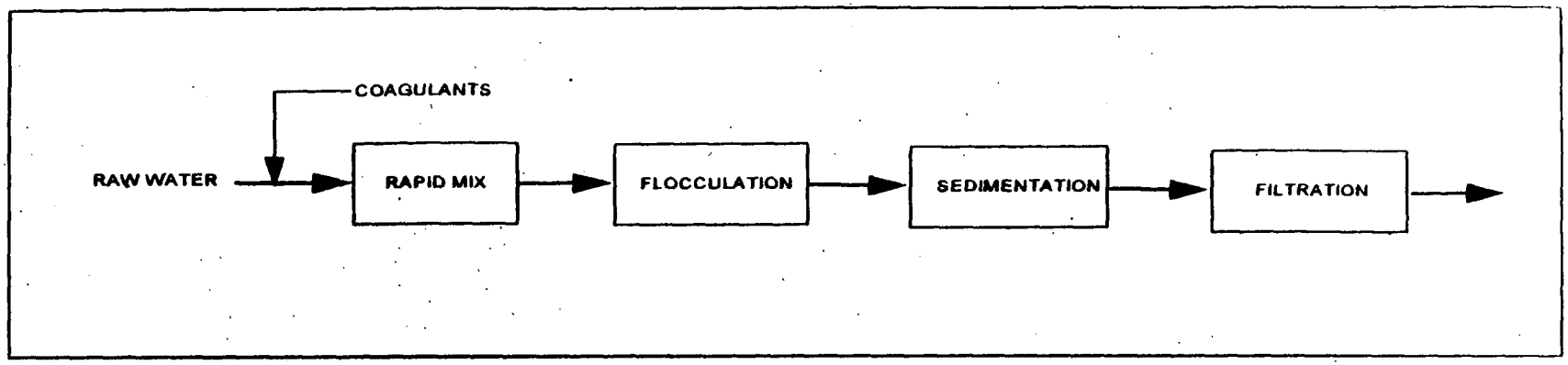

Figure 2-1. Flow Schematics for Conventional Water Treatment Plant

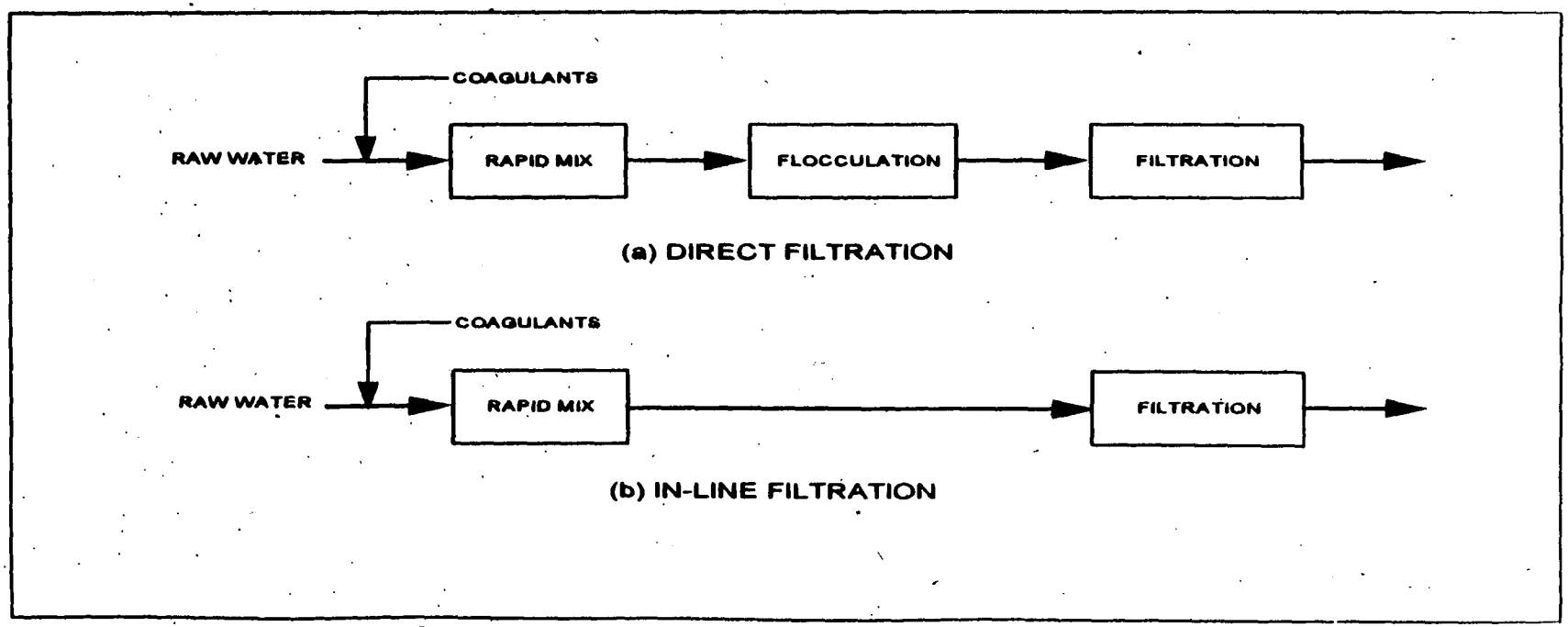

Figure 2-2. Flow Schematics for Direct Filtration Plants

2.3. Slow-Sand Filtration

Slow-sand filtration shares many of the same characteristics as direct filtration, yet a number of important differences exist. In addition to a reduced flow rate, slow-sand filters: (1) function using biological as well as physical mechanisms, (2) have smaller pores between sand particles, (3) do not require backwashing, and (4) have longer run times between cleaning. Slow-sand filtration is found principally in small communities, that have a protected surface watershed and chlorinate as the only other treatment operation. Slow-sand filters are attractive to small water systems because they require little operator attention and no coagulant addition. However, raw water must be of high quality (less than 10 NTU with no color problem) for slow-sand filters to be effective.

Disadvantages of slow-sand filters include the amount of land area required, the difficulty of achieving good results under all raw water conditions, and the possibility of having to cover the filters to protect against freezing in winter and algae growth in summer.

2.4. Package Plants

Package plants are not a distinct technology in the strictest sense, but are different enough in design criteria, operation, and maintenance requirements to be discussed separately. A "package plant" or "package equipment" are pre-assembled, modular units that are for the most part, factory-prepared and assembled. Ideally, package units arrive on-site ready to operate. Connecting the system to the water lines and electrical power may be all that is necessary to begins operation. For purposes of this document, a package plant is defined as a complete modular treatment plant, designed as a factory assembled, skid mounted unit generally incorporating a single, or at the most, several tanks. A complete modular treatment plant typically consists of chemical coagulation, flocculation, settling and filtration.

Package plants are most widely used to treat surface water supplies for removal of turbidity, color, and microbial pathogens prior to disinfection. Additonally, package plants can also remove many inorganic chemicals for which MCLs have been established. Recent improvements to modular treatment systems have resulted in treatment schemes that can be effective in the removal of pathogens, such as *Giardia* and *Cryptosporidium*. Most modular systems utilize high rate treatment

processes, and detention time in modular units is generally shorter than that of custom-engineered conventional treatment plants.

2.5. Diatomaceous Earth Filtration

Diatomaceous earth (DE) filtration, also known as precoat or diatomite filtration, is applicable to direct treatment of surface waters for removal of relatively low levels of turbidity. DE filtration was developed for the U.S. military forces during World War II to remove *Entamoeba histolytica* cysts from water.

Diatomite filters consist of a precoat layer of DE about 1/8-inch thick supported on a septum or filter element. During a filter run, the precoat layer is supplemented by a continuous-body feed of DE material in the raw water. The body feed is used to maintain the porosity of the filter cake. If no body feed is added, the particles filtered out will build up on the surface of the filter cake and cause rapid increases in headloss. Once a predetermined headloss is achieved, the filter is cleaned and precoated for subsequent operation.

2.6. Membrane Filtration

Membrane filtration is a rapidly growing technology in municipal drinking water treatment that can provide an excellent barrier to turbidity, microorganisms, and many other waterborne contaminants. The four categories of pressure-driven membranes are based on the size of the largest particle, colloid, or molecule that can pass through the membrane. A membrane with greater removal capabilities than another is said to be the "tighter" membrane and, in general, the higher the pressure is required to filter water through it. The four categories of pressure-driven membranes are as follows:

- *Microfiltration (MF)* removes particles at the micron or submicron level, including most microbial contaminants
- *Ultrafiltration (UF)* is the next tighter category of membranes and is capable of removing macromolecular materials including viruses
- *Nanofiltration (NF)* first gained interest by the water industry as a softening process, and as such can remove a high percentage of hardness ions and microbial contaminants

- *Reverse osmosis (RO)* is generally applied when brackish or seawater (waters of high mineral content) are used as municipal sources. RO membranes have the capability to remove a high percentage of ionic species as well as other materials such as synthetic organic compounds, natural organic matter, microorganisms, etc.

While there are four categories of membranes each designed for a specific purpose, only microfiltration is discussed in detail within this document. In a conventional plant, the filter is the final barrier for the removal of pathogens and suspended material. Adding microfiltration to a conventional treatment plant can significantly enhance protection of public health by the further removal of pathogens afforded by the new barrier. As such, membranes can be added to a conventional treatment plant as another barrier and a final, polishing treatment step.

3. DESIGN CRITERIA AND COSTS FOR TREATMENT TECHNOLOGIES UNDER THE INTERIM ESWTR

There are many changes that could be made to an existing water treatment plant to modify equipment and procedures to comply with the proposed IESWTR. This section discusses and provides costs for 10 categories of process enhancements discussed by the Committee that water treatment plants may have to employ to comply with the IESWTR. Where applicable, the design criteria and assumptions specified in the document describing the Watercost model, *Estimating Costs for Water Treatment As A Function of Size and Treatment Efficiency (USEPA, 1978)*, are presented in this section. Capital and O&M costs for the process technologies in this section are based upon updated costs originally presented in the EPA (1978) document with some exceptions. The updated manual for an automated costing software program titled, *W/WW Costs & Design Criteria Guidelines 2.0* by CWC Engineering Software (Watercost) (CWC, 1994) was also used as a reference for this section. Microfiltration costs presented in this section are based on the work of Adham et al. (1996). Best professional judgement has been used to estimate costs of administrative culture improvements, laboratory modifications and process control testing modifications.

The design criteria have been used to estimate associated capital and O&M costs for the impacted treatment technologies for five different population categories. In cases where the process enhancements were not in the Watercost model, current research and best professional judgement has been used to provide process descriptions, assumptions and costs. For each option, the conceptual design, and O&M requirements are presented in the text. Capital costs and annual O&M costs are presented in tables at the end of the chapter.

EPA expects that many systems may use a combination of these treatment processes to meet the requirements of the IESWTR. The option selected, be it for one process or several, will depend on site specific considerations, including plant administration, operation, and maintenance.

3.1. Basis of Cost – General

The Watercost model has been used by EPA to develop costs in *Technologies and Costs for the Treatment of Microbial Contaminants in Potable Water Supplies* (EPA, 1988) and *Technologies*

and Costs for Control of Disinfection By-Products (EPA, 1992). The cost information in the software is based on information obtained from numerous sources, including several costs documents prepared for and published by EPA (EPA, 1978, 1979, 1989) as well as project specific information available from other sources.

Construction cost information from the costing software was updated using recent Engineering News Record (ENR) Construction Cost Indices (see Appendix) . Note that the ENR indices do not measure cost differences between cities or different parts of the country, but measure the construction cost trend in the United States as a whole.

The construction costs are derived from equipment cost data supplied by various manufacturers, actual plant construction projects, unit takeoffs from designs not constructed, and published data. The construction cost for each process is presented as a function of the most appropriate design parameter for a given process (e.g., total square feet of filter area for a filtration process). Costs in this document are presented in 1997 dollars.

3.1.1. Capital Costs

The total capital costs presented in this report were generated by the computer model by entering specific process inputs and cost coefficients. Table 3-3 presents the capital costs for each treatment option. The cost coefficients selected were the program's default values and included construction contingency (15 percent), contractor's overhead and profit (12 percent), sitework and piping (18 percent), engineering, technical, and legal (15 percent), and interest during construction (10 percent). Capital costs of ancillary items, such as safety equipment and secondary containment, are included in the sitework and piping factor. The value of these factors represent an overall average of these specific project expenses as a percentage of construction costs, based on information obtained for numerous projects. For unique project or site specific cost factors, no consideration of these is given in the Capital Costs.

Generally, annualized Capital Unit Costs are the Total Capital Costs amortized over 20 years at a 3, 7, and 10 percent discount rate and are presented on a cents per 1,000 gallons average flow basis. The 3 percent discount rate is provided for sensitivity analysis. The 7 and 10 percent discount

rates used in this report are the estimated high and low end interest values that a municipality or utility would be expected to pay for a bond issued to construct improvements to meet the requirements of the IESWTR. In addition, the 10 percent discount rate provides a common basis with the 1994 proposed D/DBP rule and associated cost analyses. For some unit processes, the Annualized Capital Unit Costs are amortized over a shorter period due to unusual operating conditions and expected technology advances. For example, capital costs associated with turbidimeters and SCADA systems are amortized over 7 years, not 20 years. These differences are noted in the cost description for those processes. Tables 3-4, 3-5 and, 3-6 present the annualized capital costs at 3, 7 and 10 percent interest. Tables 3-8, 3-9, and 3-10 present the total annualized costs (capital and O&M costs).

3.1.2. Operation and Maintenance Costs

Annual O&M costs in the program's software are based on energy, maintenance materials, labor, and chemicals. O&M requirements and associated costs were determined using existing plant data, where possible. Table 3-7 presents the O&M costs per 1,000 gallons.

Energy requirements are divided into Process Energy and related Building Energy in kilowatt-hours (Kwh) per year. The energy used to operate motors for the process equipment, controls, and instrumentation is included in Process Energy. Building Energy is an average energy demand per square foot (102.6 Kwh/SF/YR) for lighting, ventilation, and heating of the building that houses a treatment process. The assumed cost of electricity is 12¢/Kwh, which is an overall average for the combined cost of demand charges and energy (average annual demand charge is 4¢/Kwh and energy is 8¢/Kwh).

The cost of periodic replacement of equipment component parts to keep the process functioning is covered in Maintenance Material Costs. The cost of chemicals used in a specific process is not included in Maintenance Material Costs and is a separate annual cost component, which is an estimate of the additional cost on the existing chemical costs that a facility would incur with the appropriate treatment technology addition or change. The unit costs of chemicals in this report are shown in Table 3-1. For the purposes of this document, no difference in unit costs of chemicals based on plant size or geographic region are assumed. However, plants will realize cost savings when purchasing chemicals in bulk.

Table 3-1. Unit Cost of Treatment Chemicals

Chemical	*Cost*	*Unit*
Activated Carbon, Granular	$2,000.00	PER ton
Alum, Liquid stock	$230.00	PER ton
Ammonia, Anhydrous	$300.00	PER ton
Carbon Dioxide, Liquid	$340.00	PER ton
Chlorine, 1 ton cylinders	$350.00	PER ton
Ferric Chloride	$350.00	PER ton
Ferric Sulfate	$350.00	PER ton
Ferrous Sulfate	$350.00	PER ton
Lime, Quicklime	$95.00	PER ton
Polymer	$2.25	PER lb.
Sodium Hydroxide, 25 percent solution	$200.00	PER ton
Sulfuric Acid	$100.00	PER ton

Labor costs are based on the man-hours required for both operation and maintenance. A man-hour cost of $30 per hour, as an average of the municipal/utility overhead and fringe benefit costs, is assumed.

3.2. Basis of Cost – Process by Process

Individual treatment processes to reduce combined filter effluent turbidity of a plant to the levels potentially required by the IESWTR are described in this Section. A conceptual design describing the structure and equipment requirements, is provided for each treatment process option. In addition, the O&M requirements are provided. Chemical usage, where appropriate, is also identified.

Process descriptions are categorized into 10 process enhancement groups. The process groups are as follows:

- Chemical Addition
- Coagulant Improvements

- Rapid Mixing Improvements
- Flocculation Improvements
- Settling Improvements
- Filtration Improvements
- Hydraulic Improvements
- Administration Culture Improvements
- Laboratory Modifications
- Process Control Modifications.

In addition, costs are presented for performing individual filter assessments and third-party Comprehensive Performance Evaluations since these evaluations will be required of systems not meeting IESWTR turbidity requirements.

Costs were calculated for systems serving seven population size categories. These categories represent the population ranges and average and design flows for drinking water systems serving 10,000 or more persons. These size and flow categories are used by EPA when identifying system size. The categories, population ranges, and plant average and design (capacity) flows (EPA, 1989 and AWWA WIDB, 1991) are shown in Table 3-2. Note that the Population Range for Category 12 and 12a are the same, but the flows differ. The difference represents the differences between the two databases used to determine the plant average and design flows for the given population range. The total capital and annual costs for each process are based on plant design and average flows, respectively.

Table 3-2. System Category Size

Category	Population Range	Avg. Flow (mgd)	Design Flow (mgd)
6	10,000 – 25,000	2.1	4.8
7	25,000 – 50,000	5.0	11.0
8	50,000 – 75,000	8.8	18.0
9	75,000 – 100,000	13.0	26.0
10	100,000 – 500,000	27.0	51.0
11	500,000 – 1,000,000	120.0	210.0
12	> 1,000,000	270.0	430.0
12a[1]	> 1,000,000	348.0	518.0

Note: [1]The flows for Category 12a are from the AWWA Water Industry Database, 1991.

3.2.1. Chemical Addition

Evaluation of potential treatment process enhancements should start with a review of chemicals used in the treatment process. This evaluation can identify the appropriateness of the treatment chemicals used presently and can identify the possible use of filter aids, coagulant aids, or ripening additives to improve filtration. This section presents some possible chemical addition changes that may promote better turbidity removal. The four treatment process enhancements that have been costed for chemical addition are:

- Install Coagulant Aid Polymer Feed Capability
- Install Filter Aid Polymer Feed Capability
- Install Backwash Water Polymer/Coagulant Feed Capability
- Install pH Adjustment for Enhancing Alkalinity Purposes.

3.2.1.1. Install Coagulant Aid Polymer Feed Capability

Most surface water treatment facilities use a coagulant (typically metal salts, either aluminum-based or iron-based) to destabilize and coagulate the colloidal particles found in the water for removal during the sedimentation process. Increasing the coagulant dosage may not improve the

settleability of the flocculated water. Therefore, use of a coagulant aid (i.e., polymeric chemicals used to improve coagulation) may be warranted.

Conceptual Design—Cost estimates for coagulant aid polymer feed systems are based on use of dry polymers, fed manually to a large storage hopper located on the chemical feeder. Chemical feed equipment is based on preparation of a 0.25 percent stock solution. For this cost estimate, no standby or redundant equipment is provided. These costs are also representative of the types of package systems that are available for mixing and feeding both dry and liquid polymers (USEPA, 1978; Culp/Wesner/Culp, 1994). Costs assumptions include a separate line and injection point for feeding the selected polymer. For sizing the system, calculations are based on feeding 2 mg/L of polymer at the design flow. The cost assumes that (1) the new polymer system is housed in existing buildings on site; (2) space is available for storing an adequate quantity of polymer between chemical deliveries; (3) the polymer is fed at the rapid mix after coagulant addition; and (4) no additional rapid mixing facilities are needed.

Operation and Maintenance Requirements—Process energy is based on 24-hour/day operation of the system. Annual maintenance material and labor requirements are provided for the general maintenance of the system as well as preparing the polymer stock solution. Chemical usage calculations are based on a polymer dosage of 1 mg/L at average flow.

3.2.1.2. Install Filter Aid Polymer Feed Capability

To improve filtration of settled water, filter aids (i.e., typically polymeric chemicals) can be added to increase the strength of the chemical floc and control the depth of penetration of the floc into the filter. For maximum effectiveness as a filtration aid, the polymer is added directly into the filter influent rather than in an upstream settling basin or flocculator.

Conceptual Design—Cost estimates for filter aid feed systems are based on use of dry polymers, fed manually to a large storage hopper located on the chemical feeder. Chemical feed equipment is based on preparation of a 0.25 percent stock solution. For this cost estimate, no standby or redundant equipment is provided. These costs are also representative of the types of package systems that are available for mixing and feeding both dry and liquid polymers (USEPA,

1978, Culp Wesner Culp, 1994). Costs include a separate line and injection point for feeding the selected polymer. For sizing the system, calculations are based on feeding 1 mg/L of polymer at the design flow. The cost assumes that (1) the new polymer system is housed in existing buildings on site; (2) space is available for storing an adequate quantity of polymer between chemical deliveries; (3) the polymer is fed at the filter influent; and (4) no additional mixing facilities are needed.

Operation and Maintenance Requirements—Process energy is based on 24-hour/day operation of the system. Annual maintenance material and labor requirements are provided for the general maintenance of the system as well as preparing the polymer stock solution. Chemical usage calculations are based on a polymer dosage of 0.2 mg/L at average flow.

3.2.1.3. Install Backwash Water Polymer/Coagulant Feed Capability

To minimize the negative impact associated with filter ripening (e.g., turbidity spikes), filter ripening additives (i.e., polymers or coagulants) can be added to the backwash water. During the backwash of a filter, the media is expanded to allow for the flushing out of the particles removed in the filter. Typically, when the filter is returned to service, the filter is still in a slightly "expanded state" that results in turbidity spikes in the effluent. With time, the filter media will settle back to its original depth, and filter effluent quality will be at or near its best.

Other data show that turbidity spikes occurring after backwash are the result of too few available particles to act as collectors of other particles (i.e., the filter media is too "clean" and the influent water passes through the filter). To increase the number of particles available for deposition on the filter media and act as collectors for subsequent particles, a filter ripening coagulant or polymer can be added to the filter backwash water.

With a filter ripening additive, more particle adsorption sites are provided in the void spaces of the filter media, and turbidity spikes are reduced. Typically, the filter ripening additive is added to the last two volumes of backwash water.

Conceptual Design—For this report, a polymer feed system is provided as the conceptual design for the filter ripening additive. For the use of a coagulant as the filter ripening additive, the

conceptual design should be based on the normal coagulation feedrate using the design backwash flowrate. Cost estimates for filter ripening additive feed systems are based on use of dry polymers, fed manually to a large storage hopper located on the chemical feeder. Chemical feed equipment is based on preparation of a 0.25 percent stock solution. For this cost estimate, no standby or redundant equipment is provided (USEPA, 1978; Culp/Wesner/Culp, 1994). These costs are also representative of the types of package systems that are available for mixing and feeding both dry and liquid polymers.

Costs include a separate line and injection point for feeding the selected polymer. The cost assumes that (1) the new polymer system is housed in existing buildings on site; (2) space is available for storing an adequate quantity of polymer between chemical deliveries; (3) the polymer is fed in the filter backwash water; and (4) no additional mixing facilities are needed. For sizing the system, design calculations are based on feeding 0.5 mg/L of polymer at the design backwash flowrate of 18 gpm/sq ft with 25 percent of the filters backwashed per day (minimum of 2 filters per day).

For a liquid coagulant chemical system design a minimum of 15 days of storage is assumed using fiberglass reinforced polyester (FRP) tanks, or, depending on the chemical, other suitable material. For smaller installations, tanks are uncovered and located indoors. Tanks at larger installations will be located outdoors. Costs are based on the outdoor tanks being covered and vented, with insulation and heating provided to prevent crystallization of the chemical, if necessary. Dual-head metering pumps are included in the cost estimate to pump the coagulant from the storage tanks to the point of application. A standby metering pump is also included in the installation costs.

Operation and Maintenance Requirements— Process energy is based on 24-hour/day operation of the system. Annual maintenance material and labor requirements are provided for the general maintenance of the system as well as preparing the polymer stock solution. Chemical usage calculations are based on a polymer dosage of 0.2 mg/L at average flow.

3.2.1.4. Install pH Adjustment for Enhancing Alkalinity Purposes

Depending on the coagulation process and chemical used, it may be necessary to provide pH adjustment. Several different acids or bases can be used to adjust the pH. For this report, it is assumed that using high doses of coagulant (e.g., a metal salt, such as alum) to improve disinfection byproduct removal will reduce pH below acceptable limits. Therefore, the pH of the water must be raised using sodium hydroxide as the chemical of choice to enhance alkalinity.

Conceptual Design—Cost estimates are based on a 25 percent sodium hydroxide solution delivered by bulk transport. Bulk FRP storage tanks are provided and sized for 15 days of storage. Dual-head metering pumps are used to convey solution to the point of application with a standby metering pump provided. Since 25 percent sodium hydroxide begins to crystallize at temperatures less than minus 5°F, the storage tanks can be located outdoors or indoors. The cost estimate is based on treating the design flow with the 25 percent solution of sodium hydroxide fed at 4 gallons per hour (gph) per MGD.

Operation and Maintenance Requirements—Process energy is based on 24-hour/day operation of the system. Annual maintenance material and labor requirements are provided for the general maintenance of the system as well as handling of the chemical stock solution. Chemical usage calculations are based on treating the average flow with the 25 percent solution of sodium hydroxide fed at 4 gallons per hour (gph) per MGD.

3.2.2. Coagulant Improvements

To improve the settling of particles in the water, changing to a new coagulant and increasing the number of coagulant application points are the proposed enhancements to existing treatment processes. The one treatment process enhancement that has been costed for coagulant improvements is: Primary Coagulant Feed Points, Control, and Measurement.

3.2.2.1. Primary Coagulant Feed Points, Control, and Measurement

Based on past performance, a plant may determine that existing coagulant addition is inadequate to meet the requirements of the IESWTR. To evaluate potential changes in coagulation,

a series of jar tests are needed to evaluate various coagulant types, the need for a coagulant aid, or to change the existing coagulant dosing point(s).

This cost estimate assumes use of a new coagulant and polymer feed system similar to that described in Section 3.2.1.1. The location of the injection points are changed to enhance the settled water quality and help produce a combined filter effluent meeting the requirements of the IESWTR. In addition, instrumentation is provided to monitor water flow for proper coagulant chemical dosages.

Conceptual Design—The same design criteria and equipment components for polymer systems described in Section 3.2.1.1 apply to coagulant improvements.

Operation and Maintenance Requirements—The same O&M requirements for polymer systems described in Section 3.2.1.1 apply to coagulant improvements.

3.2.3. Rapid Mixing

Research and experience has shown that the quick, adequate dispersion of coagulant(s) and/or coagulant aid(s) in water improves flocculation and settling. If an existing facility is not providing ample mixing of the coagulants and water, then improvements to this process should be evaluated. The two treatment process enhancements that have been costed for rapid mixing are:

- Rapid Mix Improvements – Equipment Only
- Rapid Mix Improvements – Equipment and Basin.

Process enhancements could be mechanical or equipment upgrades only or may be the addition of a complete rapid mixing system.

3.2.3.1. Rapid Mix Improvements – Equipment Only

Rapid mix provides complete and thorough mixing of the coagulant and water. Proper design of the rapid mix system allows for lower coagulant doses and improved particle aggregation during flocculation.

Conceptual Design—For the design of the rapid mix improvements, a velocity gradient (G) of 900 sec^{-1} at the design flow is used. Energy requirements are a function of G, water temperature, and an overall mechanism efficiency of 70 percent.

Estimated costs are based on the replacement of equipment only, with no structural work required. The model costs are for a vertical shaft mixer, variable speed turbine with 304 stainless steel shafts and paddles, and TEFC motors.

Operation and Maintenance Requirements—Process energy is based on 24-hour/day operation of the system. Annual maintenance material and labor requirements are provided for the general maintenance of the system as well as handling of the chemical stock solution.

3.2.3.2. Rapid Mix Improvements – Equipment and Basin

The rapid mix improvements to the plant are described in Section 3.2.3.1.

Conceptual Design—For the design of the rapid mix improvements, a G value of 900 sec^{-1} at the design flow is used. Energy requirements are a function of G, water temperature, and an overall mechanism efficiency of 70 percent.

Estimated costs are based on installation of concrete basins with common wall construction. The mixer is a vertical shaft, variable speed turbine mixers with 304 stainless steel shafts and paddles, and TEFC motors.

Operation and Maintenance Requirements—Process energy is based on 24-hour/day operation of the system. Annual maintenance material and labor requirements are provided for the general maintenance of the system as well as handling of the chemical stock solution.

3.2.4. Flocculation Improvements

The flocculation process in a water treatment plant is the aggregation or growth of destabilized colloidal suspension or particles. As these particles grow, they are more easily settled out of suspension. While rapid mixing is the addition of coagulant chemical(s) to destabilize the colloidal particles, flocculation is the step that causes the destabilized particles to form settleable floc. The two treatment process enhancements that have been costed for flocculation improvements are:

- Flocculation Improvements – Equipment Only
- Flocculation Improvements – Equipment and Basin.

3.2.4.1. Flocculation Improvements – Equipment Only

After jar testing, it may be determined that the existing flocculation process does not adequately aid in the growth of floc that can be removed in the sedimentation basins. The existing process may impart too much energy into the water causing floc shear into unsettleable small floc or a lack of energy may prevent floc growth.

Conceptual Design—The cost estimate assumes that the existing flocculation process equipment in the water treatment plant is inadequate and will be replaced. No structural improvements are required. The flocculation process is designed to provide a G value of 50 sec^{-1} at the design flow. Costs are based on vertical shaft, variable speed turbine mixers with 304 stainless steel shafts and TEFC motors. Structural costs for vertical turbine flocculators are somewhat higher than for the horizontal paddle type because of the required structural support above the basin. All drive units are variable speed to allow maximum flexibility of operation. Although common drives for two or more parallel basins are often used, the estimated costs are based on individual drives for each basin (USEPA, 1978; Culp/Wesner/Culp, 1994).

Operation and Maintenance Requirements—Process energy is based on 24-hour/day operation of the system, G values of 50 sec^{-1}, and an overall motor/mechanism efficiency of 60 percent. Labor requirements are based on routine O&M of 15 minutes per day per basin (maximum basin volume = 12,500 cu ft) and an oil change every 6 months requiring 4 labor hours per change.

3.2.4.2. Flocculation Improvements– Equipment and Basin

The flocculation improvements to the plant are described in Section 3.2.4.1.

Conceptual Design— This cost estimate assumes that the water treatment plant does not have a flocculation process, or the existing process is inadequate and will be replaced. The flocculation basin(s) are designed for providing a G value of 50 sec^{-1} at the design flow. The costs are based on a rectangular-shaped, reinforced concrete structure with a 12 ft side water depth and a length-to-width ratio of approximately 4:1. The maximum individual basin size used is 12,500 cubic feet. Common wall construction is used where the total basin volume exceeds 12,500 cubic feet and multiple basins are required. Costs are based on vertical shaft, variable speed turbine mixers with 304 stainless steel shafts and TEFC motors. Structural costs for vertical turbine flocculators are somewhat higher than for the horizontal paddle type because of the required structural support above the basin. All drive units are variable speed to allow maximum flexibility of operation. Although common drives for two or more parallel basins are often utilized, the estimated costs are based on individual drives for each basin (USEPA, 1978; Culp/Wesner/Culp, 1994).

Operation and Maintenance Requirements—Process energy is based on 24-hour/day operation of the system, G values of 50 sec^{-1}, and an overall motor/mechanism efficiency of 60 percent. Labor requirements are based on routine O&M of 15 minutes per day per basin (maximum basin volume = 12,500 cu ft) and an oil change every 6 months requiring 4 hours per change.

3.2.5. Settling Improvements

Typically, sedimentation follows rapid mix and flocculation processes. The majority of solids are removed through gravity settling, thereby reducing the load to the filters. The two treatment process enhancements that have been costed for settling improvements are:

- Equipment Modification – Weirs in Influent/Effluent
- Add Tube Settlers.

3.2.5.1. Equipment Modification – Weirs in Influent/Effluent

The key design considerations for gravity settling basins are overflow rates, inlet and outlet conditions, sludge removal and basin geometry. Typical problems with sedimentation basins are inadequate overflow rates as well as inlet and outlet flow conditions. After evaluating the hydraulics of the sedimentation basins, additional weirs/baffles are often needed on the influent and effluent of the basins to correct short circuiting and provide uniform flow through the basin.

Conceptual Design— This cost analysis assumes that a concrete baffle or wall (or stainless steel plates) will be constructed at the inlet to distribute the flow uniformly across the basin. The baffle is designed to span the basin and create approximately 0.1 foot headloss. For the outlet condition, it is assumed that additional launderers would be added to increase the length of effluent weirs. The design overflow rate for the effluent weirs is 10 gallons per minute per foot of weir.

Operation and Maintenance Requirements—Annual maintenance cost for cleaning the basins will increase to accommodate the additional work needed to the area enclosed by the baffle(s), in particular the cleaning out and handling of any sludge that has accumulated in this area. Cleaning by pressure wash is the typical method employed.

3.2.5.2. Add Tube Settlers

The overflow rate of the sedimentation basin should normally be in the range of 350 to 550 gallons per day per square foot for conventional coagulation plants. For systems with high overflow rates, more sedimentation surface area is needed to reduce the overflow rate within acceptable limits. Wind can and will induce a disturbance on the surface of the sedimentation basin causing stray currents in the water that reduces the effective settling in the basin. One method to increase the settling surface area and minimize stray currents caused by wind is to install tube settlers. The tubes, typically plastic, are designed to incline at an angle greater than 45° (60° is typical), so that as solids deposit and increase in mass on the bottom of the tube, the solids settle into the basin and are removed.

Conceptual Design—Tube modules may be applied successfully in circular or rectangular basins of either horizontal flow or upflow design. In basins of either rectangular or circular configuration, the tube modules are constructed of lightweight, high-strength plastic and simply supported by light-weight structural members. Tube modules are available from numerous manufacturers in widths of 2.5 to 3.0 ft and in lengths up to 12 ft (USEPA, 1978; Culp/Wesner/Culp, 1994). Conceptual design used in the cost estimate is based on using 280 sq ft per MGD. The basins are sized with rise rates through the area covered by tube modules and over the entire basin of 2.5 gpm and 2 gpm sq ft, respectively. Since the hydraulic and structural requirements for tube clarification systems are unique, the costs include tube modules, tube module supports and anchor brackets, transition baffle, effluent launderers with V-notch weir plates, and installation.

Operation and Maintenance Requirements—Annual maintenance costs for cleaning the basins will increase to accommodate the additional work needed to clean the tube settlers. Cleaning by low pressure wash is the typical method.

3.2.6. Filtration Improvements

The filters of a water treatment plant are the last barrier to or final process for the removal of any particulate matter remaining in the water after sedimentation. The 12 treatment process enhancements that have been costed for filtration improvements are:

- Filter Media Addition
- Filter Media Replacement without Gravel
- Filter Media and Support Gravel Replacement
- Filter Media, Support Gravel, and Underdrain Replacement
- Backwashing – Increase Flow/Velocity
- Backwash – Install Surface Wash
- Post-Backwash – Sequence (Resting)
- Post-Backwash – Sequence (install additional filter(s))
- Post-Backwash – Filter-to-Waste
- Filter Rate-of-Flow Controller Replacement
- Individual Filter Turbidimeter Installation

- Microfiltration.

These improvements can be added to or modified at an existing treatment plant to produce a combined filter effluent meeting the requirements of the IESWTR. The range of improvements include modifying the existing filters (media and underdrain modifications) to the addition of micro-filtration membranes.

3.2.6.1. Filter Media Addition (2–6")

Over time, filters lose media, typically due to excessive backwashing. To bring the filters back to original level and condition, filter media should be added.

Conceptual Design—The existing filters are assumed to be dual media with the media loss in the anthracite layer. The costs include the purchase and replacement of 6-in. of media (anthracite coal) to bring the filter(s) back to the original depth. These estimates are applicable to either gravity or pressure filters. Costs are presented as a function of filter area using a filtration rate of 2.5 gpm/sq ft at peak day demand. For filter areas between 140 and 2,000 sq ft, rail shipment in 100 lb bags is used, and for larger filter areas, rail shipment in bulk is used. The estimated costs include media cost, shipping, and installation. The cost of a trained technician to direct placement of the mixed media is also included. Freight cost represents a nationwide average.

Operation and Maintenance Requirements—There are no annual costs associated with the filter media addition.

3.2.6.2. Filter Media Replacement without Gravel

In certain instances, sand filter media may have to be replaced to meet tighter filter effluent requirements. In addition, it may be desirable to increase the filtration capacity to allow for operational changes that will help to produce a better filter water effluent.

Conceptual Design— This option provides an estimate of the cost to replace sand filter media with a dual media. As a cost savings measure, the support gravel is compatible with the new

media design and does not have to be replaced. The media replacement will increase the filtration capacity of the plant as the coarser coal permits suspended solids penetration into the filter bed, allowing operation of the filter beds at higher flow rates and for longer periods between backwash. Costs include the removal of 20 inches of sand and replacement with 20 inches of anthracite coal. The costs include labor for removing the sand from the filter with onsite disposal, material and freight costs for anthracite coal, and installation labor. Labor costs are for manual sand removal from filters smaller than 3,500 sq ft.

Operation and Maintenance Requirements—There are no annual costs associated with the filter media replacement without gravel.

3.2.6.3. Filter Media and Support Gravel Replacement

The filter media improvements to the plant are described in Section 3.2.6.2. In addition, the existing support gravel may be incompatible with the new filter media design, and require replacement.

Conceptual Design—This option provides an estimate of the cost to replace sand filter media with a dual media and the addition of a 12-inch support gravel layer. The media replacement will increase the filtration capacity of the plant the coarser coal permits suspended solids penetration into the filter bed, allowing operation of the filter beds at higher flow rates and for longer periods between backwash. The costs include purchase and placement of 30 inches of media over a 12-inch support gravel layer. These estimates are applicable to either gravity or pressure filters, although pressure filters are often designed with a somewhat deeper gravel support layer (USEPA, 1978; Culp/Wesner/Culp, 1994). Costs are presented as a function of filter area using a design filtration rate of 2.5 gpm/sq ft for the existing filters. The estimated costs include media cost, shipping, and installation. The cost of a trained technician to direct placement of the mixed media is also included. Freight cost represents a nationwide average.

Operation and Maintenance Requirements—There are no annual costs associated with the filter media replacement with gravel.

3.2.6.4. Filter Media, Support Gravel, and Underdrain Replacement

The filter media improvements to the plant are described in Section 3.2.6.3. In addition, the underdrain may require replacement.

Conceptual Design—This cost estimate assumes that the existing filter (media, gravel, and underdrain) is inadequate and must be rebuilt along with the addition of a support gravel layer and new underdrain system. With the rebuilding of the filters, it is desirable to increase the filtration capacity of the plant (USEPA, 1978; Culp/Wesner/Culp, 1994). Therefore, the existing filter media will be replaced with dual media in lieu of sand. The costs include purchase and placement of 30-inches of media over a 12-inch support gravel layer and a new underdrain system that is designed for the future use of an air-water backwash system. Costs are a function of filter area using a design filtration rate of 2.5 gpm/sq ft for the existing filters. The estimated costs include media cost, a nationwide average shipping cost, and installation. The cost of a trained technician to direct placement of the mixed media is also included. The estimated costs do not include the blower(s), air piping and valving, and filter control modifications for an air-water backwash system for the filters.

Operation and Maintenance Requirements—There are no annual costs associated with the filter media and underdrain retrofit, since the air-water backwash system is not included.

3.2.6.5. Backwash – Increase Flow/Velocity

Filters are designed for removal of any particulate matter remaining in the water. During the normal operation of the filter, the solids (particulate matter) accumulate on the surface and in the pore space of the filter. The filters are cleaned and the particulate matter is removed by hydraulic backwashing of the filter with potable water. Completely clean filters will have a longer operational time than filters that are not. If the filter is not completely clean when it is placed back into service, the particulate matter in the media at the end of the filtering cycle can penetrate deeper into the filter and may actually pass through into the effluent causing a turbidity spike.

Conceptual Design—This cost estimate assumes that the backwash flowrate is less than the optimum range and that the backwash system capacity will be increased approximately 10–20 percent. To increase the capacity of the backwash system, new, larger backwash pump(s), additional piping and valving at the pumps and some electrical improvements are required. No major piping improvements in either the filter gallery or outside of the Backwash Pump Station are necessary. The largest, single pump is assumed to be 7,000 gpm, with one standby pump included for all installations. Multiple pumps are provided where the backwash flowrate is greater than 7,000 gpm.

Operation and Maintenance Requirements—O&M costs are based on a backwash frequency of two filters or 33 percent of the total number of filters per day, whichever is greater, with a 10-minute duration per wash. For dual-cell filters, a backwash is defined as a backwash for both cells. Energy requirements are based on a backwash rate of 18 gpm/sq ft, a pumping head of 50 ft TDH, and an overall motor/pump efficiency of 70 percent. Annual maintenance material and labor requirements are provided for the general maintenance of the system.

3.2.6.6. Backwash – Install Surface Wash

Most of the particulate matter left in the settled water is removed in the first few inches of a filter. Therefore, it is desirable to enhance the backwashing of the filter by providing more energy at the levels where more dirt has been trapped. There are numerous means to improve the backwashing of a filter to help in the removal of the dirt trapped at the surface of the filter, but a surface wash is the most common and easiest to construct. Adequate surface wash improves filter cleaning and helps prevent the formation of mudballs in the filter. Fixed surface water systems distribute washwater from equally spaced nozzles in a pipe grid. Rotary systems consists of arms on a fixed swivel supported from the backwash troughs about 2 inches above the surface of the filter. The arms are fitted with nozzles and revolve from the water-jet action. Surface washes are usually started about 1 minute in advance of the normal backwash and turned off a few minutes before the end of the backwash period.

Conceptual Design—Cost estimates include dual pumps with one as standby, electrical control, piping, valves, and headers within the filter pipe gallery. Surface wash pumps are sized to provide approximately 50 to 85 psi at the arms. Four dual-arm agitators are included for filter areas

of 350 to 700 sq ft. The wet well for the surface wash pumps is the same as for the backwash pumps.

Operation and Maintenance Requirements—O&M costs are based on a backwash frequency of two filters or 33 percent of the total number of filters per day, whichever is greater, with a 10-minute duration per wash. For dual-cell filters, a backwash is defined as a backwash for both cells. Energy requirements are based on a backwash rate of 0.5 gpm/sq ft, a pumping head of 65 psi, and an overall motor/pump efficiency of 70 percent. Annual maintenance material and labor requirements are provided for the general maintenance of the system.

3.2.6.7. Post-Backwash – Sequence (Resting)

When a filter is backwashed, the media is forced to expand to allow for the flushing out of the dirt trapped in the filter. During the initial phases of a filter run, the filter media is settling or compacting back to its original level before the backwash and beginning to collect particles. Typically, most turbidity spikes that occur during a filter operational run will occur during this initial phase of filter ripening. With effluent turbidity requirements becoming increasingly more stringent, the turbidity spikes that occur during the ripening stage of a filter should be reduced. One method of reducing the ripening spikes, although some states may not allow it, is to rest the filter after backwashing. When a filter is resting, gravity causes the filter media to settle to its original level. When the "rested" filter is placed in operation, the ripening period of the filter can be reduced and the turbidity spikes reduced.

Conceptual Design—The resting of filters is normally an operational change requiring little new facilities to accommodate this treatment technique. For this report, it is assumed that the existing filters are capable of accommodating the additional flow from the filter(s) resting and no major structural modifications will be required for this particular treatment technique. The cost estimate includes some piping and control modifications to the existing filters.

Operation and Maintenance Requirements—With the resting of filters after a backwash and increasing the loading on the remaining filters, the frequency of backwashing may increase. The annual O&M cost reflects an increase of filter backwashing.

3.2.6.8. Post-Backwash – Sequence (install additional filter(s))

The benefits of resting filters are described above. For this treatment technique, additional filters are required to provide sufficient capacity while the filters are resting after backwashing.

Conceptual Design—For this cost estimate, it is assumed that the filtration capacity of the plant will have to be increased. Depending on the size of the system, filtration capacity will be increased by approximately 50 percent for small systems to 10 percent for larger systems. Conventional gravity filtration structure costs are based on use of cast-in-place concrete with a media depth of 2 to 3 ft and a total depth of 16 ft for the filter box. The costs include housing of the entire filter structure, pipe gallery, and controls. Costs for filtration structures include the filter structure, underdrains, wash water troughs, a pipe gallery, piping and cylinder operated butterfly valves, filter flow and headloss instrumentation, a filter control panel, and the total housing requirement.

Operation and Maintenance Costs—O&M costs are based on backwash frequency of two filters or 33 percent of the total number of filters per day, which ever is greater, with a 10-minute duration per wash. Energy requirements are based on a backwash rate of 18 gpm/sq ft, a pumping head of 50 ft TDH, and an overall motor/pump efficiency of 70 percent. Annual maintenance material and labor requirements are provided for the general maintenance of the system.

3.2.6.9. Post-Backwash – Filter-to-Waste

Another means of eliminating the turbidity spikes after a backwash is to waste the filtered water until the turbidity levels are acceptable.

Conceptual Design—For this cost estimate, the filter-to-waste improvements include the piping, fittings, and valves in these facilities sized to convey up to 20 minutes of filtered water at an application rate of 5 gpm/sq ft. on the filter. No facilities are provided to pump filter-to-waste within the plant. It is assumed that the filter-to-waste flow will be recycled within the plant and the existing facilities are adequate for the additional flow. If the existing facilities are not adequate, see Section 3.2.7.1 for a discussion of the facilities required.

Operation and Maintenance Costs—O&M costs are based on backwash frequency of two filters or 33 percent of the total number of filters per day, whichever is greater. Annual maintenance material and labor requirements are provided for the general maintenance of the system.

3.2.6.10. Filter Rate-of-Flow Controller Replacement

The filter rate-of-flow controller is one of the most important parts of the filter system, controlling the flow of water through the filter. By controlling the flow through each filter, the flow, either influent or effluent, can be evenly divided to all the operating filters. In addition, the controller limits the maximum flow through any filter, preventing sudden surges. By controlling the flow through the filters, the disturbances that cause increasing turbidity levels in the filter effluent can be controlled.

Conceptual Design— This cost estimate includes the control system, flow meter, flow control valve, and piping modifications required to change the controller. The piping and valving are designed for a filtration rate of 5 gpm/sq ft.

Operation and Maintenance Costs—Process energy is based on 24-hour/day operation of the system. Annual maintenance material and labor requirements are provided for the general maintenance of the system.

3.2.6.11. Individual Filter Turbidimeter Installation

Turbidimeter on each individual filter provides the ability to monitor the quality of the filtered water continuously. Should the turbidity exceed the desired level, an alarm can be sounded or a signal provided to initiate a backwash of the filter.

Conceptual Design—For this estimate, the installation of a turbidimeter at a filter will include the purchase of a turbidimeter for each filter and, a tap on the filter effluent pipe, piping to the turbidimeter, drain piping, and power. Initial training of the plant staff is also included in the cost estimate.

Operation and Maintenance Costs—Process energy is based on 24-hour/day operation of the system. Annual maintenance material and labor requirements are provided for the general maintenance of the system, and includes calibration of the units on a monthly basis.

3.2.6.12. Microfiltration

Depending on the final treatment technique requirements for turbidity, membranes, in particular microfiltration, were considered the best technology for meeting the most stringent filter effluent requirement. Membranes are a pressure-driven thin-film barrier used for the removal of a range of particles from dissolved ions to turbidity. Since turbidity is the constituent of concern to be removed, the membrane filtration process chosen for this report is microfiltration.

Conceptual Design—This cost estimate assumes that the microfiltration system will be installed after the existing clearwells, since it is deemed to be a polishing step to produce an effluent water quality meeting the most stringent requirements. The membrane system is designed for an average flux rate of 70 gpd/ft^2 with the frequency and duration of the backwash set to maintain a minimum feedwater recovery rate of greater than 97 percent after recycling of the backwash water.

Estimated capital costs include the membrane system, process equipment building, electrical supply, final disinfection facilities, treated water storage and pumping facilities, and wash water recovery system (Adham et al., 1996).

Operation and Maintenance Costs—Annual costs include labor, chemicals, energy, membrane replacement, residuals disposal, and miscellaneous replacement parts.

The estimated capital and O&M costs for microfiltration were obtained from Adham et al. (1996) and updated to reflect plants that have recently been or are being constructed.

3.2.7. Hydraulic Improvements

The sudden surge of water at the head of a water treatment plant can hydraulically upset the treatment process significantly enough to cause excessive turbidity to be carried on to and through

the filters. To control these sudden surges, hydraulic improvements may be required at the plant. The three treatment process enhancements that have been costed for hydraulic improvements are:

- Recycle Flow – Account for in Process Control Decisions
- Recycle Flow – Install Valving and/or Pumps to Control the Flow
- Flow Distribution/Control/Measurement.

3.2.7.1. Recycle Flow – Account for in Process Control Decisions

As the cost of water rises, utilities are investigating ways to save on costs by recycling all wasted plant waters, such as filter backwash and sludge blowdown from the sedimentation basins. Typically, this water is returned to the head of the plant for re-treatment. The sudden surge of water from an uncontrolled recycle flow can hydraulically upset the treatment process significantly, causing excessive turbidity to be carried through the treatment processes to the filters. Due to increased solids loading on the filters, effluent turbidities may rise. Therefore, the recycling of wastewater within the plant needs to be controlled and uniform, so that this flow can be accommodated in the treatment process.

Conceptual Design—For this cost estimate, it is assumed that the existing plant has no facilities to store wastewater; therefore, major structural improvements are required to meter recycle flows back into the water flow at a constant rate. These improvements include flow equalization basins, pumping facilities, piping modifications, and controls for monitoring flows to minimize the impact of recycle flows.

Operation and Maintenance Costs—Process energy is based on 24-hour/day operation of the system. Annual maintenance material and labor requirements are provided for the general maintenance of the system.

3.2.7.2. Recycle Flow – Install Valving and/or Pumps to Control the Flow

The recycling of wastewater in the plant is described in Section 3.2.7.1.

Conceptual Design—For this cost estimate, it is assumed that the existing plant has facilities to store and pump the wastewater back to the intake of the plant. However, the pumping facilities are uncontrolled, meaning that the operation of the station is based only on the water level in the storage facilities for wastewater. Although no major structural improvements are necessary, improvements for pumping, valving, minor piping, some controls for monitoring flows to minimize the impact of recycle flows, and electrical considerations to meter recycle flows back into the water flow at a constant rate are assumed to be required.

Operation and Maintenance Costs—Process energy is based on 24-hour/day operation of the system. Annual maintenance material and labor requirements are provided for the general maintenance of the system.

3.2.7.3. Flow Distribution/Control/Measurement

To aid in the operation of the water treatment facility, the flows within the plant should be monitored. This allows operators to set chemical feed rates and account for all treatment decisions, based on flows.

Conceptual Design—For this estimate, minor improvements are required to meter and control flows within the plant. These improvements include monitoring of the and finished water flows to minimize the impact of recycle flows.

Operation and Maintenance Costs—Process energy is based on 24-hour/day operation of the system. Annual maintenance material and labor requirements are provided for the general maintenance of the system.

3.2.8. Administrative Culture Improvements

Not all improvements at a water treatment plant need be structural or process related. Some improvements may be Administrative. The three treatment process enhancements that have been costed for administrative culture improvements are:

- Policy and Commitment to Lower Water Quality Goals
- Plant Staffing Increase (1 or 2 Persons)
- Staff Qualifications.

3.2.8.1. Policy and Commitment to Lower Water Quality Goals

Policies are developed to insure the commitment of all participants in the production of treated water to produce a better product than that required.

Conceptual Design—For this estimate, no capital costs associated with this item are assumed, since this a policy technique.

Operation and Maintenance Costs—The annual O&M costs are assumed to be an annual commitment for developing policies and following up to determine compliance.

3.2.8.2. Plant Staffing Increase (1 or 2 Persons)

It is not the purpose of this document to predict the quantity of additional staff required as a result of the IESWTR requirements. However, some facilities may need to hire additional personnel to assist in the operation and maintenance of the treatment facilities, especially if treatment processes are added or if monitoring is significantly intensified. To assist with cost estimation for those facilities requiring staff increases, the assumptions described below were made.

Conceptual Design—For this estimate, it is assumed that capital costs of $5,000 per new staff addition for office and field fixtures, computer hardware, and training. One additional staff is costed for a system size up to 75,000 population and two additional staff is included for larger systems.

Operation and Maintenance Costs—The O&M costs include an annual commitment for one or two new staff members.

3.2.8.3. Staff Qualifications

As the sophistication of the treatment facilities and regulatory requirements increase, the educational level of the operators and maintenance must increase also. The best means of continuing the education of staff is through local or state operator certification training.

Conceptual Design—For this estimate, it is assumed that there are no capital costs associated with this item.

Operation and Maintenance Costs—The O&M costs include an annual commitment for training of staff members.

3.2.9. Laboratory Modifications

Just as a typical manufacturing process has quality control checks and tests performed on a regular basis, the operators at a water treatment facility should also periodically check the treatment process to ensure that all processes are performing at the highest levels possible. Typically, the operator will perform these quality control checks within the laboratory at the plant. Often, the equipment needed to complete the quality checks is either non-functional or out-dated. The three treatment process enhancements that have been costed for laboratory modifications are:

- Bench Top Turbidimeter Purchase
- Jar Test Apparatus Purchase
- Alternative Process Control Testing Equipment.

3.2.9.1. Bench Top Turbidimeter Purchase

Typically, every plant has a bench top turbidimeter to monitor the turbidity of the water leaving the plant. However, some of these units are obsolete. With the increasing requirements, the need for an up-to-date and accurate turbidimeter is needed.

Conceptual Design—For this estimate, it is assumed that the costs include the purchase of one new benchtop turbidimeter for process control for systems up to 75,000 population; two for systems up to 500,000 population and three for systems serving more than 500,000 population.

Operation and Maintenance Costs—Annual maintenance material and labor requirements are provided for the general maintenance and monthly calibration of the equipment.

3.2.9.2. Jar Test Apparatus Purchase

One of the most important pieces of laboratory equipment that all water treatment facilities should have is jar test apparatus. With this equipment, changes to the treatment process of a plant can be checked rapidly in the laboratory. In addition, if the source water quality changes, process changes can be evaluated to determine the optimum treatment changes at any time.

Conceptual Design—For this estimate, purchase of apparatus for one, two, or three sets of jar test apparatus for process control is included. The number of sets of equipment is dependent on system size.

Operation and Maintenance Costs—Annual maintenance material and labor requirements are provided for the general maintenance and calibration of the equipment.

3.2.9.3. Alternative Process Control Testing Equipment

With the tightening of water quality requirements, means to control the treatment process automatically are helpful. The source, in-plant, or effluent water quality can be measured and compared to a set point. If that measured value is different than the set point, a signal is sent to the chemical feed system to change the feed rate dependent on the variation from the setpoint. Three types of process control equipment that can be used in this situation are a Zetameter, particle counter, or streaming current monitor.

Conceptual Design—The costs include the purchase of new alternative on-line test equipment (such as particle counter, streaming current monitor or Zetameter) for process control. The number of units is dependent on system size.

Operation and Maintenance Costs—Annual maintenance material and labor requirements are provided for the general maintenance and monthly calibration of the equipment.

3.2.10. Process Control Testing Modifications

With the implementation of the IESWTR, plant staff will need to have plant operational data to allow for changes in the treatment process as required to meet the stricter requirements. It is expected that a new process control system will be installed or an existing system will have to be upgraded and expanded. The five process control testing modifications that have been costed for laboratory modifications are:

- Modify/Implement Turbidity Monitoring and Recording
- Modify/Implement Process Monitoring Strategy (Other Than Turbidity)
- Process Control Facilitator
- Staff Training to Understand Process Control Strategy
- Modification of Process Control Instrumentation.

3.2.10.1. Modify/Implement Turbidity Monitoring and Recording

With the implementation of the individual filter monitoring requirements of the IESWTR, a means of monitoring and recording the readings from the turbidimeter at each filter are needed. The turbidimeter readings can be monitored and recorded on a data sheet by the operator on duty or electronically through a multi-channel turbidimeter and computer data acquisition software.

Conceptual Design—This cost estimate assumes that the municipality or utility will choose to record the data from individual filter turbidimeters electronically. One method to acquire the output from each individual turbidimeter is to route all the data through a remote telemetry unit (RTU) or a programmable logic controller (PLC) to a computer. Another means to acquire this data

is to use a microprocessor-based multi-channel turbidimeter. This type of turbidimeter can obtain the output from many turbidimeters (up to 64) and then transmit data directly to the computer.

In either case, the computer system will need to have adequate storage capacity as well as the appropriate software (standard SCADA program tailored to the specific plant) to manipulate the data and generate the necessary reports. This cost estimate includes costs for using the multi-channel turbidimeter, along with a personal computer based system with the appropriate software.

Operation and Maintenance Costs—Annual maintenance material and labor requirements are provided for the general maintenance and annual calibration of the equipment.

3.2.10.2. Modify/Implement Process Monitoring Strategy (Other Than Turbidity)

Aside from a SCADA system for turbidity monitoring, other critical operational parameters of a plant will be monitored. These parameters include water influent, chemical feed, filtered water effluent, clearwell level(s), and finished water flow leaving the plant. With monitoring of these critical points, the operator can implement the required process control strategy to produce a combined filter water effluent meeting the new requirements.

Conceptual Design—To provide the information required for the implementation of a process control strategy, flowmeters will be installed on the water and finished water, and chemical feed rates and clearwell level(s) will be measured. These data will then be provided to the operator through a personal computer based monitoring system (with appropriate software, which would be a standard SCADA program tailored to the specific plant). Note that only monitoring and data acquisition is provided and all process changes would have to be made by the operator.

Operation and Maintenance Costs—Annual maintenance material and labor requirements are provided for the general maintenance and annual calibration of the equipment.

3.2.10.3. Process Control Facilitator

The process control facilitator is an individual, such as a consultant, contracted by the utility to help develop, assist with the implementation, and recommend changes to the process control strategy for the water treatment plant to produce a combined filter effluent meeting the requirements of the IESWTR

Conceptual Design—There are no capital costs associated with this item.

Operation and Maintenance Costs—The costs associated with this item are assumed to be an annual O&M commitment for hiring a facilitator.

3.2.10.4. Staff Training to Understand Process Control Strategy

As requirements become more stringent, plant staff need to better understand the operation and maintenance of a water treatment plant. Typically, the utility will have experienced staff that can help train new employees through on-the-job training. In addition, a certain amount of outside training may be required to either obtain or maintain operator certification. These methods typically require many years for the staff to obtain the level of knowledge required. However, the more stringent rules will require a greater degree of operator competence in a much shorter time. Therefore, more staff training will be required.

Conceptual Design—There are no capital costs associated with this item.

Operation and Maintenance Costs—The costs associated with this item are assumed to be an annual O&M commitment for training of all staff members.

3.2.10.5. Modification of Process Control Instrumentation

With the full implementation of the process control strategy by a SCADA system, it is expected that some existing field instruments will have to be replaced or updated. Also, new instruments may have to be installed to provide all the necessary information for the automatic control of the process.

Conceptual Design—To provide the information required for the full implementation of an automatic process control strategy through the installation of a SCADA system, flowmeters and flow control valves on the water and finished water (if necessary), chemical feed rate monitoring and control, and clearwell level(s) will be installed. The SCADA system provides control of the treatment process with the operator monitoring and changing the appropriate setpoints as needed. Total capital costs include field instruments, the personal computer based system, hardware, software, software modifications, training and calibration.

Operation and Maintenance Costs—Annual maintenance material and labor requirements are provided for the general maintenance and monthly calibration of the equipment.

3.2.11. Other Costs

This section describes other costs that a utility may incur as a result of IESWTR implementation. These costs include performing individual filter assessments and comprehensive performance evaluations, both performed by third-parties.

3.2.11.1. Individual Filter Assessments

With the implementation of the IESWTR, all surface water systems that use rapid granular filtration and serve more than 10,000 people may be required to conduct continuous monitoring of turbidity for each individual filter and provide an exceptions report to the state on a monthly basis. Exceptions reporting will include the following: (1) any individual filter with a turbidity level greater than 1.0 NTU based on two consecutive measurements 15 minutes apart; and (2) any individual filter with a turbidity level greater than 0.5 NTU at the end of the first four hours of filter operation based on two consecutive measurements 15 minutes apart. In addition to the monthly exception report required for each exceedance of 1.0 NTU, additional requirements are triggered when exceedances persist. If a plant reports exceedances of 1.0 NTU at one filter, based on two consecutive measurements 15 minutes apart, for 3 consecutive months, an individual filter assessment is required.

In an individual filter assessment, in accordance with the appropriate sections of the Comprehensive Performance Evaluation Section of the Composite Correction Program, a filter profile will be produced for all filters with exception reports if no obvious reason for the abnormal filter performance can be identified. The filter profile is a graph of the filter effluent turbidity during a complete operational cycle. For this report, individual filter assessments include the following tasks:

- Obtain turbidity data from the data acquisition system for the appropriate filter
- Import the data into a program/software so that a graph can be prepared
- Interview operators to determine if any unusual operating conditions occurred
- Evaluate the backwashing of the filter
- Prepare a letter report of findings.

Based on these tasks, it is estimated that each individual filter assessment will take approximately 50 man-hours to complete at a cost of $5,000 (50 man-hours at $100 per hour).

3.2.11.2. Comprehensive Performance Evaluation

With the implementation of the IESWTR, if an individual filter has turbidity levels greater than 2.0 NTU, based on two consecutive measurements 15 minutes apart at any time in each of 2 consecutive months, the state or a state-approved third-party may be required to conduct a complete Comprehensive Performance Evaluation (CPE). The CPE will be in accordance with an EPA issued guidance manual.

Based on the experience of trained evaluators and the anticipated tasks, it is estimated that each CPE will take approximately 250 man-hours to complete at a cost of $25,000 (250 man-hours at $100 per hour).

3.3. Cost Tables

The following tables provide the Capital Costs (Table 3-3), Annualized Capital Costs at 3, 7, and 10 percent interest rates (Tables 3-4, 3-5 and 3-6), O&M Costs (Table 3-7), and Total

Annualized Costs at 3, 7 and 10 percent interest rates (Tables 3-8 and 3-9, and 3-10) based on average flow, of each treatment technology described in this section.

Table 3-3. Capital Costs (Thousand Dollars) by Treatment Option*

Plant Population Size Categories (in thousands)	**10 – 25**	**25 – 50**	**50 – 75**	**75 – 100**	**100 – 500**	**500 – 1,000**	**>1,000**	**>1,000**
Average Day Demand (MGD)	**2.1**	**5.0**	**8.8**	**13.0**	**27.0**	**120.0**	**270.0**	**348.0**
Peak Day Demand (MGD)	**4.8**	**11.0**	**18.0**	**26.0**	**51.0**	**210.0**	**430.0**	**518.0**
Chemical Addition								
Install coagulant aid polymer feed capability	107.2	135.6	160.5	181.1	226.2	360.4	456.4	485.2
Install filter aid polymer feed capability	98.4	109.9	126.2	144.1	179.8	286.8	363.2	385.9
Install backwash water polymer/coagulant feed capability	100.0	100.0	100.0	100.0	100.0	110.2	136.6	147.6
Install pH adjustment for enhancing alkalinity purposes	108.6	192.6	280.8	350.7	527.6	1,259.0	1,940.4	2,172.6
Coagulant Improvements								
Primary coagulant feed points, control, and measurement	205.7	245.4	286.7	325.2	406.0	647.2	819.6	871.1
Rapid Mixing								
Rapid Mix Improvements – Equipment (only)	22.3	104.7	187.2	269.6	352.1	434.5	517.0	621.4
Rapid Mix Improvements – Equipment and basin	66.8	314.2	561.5	808.9	1,056.2	1,303.5	1,550.9	1,864.3
Flocculation Improvements								
Flocculation Improvements – Equipment (only)	103.2	213.1	323.0	432.9	542.9	652.8	762.7	826.7
Flocculation Improvements – Equipment and basin	309.5	639.3	969.0	1,298.8	1,628.6	1,958.4	2,288.2	2,480.0
Settling Improvements								
Equipment modification – weirs in influent/effluent	31.0	66.9	106.5	151.8	294.5	1,072.6	2,140.4	2,563.7
Add tube settlers	103.2	222.9	355.2	506.1	981.7	3,575.5	7,134.6	8,545.6

Table 3-3. Capital Costs (Thousand Dollars) by Treatment Option* (Continued)

Plant Population Size Categories (in thousands)	**10 – 25**	**25 – 50**	**50 – 75**	**75 – 100**	**100 – 500**	**500 – 1,000**	**>1,000**	**>1,000**
Average Day Demand (MGD)	**2.1**	**5.0**	**8.8**	**13.0**	**27.0**	**120.0**	**270.0**	**348.0**
Peak Day Demand (MGD)	**4.8**	**11.0**	**18.0**	**26.0**	**51.0**	**210.0**	**430.0**	**518.0**
Filtration Improvements (continued)								
Post-backwash – sequence (install additional filter(s))	819.0	1,120.5	1,422.4	1,814.5	2,415.3	5,995.2	11,234.5	13,533.7
Post-backwash – filter-to-waste	95.8	154.3	215.3	298.0	562.0	2,380.0	5,244.1	6,317.3
Filter rate-of-flow controller replacement	167.7	270.0	376.8	521.5	983.5	4,165.0	9,177.2	11,055.4
Individual filter turbidimeter installation	40.0	80.0	120.0	160.0	320.0	1,360.0	2,800.0	3,400.0
Microfiltration	7,496.9	13,075.8	18,194.4	23,284.4	36,588.0	94,546.6	152,908.6	173,250.1
Hydraulic Improvements								
Recycle flow – account for in process control decisions	99.0	217.7	352.4	485.0	929.8	3,909.5	6,841.5	11,972.7
Install of valving and/or pumps to control the flow	20.3	45.0	77.6	100.8	193.1	808.9	1,415.6	2,477.2
Flow distribution/control/measurement	64.0	140.7	222.2	313.4	600.9	2,526.5	4,421.4	7,737.5
Administrative Culture Improvements								
Policy and commitment to lower water quality goals	---	---	---	---	---	---	---	---
Plant staffing increase (1 or 2 persons)	5.0	5.0	5.0	10.0	10.0	10.0	10.0	10.0
Staff qualifications	---	---	---	---	---	---	---	---
Laboratory Modifications								
Bench top turbidimeter purchase	5.0	5.0	5.0	10.0	10.0	15.0	15.0	15.0
Jar test apparatus purchase	6.5	6.5	6.5	13.0	13.0	19.5	19.5	26.0

Table 3-4. Annualized Capital Costs at 3 percent Interest Rate (Cents/1,000 gal) by Treatment Option*

Plant Population Size Categories (in thousands)	**10 – 25**	**25 – 50**	**50 – 75**	**75 – 100**	**100 – 500**	**500 – 1,000**	**>1,000**	**>1,000**
Average Day Demand (MGD)	**2.1**	**5.0**	**8.8**	**13.0**	**27.0**	**120.0**	**270.0**	**348.0**
Peak Day Demand (MGD)	**4.8**	**11.0**	**18.0**	**26.0**	**51.0**	**210.0**	**430.0**	**518.0**
Chemical Addition								
Install coagulant aid polymer feed capability	0.940	0.499	0.336	0.257	0.154	0.055	0.031	0.026
Install filter aid polymer feed capability	0.863	0.405	0.264	0.204	0.123	0.044	0.025	0.020
Install backwash water polymer/coagulant feed capability	0.877	0.368	0.209	0.142	0.068	0.017	0.009	0.008
Install pH adjustment for enhancing alkalinity purposes	0.952	0.709	0.588	0.497	0.360	0.193	0.132	0.115
Coagulant Improvements								
Primary coagulant feed points, control, and measurement	1.803	0.904	0.600	0.461	0.277	0.099	0.056	0.046
Rapid Mixing								
Rapid Mix Improvements – Equipment (only)	0.195	0.386	0.392	0.382	0.240	0.067	0.035	0.033
Rapid Mix Improvements – Equipment and basin	0.586	1.157	1.175	1.146	0.720	0.200	0.106	0.099
Flocculation Improvements								
Flocculation Improvements – Equipment (only)	0.905	0.785	0.676	0.613	0.370	0.100	0.052	0.044
Flocculation Improvements – Equipment and basin	2.714	2.355	2.028	1.840	1.111	0.301	0.156	0.131
Settling Improvements								
Equipment modification – weirs in influent/effluent	0.272	0.246	0.223	0.215	0.201	0.165	0.146	0.136
Add tube settlers	0.905	0.821	0.743	0.717	0.670	0.549	0.487	0.452

Table 3-4. Annualized Capital Costs at 3 percent Interest Rate (Cents/1,000 gal) by Treatment Option* (Continued)

Plant Population Size Categories (in thousands)	**10 – 25**	**25 – 50**	**50 – 75**	**75 – 100**	**100 – 500**	**500 – 1,000**	**>1,000**	**>1,000**
Average Day Demand (MGD)	**2.1**	**5.0**	**8.8**	**13.0**	**27.0**	**120.0**	**270.0**	**348.0**
Peak Day Demand (MGD)	**4.8**	**11.0**	**18.0**	**26.0**	**51.0**	**210.0**	**430.0**	**518.0**
Filtration Improvements (continued)								
Post-backwash – sequence (install additional filter(s))	7.182	4.127	2.977	2.571	1.647	0.920	0.766	0.716
Post-backwash – filter-to-waste	0.840	0.568	0.451	0.422	0.383	0.365	0.358	0.334
Filter rate-of-flow controller replacement	1.470	0.995	0.789	0.739	0.671	0.639	0.626	0.585
Individual filter turbidimeter installation	0.838	0.704	0.600	0.541	0.521	0.498	0.191	0.180
Microfiltration	65.746	48.162	38.077	32.986	24.956	14.510	10.430	9.169
Hydraulic Improvements								
Recycle flow – account for in process control decisions	0.868	0.802	0.738	0.687	0.634	0.600	0.467	0.634
Install of valving and/or pumps to control the flow	0.178	0.166	0.162	0.143	0.132	0.124	0.097	0.131
Flow distribution/control/measurement	0.561	0.518	0.465	0.444	0.410	0.388	0.302	0.409
Administrative Culture Improvements								
Policy and commitment to lower water quality goals	---	---	---	---	---	---	---	---
Plant staffing increase (1 or 2 persons)	0.044	0.018	0.010	0.014	0.007	0.002	0.001	0.001
Staff qualifications	---	---	---	---	---	---	---	---
Laboratory Modifications								
Bench top turbidimeter purchase	0.105	0.044	0.025	0.034	0.016	0.005	0.002	0.002
Jar test apparatus purchase	0.057	0.024	0.014	0.018	0.009	0.003	0.001	0.001
Alternative process control testing equipment	0.438	0.184	0.105	0.142	0.068	0.023	0.010	0.008

Table 3-5. Annualized Capital Costs at 7 percent Interest (Cents/1,000 gal) by Treatment Option*

Plant Population Size Categories (in thousands)	**10 – 25**	**25 – 50**	**50 – 75**	**75 – 100**	**100 – 500**	**500 – 1,000**	**>1,000**	**>1,000**
Average Day Demand (MGD)	**2.1**	**5.0**	**8.8**	**13.0**	**27.0**	**120.0**	**270.0**	**348.0**
Peak Day Demand (MGD)	**4.8**	**11.0**	**18.0**	**26.0**	**51.0**	**210.0**	**430.0**	**518.0**
Chemical Addition								
Install coagulant aid polymer feed capability	1.321	0.701	0.472	0.360	0.217	0.078	0.044	0.036
Install filter aid polymer feed capability	1.212	0.568	0.371	0.287	0.172	0.062	0.035	0.029
Install backwash water polymer/coagulant feed capability	1.231	0.517	0.294	0.199	0.096	0.024	0.013	0.011
Install pH adjustment for enhancing alkalinity purposes	1.337	0.996	0.825	0.698	0.505	0.271	0.186	0.161
Coagulant Improvements								
Primary coagulant feed points, control, and measurement	2.532	1.269	0.843	0.647	0.389	0.139	0.079	0.065
Rapid Mixing								
Rapid Mix Improvements – Equipment (only)	0.274	0.542	0.550	0.536	0.337	0.094	0.050	0.046
Rapid Mix Improvements – Equipment and basin	0.823	1.625	1.650	1.609	1.012	0.281	0.149	0.139
Flocculation Improvements								
Flocculation Improvements – Equipment (only)	1.270	1.102	0.949	0.861	0.520	0.141	0.073	0.061
Flocculation Improvements – Equipment and basin	3.811	3.306	2.848	2.584	1.560	0.422	0.219	0.184
Settling Improvements								
Equipment modification – weirs in influent/effluent	0.381	0.346	0.313	0.302	0.282	0.231	0.205	0.191
Add tube settlers	1.271	1.153	1.044	1.007	0.940	0.771	0.683	0.635

Table 3-5. Annualized Capital Costs at 7 percent Interest (Cents/1,000 gal) by Treatment Option* (Continued)

Plant Population Size Categories (in thousands)	10 – 25	25 – 50	50 – 75	75 – 100	100 – 500	500 – 1,000	>1,000	>1,000
Average Day Demand (MGD)	**2.1**	**5.0**	**8.8**	**13.0**	**27.0**	**120.0**	**270.0**	**348.0**
Peak Day Demand (MGD)	**4.8**	**11.0**	**18.0**	**26.0**	**51.0**	**210.0**	**430.0**	**518.0**
Filtration Improvements (continued)								
Post-backwash – sequence (install additional filter(s))	10.086	5.795	4.180	3.609	2.313	1.292	1.076	1.006
Post-backwash – filter-to-waste	1.180	0.798	0.633	0.593	0.538	0.513	0.502	0.469
Filter rate-of-flow controller replacement	2.065	1.397	1.107	1.037	0.942	0.898	0.879	0.822
Individual filter turbidimeter installation	0.968	0.813	0.693	0.626	0.602	0.576	0.268	0.253
Microfiltration	92.320	67.629	53.467	46.319	35.044	20.375	14.645	12.874
Hydraulic Improvements								
Recycle flow – account for in process control decisions	1.219	1.126	1.036	0.965	0.891	0.842	0.655	0.890
Install of valving and/or pumps to control the flow	0.249	0.233	0.228	0.200	0.185	0.174	0.136	0.184
Flow distribution/control/measurement	0.788	0.728	0.653	0.623	0.576	0.544	0.423	0.575
Administrative Culture Improvements								
Policy and commitment to lower water quality goals	---	---	---	---	---	---	---	---
Plant staffing increase (1 or 2 persons)	0.062	0.026	0.015	0.020	0.010	0.002	0.001	0.001
Staff qualifications	---	---	---	---	---	---	---	---
Laboratory Modifications								
Bench top turbidimeter purchase	0.121	0.051	0.029	0.039	0.019	0.006	0.003	0.002
Jar test apparatus purchase	0.080	0.034	0.019	0.026	0.012	0.004	0.002	0.002
Alternative process control testing equipment	0.616	0.259	0.147	0.199	0.096	0.032	0.014	0.011

Table 3-6. Annualized Capital Costs at 10 percent Interest (Cents/1,000 gal) by Treatment Option*

Plant Population Size Categories (in thousands)	**10 – 25**	**25 – 50**	**50 – 75**	**75 – 100**	**100 – 500**	**500 – 1,000**	**>1,000**	**>1,000**
Average Day Demand (MGD)	**2.1**	**5.0**	**8.8**	**13.0**	**27.0**	**120.0**	**270.0**	**348.0**
Peak Day Demand (MGD)	**4.8**	**11.0**	**18.0**	**26.0**	**51.0**	**210.0**	**430.0**	**518.0**
Chemical Addition								
Install coagulant aid polymer feed capability	1.643	0.872	0.587	0.448	0.270	0.097	0.054	0.045
Install filter aid polymer feed capability	1.508	0.707	0.462	0.357	0.214	0.077	0.043	0.036
Install backwash water polymer/coagulant feed capability	1.532	0.643	0.366	0.247	0.119	0.030	0.016	0.014
Install pH adjustment for enhancing alkalinity purposes	1.664	1.240	1.027	0.868	0.629	0.338	0.231	0.201
Coagulant Improvements								
Primary coagulant feed points, control, and measurement	3.151	1.580	1.048	0.805	0.484	0.174	0.098	0.081
Rapid Mixing								
Rapid Mix Improvements – Equipment (only)	0.341	0.674	0.684	0.667	0.420	0.117	0.062	0.057
Rapid Mix Improvements – Equipment and basin	1.024	2.022	2.053	2.002	1.259	0.350	0.185	0.172
Flocculation Improvements								
Flocculation Improvements – Equipment (only)	1.581	1.371	1.181	1.072	0.647	0.175	0.091	0.076
Flocculation Improvements – Equipment and basin	4.742	4.114	3.544	3.215	1.941	0.525	0.273	0.229
Settling Improvements								
Equipment modification – weirs in influent/effluent	0.474	0.430	0.390	0.376	0.351	0.288	0.255	0.237
Add tube settlers	1.582	1.435	1.299	1.253	1.170	0.959	0.850	0.790

Table 3-6. Annualized Capital Costs at 10 percent Interest (Cents/1,000 gal) by Treatment Option* (Continued)

Plant Population Size Categories (in thousands)	**10 – 25**	**25 – 50**	**50 – 75**	**75 – 100**	**100 – 500**	**500 – 1,000**	**>1,000**	**>1,000**
Average Day Demand (MGD)	**2.1**	**5.0**	**8.8**	**13.0**	**27.0**	**120.0**	**270.0**	**348.0**
Peak Day Demand (MGD)	**4.8**	**11.0**	**18.0**	**26.0**	**51.0**	**210.0**	**430.0**	**518.0**
Filtration Improvements (continued)								
Post-backwash – sequence (install additional filter(s))	12.551	7.212	5.202	4.492	2.879	1.608	1.339	1.252
Post-backwash – filter-to-waste	1.468	0.993	0.787	0.738	0.670	0.638	0.625	0.584
Filter rate-of-flow controller replacement	2.569	1.738	1.378	1.291	1.172	1.117	1.094	1.022
Individual filter turbidimeter installation	1.072	0.900	0.767	0.693	0.667	0.638	0.334	0.314
Microfiltration	114.884	84.158	66.535	57.639	43.609	25.355	18.225	16.021
Hydraulic Improvements								
Recycle flow – account for in process control decisions	1.517	1.401	1.289	1.201	1.108	1.048	0.815	1.107
Install of valving and/or pumps to control the flow	0.310	0.290	0.284	0.249	0.230	0.217	0.169	0.229
Flow distribution/control/measurement	0.981	0.906	0.813	0.776	0.716	0.678	0.527	0.716
Administrative Culture Improvements								
Policy and commitment to lower water quality goals	---	---	---	---	---	---	---	---
Plant staffing increase (1 or 2 persons)	0.077	0.032	0.018	0.025	0.012	0.003	0.001	0.001
Staff qualifications	---	---	---	---	---	---	---	---
Laboratory Modifications								
Bench top turbidimeter purchase	0.134	0.056	0.032	0.043	0.021	0.007	0.003	0.002
Jar test apparatus purchase	0.100	0.042	0.024	0.032	0.015	0.005	0.002	0.002
Alternative process control testing equipment	0.766	0.322	0.183	0.248	0.119	0.040	0.018	0.014

Table 3-7. Operation and Maintenance Costs (Cents/1,000 gal) by Treatment Option*

Plant Population Size Categories (in thousands)	**10 – 25**	**25 – 50**	**50 – 75**	**75 – 100**	**100 – 500**	**500 – 1,000**	**>1,000**	**>1,000**
Average Day Demand (MGD)	**2.1**	**5.0**	**8.8**	**13.0**	**27.0**	**120.0**	**270.0**	**348.0**
Peak Day Demand (MGD)	**4.8**	**11.0**	**18.0**	**26.0**	**51.0**	**210.0**	**430.0**	**518.0**
Chemical Addition								
Install coagulant aid polymer feed capability	3.001	2.359	2.156	2.071	1.980	1.906	1.892	1.889
Install filter aid polymer feed capability	1.678	1.034	0.833	0.747	0.654	0.587	0.575	0.573
Install backwash water polymer/coagulant feed capability	1.139	0.479	0.273	0.186	0.091	0.024	0.012	0.009
Install pH adjustment for enhancing alkalinity purposes	11.223	11.018	10.955	10.928	10.879	10.811	10.791	10.805
Coagulant Improvements								
Primary coagulant feed points, control, and measurement	4.680	3.393	2.989	2.818	2.633	2.493	2.467	2.462
Rapid Mixing								
Rapid Mix Improvements – Equipment (only)	2.363	5.839	6.071	5.974	3.774	1.051	0.557	0.552
Rapid Mix Improvements – Equipment and basin	2.363	5.839	6.071	5.974	3.774	1.051	0.557	0.552
Flocculation Improvements								
Flocculation Improvements – Equipment (only)	1.618	0.968	0.931	0.889	0.552	0.152	0.080	0.078
Flocculation Improvements – Equipment and basin	1.618	0.968	0.931	0.889	0.552	0.152	0.080	0.078
Settling Improvements								
Equipment modification – weirs in influent/effluent	0.652	0.274	0.156	0.158	0.101	0.046	0.020	0.020
Add tube settlers	0.652	0.274	0.156	0.158	0.101	0.046	0.020	0.020

Table 3-7. Operation and Maintenance Costs (Cents/1,000 gal) by Treatment Option* (Continued)

Plant Population Size Categories (in thousands)	**10 – 25**	**25 – 50**	**50 – 75**	**75 – 100**	**100 – 500**	**500 – 1,000**	**>1,000**	**>1,000**
Average Day Demand (MGD)	**2.1**	**5.0**	**8.8**	**13.0**	**27.0**	**120.0**	**270.0**	**348.0**
Peak Day Demand (MGD)	**4.8**	**11.0**	**18.0**	**26.0**	**51.0**	**210.0**	**430.0**	**518.0**
Filtration Improvements (continued)								
Post-backwash – sequence (install additional filter(s))	6.858	2.880	2.455	2.492	2.100	1.890	1.680	2.607
Post-backwash – filter-to-waste	1.566	0.658	0.672	0.654	0.639	0.514	0.419	0.396
Filter rate-of-flow controller replacement	3.131	1.315	1.121	0.969	0.913	0.685	0.558	0.527
Individual filter turbidimeter installation	0.282	0.237	0.239	0.236	0.241	0.112	0.102	0.096
Microfiltration	19.229	18.365	17.823	17.458	16.795	15.518	14.865	14.666
Hydraulic Improvements								
Recycle flow – account for in process control decisions	1.252	0.789	0.628	0.595	0.401	0.126	0.079	0.085
Install of valving and/or pumps to control the flow	0.848	0.534	0.425	0.403	0.271	0.086	0.053	0.058
Flow distribution/control/measurement	0.848	0.534	0.425	0.403	0.271	0.086	0.053	0.058
Administrative Culture Improvements								
Policy and commitment to lower water quality goals	0.543	0.228	0.130	0.175	0.084	0.019	0.008	0.007
Plant staffing increase (1 or 2 persons)	5.427	2.279	1.295	1.753	0.844	0.190	0.084	0.066
Staff qualifications	0.651	0.274	0.155	0.140	0.101	0.023	0.010	0.008
Laboratory Modifications								
Bench top turbidimeter purchase	0.190	0.080	0.073	0.062	0.030	0.010	0.004	0.003
Jar test apparatus purchase	0.065	0.027	0.025	0.021	0.010	0.003	0.002	0.001
Alternative process control testing equipment	0.326	0.137	0.121	0.105	0.051	0.017	0.008	0.006

Table 3-8. Total Annualized Costs at 3 percent Interest Rate (Cents/1,000 gal) by Treatment Option*

Plant Population Size Categories (in thousands)	**10 – 25**	**25 – 50**	**50 – 75**	**75 – 100**	**100 – 500**	**500 – 1,000**	**>1,000**	**>1,000**
Average Day Demand (MGD)	**2.1**	**5.0**	**8.8**	**13.0**	**27.0**	**120.0**	**270.0**	**348.0**
Peak Day Demand (MGD)	**4.8**	**11.0**	**18.0**	**26.0**	**51.0**	**210.0**	**430.0**	**518.0**
Chemical Addition								
Install coagulant aid polymer feed capability	3.941	2.858	2.492	2.328	2.134	1.961	1.923	1.915
Install filter aid polymer feed capability	2.541	1.439	1.097	j0.951	0.777	0.631	0.600	0.593
Install backwash water polymer/coagulant feed capability	2.016	0.847	0.482	0.328	0.159	0.041	0.021	0.017
Install pH adjustment for enhancing alkalinity purposes	12.175	11.727	11.543	11.425	11.239	11.004	10.923	10.920
Coagulant Improvements								
Primary coagulant feed points, control, and measurement	6.483	4.297	3.589	3.279	2.910	2.592	2.523	2.508
Rapid Mixing								
Rapid Mix Improvements – Equipment (only)	2.558	6.225	6.463	6.356	4.014	1.118	0.592	0.585
Rapid Mix Improvements – Equipment and basin	2.949	6.996	7.246	7.120	4.494	1.251	0.663	0.651
Flocculation Improvements								
Flocculation Improvements – Equipment (only)	2.523	1.753	1.607	1.502	0.922	0.252	0.132	0.122
Flocculation Improvements – Equipment and basin	4.332	3.323	2.959	2.729	1.663	0.453	0.236	0.209
Settling Improvements								
Equipment modification – weirs in influent/effluent	0.924	0.520	0.379	0.373	0.302	0.211	0.166	0.156
Add tube settlers	1.557	1.095	0.899	0.875	0.771	0.595	0.507	0.472

Table 3-8. Total Annualized Costs at 3 percent Interest Rate (Cents/1,000 gal) by Treatment Option* (Continued)

Plant Population Size Categories (in thousands)	**10 – 25**	**25 – 50**	**50 – 75**	**75 – 100**	**100 – 500**	**500 – 1,000**	**>1,000**	**>1,000**
Average Day Demand (MGD)	**2.1**	**5.0**	**8.8**	**13.0**	**27.0**	**120.0**	**270.0**	**348.0**
Peak Day Demand (MGD)	**4.8**	**11.0**	**18.0**	**26.0**	**51.0**	**210.0**	**430.0**	**518.0**
Filtration Improvements (continued)								
Post-backwash – sequence (install additional filter(s))	14.040	7.007	5.432	5.063	3.747	2.810	2.446	3.323
Post-backwash – filter-to-waste	2.406	1.226	1.123	1.076	1.022	0.879	0.777	0.730
Filter rate-of-flow controller replacement	4.601	2.310	1.910	1.708	1.584	1.324	1.184	1.112
Individual filter turbidimeter installation	1.120	0.941	0.839	0.777	0.762	0.610	0.293	0.276
Microfiltration	84.975	66.527	55.900	50.444	41.751	30.028	25.295	23.835
Hydraulic Improvements								
Recycle flow – account for in process control decisions	2.120	1.591	1.366	1.282	1.035	0.726	0.543	0.719
Install of valving and/or pumps to control the flow	1.026	0.700	0.587	0.546	0.403	0.210	0.150	0.189
Flow distribution/control/measurement	1.409	1.052	0.890	0.847	0.681	0.474	0.355	0.467
Administrative Culture Improvements								
Policy and commitment to lower water quality goals	0.543	0.228	0.130	0.175	0.084	0.019	0.008	0.007
Plant staffing increase (1 or 2 persons)	5.471	2.297	1.305	1.767	0.851	0.192	0.085	0.067
Staff qualifications	0.651	0.274	0.155	0.140	0.101	0.023	0.010	0.008
Laboratory Modifications								
Bench top turbidimeter purchase	0.295	0.124	0.098	0.096	0.046	0.015	0.006	0.005
Jar test apparatus purchase	0.122	0.051	0.039	0.039	0.019	0.006	0.003	0.002
Alternative process control testing equipment	0.764	0.321	0.226	0.247	0.119	0.040	0.018	0.014

Table 3-9. Total Annualized Costs at 7 percent Interest (Cents/1,000 gal) by Treatment Option*

Plant Population Size Categories (in thousands)	**10 – 25**	**25 – 50**	**50 – 75**	**75 – 100**	**100 – 500**	**500 – 1,000**	**>1,000**	**>1,000**
Average Day Demand (MGD)	**2.1**	**5.0**	**8.8**	**13.0**	**27.0**	**120.0**	**270.0**	**348.0**
Peak Day Demand (MGD)	**4.8**	**11.0**	**18.0**	**26.0**	**51.0**	**210.0**	**430.0**	**518.0**
Chemical Addition								
Install coagulant aid polymer feed capability	4.322	3.060	2.628	2.431	2.197	1.984	1.936	1.925
Install filter aid polymer feed capability	2.890	1.602	1.204	1.034	0.826	0.649	0.610	0.602
Install backwash water polymer/coagulant feed capability	2.370	0.996	0.567	0.385	0.187	0.048	0.025	0.020
Install pH adjustment for enhancing alkalinity purposes	12.560	12.014	11.780	11.626	11.384	11.082	10.977	10.966
Coagulant Improvements								
Primary coagulant feed points, control, and measurement	7.212	4.662	3.832	3.465	3.022	2.632	2.546	2.527
Rapid Mixing								
Rapid Mix Improvements – Equipment (only)	2.637	6.381	6.621	6.510	4.111	1.145	0.607	0.598
Rapid Mix Improvements – Equipment and basin	3.186	7.464	7.721	7.583	4.786	1.332	0.706	0.691
Flocculation Improvements								
Flocculation Improvements – Equipment (only)	2.888	2.070	1.880	1.750	1.072	0.293	0.153	0.139
Flocculation Improvements – Equipment and basin	5.429	4.274	3.779	3.473	2.112	0.574	0.299	0.262
Settling Improvements								
Equipment modification – weirs in influent/effluent	1.033	0.620	0.469	0.460	0.383	0.277	0.225	0.211
Add tube settlers	1.923	1.427	1.200	1.165	1.041	0.817	0.703	0.655

Table 3-9. Total Annualized Costs (Cents/1,000 gal) by Treatment Option* (Continued)

Plant Population Size Categories (in thousands)	**10 – 25**	**25 – 50**	**50 – 75**	**75 – 100**	**100 – 500**	**500 – 1,000**	**>1,000**	**>1,000**
Average Day Demand (MGD)	**2.1**	**5.0**	**8.8**	**13.0**	**27.0**	**120.0**	**270.0**	**348.0**
Peak Day Demand (MGD)	**4.8**	**11.0**	**18.0**	**26.0**	**51.0**	**210.0**	**430.0**	**518.0**
Filtration Improvements (continued)								
Post-backwash – sequence (install additional filter(s))	16.944	8.675	6.635	6.101	4.413	3.182	2.756	3.613
Post-backwash – filter-to-waste	2.746	1.456	1.305	1.247	1.177	1.027	0.921	0.865
Filter rate-of-flow controller replacement	5.196	2.712	2.228	2.006	1.855	1.583	1.437	1.349
Individual filter turbidimeter installation	1.250	1.050	0.932	0.862	0.843	0.688	0.370	0.349
Microfiltration	111.549	85.994	71.290	63.777	51.839	35.893	29.510	27.540
Hydraulic Improvements								
Recycle flow – account for in process control decisions	2.471	1.915	1.664	1.560	1.292	0.968	0.734	0.975
Install of valving and/or pumps to control the flow	1.097	0.767	0.653	0.603	0.456	0.260	0.189	0.242
Flow distribution/control/measurement	1.636	1.262	1.078	1.026	0.847	0.630	0.476	0.633
Administrative Culture Improvements								
Policy and commitment to lower water quality goals	0.543	0.228	0.130	0.175	0.084	0.019	0.008	0.007
Plant staffing increase (1 or 2 persons)	5.489	2.305	1.310	1.773	0.854	0.192	0.085	0.067
Staff qualifications	0.651	0.274	0.155	0.140	0.101	0.023	0.010	0.008
Laboratory Modifications								
Bench top turbidimeter purchase	0.311	0.131	0.102	0.101	0.049	0.016	0.007	0.005
Jar test apparatus purchase	0.145	0.061	0.044	0.047	0.022	0.007	0.004	0.003
Alternative process control testing equipment	0.942	0.396	0.268	0.304	0.147	0.049	0.022	0.017

Table 3-10. Total Annualized Costs at 10 percent Interest Rate (Cents/1,000 gal) by Treatment Option*

Plant Population Size Categories (in thousands)	10 – 25	25 – 50	50 – 75	75 – 100	100 – 500	500 – 1,000	>1,000	>1,000
Average Day Demand (MGD)	**2.1**	**5.0**	**8.8**	**13.0**	**27.0**	**120.0**	**270.0**	**348.0**
Peak Day Demand (MGD)	**4.8**	**11.0**	**18.0**	**26.0**	**51.0**	**210.0**	**430.0**	**518.0**
Chemical Addition								
Install coagulant aid polymer feed capability	4.644	3.231	2.743	2.519	2.250	2.003	1.946	1.934
Install filter aid polymer feed capability	3.186	1.741	1.295	1.104	0.868	0.664	0.618	0.609
Install backwash water polymer/coagulant feed capability	2.671	1.122	0.639	0.433	0.210	0.054	0.028	0.023
Install pH adjustment for enhancing alkalinity purposes	12.887	12.258	11.982	11.796	11.508	11.149	11.022	11.006
Coagulant Improvements								
Primary coagulant feed points, control, and measurement	7.831	4.973	4.037	3.623	3.117	2.667	2.565	2.543
Rapid Mixing								
Rapid Mix Improvements – Equipment (only)	2.704	6.513	6.755	6.641	4.194	1.168	0.619	0.609
Rapid Mix Improvements – Equipment and basin	3.387	7.861	8.124	7.976	5.033	1.401	0.742	0.724
Flocculation Improvements								
Flocculation Improvements – Equipment (only)	3.199	2.339	2.112	1.961	1.199	0.327	0.171	0.154
Flocculation Improvements – Equipment and basin	6.360	5.082	4.475	4.104	2.493	0.677	0.353	0.307
Settling Improvements								
Equipment modification – weirs in influent/effluent	1.126	0.704	0.546	0.534	0.452	0.334	0.275	0.257
Add tube settlers	2.234	1.709	1.455	1.411	1.271	1.005	0.870	0.810

Table 3-10. Total Annualized Costs at 10 percent Interest Rate (Cents/1,000 gal) by Treatment Option* (Continued)

Plant Population Size Categories (in thousands)	10 – 25	25 – 50	50 – 75	75 – 100	100 – 500	500 – 1,000	>1,000	>1,000
Average Day Demand (MGD)	**2.1**	**5.0**	**8.8**	**13.0**	**27.0**	**120.0**	**270.0**	**348.0**
Peak Day Demand (MGD)	**4.8**	**11.0**	**18.0**	**26.0**	**51.0**	**210.0**	**430.0**	**518.0**
Filtration Improvements (continued)								
Post-backwash – sequence (install additional filter(s))	19.409	10.092	7.657	6.984	4.979	3.498	3.019	3.859
Post-backwash – filter-to-waste	3.034	1.651	1.459	1.392	1.309	1.152	1.044	0.980
Filter rate-of-flow controller replacement	5.700	3.053	2.499	2.260	2.085	1.802	1.652	1.549
Individual filter turbidimeter installation	1.354	1.137	1.006	0.929	0.908	0.750	0.436	0.410
Microfiltration	134.113	102.523	84.358	75.097	60.404	40.873	33.090	30.687
Hydraulic Improvements								
Recycle flow – account for in process control decisions	2.769	2.190	1.917	1.796	1.509	1.174	0.894	1.192
Install of valving and/or pumps to control the flow	1.158	0.824	0.709	0.652	0.501	0.303	0.222	0.287
Flow distribution/control/measurement	1.829	1.440	1.238	1.179	0.987	0.764	0.580	0.774
Administrative Culture Improvements								
Policy and commitment to lower water quality goals	0.543	0.228	0.130	0.175	0.084	0.019	0.008	0.007
Plant staffing increase (1 or 2 persons)	5.504	2.311	1.313	1.778	0.856	0.193	0.085	0.067
Staff qualifications	0.651	0.274	0.155	0.140	0.101	0.023	0.010	0.008
Laboratory Modifications								
Bench top turbidimeter purchase	0.324	0.136	0.105	0.105	0.051	0.017	0.007	0.005
Jar test apparatus purchase	0.165	0.069	0.049	0.053	0.025	0.008	0.004	0.003
Alternative process control testing equipment	1.092	0.459	0.304	0.353	0.170	0.057	0.026	0.020

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APPENDIX A. EXAMPLE CALCULATIONS

Estimated Capital, O&M, and Total Costs

This appendix provides a detailed look at the process calculations presented in Section 3. This appendix provides the detailed calculations for each treatment process for one flow category. This process was repeated for each category costed in Section 3.

I. Costing Software

The computer software used in this document is titled, "W/WW Costs & Design Criteria Guidelines 2.0" written by CWC Engineering Software in 1994. This program is also referred to as WATERCOST, which was developed for water treatment technologies with design flows of 1.0 mgd and greater.

II. Factors for Updating Costs

- Engineering News Record (ENR) Construction Cost Indices
  - Date: March 17, 1997
  - Building Cost Index = 3315.79
  - Skilled Labor = 5160.12
  - Material Prices = 2000.13

- WATERCOST is a model capable of estimating costs for a given date by inputting specific parameters. To develop a reliable cost estimate, the process involves selecting the appropriate unit processes, entering all required user inputs, and printing the model results for a specific objective. The necessary values needed are in the form of cost indices, unit costs, and cost factors.

III. Design and Average Flows

Many treatment processes and flow categories are referenced in this document. Only one flow category is presented in this appendix as an example of calculations used to develop capital and O&M costs.

- Design (capacity) Flow = 26 mgd
- Average Flow = 13 mgd

IV. Modifications

A. Chemical Addition

1. INSTALL COAGULANT AID POLYMER FEED CAPABILITY (WATERCOST Process 43)

   - Design Capacity: Capacity of system based on dosage (feed rate) of 2 mg/L.

     - *Dosage (mg/l) × 8.34 × Flow (mgd) = lbs/day*
     - *2 mg/L × 8.34 × 26 mgd = 434 lbs/day*

   - Annual O&M: Annual system usage based on dosage (feed rate) of 1 mg/L.

     - *Dosage (mg/l) × 8.34 × Flow (mgd) = lbs/day*
     - *1 mg/L × 8.34 × 13 mgd = 108 lbs/day*

   - Costs

     - Total Capital Costs = $181,100
     - Annual O&M Costs = $98,300

2. INSTALL FILTER AID POLYMER FEED CAPABILITY (WATERCOST Process 43)

   - Design Capacity: Capacity of system based on dosage (feed rate) of 1 mg/L.

     - *Dosage (mg/l) × 8.34 × Flow (mgd) = lbs/day*
     - *1 mg/L × 8.34 × 26 mgd = 217 lbs/day*

   - Annual O&M: Annual system usage based on dosage (feed rate) of 0.2 mg/L.

     - *Dosage (mg/l) × 8.34 × Flow (mgd) = lbs/day*
     - *0.2 mg/L × 8.34 × 13 mgd = 32 lbs/day*

   - Costs

     - Total Capital Costs = $144,100
     - Annual O&M Costs = $35,400

3. INSTALL BACKWASH WATER POLYMER/COAGULANT FEED CAPABILITY (WATERCOST Process 43)

- Design Capacity: Capacity of system based on dosage (feed rate) of 0.5 mg/L at a Backwash Flow of 11.2 mgd.

  - *Dosage (mg/l) × 8.34 × Flow (mgd) = lbs/day*
  - *0.5 mg/L × 8.34 × 11.2 mgd = 46.7 lbs/day*

- Annual O&M: Annual system usage based on dosage (feed rate) of 0.2 mg/L at a Backwash Flow of 11.2 mgd.

  - *Dosage (mg/l) × 8.34 × Flow (mgd) = lbs/day*
  - *0.2 mg/L × 8.34 × 11.2 mgd = 19 lbs/day*

- Costs

  - Total Capital Costs = $100,000
  - Annual O&M Costs = $8,800

4. INSTALL PH ADJUSTMENT FOR ENHANCING ALKALINITY PURPOSES (WATERCOST Process 45)

- Design Capacity: Capacity of system based on dosage (feed rate) of 4 gallons per hour per mgd or 74 mg/L.

  - *Dosage (mg/l) × 8.34 × Flow (mgd) = lbs/day*
  - *74 mg/L × 8.34 × 26 mgd = 15,974 lbs/day*

- Annual O&M: Annual system usage based on dosage (feed rate) of 4 gallons per hour per mgd or 74 mg/L.

  - *Dosage (mg/l) × 8.34 × Flow (mgd) = lbs/day*
  - *74 mg/L × 8.34 × 13 mgd = 7,987 lbs/day*

- Costs

  - Total Capital Costs = $350,700
  - Annual O&M Costs = $518,500

B. Coagulant Improvements

1. PRIMARY COAGULANT FEED POINTS, CONTROL, AND MEASUREMENT
The same design criteria and equipment components for coagulant and systems discussed in Section 3.2.1.1 apply in this section.

- Design Capacity: Capacity of system based on dosage (feed rate) of 2 mg/L.
  - *Dosage (mg/l) × 8.34 × Flow (mgd) = lbs/day*
  - *2 mg/L × 8.34 × 26 mgd = 434 lbs/day*
- Annual O&M: Annual system usage based on dosage (feed rate) of 1 mg/L.
  - *Dosage (mg/l) × 8.34 × Flow (mgd) = lbs/day*
  - *1 mg/L × 8.34 × 13 mgd = 108 lbs/day*
- Costs
  - Total Capital Costs = $325,200
  - Annual O&M Costs = $133,700

C. Rapid Mixing

1. RAPID MIX IMPROVEMENTS — EQUIPMENT ONLY
(WATERCOST Process 106)

- Design Capacity: Capacity of system based on velocity gradient (G) of 900 sec^{-1} at the design flow.
- Annual O&M: Annual usage based on 24-hour/day operation of the system
- Costs
  - Total Capital Costs = $269,600
  - Annual O&M Costs = $283,500

2. RAPID MIX IMPROVEMENTS — EQUIPMENT AND BASIN
(WATERCOST Process 106)

- Design Capacity: Capacity of system based on velocity gradient (G) of 900 sec^{-1} at the design flow.
- Annual O&M: Annual usage based on 24-hour/day operation of the system

- Costs
  - Total Capital Costs = $808,900
  - Annual O&M = $283,500

D. Flocculation Improvements

1. FLOCCULATION IMPROVEMENTS--EQUIPMENT ONLY (WATERCOST Process 74)

   - Design Capacity: Capacity of system based on velocity gradient (G) of 50 sec^{-1} at the design flow.
   - Annual O&M: Annual usage based on 24-hour/day operation of the system
   - Costs
     - Total Capital Costs = $432,900
     - Annual O&M Costs = $42,200

2. FLOCCULATION IMPROVEMENTS — EQUIPMENT AND BASIN (WATERCOST Process 74)

   - Design Capacity: Capacity of system based on velocity gradient (G) of 50 sec^{-1} at the design flow.
   - Annual O&M: Annual usage based on 24-hour/day operation of the system
   - Costs
     - Total Capital Costs = $1,298,800
     - Annual O&M Costs = $42,200

E. Settling Improvements

1. EQUIPMENT MODIFICATION — WEIRS IN INFLUENT/EFFLUENT

   - Design Capacity: Baffle at inlet to sedimentation basin designed to provide 0.1 foot headloss. Additional launderers added to increase the length of effluent weirs. The design overflow rate for the effluent weirs is 10 gallons per minute per foot of weir.
   - Annual O&M: Annual usage based on 24-hour/day operation of the system

- Costs

  - Total Capital Costs = $151,800
  - Annual O&M Costs = $7,500

2. ADD TUBE SETTLERS (WATERCOST Process 120)

   - Design Capacity: The design overflow rate for the tube settlers is 2.5 gallons per minute per square foot.

   - Annual O&M: Annual usage based on 24-hour/day operation of the system

   - Costs

     - Total Capital Costs = $506,100
     - Annual O&M Costs = $7,500

F. Filtration Improvements

1. FILTER MEDIA ADDITION (2" – 6") (WATERCOST Process 63)

   - Design Capacity: The existing filter design is assumed to be dual media (anthracite and sand). Filter area is the major design factor for this item, which is determined using a filtration rate of 2.5 gpm/sq ft at peak day demand.

   - Annual O&M: There are no additional annual costs associated with the filter media addition.

   - Costs

     - Total Capital Costs = $110,100
     - Annual O&M Costs = $0

2. FILTER MEDIA REPLACEMENT WITHOUT GRAVEL (WATERCOST Process 56)

   - Design Capacity: The existing filter design is assumed to be sand media. Filter area is the major design factor for this item, which is determined using a filtration rate of 2.5 gpm/sq ft at peak day demand.

   - Annual O&M: There are no additional annual costs associated with the filter media replacement without gravel.

- Costs

  - Total Capital Costs = $288,200
  - Annual O&M Costs = $0

3. FILTER MEDIA AND SUPPORT GRAVEL REPLACEMENT (WATERCOST Process 56)

   - Design Capacity: The existing filter design is assumed to be sand media. Filter area is the major design factor for this item, and is determined using a filtration rate of 2.5 gpm/sq ft at peak day demand. Dual media filters (coal-sand) use 20 inches of 1.0 to 1.2 mm effective size anthracite coal with a uniformity coefficient less than 1.7, and 10 inches of 0.42 to 0.55 mm effective size silica sand with a uniformity coefficient less than 1.6. Gravel support is made up of 3 inches of 1-1/2" × 3/4" silica gravel, 3 inches of 3/4"× 3/8"silica gravel, and 3 inches of 3/16" × #10 silica gravel.

   - Annual O&M: There are no additional annual costs associated with the filter media and support gravel replacement.

   - Costs

     - Total Capital Costs = $432,300
     - Annual O&M Costs = $0

4. FILTER MEDIA AND SUPPORT GRAVEL REPLACEMENT AND UNDERDRAIN SYSTEM (WATERCOST Process 56)

   - Design Capacity: The existing filter design is assumed to be sand media. Filter area is the major design factor for this item, which is determined using a filtration rate of 2.5 gpm/sq ft at peak day demand. Dual media filters (coal-sand) use 20 inches of 1.0 to 1.2 mm effective size anthracite coal with a uniformity coefficient less than 1.7, and 10 inches of 0.42 to 0.55 mm effective size silica sand with a uniformity coefficient less than 1.6. Gravel support is made up of 3 inches of 1-1/2" × 3/4" silica gravel, 3 inches of 3/4" × 3/8" silica gravel, and 3 inches of 3/16" × #10 silica gravel. A new underdrain system is added that is designed for the future use of an air-water backwash system.

   - Annual O&M: There are no additional annual costs associated with the filter media and support gravel replacement.

   - Costs

     - Total Capital Costs = $576,400
     - Annual O&M Costs = $0

5. BACKWASHING — INCREASE FLOW/VELOCITY (WATERCOST Process 50)

- Design Capacity: The normal optimum backwashing rate is 15 to 18 gpm/sqft. Filter area is the major design factor for this item. The backwash flowrate is less than optimum and that the backwash system capacity will be increased approximately 10 to 20 percent. To increase the capacity of the backwash system, larger backwash pump(s), and associated piping and valving at the pumps and some electrical improvements are required. No major piping improvements in either the filter gallery or outside of the Backwash Pump Station are necessary. The backwash pump total dynamic head (TDH) is 50 ft and the maximum design rate for backwash is 18 gpm/sq ft.

- Annual O&M: O&M costs are based on backwash frequency of two filters or 33 percent of the total number of filters per day, whichever is greater, with a 10-minute duration per wash. For dual-cell filters, a backwash is defined as a backwash for both cells. Energy requirements are based on a backwash rate of 18 gpm/sq ft, a pumping head of 50 ft TDH, and an overall motor/pump efficiency of 70 percent. Annual maintenance material and labor requirements are provided for the general maintenance of the system.

- Costs

  - Total Capital Costs = $197,300
  - Annual O&M Costs = $12,500

6. BACKWASH - INSTALL SURFACE WASH (WATERCOST Process 57)

- Design Capacity: Surface wash pumps are sized to provide approximately 50 to 85 psi at the arms. Four dual-arm agitators are included for filter areas of 350 to 700 sq ft. The wet well for the surface wash pumps is the same as for the backwash pumps.

- Annual O&M: O&M costs are based on backwash frequency of two filters or 33 percent of the total number of filters per day, whichever is greater, with a 10-minute duration per wash. For dual-cell filters, a backwash is defined as a backwash for both cells. Energy requirements are based on a backwash rate of 0.5 gpm/sq ft, a pumping head of 65 psi, and an overall motor/pump efficiency of 70 percent. Annual maintenance material and labor requirements are provided for the general maintenance of the system.

- Costs

  - Total Capital Costs = $582,600
  - Annual O&M Costs = $22,700

7. POST-BACKWASH — SEQUENCE (Resting)

- Design Capacity: For this report, it is assumed that the existing filters are capable of accommodating the additional flow from the filter(s) resting and no major structural modifications will be required for this particular treatment technique. The cost estimate includes some piping and control modifications to the existing filters.

- Annual O&M: With the resting of filters after a backwash and increasing the loading on the remaining filters, the frequency of backwashing may increase. The annual O&M cost reflects a 10 to 20 percent increase of filter backwashing.

- Costs

  - Total Capital Costs = $181,500
  - Annual O&M Costs = $23,000

8. POST-BACKWASH — SEQUENCE (INSTALL ADDITIONAL FILTER(S)) (WATERCOST Process 54)

- Design Capacity: Based on good engineering practice, at least two filters will be added regardless of size of plant. Conventional gravity filtration structure costs are based on use of cast-in-place concrete with a media depth of 2 to 3 ft and a total depth of 16 ft for the filter box. The costs include housing of the entire filter structure; pipe gallery and controls. Costs for filtration structures include the filter structure, underdrains, wash water troughs, a pipe gallery, required piping and cylinder operated butterfly valves, filter flow and headloss instrumentation, a filter control panel, and the total housing requirement.

- Annual Usage: O&M costs are based on backwash frequency of two filters or 33 percent of the total number of filters per day, whichever is greater, with a 10-minute duration per wash. Energy requirements are based on a backwash rate of 18 gpm/sq ft, a pumping head of 50 ft TDH, and an overall motor/pump efficiency of 70 percent. Annual maintenance material and labor requirements are provided for the general maintenance of the system.

- Costs

  - Total Capital Costs = $1,814,500
  - Annual O&M Costs = $78,800

9. POST-BACKWASH — FILTER-TO-WASTE

- Design Capacity: The filter-to-waste improvements include the piping, fittings, and valves in these facilities sized to convey up to 20 minutes of filtered water at an application rate of 5 gpm/sq ft. on the filter. No facilities are provided to pump

filter-to-waste within the plant. It is assumed that the filter-to-waste flow will be recycled within the plant and the existing facilities are adequate for the additional flow.

- Annual O&M: O&M costs are based on backwash frequency of two filters or 33 percent of the total number of filters per day, whichever is greater, per day. Annual maintenance material and labor requirements are provided for the general maintenance of the system.

- Costs

  - Total Capital Costs = $298,000
  - Annual O&M Costs = $23,000

10. FILTER RATE-OF-FLOW CONTROLLER REPLACEMENT

- Design Capacity: The control system, flow meter, flow control valve, and piping modifications required to change the controller are included. The piping and valving are designed for a filtration rate of 5 gpm/sq ft.

- Annual O&M: Process energy is based on 24-hour/day operation of the system. Annual maintenance material and labor requirements are provided for the general maintenance of the system.

- Costs

  - Total Capital Costs = $521,500
  - Annual O&M Costs = $46,000

11. INDIVIDUAL FILTER TURBIDIMETER INSTALLATION

- Design Capacity: The installation of a turbidimeter at a filter will include the purchase of a turbidimeter for each filter and, a tap on the filter effluent pipe, piping to the turbidimeter, drain piping, and power. Initial training of the plant staff is also included in the cost estimate. Capital costs are amortized over 7 years.

- Annual O&M: Process energy is based on 24-hour/day operation of the system. Annual maintenance material and labor requirements are provided for the general maintenance of the system, which will include calibration of the units on a monthly basis.

- Costs

  - Total Capital Costs = $160,000
  - Annual O&M Costs = $11,200

12. MICROFILTRATION

- Design Capacity: This cost estimate assumes that the microfiltration system will be installed after the existing clearwells, since it is deemed to be a polishing step to produce an effluent water quality meeting the most stringent requirements. The membrane system is designed for an average flux rate of 70 gpd/ft^2 at 68^{0}F with the frequency and duration of the backwash set to maintain a minimum feedwater recovery rate of greater than 97 percent after recycling of the backwash water. Estimated capital costs include the membrane system, process equipment building, electrical supply, final disinfection facilities, treated water storage and pumping facilities, and wash water recovery system.

- Annual O&M: Annual costs include labor, chemicals, energy, membrane replacement, residuals disposal, and miscellaneous replacement parts.

- Costs

  - Total Capital Costs = $23,284,400
  - Annual O&M Costs = $828,400

G. Hydraulic Improvements

1. RECYCLE FLOW - ACCOUNT FOR PROCESS CONTROL DECISIONS

- Design Capacity: It is assumed that the existing plant has no facilities to store wastewater; therefore, major structural improvements are required to meter recycle flows back into the raw water flow at a constant rate. These improvements include flow equalization basins, pumping facilities, piping modifications, and controls for monitoring flows to minimize the impact of recycle flows.

- Annual O&M: Process energy is based on 24-hour/day operation of the system. Annual maintenance material and labor requirements are provided for the general maintenance of the system.

- Costs

  - Total Capital Costs = $485,000
  - Annual O&M Costs = $28,200

2. RECYCLE FLOW — INSTALL VALVING AND/OR PUMPS TO CONTROL THE FLOW

- Design Capacity: It is assumed that the existing plant has facilities to store and pump the wastewater back to the intake of the plant. However, the pumping facilities are uncontrolled, meaning that the operation of the station is on/off based

on the water level in the storage facilities for wastewater. Therefore, no major structural improvements are necessary, but improvements still are necessary for pumping, valving, minor piping, some controls for monitoring flows to minimize the impact of recycle flows, and electrical considerations are required to meter recycle flows back into the raw water flow at a constant rate.

- Annual O&M: Process energy is based on 24-hour/day operation of the system. Annual maintenance material and labor requirements are provided for the general maintenance of the system.

- Costs

  - Total Capital Costs = $100,800
  - Annual O&M Costs = $19,100

3. FLOW DISTRIBUTION/CONTROL/MEASUREMENT

- Design Capacity: It is assumed that minor improvements are required to meter and control flows within the plant. These improvements include monitoring of the raw and finished water flows to minimize the impact of recycle flows.

- Annual O&M: Process energy is based on 24-hour/day operation of the system. Annual maintenance material and labor requirements are provided for the general maintenance of the system.

- Costs

  - Total Capital Costs = $313,400
  - Annual O&M Costs = $19,100

H. Administrative Culture Improvements

1. POLICY AND COMMITMENT TO LOWER WATER QUALITY GOALS

- Design Capacity: It is assumed there are no capital costs associated with this item, since it is a policy technique.

- Annual O&M: The annual O&M costs are assumed to be an annual commitment for developing policies and following up to determine compliance.

- Costs

  - Total Capital Costs = $0
  - Annual O&M Costs = $8,300

2. PLANT STAFFING INCREASE (1 OR 2 PERSONS)

- Design Capacity: It is assumed that capital costs of $5000 per new staff addition for office/field fixtures, computer hardware, and training. One additional staff is costed for a System Size up to 75,000 population and two additional staff are included for larger systems.

- Annual O&M: The O&M costs include an annual commitment for one or two new staff members.

- Costs

  - Total Capital Costs = $10,000
  - Annual O&M Costs = $83,200

3. STAFF QUALIFICATIONS

- Design Capacity: It is assumed that there are no capital costs associated with this item.

- Annual O&M: The O&M costs include an annual commitment for training of staff members.

- Costs

  - Total Capital Costs = $0
  - Annual O&M Costs = $6,700

I. Laboratory Modifications

1. BENCH TOP TURBIDIMETER PURCHASE

- Design Capacity: It is assumed that the costs include the purchase of one new benchtop turbidimeter for process control for systems up to 75,000 population; two for systems up to 500,000 population and three for systems serving more than 500,000 population.

- Annual O&M: Annual maintenance material and labor requirements are provided for the general maintenance and monthly calibration of the equipment.

- Costs

  - Total Capital Costs = $10,000
  - Annual O&M Costs = $2,900

2. JAR TEST APPARATUS PURCHASE

- Design Capacity: The costs include the purchase of one, two, or three sets of jar test apparatus for process control. The number of sets of equipment is dependent on system size.

- Annual O&M: Annual maintenance material and labor requirements are provided for the general maintenance and calibration of the equipment.

- Costs

  - Total Capital Costs = $13,000
  - Annual O&M Costs = $1,000

3. ALTERNATIVE PROCESS CONTROL TESTING EQUIPMENT

- Design Capacity: The costs include the purchase of new alternative on-line test equipment (such as particle counter, streaming current monitor or Zetameter) for process control. The number of units is dependent on system size.

- Annual Usage: Annual maintenance material and labor requirements are provided for the general maintenance and monthly calibration of the equipment.

- Costs

  - Total Capital Costs = $100,000
  - Annual O&M Costs = $5,000

J. Process Control Testing Modifications

1. MODIFY/IMPLEMENT TURBIDITY MONITORING AND RECORDING

- Design Capacity: This cost estimate assumes that the municipality or utility will choose to record the data from individual filter turbidimeters electronically. One method to acquire the output from each individual turbidimeter is to route all the data through a remote telemetry unit (RTU) or a programmable logic controller (PLC) to a computer. Another means to acquire these data is to use a microprocessor-based multi-channel turbidimeter. This type of turbidimeter can obtain the output from many turbidimeters (up to 64) and then transmit data directly to the computer.

- Annual O&M: Annual maintenance material and labor requirements are provided for the general maintenance and annual calibration of the equipment.

- Costs

  - Total Capital Costs = $36,000
  - Annual O&M Costs = $8,100

2. MODIFY/IMPLEMENT PROCESS MONITORING STRATEGY (OTHER THAN TURBIDITY)

   - Design Capacity: To provide the information required for the implementation of a process control strategy, flowmeters will be installed on the raw water and finished water, and chemical feed rates and clearwell level(s) will be measured. These data will then be provided to the operator through a personal computer based monitoring system (with appropriate software). Note that only monitoring and data acquisition is provided and all process changes would have to be made by the operator.

   - Annual O&M: Annual maintenance material and labor requirements are provided for the general maintenance and annual calibration of the equipment.

   - Costs

     - Total Capital Costs = $111,100
     - Annual O&M Costs = $16,200

3. MODIFY/IMPLEMENT PROCESS MONITORING STRATEGY (OTHER THAN TURBIDITY)

   - Design Capacity: To provide the information required for the implementation of a process control strategy, flowmeters will be installed on the raw water and finished water, and chemical feed rates and clearwell level(s) will be measured. These data will then be provided to the operator through a personal computer based monitoring system (with appropriate software, which would be a standard SCADA program tailored to the specific plant). Note that only monitoring and data acquisition is provided and all process changes would have to be made by the operator. Capital costs are amortized over 7 years.

   - Annual O&M: Annual maintenance material and labor requirements are provided for the general maintenance and annual calibration of the equipment.

   - Costs

     - Total Capital Costs = $111,100
     - Annual O&M Costs = $16,200

4. PROCESS CONTROL FACILITATOR

- Design Capacity: There are no capital costs associated with this item.

- Annual O&M: The costs associated with this item are assumed to be an annual O&M commitment for hiring a facilitator. Depending on the size of the system, the facilitator would be provided by an outside source or a new position within a larger utility. It is assumed that the facilitator would be between one-quarter and full time at the plant.

- Costs

  - Total Capital Costs = $0
  - Annual O&M Costs =$30,000

5. STAFF TRAINING TO UNDERSTAND PROCESS CONTROL STRATEGY

- Design Capacity: There are no capital costs associated with this item.

- Annual O&M: The costs associated with this item are assumed to be an annual O&M commitment for training of all staff members.

- Costs

  - Total Capital Costs = $0
  - Annual O&M Costs = $7,500

6. MODIFICATION OF PROCESS CONTROL INSTRUMENTATION

- Design Capacity: To provide the information required for the full implementation of an automatic process control strategy through the installation of a SCADA system, flowmeters and flow control valves on the raw water and finished water (if necessary), chemical feed rate monitoring and control, and clearwell level(s) will be installed. The SCADA system provides control of the treatment process with the operator monitoring and changing the appropriate setpoints as needed. Total capital costs include field instruments, the personal computer based system, hardware, software, software modifications, training and calibration. SCADA capital costs are amortized over 7 years.

- Annual O&M: Annual maintenance material and labor requirements are provided for the general maintenance and monthly calibration of the equipment.

- Costs

  - Total Capital Costs = $716,000
  - Annual O&M Costs = $16,200