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Agency

Drinking Water Treatment Plant Residuals Management
Technical Report

Summary of Residuals Generation, Treatment, and Disposal at Large Community Water Systems

September 2011

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DISCLAIMER

This report on the drinking water treatment industry does not set forth any regulatory requirements under the Clean Water Act. It is intended solely as a presentation of information of which the U.S. Environmental Protection Agency (EPA) is currently aware concerning the generation, treatment, and disposal of wastewater and solid residuals at water treatment plants (WTPs). Thus, it does not impose any requirements on any party, including EPA, states, permitting authorities, publicly-owned treatment works (POTWs), or the regulated community. This report was prepared using information from the following sources: review of selected literature, reports, and other materials; meetings with several interested parties; site visits at WTPs; an industry survey; and other information solicited from stakeholders.

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SECTION 1

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) completed a review of discharges from water treatment plants (WTPs). The purpose of this report is to summarize the data collected during this review (principally covered in Sections 2, 3, 9, 10, and 11) and to serve as a technical resource to permit writers (primarily covered in Sections 4 through 8 and Sections 12 and 13).

EPA selected the drinking water treatment (DWT) industry for a rulemaking as part of its 2004 Biennial Effluent Limitations and Guidelines Program planning process. EPA is not at this time continuing its effluent guidelines rulemaking for the DWT industry. In the 2004 Plan, EPA announced that it would begin development of a regulation to control the pollutants discharged from medium and large DWT plants. See 69 FR 53720 (September 2, 2004). Based on a preliminary study and on public comments, EPA was interested in the potential volume of discharges associated with drinking water facilities. The preliminary data were not conclusive, and the Agency proceeded with additional study and analysis of treatability, including an industry survey. After considering extensive information about the industry, its treatment residuals, wastewater treatment options, and discharge characteristics, and after considering other priorities, EPA has suspended work on this rulemaking.

The DWT industry serves to provide potable water to its customers. The DWT industry falls under Standard Industrial Classification (SIC) code 4941, which crosswalks with North American Industry Classification System (NAICS) code 22131. In addition to drinking water, SIC code 4941 includes other water supply plants—those that treat water for use in commercial and industrial applications. NAICS code 22131 includes all of SIC code 4941 plus irrigation systems (defined by SIC code 4971). For this industry review, EPA focused on drinking water systems that serve more than 10,000 people. Most systems that serve more than 10,000 people are defined as community water systems (CWSs) under the Safe Drinking Water Act. CWSs serve the same customer base year round (e.g., city water authority).

Drinking water systems may obtain their water supply either directly from the source (e.g., river, lake, reservoir for surface water sources or via wells for ground water sources) or may purchase from wholesalers. Systems may treat the source water (i.e., intake water) prior to distribution or only provide delivery of the drinking water. If the system treats the source water prior to delivery, the system operates one or more WTPs.

Based on EPA's industry survey, 2,151 WTPs serve populations greater than 10,000 people and generate waste streams from the treatment of source water. Sixty-eight percent (1,464 plants) serve between 10,001 and 50,000 people, and on average produce 3.49 million gallons per year of finished drinking water. The remaining 32 percent (688 plants) serve more than 50,000 people and produce between three and 55,000 million gallons per year of finished drinking water. The average drinking water production per day for the 688 WTPs is 23.46 million gallons. For all 2,151 WTPs, the average quantity of drinking water produced per person per year is over 53,000 gallons.

During the treatment of source water, WTPs remove contaminants that are unhealthy or undesirable for consumption. The generated waste streams are treatment residuals. EPA estimates that approximately 31 percent of the 2,151 WTPs directly discharge to surface water. An additional 7 percent discharge both directly to surface water and indirectly by transferring residuals to POTWs. The discharge of treatment residuals is the issue of interest in this industry review.

Since 2004, EPA has conducted site visits, completed an industry survey, worked with the industry (e.g., American Water Works Association), and collected other information. EPA produced this technical report to summarize the collected information and our analysis. Section 2.0 summarizes EPA's activities to identify and collect data as part of the industry review. Subsequent sections of this report summarize analyses conducted using data from these sources. In particular:

- **Section 3.0 characterizes the water treatment industry** by size of population served, primary water source (e.g., ground, surface), treatment method(s) used (e.g., precipitative softening, conventional filtration, membrane desalination, ion exchange), and discharges. It provides an overview of financial characteristics of the industry and a discussion of water consumption and rates.

- **Section 4.0 analyzes state permit requirements** including both general and individual permits, pollutants regulated (e.g., aluminum, iron, manganese, pH, settleable solids), range of pollutant limitations, and special requirements for systems based on treatment technologies used.

- **Section 5.0 discusses source water quality and the factors that influence it.** Influencing factors include naturally-occurring attributes (climate, geology, soil type, land cover, hydrology, precipitation and runoff, and wildlife) and man-made attributes (land management practices and runoff or upstream discharge from point and nonpoint sources).

- **Section 6.0 reviews source water treatment technologies** including conventional filtration, direct filtration, and filtration only; precipitative softening; membrane separation; ion exchange; activated carbon; disinfection; and other chemical additions.

- **Section 7.0 examines residuals produced by each of the source water treatment technologies.** Residuals generated by WTPs include solids contaminants removed during precipitative softening (softening sludge); solids and contaminants removed during coagulation, flocculation, and sedimentation (coagulation sludge); filter backwash water; concentrates from membrane desalination; spent membrane cleaning solutions; ion exchange waste concentrates; and regeneration wastes from adsorption processes.

- **Section 8.0 discusses pollutants in drinking water treatment residuals** including suspended and dissolved solids, metals (e.g., aluminum, iron, lead, and manganese), disinfection by-products (e.g., trihalomethanes and haloacetic acids), and other pollutants.

- **Section 9.0 provides EPA's national estimate of pollutant discharges from WTPs.** In addition to the estimate, this section describes data sources and methodology used; selection of pollutants to include in the loadings estimates; development of long-term averages for pollutants; and pollutant loadings estimates for model plants.

- **Section 10.0 describes the potential environmental impacts of pollutant discharges.** EPA completed a literature review to gather data on potential environmental impacts from discharges of WTP residuals. The majority of studies focused on discharges of lime sludge and alum sludge from lime softening and conventional filtration plants. This section summarizes EPA's review of environmental impacts from WTP discharges.

- **Section 11.0 discusses best management practices for handling, minimizing, and preventing source water treatment residuals.** Example best management practices include source reduction activities (e.g., optimization of surface water intake to reduce suspended solids, optimization of filter media for finished water), and treatment of residuals, recycling and reuse of residuals, and land application of residuals.

- **Section 12.0 reviews cost considerations for residuals thickening and dewatering.** Technology options exist to reduce discharges of residuals. This section examines the factors that affect the cost of installing and operating residuals treatment systems for conventional filtration (i.e., coagulation and filtration) and lime softening plants.

- **Section 13.0 discusses the methodology to assess economic achievability.** EPA outlines an approach to determine the economic achievability of installing new technology to treat residuals at WTPs.

- **Section 14.0 includes a glossary, acronyms, and abbreviations** used in this report.

SECTION 2

DATA SOURCES

EPA conducted a number of data collection activities and reviewed a number of data sources in support of the drinking water treatment (DWT) industry review. Section 2.1 describes EPA's site visits and Section 2.2 describes EPA's industry questionnaire. Section 2.3 discusses ground water and drinking water data collected by EPA under the Safe Drinking Water Act (SDWA). Section 2.4 presents other information collection activities and data sources, including literature searches, National Pollutant Discharge Elimination System (NPDES) permits, NPDES Discharge Monitoring Reports (DMRs), other EPA data sources, and industry data. Section 2.5 describes EPA's outreach efforts through stakeholder meetings and Section 2.6 describes the DWT technology review.

2.1 SUMMARY OF EPA'S WATER TREATMENT PLANT SITE VISITS

EPA conducted 14 engineering site visits to drinking water treatment plants (WTPs) and a technology vendor research and manufacturing plant to gather information about industry operations, sources of residuals, residuals management practices, and residuals treatment technologies. EPA used information collected from literature searches and contact with trade association members to identify representative WTPs for site visits. In general, EPA considered the following when selecting WTPs to visit:

- Size of plant (medium and large plants);
- Geographic location (variable source water qualities); and
- Residuals management practices (for treatment technologies that generate residuals).

Plant-specific selection criteria are contained in site visit reports prepared for each plant visited by EPA. During the site visits, EPA collected the following information:

- Plant description (e.g., size, production volume, location);
- Source water treatment technologies;

- Residuals generation, treatment, and management; and
- Permitting requirements.

This information is documented in the site visit report for each WTP visited. Table 2-1 lists the site visits EPA performed and the document control number (DCN) for the site visit report.

2.2 EPA DWT INDUSTRY QUESTIONNAIRE

2.2.1 Overview of Industry Questionnaire

EPA used an industry questionnaire to collect site-specific technical and economic information for Community Water Systems (CWSs) and WTPs operated by the systems. CWSs are drinking water systems that serve the same customer base year round (e.g., city water authority). The majority of drinking water is distributed by CWSs.

EPA published a notice in the *Federal Register* on July 5, 2005 (70 FR 38675) announcing its intent to submit a survey Information Collection Request (ICR) to the Office of Management and Budget (OMB). The notice requested comment on the draft ICR and two draft survey questionnaires (screener and detailed). EPA revised the survey questionnaires as a result of the public comments received, which included comments from the Association of Metropolitan Water Agencies (AMWA) and American Water Works Association (AWWA). Among other changes EPA collapsed the two questionnaires into one. EPA subsequently obtained OMB approval to administer one survey questionnaire (71 FR 41012, July 19, 2006).

Table 2-1. EPA Site Visits to Drinking Water Treatment Plants

Water Treatment Plant (WTP) Name	Date of EPA Site Visit	Type of Source Water Treatment	Type of Residuals Treatment	Site Visit Report DCN
James J. Corbalis WTP (Fairfax County, VA)	November 3, 2004	Conventional filtration of surface water; disinfection using chlorine and chloramines	Solids dewatering: gravity thickening and plate and filter press; Recycle water from dewatering	DW00178
Bexar Metropolitan Ultrafiltration WTP (San Antonio, TX)	November 18, 2004	Ultrafiltration with coagulation/sedimentation of surface water; disinfection using chlorine	Equalization; Evaporation ponds; Recycle filter backwash	DW03706
Washington Aqueduct: Dalecarlia WTP (Washington, DC)	November 30, 2004	Conventional filtration of surface water; disinfection using chloramine	Dewatering facility is under construction	DW03707
Rivanna Water and Sewer Authority: South Rivanna WTP (Charlottesville, VA)	March 31, 2005	Conventional filtration of surface water; disinfection using chlorine	Equalization, clarification, and recycling of wastewater; Solids dewatering: belt filter press	DW03708
Rivanna Water and Sewer Authority: Scottsvillle WTP (Charlottesville, VA)	March 31, 2005	Conventional filtration of surface water; disinfection using chlorine	Equalization, clarification, and recycling of wastewater; Settling in lagoons prior to discharge	
Evitts Creek WTP (Cumberland, MD)	July 14, 2005	Direct filtration of surface water, including use of dissolved air flotation (DAF); disinfection using chlorine (ammonia added to distribution system to form chloramines)	Solids dewatering: thickening and belt filter press	DW03709
F.B. Leopold Company (Zelienople, PA)	July 15, 2005	Vendor research and manufacturing facility		DW00223
Fleur Drive WTP (Des Moines, IA)	October 6, 2005	Source water: surface water (Aspects of this report are claimed by the facility to be Confidential Business Information)		DW00918
Newport News Water Works: Lee Hall Facility (Newport News, VA)	October 7, 2005	Conventional filtration of surface water (with DAF); Reverse osmosis of ground water; Disinfection of finished water from both plants using chlorine or ozone	Equalization and gravity thickeners; Thickening sludge treated off-site in centrifuges	DW03710
City of Melbourne: Joe Mullins Reverse Osmosis WTP (Melbourne, FL)	October 14, 2005	Reverse osmosis of ground water; disinfection of finished water using chlorine	Concentrate is degasified to remove hydrogen sulfide and carbon dioxide; Acid is added to lower the pH; Air injected prior to discharge to increase dissolved oxygen levels	DW00903

Table 2-1. EPA Site Visits to Drinking Water Treatment Plants

Water Treatment Plant (WTP) Name	Date of EPA Site Visit	Type of Source Water Treatment	Type of Residuals Treatment	Site Visit Report DCN
City of Melbourne: John A. Buckley Surface WTP (Melbourne, FL)	October 14, 2005	Conventional filtration (activated carbon filters) of surface water; disinfection of finished water using chlorine	Equalization (filter backwash); Solids dewatering: filter presses; Wastewater recycled	DW00903
E.M. Johnson WTP (Raleigh, NC)	October 17, 2005	Conventional filtration of surface water; disinfection using chlorine (sodium hypochlorite) and chloramine (at clear well)	Clarification of filter backwash; Solids dewatering: gravity thickening and belt filter press	DW00905
Val Vista WTP (Mesa, AZ)	January 18, 2006	Conventional filtration of purchased water (surface water); disinfection using chlorine	Filter backwash clarifiers; Solids dewatering: gravity thickeners and centrifuges	DW00891
Alvarado WTP (San Diego, CA)	January 19, 2006	Conventional filtration of purchased and surface water; disinfection using chlorine but plans to introduce ozone disinfection	None: residuals returned to intake reservoir (source water)	DW00907
Puerto Rico Aqueduct and Sewer Authority (PRASA): Arecibo WTP	August 8 – 10, 2006	Conventional filtration of surface water; disinfection using chlorine	None	DW03711
PRASA: El Yunque WTP	August 8 – 10, 2006	Conventional filtration of surface water; disinfection using chlorine	Sludge drying: vacuum-assisted	
PRASA: Canovanas WTP	August 8 – 10, 2006	Conventional filtration of surface water; disinfection using chlorine	Recycle	
PRASA: Enrique Ortega (La Plata) WTP	August 8 – 10, 2006	Conventional filtration of surface water; disinfection using chlorine	Sludge drying: vacuum-assisted	
PRASA: Los Filtros (Guaynabo) WTP	August 8 – 10, 2006	Conventional filtration of surface water; disinfection using chlorine	Sludge drying: vacuum-assisted	
PRASA: Sergio Cuevas Bustamante WTP	August 8 – 10, 2006	Conventional filtration of surface water; disinfection using chlorine	Sludge drying: vacuum-assisted	
Thames Water: Superaqueduct WTP	August 8 – 10, 2006	Conventional filtration of surface water; disinfection using chlorine	Solids dewatering: lagoon	

Table 2-1. EPA Site Visits to Drinking Water Treatment Plants

Water Treatment Plant (WTP) Name	Date of EPA Site Visit	Type of Source Water Treatment	Type of Residuals Treatment	Site Visit Report DCN
Missouri American Water Company: St. Joseph Plant (St. Joseph, MO)	October 16, 2006	Precipitative (lime) softening of ground water; disinfection using chlorine	Filter backwash recycled; Settling basin prior to discharge	DW03772
Kansas City WTP (Kansas City, MO)	October 17, 2006	Precipitative (lime) softening of surface and ground water; disinfection using chloramine	None	
Courtney Bend Water Plant (Independence, MO)	October 17, 2006	Precipitative (lime) softening of ground water; disinfection using chloramines	Filter backwash recycled	
Boonville WTP (Boonville, MO)	October 18, 2006	Direct filtration of surface water	None	
Missouri American Water Company: Jefferson City Plant (Jefferson City, MO)	October 18, 2006	Precipitative (lime) softening of surface water	None	
St. Louis Water Division: Chain of Rocks WTP (St. Louis, MO)	October 19, 2006	Precipitative (lime) softening of surface water; disinfection using chlorine	None	
St. Louis Water Division: Central Plant (St. Louis, MO)	October 19, 2006	Precipitative (lime) softening of surface water; disinfection using chlorine	None	
St. Louis Water Division: Howard Bend Plant (St. Louis, MO)	October 19, 2006	Precipitative (lime) softening of surface water; disinfection using chlorine	None	
St. Louis Water Division: PWSD #2 (St. Louis, MO)	October 19, 2006	Precipitative (lime) softening and aeration of ground water; disinfection using chlorine	None	
St. Louis Water Division: North Plant (St. Louis, MO)	October 19, 2006	Precipitative (lime) softening of surface water; disinfection using chlorine	None	
Illinois American Water Company: Alton Plant (Alton, IL)	October 19, 2006	Conventional filtration of surface water, disinfection using chloramines (ammonia and chlorine)	Dechlorination	DW03781

Source: Site Visit Reports.
Conventional filtration includes coagulation/flocculation, sedimentation, and filtration processes.
Direct filtration includes coagulation/flocculation and filtration processes.
DCN – Document control number (for project record).

2.2.2 Description of Questionnaire

In February 2007, EPA mailed the *Water Treatment Plant Questionnaire* to 616 CWSs. EPA designed the survey to collect system- and plant-specific information. The survey included three parts: 1) the first part identified the system and asked screening questions to determine if the remainder of the survey should be completed; 2) the second part requested information on WTPs operated by the CWS that generate residuals and serve more than 10,000 people; and 3) the third part requested financial data about the system.

EPA excluded small systems (serving less than 10,000 people) from the survey mailing list. Even though there are a large number of small systems—over 48,000 small CWSs (U.S. EPA, 2008), EPA estimated that these systems contribute a small percent of residuals generated and discharged by the industry. In its supporting statement to the ICR, EPA estimated that CWSs that serve less than 50,000 people would contribute less than nine percent of the residuals from the industry.

The first part of the survey (question 1) requested system information (system name, address, and contact information) and asked questions to determine if the system was included in the scope of the questionnaire. A system was considered in scope if it was classified as a community water system and if one or more of the WTPs operated by the CWS met two criteria: 1) generated residuals in 2006; and 2) served a population greater than 10,000 people. Because the CWS could operate more than one WTP, EPA only wanted to collect data on the larger WTPs that generated residuals. If the respondent answered “no” to any of the questions, the respondent was not required to proceed with completion of the survey. This part also asked whether the system conducted or participated in any monitoring or other studies to assess potential impacts from discharges of residuals.

The second part of the survey (questions 2 and 3) requested general treatment plant information, production data, and current residuals treatment and disposal practices:

- Plant address;
- Population served;

- Annual production;
- Age of plant and any current upgrades;
- Source water types (i.e., ground water, surface water, or purchased water);
- Source water treatment;
- Treatment chemicals used;
- Types and quantities of residuals generated, along with any treatment or disposal practices;
- Pollution prevention practices;
- Discharge information; and
- NPDES permit and 2004 through 2006 DMR data for direct dischargers.

EPA used the collected data to develop a profile of the industry and to evaluate relationships between production factors (e.g., population served, source water treatment operations) and residuals quantity, characteristics, and waste management practices. The Agency also used data received in response to these questions to identify treatment technologies in place and zero discharge practices.

The last part of the survey (questions 4 through 13) requested financial data on the parent utility. Survey questions included production data, population served, and water sales revenue; drinking water systems that purchase water from that utility; other revenue sources; total revenue; residential customers and sales revenue from 2004 to 2006; residential customer zip codes; billing structure; programs to lower cost for low- or fixed-income households; expenses; and cost for capital improvements, repairs, or expansions. EPA used this information to characterize the economic profile of the industry.

2.2.3 Development of the Survey Mailing List

The questionnaire focused on CWSs that operate treatment plants that serve more than 10,000 people (estimated based on system population served and corresponding plant production) and generate residuals. To develop the list of potential survey recipients, EPA identified CWSs that serve more than 10,000 people using EPA's Safe Drinking Water Information System (SDWIS) database from November 9, 2006 (U.S. EPA, 2006). In addition, EPA identified wholesale systems in SDWIS (e.g., list service population of 25) and determined the systems' downstream population served by reviewing EPA's *2000 Community Water System Survey* (U.S. EPA, 2002) and system websites (ERG, 2005). If a wholesale system served a downstream population exceeding 10,000 people, EPA included that system in its survey mailing list. EPA identified 4,115 CWSs that serve more than 10,000 people.

EPA then identified whether these systems operated WTPs that potentially generated residuals. To identify treatment operations, EPA used data from SDWIS, the *2000 Community Water System Survey*, Internet searches, and the OGWDW Information Collection Rule Auxiliary 1 database.[1] EPA excluded systems with plants that perform only disinfection or chemical addition as these plants do not generate residuals. EPA's final list of potential survey recipients included 2,290 CWSs. EPA used the mailing addresses listed in SDWIS. For more information about SDWIS and other OGWDW data sources, see Section 2.3.

2.2.4 Sample Selection

EPA focused its analysis on the characteristics of large systems serving more than 50,000 people and those that primarily use surface water because these systems (and their WTPs) are expected to discharge the majority of the WTP residuals, i.e., pollutant loadings. Consequently, EPA sampled a greater percentage of systems serving more than 50,000 people and surface water systems than systems serving 10,001 to 50,000 people and ground water systems. Appendix A provides information on how the Agency designed the survey, developed the sample size, and extrapolated the survey results.

2.2.5 Survey Response

EPA mailed 616 electronic surveys, and received 552 responses for a 90 percent response rate. Of the 552 responses, 482 were in scope based on responses to Questions 1c to 1e,

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[1] Data collected by the Information Collection Rule (U.S. EPA, 2000) pertains to the Safe Drinking Water Act and differs from EPA's Information Collection Request performed as part of this industry review.

on generation of residuals in 2006, operation of one or more WTPs serving more than 10,000 people, and classification as community water system.

As part of its technical analysis, EPA developed a survey review checklist to determine whether the responses received for the second part of the survey (questions 2 and 3) were complete. If survey responses were not complete or unclear, EPA contacted the system or WTP representative for clarification.

Follow-up included review of responses and personal communication with system contacts if survey responses were incomplete or if there were questions concerning the data reported. Based on the survey review and follow-up communication, EPA incorporated changes to the survey response to the extent possible. EPA either updated the electronic survey database submitted by the CWS or marked a hard copy of the survey submittal prior to data entry into a database. All in-scope and complete responses were combined into a single survey response database. EPA determined that 378 of the in-scope technical survey responses were complete and included those responses in the survey response database – technical data (U.S. EPA, 2009).

As part of its economic analysis, EPA reviewed the third part of the survey (questions 4 through 13). These questions allowed respondents to provide information for the parent utility (i.e., representing multiple systems). EPA included economic data for 482 systems in the survey response database – financial data (U.S. EPA, 2010). Not all the DWT systems included in the survey response database – financial data were included in the database with technical responses. For the DWT systems not included in the survey response database – technical data, EPA reviewed a subset of the technical responses to determine the types and sizes of the systems. These data were used for the national estimates (see Appendix A).

2.2.6 Protection of Confidential Business Information

EPA recognizes that certain data submitted by the industry has been claimed as confidential business information (CBI). The Agency has withheld CBI from this report, including aggregate data that represents a small number of systems or WTPs. The Agency's approach to CBI protection ensures that data made available to the public explain the industry review without compromising data confidentiality.

2.3 EPA'S GROUND WATER AND DRINKING WATER DATA

EPA, along with delegated states and tribes, implements the requirements of the Safe Drinking Water Act, which safeguards drinking water delivered to consumers' taps. EPA regulates 90 percent of the public drinking water supply in the United States. Public water is supplied by publicly- or privately-owned systems that serve at least 25 people or at least 15 service connections for 60 days or more per year. EPA does not regulate private water supplies that serve one or a few homes, such as household wells (U.S. EPA, 2003).

EPA maintains the SDWIS database (Section 2.3.1); collects system- and plant-level data from the industry (Sections 2.3.2 and 2.3.3); and provides other data on the industry (Section 2.3.4). EPA used these data to identify systems that serve more than 10,000 people, including system and treatment plant characteristics. EPA created the survey mailing list for the industry questionnaire using these data.

2.3.1 Safe Drinking Water Information System

EPA maintains basic information about the nation's drinking water supply in SDWIS[2]. States and EPA regional offices report data to EPA quarterly on all public water systems. Each public water system is identified in SDWIS using a nine character identification number, which includes the identification of the state or EPA regional office that oversees the system's compliance. Data reported include basic information on the systems such as the following:

- System name and address;
- Retail population served;
- Number of service connections;

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[2] U.S. EPA maintains SDWIS/Federal database which is described in Section 2.3.1. In addition to the federal database, SDWIS/State is maintained by the drinking water primacy agency (e.g., state) and may contain additional data not available in the federal database.

- Primary county or city served;
- Type of system (i.e., CWS or other);
- Ownership;
- Primary source water type (ground water or surface water); and
- Enforcement data.

SDWIS includes both mandatory and optional reporting components. Optional reporting components include ownership and type of treatment. Because providing some data is discretionary, EPA does not have complete data on every system for these parameters. If treatment is included in SDWIS, the data are on a plant-specific basis and include treatment objectives such as the following:

- Corrosion control;
- Dechlorination;
- Disinfection;
- Disinfection by-products control;
- Inorganics removal;
- Iron removal;
- Manganese removal;
- Organics removal;
- Particulate removal;
- Radionuclides removal;
- Taste/odor control;
- Softening (hardness removal); and
- Other.

SDWIS does not include data on the type and quantity of residuals generated, residuals treatment method, or residuals disposal method. Therefore, EPA gathered data on residuals generation, treatment, and disposal using the industry questionnaire (see Section 2.2).

SDWIS is continually updated, but EPA maintains snapshots (or freezes) of the database. In 2006, there were 156,644 public drinking water systems (U.S. EPA, 2008):

- 52,339 community water systems (i.e., systems that supply water to the same population throughout the year) serving 282 million people.

- 19,045 non-transient, non-community water systems (i.e., systems that regularly supply water to at least 25 of the same people for six months or more per year, such as schools) serving 6 million people.

- 85,260 transient, non-community water systems (i.e., systems that supply water at locations where people do not remain for an extended time period, such as a campground) serving 14 million people.

2.3.2 2000 Community Water System Survey

To support the development and evaluation of drinking water regulations, EPA collected industry data in the 2000 Community Water System Survey (CWSS). EPA collected operational and financial characteristics in the CWSS. Because CWSs are a very diverse group, CWSS is stratified to represent the complete population of CWSs across the United States, based on a list of approximately 52,000 systems from SDWIS. For the 2000 CWSS, questionnaires were mailed to 1,200 medium and large systems, and 600 site visits to small systems (serving 3,300 people or fewer) were conducted.[3] Operational data requested include the following:

- System ownership type;
- Source water type (ground water, surface water, or purchased water) and description of source;
- Raw water concentrations;
- Production quantity, flow rate, and capacity for plants;
- Type of source water treatment;
- Filter backwash technique;
- Residuals treatment and management;
- Discharge type;
- Operator information; and
- Storage and distribution information.

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[3] Site visits were used instead of mailed questionnaires from small CWSs to reduce the burden of the information collection effort on small systems.

Financial characteristics collected include customer type, revenue, billing structure, expenses, and source of funds. The overall response rate was 69 percent. Responses from CWSS were then weighted to develop estimates from the CWS community as a whole.

The 2000 CWSS data included a report, an MS Access® database of the survey information, and an MS Excel® spreadsheet containing treatment plant-specific data. The 2000 CWSS includes data on 2,603 WTPs at 1,246 systems. EPA used information from the 2000 CWSS to assist in sample frame development and to characterize the economic profile of the industry.

2.3.3 Information Collection Rule

The purpose of the EPA Information Collection Rule, 40 CFR Part 141 (May 14, 1996), was to generate and provide EPA with the following information from drinking water systems:

- Monitoring data on microbiological contaminants;
- Monitoring data on disinfection by-products;
- General water quality data; and
- Treatment plant design and operating information to characterize the system.

EPA collected these data from drinking water systems and analytical laboratories and entered them in the Information Collection Rule Federal Database. To facilitate review of the data, EPA designed seven auxiliary databases to store subsets of data extracted from the Information Collection Rule Federal Database. EPA used data from the Information Collection Rule Auxiliary 1 Database (U.S. EPA, 2000), along with supporting documentation, to characterize systems and treatment plants in the DWT industry as part of the survey mailing list development. The Auxiliary 1 Database includes information for 296 systems (all but nine systems serve populations greater than 50,000 people).

Data available in the Auxiliary 1 Database include the following:

- System design (e.g., EPA region, storage volume, distribution time, number of booster stations and dose range);
- System monitoring (e.g., population served, average flow rate—wholesale and retail);
- Wholesale purchase flow rate;
- Treatment plant design (e.g., treatment process, average percent solid, solid handling capacity, clearwell data, and minimum temperature);
- Plant monitoring data (e.g., alum dose (parts per million, ppm), iron dose (ppm), coagulant type, source water type (surface water or ground water), sludge production, sludge percent solids, disinfection type, average influent flow rate, sampling event influent flow rate, chlorine (Cl_2) demand, effluent flow rate (average and sample event), wastewater residuals treatment performed, wastewater treatment flow rate (average and sample event));
- Unit process data (e.g., sequence in treatment train, volume, filtration surface area, residence times, process flow rate, filtration media type and depth, granular activated carbon (GAC) depth, disinfectant name and dose (ppm));
- Chemical feed information (e.g., alum, iron, Cl_2);
- Ozone chamber data;
- Sampling data;
- Water quality monitoring data; and
- Intake information (e.g., latitude and longitude, reach).

2.3.4 Other Ground Water and Drinking Water Data

EPA staff and the EPA website provided additional information to support this industry review. The EPA website includes the following information:

- Basic drinking water treatment references;
- Drinking water regulations and standards;

- List of drinking water contaminants and maximum contaminant levels (MCLs) allowed in drinking water;
- Guidance on drinking water regulations and standards; and
- Additional data on the Safe Drinking Water Act.

2.4 OTHER INFORMATION COLLECTION ACTIVITIES

EPA completed other data collection efforts to supplement information gathered through the aforementioned site visits, surveys, and EPA data sources, the purpose of which was to obtain information on the documented environmental impacts of discharges from WTPs, water treatment operations, residuals characteristics, pollution prevention practices, residuals treatment technology innovation, and best management practices. These other data collection activities included a review of literature sources, current NPDES permits, NPDES monitoring reports, other EPA data sources, industry data (on-line data from drinking water system web pages), and AWWA surveys and reports.

2.4.1 Literature Search

EPA conducted a literature search to obtain information on various aspects of the DWT industry. EPA performed several Internet and literature searches to identify papers, presentations, and other applicable materials. Literature collected by EPA covers such topics as:

- Source water treatment technologies;
- Water quality and treatment;
- Pollution prevention;
- Characterization of WTP residuals;
- Residuals treatment, including performance and costs;
- Disposal practices and waste management of residuals (e.g., sludge, concentrate streams);
- Recycling and reuse of waste streams;

- Industry trends;
- Environmental impacts; and
- Effect of discharges on the environment.

EPA used data from these literature sources to develop the industry questionnaire, identify and characterize residuals, determine applicability of pollution prevention techniques, identify residuals treatment technologies, and identify best management practices (BMPs).

2.4.2 Current NPDES Permits

EPA collected available permit information to determine current practices in setting discharge limits for WTPs. States and, in some cases, EPA regions, issue NPDES permits to WTPs that allow direct discharge of wastewater. States might issue general permits for groups of plants that have similar operations and wastewater characteristics. States issue individual permits for specific plants that do not meet the requirements of the states' general permits. Section 4.1.7 provides an overview of NPDES permits. Depending on the permit requirements, dischargers report compliance with NPDES permits via monthly discharge monitoring reports (DMRs) submitted to the permitting authority.

EPA's Permit Compliance System (PCS) database contains monitoring and NPDES permit data from some permittees that discharge wastewater directly to surface waters. States (or other permitting authority) have some discretion as to which data they make available to PCS.[4] For example, permitting authorities enter DMR and permit information for facilities that are considered major dischargers. However, they do not necessarily enter DMR or permit information into PCS for minor dischargers (as opposed to major dischargers) or facilities covered by a general permit.

Permitting authorities designate which facilities are considered major dischargers or minor dischargers based on the likelihood that the discharge will impact receiving waters if

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[4] EPA used DMR data from 2005, when DMR data were still maintained solely in PCS. Starting in 2006, states began reporting their data to the Integrated Compliance Information System for NPDES (ICIS-NPDES). However, this system was not in use at the time of this study.

not controlled. Facilities designated as major dischargers must submit monthly DMRs to the permitting authority, who enters the reported DMR data into PCS. States have the option to enter DMR data for minor discharges into PCS, however, EPA does not require states to enter the data. For this reason, the permitting authority may choose to include data only for a limited set of minor dischargers in PCS. Similarly, EPA does not require DMRs for facilities covered under general permits, and PCS may include limited or no data on general permits.

Therefore, the completeness of the data in the PCS system is much higher for larger facilities that are more likely to impact surface waters. Information on smaller facilities with less likelihood to impact surface waters is not consistently tracked in PCS. Also, information may not be available for facilities with discharges covered under a general permit.

Despite the expected data limitations, EPA extracted available information from PCS to identify WTPs with NPDES permits. The extraction was performed by searching PCS using the Standard Industrial Classification (SIC) code 4941 for the drinking water treatment and supply industry. EPA found that PCS contains information on approximately 3,000 WTPs with NPDES permits; however only 20 plants are major dischargers. As a result, only limited data were available on WTP NPDES permits in PCS. EPA used this information as part of its initial screening process to determine the number of plants that discharge directly to waters of the United States.

EPA expanded its search for WTP permit information beyond PCS, obtaining permits available online and those collected by other EPA activities (i.e., site visits and surveys). EPA used these permits to study permit requirements and treatment in place at WTPs that had certain water treatment operations. The majority of the limits in NPDES permits for WTPs were based on best professional judgment (BPJ). EPA summarized the current permit discharge requirements based on best professional judgment (BPJ)-based permit limitations (see Section 5).

2.4.3 NPDES Discharge Monitoring Reports (DMRs)

NPDES-permitted plants submit DMRs to their permitting authority (state or EPA Region). DMRs summarize the quality and volume of wastewater discharged from plants with

NPDES permits. They are critical for determining compliance with NPDES permit provisions for reporting and monitoring and for generating national trends in Clean Water Act compliance. DMRs may be submitted monthly, quarterly, or annually depending on the requirements of the NPDES permit.

EPA requested DMR data (for years 2004, 2005, and 2006) as part of the 2007 industry survey. EPA received primarily 2006 DMR data. EPA used the DMR data to identify pollutants of concern (pollutants currently included in NPDES permits) and to calculate pollutant loading estimates. EPA received 2006 DMR data for 140 WTPs (U.S. EPA, 2007).

Indirect dischargers file compliance monitoring reports with their control authority (e.g., POTW) at least twice a year as required under the General Pretreatment Standards (40 CFR Part 403), while direct dischargers file DMRs with their permitting authority at least once a year. EPA did not collect compliance monitoring reports for WTPs that are indirect dischargers. This information is less centralized and therefore more difficult to collect than information on direct dischargers.

2.4.4 Other EPA Data

EPA reviewed two additional databases, the Facility Registry System (FRS) and the Resource Conservation and Recovery Act (RCRA) database, to gather additional data on the DWT industry. These databases classify facilities using a four-digit Standard Industrial Classification (SIC) code or five-digit North American Industry Classification System (NAICS) code. EPA used SIC code 4941 or NAICS code 22131 (Drinking Water Treatment and Supply Industry) to search the databases.

2.4.4.1 Facility Registry System (FRS)

The FRS is a centrally managed database that identifies facilities, sites, or places subject to environmental regulations or of environmental interest. This database links the various identification numbers from federal and state environmental programs for a single facility. At the time of EPA’s review of the FRS data, the public water system identification numbers from

SDWIS were not all matched to FRS identification numbers. The matching is complicated by the fact that a water system (assigned a single Public Water System identification number, PWSID, in SDWIS) may operate more than one plant subject to environmental regulations (e.g., multiple NPDES permit IDs may apply to a single PWSID). The FRS database includes information for over 8,000 plants in SIC code 4941. EPA matched FRS IDs (and corresponding NPDES permit IDs) to specific WTPs (and their PWSID) where possible to assist in identifying direct dischargers included in the survey mailing list.

2.4.4.2 Resource Conservation and Recovery Act (RCRA)

If a WTP generates solid waste, it may be subject to RCRA storage, treatment, and disposal requirements. RCRA provides guidelines for the management of solid and hazardous wastes. In order to be classified as hazardous, wastes must be listed under 40 CFR Part 261 of RCRA. To be considered a RCRA hazardous waste, drinking water residuals must either contain a constituent listed as a hazardous waste in RCRA, or exhibit certain characteristics of ignitability, corrosivity, reactivity, or toxicity. Information that EPA collected on the constituents of residuals indicates that the residuals could be considered RCRA hazardous if they meet the criteria of toxicity or corrosivity. The FRS database lists 457 WTPs assigned a RCRA identification number. RCRA waste management requirements, and any associated costs, may be part of the review process when developing BMPs or considering alternatives to effluent discharges.

2.4.5 Industry Data

EPA used industry data, such as system websites and consumer confidence reports, to supplement data on specific systems and their operations. For example, EPA identified wholesale systems (i.e., those that sell drinking water to other systems but do not distribute to retail customers) serving more than 10,000 people by reviewing system websites. EPA also used on-line data to gather information on a plant-specific level, such as treatment performed and source water type. These industry data filled data gaps or confirmed data provided by other data sources (e.g., OGWDW data sources).

2.4.6 American Water Works Association (AWWA) Surveys and Reports

The AWWA trade association represents water treatment systems and service providers (e.g., consultants, manufacturers of water treatment products, etc.), as well as individual members who are most often professionals in the drinking water industry. AWWA provides regulatory support, technology updates, and other services to its members. EPA reviewed reports and other data available from AWWA. A summary of the AWWA surveys and resulting reports is provided below.

2.4.6.1 2004 Water and Wastewater Rate Survey

The *2004 Water and Wastewater Rate Survey* includes summary data and system-specific data for water and wastewater systems. Data from the survey include the following:

- Rate trends;
- Rates by geographic area;
- Utility characteristics (e.g., population served, daily gallons sold, daily capacity, maximum daily production, number of employees, and financial data, including annual capital needs, total assets, long-term debt, and total equity);
- Rate structure, monthly water charges, other water charges (e.g., minimum monthly charge for residential and industrial, connection charge, system development charge), total revenues, and total operating expenses;
- Indication of whether utilities provide water outside the municipal or district boundaries (e.g., wholesale) and retail differential (i.e., how much more “outside” customers pay compared to “inside” customers); and
- Median household affordability index.

Survey participants include 266 water treatment utilities from 50 states and six Canadian provinces. For comparison, the survey contains international utility data from 44 cities in 27 countries (AWWA, 2004). EPA reviewed the survey results for background data on the industry; however, EPA did not make additional use of the survey results for this report.

2.4.6.2 2002 AWWA Recycle Survey Analysis

AWWA surveyed WTPs to determine their recycling practices for spent filter backwash water and other waste streams. AWWA compiled and analyzed data from 333 plants that responded to the survey and indicated recycling of one or more streams. The survey gathered data on the following:

- Size of treatment plant (capacity and population served);
- Location (state);
- Source water type and its treatment;
- Percent recycled backwash;
- Treatment performed on waste stream prior to recycling back into plant;
- Point where recycled stream reenters the source water treatment;
- Discharge permit availability for the waste stream; and
- Indication of whether monitoring data on the waste stream are available.

The analysis included determination of whether each plant's equalization basin was adequately sized for the recycle stream and whether each plant's sedimentation basin was adequately sized to serve as the equalization basin for the recycle stream (AWWA, 2002). EPA reviewed the survey results for background data on the industry; however, EPA did not make additional use of the survey results for this report.

2.4.6.3 Residuals Management Costing Analysis

To evaluate the cost considerations to construct and operate residuals treatment systems, EPA reviewed an AWWA-sponsored report entitled *Costing Analysis to Support National Drinking Water Treatment Plant Residuals Management Regulatory Options*, dated April 2008 (AWWA, 2008). In this report, AWWA estimated costs to install and operate a typical sludge treatment system at model plants. AWWA developed cost curves for conventional filtration plants and lime softening plants, over a range of flows and solids loadings. AWWA presented their results as a series of curves, showing cost relative to population served, by plant type and solids loading. EPA used the costing analysis to augment its summary of cost considerations for residuals treatment (see Section 13).

2.5 STAKEHOLDER MEETINGS

From 2004 through 2008, EPA participated in several meetings with other EPA offices, permitting authorities, industry representatives, industry associations, technology vendors, and other interested parties to gather technical information on environmental and operational issues related to drinking water treatment and supply operations. The purpose of the meetings was to gather current detailed information about the industry. These meetings also served as forums for the transfer of information between EPA and industry representatives on all aspects of WTP operations.

EPA participated in meetings with the following groups:

- EPA offices: OGWDW, Office of Enforcement and Compliance Assurance (OECA), Office of Research and Development (ORD), and Office of Pollution Prevention and Toxics (OPPT).

- Permit contacts from EPA Regions 1 through 10 and the following states and territories: Arkansas, Colorado, Florida, Maryland, Puerto Rico, Texas, and Virginia.

- Trade associations and industry representatives:
  - American Water Works Association,
  - Association of Metropolitan Water Agencies,
  - American Membrane Technology Association,
  - Water and Wastewater Equipment Manufacturer Association,
  - Wateruse,
  - Passaic Valley Water Commission,
  - National Association of Clean Water Agencies,
  - Greater Cincinnati Water Works,
  - East Bay Municipal Utility District, and
  - Los Angeles Department of Water and Power.

- Drinking water treatment technology vendors and/or consultants:
  - F.B. Leopold Company,
  - US Filter,
  - General Electric, and
  - Black & Veatch.

- Other interested parties:
  - Natural Resources Defense Council.

In addition to the meetings, EPA also attended several AWWA conferences including the following:

- AWWA Water Quality Technology Conference, November 2004;
- AWWA Annual Meeting and Conference, June 2005;
- Water Environment Technical Exhibit and Conference, October 2005; and
- AWWA Annual Meeting and Conference, June 2006.

By participating in these meetings and conferences, EPA was able to obtain up-to-date information about source water treatment methods; residuals generation, collection, treatment, and disposal practices; and economic and financial aspects of the industry. EPA used this information throughout its industry review.

2.6 DRINKING WATER TREATMENT TECHNOLOGY REVIEW

As part of the industry review, EPA solicited early individual input from stakeholders on technical issues related to the management of drinking water residuals. Goals for this stakeholder review included the following:

- Characterization of typical residuals;
- Identification of pollutants of concern;
- Identification of pollution prevention and treatment technologies for residuals;
- Evaluation of 1993 and 1987 cost estimates developed by EPA and AWWA, respectively, for these residuals treatment technologies (U.S. EPA, 1993; AWWA, 1987); and
- Application of prevention and treatment technologies.

From 2005 through 2007, EPA held several meetings and provided stakeholders with various technical papers to review. EPA reviewed the comments received from stakeholders and prepared technical paper comment-response documents.

Stakeholders included personnel from American Membrane Technology Association, AMWA, Association of State Drinking Water Administrators (ASDWA), AWWA, Black & Veatch, CH2M Hill, EE&T, East Bay Municipal Utility District, Carollo Engineers, P.C., Cincinnati Water Works, City of St. Louis Water Division, Environmental Law and Policy Center of the Midwest, F.B. Leopold Co., Los Angeles Department of Water and Power, NACWA, US Filter, and Water Environment Research Federation, as well as EPA's OGWDW and ORD.

2.7 REFERENCES

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SECTION 3

INDUSTRY PROFILE

The purpose of the drinking water treatment (DWT) industry is to provide potable water to its customers. The DWT industry falls under Standard Industrial Classification (SIC) code 4941, which crosswalks with North American Industry Classification System (NAICS) code 22131. In addition to drinking water, SIC code 4941 includes other water supply plants—those that treat water for use in commercial and industrial applications. NAICS code 22131 includes all of SIC code 4941 plus irrigation systems (defined by SIC code 4971). For this industry review, EPA focused on drinking water systems that serve more than 10,000 people. Most systems that serve more than 10,000 people are defined as community water systems (CWSs) under the Safe Drinking Water Act. CWSs serve the same customer base year round (e.g., city water authority).

Drinking water systems may obtain their water supply either directly from the source (e.g., river, lake, reservoir for surface water sources or via wells for ground water sources) or may purchase from wholesalers. Systems may treat the source water (i.e., intake water) prior to distribution or only provide delivery of the drinking water. If the system treats the source water prior to delivery, the system operates one or more water treatment plants (WTPs).

3.1 OVERVIEW OF DWT INDUSTRY

As discussed in Section 2.3.1, there are 52,339 community water systems (CWSs) in the United States. EPA determined that 4,115 CWSs serve more than 10,000 people.[5] EPA's industry questionnaire collected data on CWSs that operate large WTPs (i.e., plants that produce drinking water for more than 10,000 people). Of the 4,115 CWSs, 42 percent (1,742 CWS) operated large WTPs that generate residuals (e.g., wastewater, slurry). See Appendix A. The other 58 percent of CWSs either operate only small WTPs (produce drinking water for less than

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[5] 2006 data from EPA's Safe Drinking Water Information System and on-line review of wholesale systems (U.S. EPA, 2006; ERG, 2005).

10,000 people) or do not generate residuals at the large WTPs (e.g., perform disinfection of the source water only).

WTPs may dispose of residuals by discharging into waters of the United States (direct discharge) or by discharging via sewer to a publicly-owned treatment works (indirect discharge). Of the WTPs serving more than 10,000 people and generating residuals, EPA estimates that 31 percent are direct dischargers, 37 percent are indirect dischargers, and 7 percent are both direct and indirect dischargers. The Agency estimates that the remaining 25 percent of WTPs are zero dischargers (i.e., do not discharge directly or indirectly). Zero discharge methods include recycling, evaporation, composting, landfill disposal, spray irrigation, underground injection, and land application. Table 3-1 summarizes the number of WTPs operated by CWSs by source water treatment method and discharge status (see Appendix A).

Table 3-1. Discharge Status for Water Treatment Plants Serving More than 10,000 People

Size of CWS Population Served	Primary Water Source	Source Water Treatment Method	Total Number of WTPs [a]	Estimated Number of WTPs by Discharge Type		
				Direct Discharge [a]	Indirect Discharge [a]	Zero Discharge Only [b]
10,001 – 50,000	Ground	Any	526	121	307	107
	Surface	Any	938	406	405	206
More than 50,000	Ground	Precipitative softening	66	31	2	32
		Conventional filtration	14	[CBI Redacted]	[CBI Redacted]	[CBI Redacted]
		Membrane [c]	19	2	6	13
		Ion exchange	8	[CBI Redacted]	[CBI Redacted]	[CBI Redacted]
		Other treatment [d]	4	[CBI Redacted]	[CBI Redacted]	[CBI Redacted]
	Surface	Precipitative softening	168	90	55	40
		Conventional filtration	383	167	142	123
		Membrane [c]	19	4	12	2
		Ion exchange	0	0	0	0
		Other treatment [d]	6	[CBI Redacted]	[CBI Redacted]	[CBI Redacted]
Total			**2,151** [a]	**832** [a]	**943** [a]	**531**

Source: Appendix A.

a – WTPs may handle residuals using multiple methods; therefore, totals for each column exceed the total number of plants (e.g., 155 WTPs discharge both directly and indirectly).

b – Zero discharge methods include recycling, evaporation, composting, landfill disposal, spray irrigation, underground injection, and land application. Direct and indirect dischargers may also use these methods, however, those WTPs are not included in the zero discharge only plant counts.

c – Membrane treatment method includes microfiltration, ultrafiltration, and membrane desalination (reverse osmosis, nanofiltration, electrodialysis, and electrodialysis reversal).

d – Other treatment methods include filtration without coagulation and adsorption processes. This group also includes plants that did not indicate any treatment operation in the survey (classified as "none").

3.1.1 Types of Drinking Water Systems

Drinking water systems that provide water to at least 25 people or 15 service connections are defined as “public water systems” (Section 1401(4)(a)). Public water systems encompass a wide variety of systems and plants. In total, there are 155,693 active public water systems serving 307 million people in the United States (U.S. EPA, 2007). These systems differ in terms of the type of population that they serve (residential, non-residential, transient, or permanent) and in terms of the entity that owns them (public, private, or a mixture of both).

EPA further defines public water systems into the following three types:

- Community water system (CWS): supplies water to the same population year round.
- Non-transient, non-community water system (NTNCWS): regularly supplies water to at least 25 of the same people six months or more per year, but not year round (e.g., schools, factories, offices, and hospitals with their own water system).
- Transient, non-community water system (TNCWS): supplies water in such places as a gas stations or campgrounds where people do not remain for an extended time period.

These are the drinking water systems usually associated with tap water. Households outside the service area of a water system obtain drinking water from private wells.

3.1.2 How EPA Classifies Drinking Water Systems

EPA classifies the size of a drinking water system by population served (size), ownership type, and source water type. Other measurements for classifying the size include finished water production volume and number of employees. The population served often corresponds to the production volume and number of employees needed to run the system. The majority of the drinking water systems serve 10,000 people or less; however, the majority of the drinking water is produced by larger systems (those serving more than 10,000 people) (U.S. EPA, 2008a).

3.2 SUMMARY OF QUESTIONNAIRE RESPONSES

This section summarizes the responses to the industry questionnaire (i.e., survey) about WTP and system conditions in 2006. Because EPA used statistical procedures to select systems for the survey to be representative, the responses can be used to derive statistical estimates for all systems and WTPs in the target population[6]. For this survey, the target population is defined as all systems that operate WTPs that have the capability to generate (and potentially treat) residuals and serve populations greater than 10,000 people. In addition, the systems must be community water systems (CWSs).

The following subsections present a series of tables with the results of the statistical analysis of the survey data. Each table presents national estimates based upon responses from systems and WTPs statistically selected for the questionnaire. Section 3.2.1 describes the classification[7] of systems and WTPs by population served, source water, and treatment type. Section 3.2.2 summarizes WTP characteristics reported in responses to questions 2 and 3 of the survey. Section 3.2.3 summarizes the system characteristics reported in response to economic and financial questions 4 through 13. Appendix A describes the sample design, the selection procedure, response rates, and the development of the national estimates.

3.2.1 System and WTP Classification

EPA used the responses to classify the WTPs by the size of the population served, primary water source, and the source water treatment method. Systems, however, sometimes have WTPs assigned to different classifications. For example, the system may operate two small WTPs and one larger WTP. In another example, it may operate WTPs using different treatment technologies. To assign each system into a single classification, EPA used the information associated with the largest WTP reported in its response. Thus, each system is classified by the population served, primary water source, and treatment method of its largest WTP. EPA estimates that there are 2,151 WTPs in 1,742 systems in the target population.

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[6] The target population for a data system is the specific population about which information is desired.

[7] As explained in Appendix A, classifications are “domains” in statistical nomenclature.

Table 3-2 provides a summary of the number of WTPs and systems in each classification. Because ion exchange operations were not reported for larger WTPs (i.e., serving populations more than 50,000) using surface water, Table 3-2 shows the estimated number of WTPs and systems to be zero. Because EPA does not have any data on such WTPs or systems, the classification has been excluded from all other tables presented in this section.

To determine size classifications for Table 3-2 and the other tables in this section, EPA used the response to question 2b (shown below in Figure 3-1) about the number of people served by the WTP.

2.b. Please indicate the number people served by the water treatment plant in 2006. *Report your estimate to the nearest thousand (e.g., round 21,854 people served to 22,000). If you do not have this data readily available, see the instructions and example in Question 1.d on page 2 to learn how to estimate the population served by your water treatment plant.*

_ _ _, _ _ _, 0 0 0 people

Figure 3-1. Question 2b: Population Served by the WTP in 2006

To assign each WTP to a single water source, EPA used the response to question 2e that asks about the percentages of water used from different sources (see Figure 3-2). Most WTPs reported the majority of the water was either surface or ground water. For the seven WTPs that only reported purchased water, EPA assigned them to surface water as their source because it was the most likely source to require treatment after purchase. For two WTPs reporting other water sources and one WTP with an even ground water/surface water allocation, EPA used the most commonly reported source water in their size category.

2.e. Please describe the type(s) of water used as the drinking water source in 2006.

Type of Source Water	***Percentage of Total Source Water***
Surface Water	
Ground Water	
Purchased Water	
Other (specify):________________	
Total	***100%***

Figure 3-2. Question 2e: Source Water Type

In assigning WTPs to treatment methods, EPA evaluated their responses to treatment and the types of chemicals reported in question 2.f of the survey.

Table 3-2. Industry National Estimates: Numbers of WTPs and Systems

Classification			Estimated Number of:	
Size of Population Served	**Primary Water Source**	**Treatment Method**	**Systems**	**WTPs**
10,001-50,000	Ground	Any	378	526
	Surface	Any	811	938
	Subtotal		1,189	1,464
More than 50,000	Ground	Conventional Filtration	8	14
		Membrane	19	19
		Other	2	2
		Softening	57	66
		Ion Exchange	8	8
		None	2	2
		Subtotal	97	111
	Surface	Conventional Filtration	295	383
		Membrane	17	19
		Other	4	4
		Softening	139	168
		Ion Exchange	0	0
		None	2	2
		Subtotal	456	576
	Subtotal		554	688
Total			**1,742**	**2,151**

3.2.2 WTP Characteristics (Summary of Responses to Technical Questions)

This section provides national estimates based upon the responses to questions 2 and 3 that addressed WTP operations. The following information is summarized in each section:

- Section 3.2.2.1: basic WTP operating characteristics (Questions 2b – 2d);
- Section 3.2.2.2: source water treatment operations (Question 2f);
- Section 3.2.2.3: residuals treatment and pollution prevention practices (Questions 2h and 2i);

- Section 3.2.2.4: residuals discharge practices (Question 2k); and
- Section 3.2.2.5: copper usage (Question 3).

The tables appear at the end of each subsection.

3.2.2.1 WTP Operating Characteristics (Question 2)

The survey collected basic operating characteristics data, including produced water volume, number of people served, plant age, and water source in response to questions 2b, 2c, and 2d. Figure 3-3 shows the wording of the questions and the responses are summarized in this section.

Table 3-3 presents the number of people served by WTP classification. Based upon the responses, the target population served approximately 143 million people (i.e., 2,151 WTPs, each serving an average of 66,430 people).

Table 3-4 presents the total volume of finished water, the amount per person, and water per day. The target population produced approximately 7.5 trillion gallons of finished water per year (i.e., 2,151 WTPs, each producing an average of 3,490.2 million gallons per year).

Table 3-5 reports the minimum and maximum number of operating days based upon the responses to question 2c. It also estimates the mean (average) number of days that the WTP operated during the year. Most WTPs operate all or most of the year, although one WTP reported only 12 days of operation. According to its website, it generally operates only when its sister WTP is not operating.[8]

Table 3-6 identifies when WTPs were built and most recently upgraded. The oldest WTP in the survey was built in 1867, making it 140 years old in 2006 (i.e., year reported in the survey). The median age of all WTPs was 36 years old (built in 1970). The WTP operating

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[8] Erie Water Works, http://www.eriewater.org/our-water/, retrieved December 15, 2008.

the longest since its last upgrade has been doing so since 1885 (121 years). The median time since the last upgrade was 12 years.

2.b. Please indicate the number people served by the water treatment plant in 2006.
Report your estimate to the nearest thousand (e.g., round 21,854 people served to 22,000). If you do not have this data readily available, see the instructions and example in Question 1.d on page 2 to learn how to estimate the population served by your water treatment plant.

_ _ _, _ _ _, 0 0 0 people

2.c. Please indicate the total amount of **finished** water produced at the water treatment plant in 2006.
Report your estimate to the nearest million gallons (e.g., round 6,432,100 gallons produced to 6,000,000).

_ _ _, _ _ _ , _ _ _ , 0 0 0, 0 0 0 gallons of finished water produced in 2006

Number of days in operation in 2006:
☐ 365 days
☐ _ _ _ days

2.d.i. Please indicate the year that this plant was first built (e.g., 1956).

_ _ _ _
Year

2.d.ii. Please indicate the year of the last treatment upgrade or significant expansion of water treatment operations at this plant. *A significant expansion is one that increases capacity by 50% or more.*

Figure 3-3. Questions 2b-d: WTP Operating Characteristics

Table 3-3. Number of People Served per WTP in 2006 (National Estimates Based on Responses to Question 2b)

Classification			**Estimated Number of WTPs**	**Number of People Served (in thousands)**			
Size of Population Served	**Primary Water Source**	**Treatment Method**		**Minimum Reported**	**Maximum Reported**	**Estimated Mean**	**Std Error of Mean**
10,001-50,000	Ground	Any	526	10	50	18.86	1.72
	Surface	Any	938	10	50	25.19	0.88
	Subtotal		1464	10	50	22.92	0.95
More than 50,000	Ground	Conventional Filtration	14	[CBI Redacted]			
		Membrane	19	59	132	79.37	5.53
		Other	2	[CBI Redacted]			
		Softening	66	52	333	87	6.18
		Ion Exchange	8	[CBI Redacted]			
		None	2	[CBI Redacted]			
		Subtotal [a]	111	52	490	101.79	7.29
	Surface	Conventional Filtration	383	51	850	165.29	7.56
		Membrane	19	56	104	82.14	5.52
		Other	4	[CBI Redacted]			
		Softening	168	51	1,128	183.49	15.13
		None	2	[CBI Redacted]			
		Subtotal [a]	576	51	1,128	170.1	6.74
	Subtotal [a]		688	51	1,128	159.05	6.21
Total [a]			**2,151**	**10**	**1,128**	**66.43**	**2.89**

a – CBI redacted counts of people served are included in subtotal and total rows.

Table 3-4. Estimated Water Production per WTP in 2006 (National Estimates Based on Responses to Questions 2b and 2c)

Classification			Estimated Number of WTPs	Total Amount of Finished Water (million gallons per year (MGY))				Estimated Water for Each Person Served Per Year (gal/person/yr)		Estimated Water Produced per Day (MG/Day)	
Size of Population Served	**Primary Water Source**	**Treatment Method**		**Min.**	**Max.**	**Estimated Mean**	**Std Error of Mean**	**Mean**	**Std Error**	**Mean**	**Std Error**
10,001-50,000	Ground	Any	526	28	2,776	748.25	139.55	40,866.72	7,547.49	2.12	0.39
	Surface	Any	938	79	7,061	1,482.26	78.42	58,655.62	2,416.70	4.26	0.21
	Subtotal		1,464	28	7,061	1,218.54	88.45	52,264.40	3,593.76	3.49	0.25
More than 50,000	Ground	Conventional Filtration	14	[CBI Redacted]							
		Membrane	19	37	4,462	2,265.77	215.84	28,648.91	4,640.99	6.21	0.59
		Other	2	[CBI Redacted]							
		Softening	66	840	17,000	4,243.80	1,064.31	48,447.97	11,779.86	11.68	2.93
		Ion Exchange	8	[CBI Redacted]							
		None	2	[CBI Redacted]							
		Subtotal [a]	111	37	17,000	4,170.62	642.52	42,127.70	6,421.41	12.05	1.92
	Surface	Conventional Filtration	383	60	55,000	8,668.41	414.86	55,553.16	1,209.13	24.62	1.23
		Membrane	19	2,165	7,000	4,355.71	265.22	54,155.94	3,006.79	12.19	0.68
		Other	4	[CBI Redacted]							
		Softening	168	3	44,000	10,003.66	665.05	61,044.84	3,625.78	27.63	1.84
		None	2	[CBI Redacted]							
		Subtotal [a]	576	3	55,000	9,128.09	353.52	57,329.19	1,381.09	25.66	1.02
	Subtotal [a]		688	3	55,000	8,326.38	364.13	54,870.84	1,774.75	23.46	1.04
Total [a]			**2,151**	**3**	**55,000**	**3,490.24**	**172.10**	**53,097.43**	**2,529.14**	**9.87**	**0.49**

a – CBI redacted water production estimates are included in subtotal and total rows.

Table 3-5. Operating Days per WTP in 2006 (National Estimates Based on Responses to Question 2c)

Classification			Estimated Number of WTPs	Operating Days in 2006			
Size of Population Served	**Primary Water Source**	**Treatment Method**		**Minimum Reported**	**Maximum Reported**	**Est. Mean**	**Std. Error of Mean**
10,001-50,000	Ground	Any	526	92	365	347.08	5.79
	Surface	Any	938	73	365	350.42	4.07
	Subtotal		1,464	73	365	349.22	3.32
More than 50,000	Ground	Conventional Filtration	14	[CBI Redacted]			
		Membrane	19	365	365	365	0
		Other	2	[CBI Redacted]			
		Softening	66	349	365	364.5	0.3
		Ion Exchange	8	[CBI Redacted]			
		None	2	[CBI Redacted]			
		Subtotal [a]	111	202	365	359.18	2.97
	Surface	Conventional Filtration	383	12	365	354.54	1.86
		Membrane	19	292	365	354.75	4.77
		Other	4	[CBI Redacted]			
		Softening	168	250	365	360.8	1.24
		None	2	[CBI Redacted]			
		Subtotal [a]	576	12	365	356.49	1.3
	Subtotal [a]		688	12	365	356.93	1.19
Total [a]			**2,151**	**12**	**365**	**351.68**	**2.31**

a – CBI redacted operating days are included in subtotal and total rows.

Table 3-6. WTP Age (National Estimates Based on Responses to Question 2d)

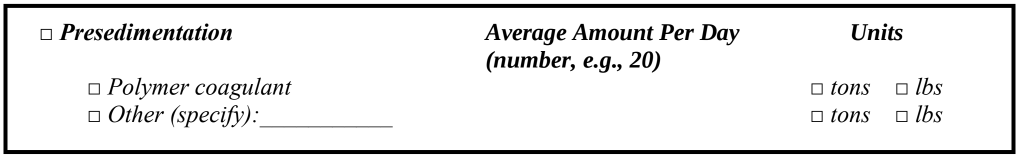
Classification			WTP Built (Year)			Last upgrade (Year)		
Size of Population Served	**Primary Water Source**	**Treatment Method**	**Earliest**	**Most Recent**	**Median**	**Earliest**	**Most Recent**	**Median**
10,001-50,000	Ground	Any	1928	2006	1991	1946	2006	1992
	Surface	Any	1881	2006	1966	1912	2007	1994
	Subtotal		1881	2006	1973	1912	2007	1994
More than 50,000	Ground	Conventional Filtration	[CBI Redacted]					
		Membrane	1977	2002	1992	1986	2002	2002
		Other	[CBI Redacted]					
		Softening	1953	2003	1992	1953	2006	2004
		Ion Exchange	[CBI Redacted]					
		None	[CBI Redacted]					
		Subtotal [a]	1928	2005	1992	1953	2006	2002
	Surface	Conventional Filtration	1873	2004	1967	1885	2007	1996
		Membrane	1939	2006	2003	1998	2006	2003
		Other	[CBI Redacted]					
		Softening	1867	2003	1956	1906	2006	1990
		None	[CBI Redacted]					
		Subtotal [a]	1867	2006	1965	1885	2007	1995
	Subtotal [a]		1867	2006	1967	1885	2007	1996
Total [a]			**1867**	**2006**	**1970**	**1885**	**2007**	**1994**

a – CBI redacted WTP years built and upgraded are included in subtotal and total rows.

3.2.2.2 Source Water Treatment Operations (Question 2f)

This subsection summarizes the responses to Question 2f which collected data about source water treatment operations employed at the WTP, chemicals used in the operations, and the amounts of the chemicals used. Section 3.2.1 describes the assignment of WTPs to each treatment method based upon information in question 2f. Tables 3-7 through 3-10 provide national estimates about source water treatment operations. If the respondent did not check a particular box, EPA assumed that the answer was ‘no’ (e.g., if the respondent did not check the box for presedimentation, EPA assumed that this procedure was not conducted at the WTP). Each table provides the estimated total number of WTPs in the classification and the smaller subset that performed each different operation in 2006. For example, an estimated 38 of the 526 ground water plants that serve less than 50,000 people use presedimentation (Table 3-7). The discussion below identifies the specific portions of the question related to each table.

Table 3-7 estimates the number of WTPs that use presedimentation as part of their source water treatment operations. Of the estimated 2,151 WTPs in the target population, approximately 141 WTPs (7 percent) use presedimentation.



□ ***Presedimentation***	***Average Amount Per Day (number, e.g., 20)***	***Units***
□ *Polymer coagulant*		□ *tons* □ *lbs*
□ *Other (specify):___________*		□ *tons* □ *lbs*

Figure 3-4. Question 2f: Source Water Treatment and Chemical Addition: Presedimentation

Table 3-8 estimates the number of WTPs using primary disinfection and the type of disinfection. The estimates are based upon responses to two parts of Question 2f as shown in Figure 3-5. Based upon the responses, 93 percent of the WTPs in the target population perform primary disinfection (i.e., 2,002 of the 2,151 WTPs). No respondent selected hydrogen peroxide, which appeared as one option in the survey. Thus, it does not appear in the table. Table 3-8 also shows the estimated 230 WTPs, by classification, that perform dechlorination.

☐ ***Primary Disinfection (Please indicate type)***

- ☐ *Free chlorine*
- ☐ *Chloramination*
- ☐ *Ozone*
- ☐ *Ultraviolet light*
- ☐ *Hydrogen peroxide (H_2O_2)*
- ☐ *Other (specify):___________________*

***Note**: Primary disinfection is intended to remove or inactivate harmful microorganisms at the treatment plant, often conducted at the head of the plant or prior to filtration. This disinfection treatment is different from secondary disinfection, which is conducted as one of the final steps prior to distribution of the finished water. Secondary disinfection provides a residual level of disinfection to help protect finished water as it travels through the system's distribution network.*

☐ ***Dechlorination***	***Average Amount Per Day (number, e.g., 20)***	***Units***
☐ *Sodium metabisulfite ($Na_2S_2O_5$)*		☐ *tons* ☐ *lbs*
☐ *Other (specify):_______________*		☐ *tons* ☐ *lbs*

Figure 3-5. Question 2f: Source Water Treatment and Chemical Addition: Primary Disinfection and Dechlorination

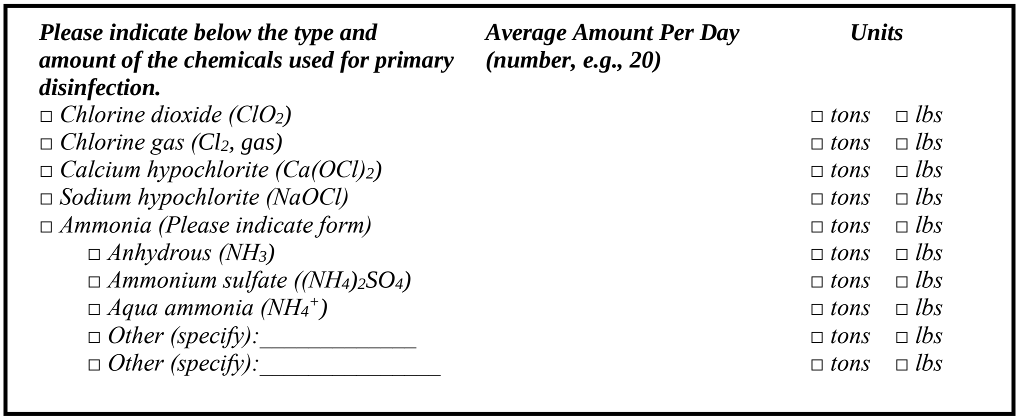
Table 3-9 provides information about disinfection residuals in the filter backwash and filter-to-waste. The estimates are based upon responses to two parts of Question 2f as shown in Figure 3-6. For each of these two items, WTPs were asked to check whether they had free chlorine, chloramination, other, or no backwash or filter-to-waste at the plant. EPA estimates that most WTPs generate filter backwash and filter-to-waste (i.e., 1,906 and 1,809, respectively, of the 2,151 WTPs).

☐ ***What type of disinfection residual is in the filter backwash? (Please indicate type)***
☐ *Free chlorine*
☐ *Chloramination*
☐ *Other (specify):___________________*
☐ *No filter backwash at this plant*

☐ ***What type of disinfection residual is in the filter-to-waste? (Please indicate type)***
☐ *Free chlorine*
☐ *Chloramination*
☐ *Other (specify):___________________*
☐ *No filter to-waste at this plant*

Figure 3-6. Question 2f: Source Water Treatment and Chemical Addition: Disinfection Residuals

Table 3-10 provides the estimated number of WTPs using different types of chemicals for primary disinfection. The questionnaire identified five primary categories that the WTP could select, with one of the categories (ammonia) subdivided into four options as shown in Figure 3-7. For the sake of summary, all ammonia responses were combined. EPA estimated that approximately two-thirds of the WTPs (i.e., 1,418 of the 2,151 WTPs) use chlorine gas as a primary disinfectant.



Please indicate below the type and amount of the chemicals used for primary disinfection.	***Average Amount Per Day (number, e.g., 20)***	***Units***
☐ *Chlorine dioxide (ClO_2)*		☐ *tons* ☐ *lbs*
☐ *Chlorine gas (Cl_2, gas)*		☐ *tons* ☐ *lbs*
☐ *Calcium hypochlorite ($Ca(OCl)_2$)*		☐ *tons* ☐ *lbs*
☐ *Sodium hypochlorite ($NaOCl$)*		☐ *tons* ☐ *lbs*
☐ *Ammonia (Please indicate form)*		☐ *tons* ☐ *lbs*
☐ *Anhydrous (NH_3)*		☐ *tons* ☐ *lbs*
☐ *Ammonium sulfate ($(NH_4)_2SO_4$)*		☐ *tons* ☐ *lbs*
☐ *Aqua ammonia (NH_4^+)*		☐ *tons* ☐ *lbs*
☐ *Other (specify):_____________*		☐ *tons* ☐ *lbs*
☐ *Other (specify):_______________*		☐ *tons* ☐ *lbs*

Figure 3-7. Question 2f: Source Water Treatment and Chemical Addition: Primary Disinfectant

Table 3-7. Estimated Number of WTPs Using Presedimentation (National Estimates Based on Responses to Question 2f)

Classification			Estimated Number of WTPs in Classification	Estimated Number of WTPs with Presedimentation
Size of Population Served	**Primary Water Source**	**Treatment Method**		
10,001-50,000	Ground	Any	526	38
	Surface	Any	938	66
	Subtotal		1,464	104
More than 50,000	Ground	Conventional Filtration	14	[CBI Redacted]
		Membrane	19	[CBI Redacted]
		Other	2	[CBI Redacted]
		Softening	66	[CBI Redacted]
		Ion Exchange	8	[CBI Redacted]
		None	2	[CBI Redacted]
		Subtotal	111	[CBI Redacted]
	Surface	Conventional Filtration	383	[CBI Redacted]
		Membrane	19	[CBI Redacted]
		Other	4	[CBI Redacted]
		Softening	168	[CBI Redacted]
		None	2	[CBI Redacted]
		Subtotal	576	[CBI Redacted]
	Subtotal [a]		688	37
Total [a]			**2,151**	**141**

a – CBI redacted WTP estimates are included in subtotal and total rows.

Table 3-8. Estimated Numbers of WTPs Using Various Primary Disinfection Methods (National Estimates Based on Responses to Question 2f)

Classification			**Estimated Number of WTPs in Classification**	**Estimated Number of WTPs with Primary Disinfection**	**Estimated Number of WTPs Using:***					**Estimated Number of WTPs that Dechlorinate**
Size of Population Served	**Primary Water Source**	**Treatment Method**			**Free Chlorine**	**Chloramination**	**Ozone**	**UV**	**Other**	
10,001-50,000	Ground	Any	526	452	331	118	0	0	0	64
	Surface	Any	938	895	771	74	7	2	68	79
	Subtotal		1,464	1,347	1,102	192	7	2	68	143
More than 50,000	Ground	Conventional Filtration	14	[CBI Redacted]						[CBI Redacted]
		Membrane	19	11	5	6	0	0	0	
		Other	2	[CBI Redacted]						
		Softening	66	66	21	44	0	0	0	
		Ion Exchange	8	[CBI Redacted]						
		None	2	[CBI Redacted]						
		Subtotal	111	101	43	51	2	2	4	
	Surface	Conventional Filtration	383	377	316	37	46	2	19	
		Membrane	19	15	12	0	0	0	6	
		Other	4	[CBI Redacted]						
		Softening	168	159	122	39	10	0	10	
		None	2	[CBI Redacted]						
		Subtotal	576	554	454	76	56	2	35	
	Subtotal [a]		688	655	496	126	58	4	39	87
Total [a]			**2,151**	**2,002**	**1,599**	**318**	**65**	**6**	**107**	**230**

a – CBI redacted WTP estimates are included in subtotal and total rows.

Table 3-9. Disinfection Residuals in Filter Backwash and Filter-to-Waste (National Estimates Based on Responses to Question 2f)

Classification			**Estimated Number of WTPs in Classification**	**Estimated Number of WTPs with Primary Disinfection**	**Est. Number of WTPs Backwash [a]**					**Est. Number of WTPs with Filter-to-Waste [a]**				
Size of Population Served	**Primary Water Source**	**Treatment Method**			**Total**	**Free chlorine**	**Chlora-mination**	**Other**	**None**	**Total**	**Free Chlorine**	**Chlora-mination**	**Other**	**None**
10,001-50,000	Ground	Any	526	452	433	315	63	2	52	423	254	19	0	169
	Surface	Any	938	895	847	674	114	52	15	775	464	56	69	201
	Subtotal		1,464	1,347	1,279	989	178	54	67	1,198	718	75	69	370
More than 50,000	Ground	Conventional Filtration	14	[CBI Redacted]										
		Membrane	19	11	5	0	0	0	5	5	0	0	0	5
		Other	2	[CBI Redacted]										
		Softening	66	66	66	17	48	0	0	66	4	44	2	17
		Ion Exchange	8	[CBI Redacted]										
		None	2	[CBI Redacted]										
		Subtotal [b]	111	101	95	32	56	0	7	95	18	44	2	33
	Surface	Conventional Filtration	383	377	362	263	87	15	10	352	221	23	29	82
		Membrane	19	15	15	13	2	0	0	15	6	0	0	9
		Other	4	[CBI Redacted]										
		Softening	168	159	152	88	58	11	0	146	62	18	10	58
		None	2	[CBI Redacted]										
		Subtotal [b]	576	554	532	368	147	27	10	516	293	41	39	148
	Subtotal [b]		688	655	627	400	203	27	17	611	311	86	41	181
Total [b]			**2,151**	**2,002**	**1,906**	**1,388**	**380**	**80**	**84**	**1,809**	**1,028**	**161**	**110**	**552**

a – WTPs may have more than one method of backwash or filter-to-waste. As a result, the sum of the number of WTPs in each of the three chemical categories may exceed the value in the corresponding total column.

b – CBI redacted WTP estimates are included in subtotal and total rows.

Table 3-10. Primary Disinfectants (National Estimates Based on Responses to Question 2f)

Classification			Estimated Number of WTPs in Classification	Estimated Number of WTPs with Primary Disinfection	Estimated Number of WTPs Using Various Chemicals [a]					
Size of Population Served	**Primary Water Source**	**Treatment Method**			**ClO_2**	**Cl_2 gas**	**$Ca(OCl)_2$)**	**NaOCl**	**Ammonia**	**Other**
10,001-50,000	Ground	Any	526	452	0	330	.	102	44	0
	Surface	Any	938	895	43	648	8	249	185	29
	Subtotal		1,464	1,347	43	979	8	351	228	29
More than 50,000	Ground	Conventional Filtration	14	[CBI Redacted]						
		Membrane	19	11	0	0	0	5	0	0
		Other	2	[CBI Redacted]						
		Softening	66	66	0	40	0	25	25	0
		Ion Exchange	8	[CBI Redacted]						
		None	2	[CBI Redacted]						
		Subtotal [b]	111	101	4	59	0	36	35	0
	Surface	Conventional Filtration	383	377	31	239	2	116	129	23
		Membrane	19	15	4	8	0	7	2	0
		Other	4	[CBI Redacted]						
		Softening	168	159	4	131	0	24	67	14
		None	2	[CBI Redacted]						
		Subtotal [b]	576	554	39	380	2	147	198	37
	Subtotal [b]		688	655	42	439	2	182	233	37
Total [b]			**2,151**	**2,002**	**85**	**1,418**	**10**	**533**	**462**	**66**

a – WTPs may use more than one chemical as primary disinfectant (e.g., ammonia and chlorine source to produce chloramines). As a result, the sum of the number of WTPs in each of the chemical categories may exceed the value in the corresponding total column.

b – CBI redacted WTP estimates are included in subtotal and total rows.

3.2.2.3 Residuals Treatment and Pollution Prevention Practices (Questions 2h and 2i)

This subsection summarizes the responses to Questions 2h and 2i that address residuals treatment and pollution prevention practices.[9] The responses are used to estimate the number of WTPs within the target population with the different practices. If the respondent did not check a particular box, EPA assumed that the answer was 'no' (e.g., if the respondent did not check drying as a residuals treatment option, EPA assumed that drying operations were not conducted at the plant).

Table 3-11 estimates different residuals management practices based upon the responses to question 2h as shown in Figure 3-8. In the table, the term "non-mechanical dewatering" also includes sedimentation tanks and ponds, thickening, evaporation ponds, and drying. After excluding WTPs with pH adjustment, aeration, and hydrogen sulfide removal, EPA estimates that approximately three-fourths of the WTPs in the target population treat residuals. In other words, an estimated 522 of the 2,151 WTPs do not treat residuals.

2.h. Please indicate (✓) below which residual treatment options were performed at the water treatment plant in 2006. *Treatment of residuals refers to any activity designed to change the character or composition of liquid and solid residuals streams from water treatment processes as needed to render it amenable to recycle/recovery, reduce its volume, or prepare it for transportation, storage, disposal, or discharge.*

☐ No treatment
☐ Drying
☐ pH adjustment
☐ Equalization of residuals prior to treatment or disposal
☐ Sedimentation tanks and ponds
☐ Other (specify):_______________________________
☐ Thickening
☐ Mechanical dewatering
☐ Non-mechanical dewatering
☐ Aeration
☐ Hydrogen sulfide removal
☐ Evaporation ponds
☐ Dechlorination

Figure 3-8. Question 2h: Residuals Treatment

Table 3-12 estimates different pollution prevention practices based upon the responses to question 2i as shown in Figure 3-9. The responses options include no pollution prevention, recovery of treatment chemicals, recycling filter backwash, optimizing surface water intake to reduce suspended solids intake, reuse of precipitative softening chemicals by recycling

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[9] Because few plants had affirmative responses, EPA did not provide national estimates for question 2g ("Is the primary water treatment objective of the plant to remove salt from the source water (i.e., desalination)?"

softening residuals to the head of the plant, recycling filter-to-waste, and other. EPA estimates that approximately half of the WTPs in the target population (i.e., 1,036 of the 2,151 WTPs) practice pollution prevention.

2.i. Please indicate (✓) below which pollution prevention practices were performed at the water treatment plant in 2006. *Pollution prevention refers to the use of materials, processes, or practices that reduce or eliminate the creation of pollutants or residuals.*

☐ No pollution prevention
☐ Recovery of treatment chemicals
☐ Recycling filter backwash
☐ Optimizing surface water intake to reduce suspended solids intake
☐ Reuse of precipitative softening chemicals by recycling softening residuals to head of the plant
☐ Recycling filter-to-waste
☐ Other (specify):_______________________________

Figure 3-9. Question 2i: Pollution Prevention

Table 3-11. Residuals Treatment Methods (National Estimates Based on Responses to Question 2h)

Classification			Estimated Number of WTPs in Classification	Estimated Number of WTPs With:				
Size of Population Served	**Primary Water Source**	**Treatment Method**		**No treatment**	**Equalization only**	**Mechanical dewatering**	**Non-mechanical dewatering**	**Other**
10,001-50,000	Ground	Any	526	253	31	8	225	14
	Surface	Any	938	193	84	40	651	25
	Subtotal		1,464	447	115	47	876	39
More than 50,000	Ground	Conventional Filtration	14	[CBI Redacted]				
		Membrane	19	6	5	0	6	2
		Other	2	[CBI Redacted]				
		Softening	66	2	0	15	61	0
		Ion Exchange	8	[CBI Redacted]				
		None	2	[CBI Redacted]				
		Subtotal [a]	111	12	7	19	89	2
	Surface	Conventional Filtration	383	32	25	88	308	8
		Membrane	19	4	0	9	11	2
		Other	4	[CBI Redacted]				
		Softening	168	27	12	28	123	6
		None	2	[CBI Redacted]				
		Subtotal [a]	576	63	37	129	448	16
	Subtotal [a]		688	75	44	148	537	18
Total [a]			**2,151**	**522**	**159**	**195**	**1,413**	**57**

a – CBI redacted WTP estimates are included in subtotal and total rows.

Table 3-12. Pollution Prevention Methods (National Estimates Based on Responses to Question 2i)

Classification			Estimated Number of WTPs in Classification	Estimated Number of WTPs With:						
Size of Population Served	**Primary Water Source**	**Treatment Method**		**No pollution prevention**	**Recovery of treatment chemicals**	**Recycling filter backwash**	**Optimizing surface water intake**	**Recycle softening chemicals**	**Recycling filter-to-waste**	**Other**
10,001-50,000	Ground	Any	526	368	5	138	0	25	84	15
	Surface	Any	938	514	39	285	140	31	159	42
	Subtotal		1,464	882	43	423	140	56	243	57
More than 50,000	Ground	Conventional Filtration	14	[CBI Redacted]						
		Membrane	19	11	0	6	2	6	0	0
		Other	2	[CBI Redacted]						
		Softening	66	27	4	36	0	16	12	2
		Ion Exchange	8	[CBI Redacted]						
		None	2	[CBI Redacted]						
		Subtotal [a]	111	46	4	59	2	22	20	4
	Surface	Conventional Filtration	383	111	0	222	82	0	157	42
		Membrane	19	10	0	7	2	0	2	5
		Other	4	[CBI Redacted]						
		Softening	168	64	4	80	27	16	40	12
		None	2	[CBI Redacted]						
		Subtotal [a]	576	187	4	310	110	16	198	61
	Subtotal [a]		688	233	8	369	112	39	219	65
Total [a]			**2,151**	**1,115**	**51**	**792**	**253**	**95**	**461**	**122**

a – CBI redacted WTP estimates are included in subtotal and total rows.

3.2.2.4 Residuals Discharge Practices (Question 2k)

This subsection summarizes the responses to Question 2k which collected data about direct, indirect, and zero discharge streams. Tables 3-13 through 3-20 present national estimates based upon the survey responses. The following paragraphs describe the tables and identify the specific portions of the question related to each table. If the respondent did not check a particular box, EPA assumed that the answer was ‘no’ (e.g., if a WTP did not check the box for direct discharge, EPA assumed that none of its residuals were discharged in this manner).

Table 3-13 shows the estimated number of WTPs with each of the three discharge methods: direct, indirect, and zero. It also estimates the number of WTPs that use one, two, or all three discharge methods in their operations. The columns “Total Direct,” “Total Indirect,” and “Total Zero” include WTPs that are estimated to discharge at least some of the residuals by that method. The table also provides mutually exclusive estimates for each of the seven possible combinations of discharge methods (e.g., “Direct Only” and “Direct and Zero”). For example, a WTP that discharges some residuals to a stream and the rest to a POTW will form the basis of the national estimates in the columns “Total Direct,” “Total Indirect,” and “Direct and Indirect.” It will not be part of the estimates for any of the other columns for direct and/or indirect dischargers. Figure 3-10 shows the portions of Question 2.k that were used to determine the discharge type. EPA estimates that approximately 70 percent of the target population uses zero discharge methods for some or all of its residuals (i.e., 1,502 of 2,151 WTPs). (See Table 3-20 for more details about zero discharge.)

2.k. Please indicate (✓) in **2.k.i**, **2.k.ii**, and **2.k.iii** below the method(s) of residuals discharge performed in 2006 at the water treatment plant and identify the year that this discharge method started. Please select all categories that apply. *(See Definitions of Key Terms on page 26 for explanations of discharge types, pollutants, and residuals.)*

i. ☐ Direct discharge of treated and/or untreated residuals. **Do not select direct discharge if your plant only discharges non-contact stormwater to surface waters. Select direct discharge if your plant has a permit that regulates or monitors the discharge of treated and/or untreated residuals to surface waters.**

ii. ☐ Indirect discharge of treated and/or untreated residuals. **Select indirect discharge if your plant has a permit that regulates or monitors the discharge of treated and/or untreated residuals to a treatment works (POTW, PrOTW, FOTW). Indirect discharge does not include spent filter backwash discharged to surface water.**

iii. ☐ Zero discharge.

Figure 3-10. Question 2k: Residuals Discharge Method

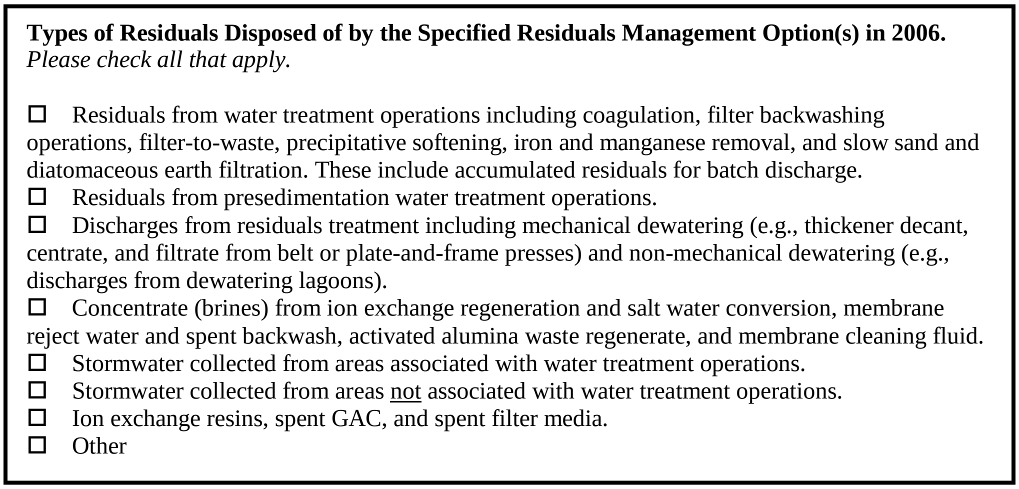
Tables 3-14a and 3-14b provide national estimates of the types of residuals discharged in 2006. Although they are located under different sections of question 2k, the choices are essentially the same for each discharge method and are shown in Figure 3-11. EPA estimated the number of WTPs with residuals from four management practices: water treatment operations, presedimentation operations, dewatering operations, and brines. EPA divided the information into two tables to be more readable. The tables do not include national estimates for the other survey options: residuals from stormwater, ion exchange resins, and other management practices.

Dewatering operations generate more residuals than other types (1,402 of the 2,151 WTPs have residuals from dewatering operations). Some facilities indicated that they operate presedimentation in Questions 2f (treatment operations) but not in Question 2k (residuals discharge), which resulted in 141 WTPs indicating presedimentation operations, but only 70 WTPs with residuals from presedimentation. EPA chose to use the responses in Question 2f to represent the number of WTPs operating presedimentation (141 WTPs) for the following reasons:

- For Question 2f, plants would indicate operating presedimentation. The residuals from presedimentation might then be discharged (directly or indirectly), managed via zero discharge method (e.g., evaporation lagoon), or sent to the residuals treatment plant for dewatering.

- Plants may not indicate presedimentation residuals in Question 2k. If the WTP dewaters the residuals from presedimentation, the WTP could select "discharges from residuals treatment" instead of presedimentation residuals. The WTP would make this selection especially if the residuals from presedimentation are commingled with other waste streams.

EPA used responses to Question 2k to represent the discharges from presedimentation that are directly discharged, indirectly discharged, or managed via zero discharge method.



Types of Residuals Disposed of by the Specified Residuals Management Option(s) in 2006.
Please check all that apply.

☐ Residuals from water treatment operations including coagulation, filter backwashing operations, filter-to-waste, precipitative softening, iron and manganese removal, and slow sand and diatomaceous earth filtration. These include accumulated residuals for batch discharge.
☐ Residuals from presedimentation water treatment operations.
☐ Discharges from residuals treatment including mechanical dewatering (e.g., thickener decant, centrate, and filtrate from belt or plate-and-frame presses) and non-mechanical dewatering (e.g., discharges from dewatering lagoons).
☐ Concentrate (brines) from ion exchange regeneration and salt water conversion, membrane reject water and spent backwash, activated alumina waste regenerate, and membrane cleaning fluid.
☐ Stormwater collected from areas associated with water treatment operations.
☐ Stormwater collected from areas not associated with water treatment operations.
☐ Ion exchange resins, spent GAC, and spent filter media.
☐ Other

Figure 3-11. Question 2k: Type of Residuals Discharged

Table 3-15 presents the number of direct and indirect WTPs with different discharge frequencies: continuous, batch, and emergency. Because a WTP could discharge more than one of these types of releases, the sum of the estimated number of WTPs within each of the three categories may be greater than the total number of direct or indirect discharging WTPs. As shown in Figure 3-12, question 2k uses slightly different ways to collect the information from direct and indirect dischargers, but the three discharge frequencies (continuous, batch, emergency) were the same. As shown in the tables, batch discharges are estimated to be the most common practice for both direct and indirect dischargers.

If the water treatment plant directly discharged its residuals to surface water bodies in 2006, please indicate (✓) below the frequency of the discharge. In the blank spaces below the batch and emergency discharge categories, please specify the number of times residuals were discharged to surface waters in 2006. Please indicate (✓) below both ‘Continuous discharge’ and ‘Batch (intermittent) discharge’ if you are doing both types of discharges (e.g., continuous filter backwash and batch discharge of residuals in settling basins).

☐ Continuous discharge
☐ Batch (intermittent) discharge
    Residuals were discharged ________ times in 2006.
☐ Emergency discharge only
    Residuals were discharged ________ times in 2006.

If the water treatment plant indirectly discharged its residuals to a treatment works (POTW, PrOTW, FOTW) in 2006, please indicate (✓) below the frequency and volume of the discharge to the nearest 1,000 gallons. In the blank spaces below the batch and emergency discharge categories, please specify the number of times residuals were discharged in 2006.
☐ Continuous discharge
    Volume of discharge ________ gallons per day.
☐ Batch (intermittent) discharge
    Residuals were discharged ________ times in 2006.
    Volume of discharge ________ gallons per day.
☐ Emergency discharge only
    Residuals were discharged ________ times in 2006.
    Volume of discharge ________ gallons per day

Figure 3-12. Question 2k: Frequency of Residuals Discharge

For direct dischargers, Tables 3-16 and 3-17 provide more information about discharge practices. Table 3-16 presents the estimated number of batch and emergency discharges in 2006 by direct dischargers. Table 3-17 presents the number of WTPs discharging into different types of waterbodies: river, creek, wetland, ocean, lake and other. Based upon the responses, the most common destinations for direct dischargers are likely to be rivers or creeks. Figure 3-13 shows the portions of question 2k used to derive the national estimates in Tables 3-16 and 3-17.

If the water treatment plant directly discharged its residuals to surface water bodies in 2006, …

☐ Continuous …
☐ Batch …
☐ Emergency discharge only
    Residuals were discharged ________ times in 2006.

Type of Receiving Water *(See Definitions of Key Terms on page 26 for explanations of types.)*
☐ River ☐ Creek ☐ Wetland ☐ Ocean ☐ Lake
☐ Other (specify):____________________

Figure 3-13. Question 2k: Direct Discharge—Continuous, Batch or Emergency and Type of Receiving Stream

For indirect dischargers, Tables 3-18 and 3-19 provide more information about discharge practices. They provide national estimates for the number of WTPs and daily volumes for continuous and batch discharges. (Only one WTP provided volumes for emergency discharges.) The information was collected from the portion of question 2k shown in Figure 3-14.

If the water treatment plant indirectly discharged its residuals to a treatment works (POTW, PrOTW, FOTW) in 2006, please indicate (✓) below the frequency and volume of the discharge to the nearest 1,000 gallons. In the blank spaces below the batch and emergency discharge categories, please specify the number of times residuals were discharged in 2006.

☐ Continuous discharge
    Volume of discharge ________ gallons per day.
☐ Batch (intermittent) discharge
    Residuals were discharged ________ times in 2006.
    Volume of discharge ________ gallons per day.
☐ Emergency discharge only
    Residuals were discharged ________ times in 2006.
    Volume of discharge ________ gallons per day

Figure 3-14. Question 2k: Indirect Discharge—Continuous, Batch or Emergency and Volume Discharged

Table 3-20 provides the national estimates for the number of WTPs using alternative discharge methods by one or more of eight “zero discharge” disposal methods: recycling, evaporation, composting, landfill disposal, spray irrigation, underground injection, land application, and other. The relevant part of the question is shown in Figure 3-15. Based upon the responses, more than half of the WTPs recycle and/or use landfills to reduce or eliminate wastewater discharges. Of the estimated 1,502 WTPs using zero discharge methods, an estimated 790 recycle waste streams and 792 use landfills.

If the water treatment plant operated as a zero-discharge plant in 2006, please identify (✓) the disposal method(s) for the residuals.

☐ Recycle (i.e., return to water treatment plant pre-coagulation)
☐ Evaporation
☐ Composting
☐ Landfill disposal
☐ Spray irrigation
☐ Underground injection
☐ Land application (e.g., soil amendment)
☐ Other (specify):_______________________________
☐ Other (specify): _______________________________
☐ Other (specify): _______________________________

Figure 3-15. Question 2k: Zero Discharge Methods

Table 3-13. Estimated Numbers of WTPs Using Direct, Indirect, or Zero Residuals Discharge Practices (National Estimates Based on Responses to Question 2k)

Classification			**Estimated Number of WTPs in Classification**	**Estimated Number**									
Size of Population Served	**Primary Water Source**	**Treatment Method**		**Direct only**	**Indirect only**	**Zero only**	**Direct and Indirect**	**Direct and Zero**	**Indirect and Zero**	**Direct, Indirect, and Zero**	**Total Direct**	**Total Indirect**	**Total Zero [a]**
10,001-50,000	Ground	Any	526	49	195	107	8	63	103	0	121	307	273
	Surface	Any	938	49	173	206	50	279	154	28	406	405	666
	Subtotal		1,464	98	368	312	59	342	257	28	527	711	939
More than 50,000	Ground	Conventional Filtration	14	[CBI Redacted]									
		Membrane	19	0	4	13	2	0	0	0	2	6	13
		Other	2	[CBI Redacted]									
		Softening	66	2	0	32	0	29	2	0	31	2	64
		Ion Exchange	8	[CBI Redacted]									
		None	2	[CBI Redacted]									
		Subtotal [b]	111	4	5	54	2	34	13	0	40	20	100
	Surface	Conventional Filtration	383	15	18	123	32	103	74	18	167	142	318
		Membrane	19	0	6	2	0	4	7	0	4	12	13
		Other	4	[CBI Redacted]									
		Softening	168	14	17	40	8	59	21	8	90	55	129
		None	2	[CBI Redacted]									
		Subtotal [b]	576	32	41	165	40	168	104	26	266	211	463
	Subtotal [b]		688	36	47	219	42	202	117	26	305	231	563
Total [b]			**2,151**	**134**	**415**	**531**	**100**	**544**	**374**	**54**	**832**	**943**	**1,502**

a – Number of WTPs using one or more zero discharge method (e.g., landfill disposal, recycling). WTP may also discharge some residuals directly or indirectly.
b – CBI redacted WTP estimates are included in subtotal and total rows.

Table 3-14a. Estimated Numbers of WTPs by Types of Residuals Discharged and Discharge Practice (National Estimates Based on Responses to Question 2k)

Classification			Estimated Number of WTPs in Classification	Estimated Number of WTPs with Residuals from:							
				Source water treatment operations				Presedimentation operations			
Size of Population Served	Primary Water Source	Treatment Method		Total	Direct	Indirect	Zero [a]	Total	Direct	Indirect	Zero [a]
10,001-50,000	Ground	Any	526	281	45	179	84	0	0	0	0
	Surface	Any	938	351	91	227	61	39	15	15	8
	Subtotal		1,464	632	136	407	145	39	15	15	8
More than 50,000	Ground	Conventional Filtration	14	[CBI Redacted]							
		Membrane	19	0	0	0	0	0	0	0	0
		Other	2	[CBI Redacted]							
		Softening	66	26	2	0	24	0	0	0	0
		Ion Exchange	8	[CBI Redacted]							
		None	2	[CBI Redacted]							
		Subtotal [b]	111	34	4	2	29	0	0	0	0
	Surface	Conventional Filtration	383	150	35	69	81	13	0	0	13
		Membrane	19	6	0	6	0	0	0	0	0
		Other	4	[CBI Redacted]							
		Softening	168	86	35	37	28	17	8	2	6
		None	2	[CBI Redacted]							
		Subtotal [b]	576	244	72	111	110	32	8	2	21
	Subtotal [b]		688	278	76	114	138	32	8	2	21
Total [b]			**2,151**	**910**	**212**	**520**	**283**	**70**	**24**	**18**	**29**

a – Number of WTPs using one or more zero discharge method (e.g., landfill disposal, recycling). WTP may also discharge some residuals directly or indirectly.
b – CBI redacted WTP estimates are included in subtotal and total rows.

Table 3-14b. Estimated Numbers of WTPs by Types of Residuals Discharged and Discharge Practice (National Estimates Based on Responses to Question 2k)

Classification			Estimated Number of WTPs in Classification	Estimated Number of WTPs with Residuals from:							
				Dewatering Operations				Concentrates (i.e., Brines)			
Size of Population Served	**Primary Water Source**	**Treatment Method**		**Total**	**Direct**	**Indirect**	**Zero [a]**	**Total**	**Direct**	**Indirect**	**Zero [a]**
10,001-50,000	Ground	Any	526	197	44	69	173	107	32	78	25
	Surface	Any	938	662	289	161	585	21	2	17	9
	Subtotal		1,464	859	334	230	758	127	34	95	34
More than 50,000	Ground	Conventional Filtration	14	[CBI Redacted]							
		Membrane	19	6	0	0	6	19	2	6	13
		Other	2	[CBI Redacted]							
		Softening	66	60	29	2	60	0	0	0	0
		Ion Exchange	8	[CBI Redacted]							
		None	2	[CBI Redacted]							
		Subtotal [b]	111	86	32	4	85	30	4	14	13
	Surface	Conventional Filtration	383	318	129	95	266	0	0	0	0
		Membrane	19	13	4	2	13	7	0	5	7
		Other	4	[CBI Redacted]							
		Softening	168	122	53	25	114	0	0	0	0
		None	2	[CBI Redacted]							
		Subtotal [b]	576	457	186	124	396	7	0	5	7
	Subtotal [b]		688	542	218	128	481	36	4	19	20
Total [b]			**2,151**	**1,402**	**552**	**358**	**1,239**	**164**	**38**	**113**	**54**

a – Number of WTPs using one or more zero discharge method (e.g., landfill disposal, recycling). WTP may also discharge some residuals directly or indirectly.

b – CBI redacted WTP estimates are included in subtotal and total rows.

Table 3-15. Estimated Number of WTPs by Discharge Frequency for Direct and Indirect Discharges (National Estimates Based on Responses to Question 2k)

Classification			**Estimated Number of WTPs in Classification**	**Estimated Number of Direct and Indirect WTPs**	**Estimated Number of WTPs with:**							
					Direct Discharge [a]				**Indirect Discharge** [a]			
Size of Population Served	**Primary Water Source**	**Treatment Method**			**Total**	**Cont.**	**Batch**	**Emer-gency**	**Total**	**Cont.**	**Batch**	**Emer-gency**
10,001-50,000	Ground	Any	526	419	121	35	86	0	307	44	265	0
	Surface	Any	938	732	406	158	220	35	405	129	271	4
	Subtotal		1,464	1,151	527	194	306	35	711	173	537	4
More than 50,000	Ground	Conventional Filtration	14	8	[CBI Redacted]							
		Membrane	19	6	2	2	0	0	6	6	0	0
		Other	2	2	[CBI Redacted]							
		Softening	66	33	31	2	27	2	2	0	2	0
		Ion Exchange	8	8	[CBI Redacted]							
		None	2	0	[CBI Redacted]							
		Subtotal [b]	111	57	40	8	29	2	20	7	13	0
	Surface	Conventional Filtration	383	260	167	78	76	15	142	48	102	0
		Membrane	19	17	4	4	0	0	12	6	7	0
		Other	4	4	[CBI Redacted]							
		Softening	168	129	90	44	45	8	55	24	31	0
		None	2	2	[CBI Redacted]							
		Subtotal [b]	576	412	266	126	123	25	211	78	141	0
	Subtotal [b]		688	469	305	135	152	27	231	85	154	0
Total [b]			**2,151**	**1,620**	**832**	**328**	**458**	**62**	**943**	**258**	**691**	**4**

a – WTPs may use more than discharge flow type (continuous, batch or emergency). As a result, the sum of the number of WTPs in each of the three discharge flow types may exceed the value in the corresponding total column.

b – CBI redacted WTP estimates are included in subtotal and total rows.

Table 3-16. Estimated Number of Batch and Emergency Dischargers by Direct-Discharging WTPs (National Estimates Based on Responses to Question 2k)

Classification			Estimated Number of WTPs in Classification	Estimated Number of Direct Dischargers	Estimated Number of WTPs and Frequency of Residual Discharges							
					Batch Discharge (Times in 2006)				Emergency Discharge (Times in 2006)			
Size of Population Served	**Primary Water Source**	**Treatment Method**			**Estimated Number of WTPs**	**Min**	**Max**	**Median**	**Estimated Number of WTPs**	**Min**	**Max**	**Median**
10,001-50,000	Ground	Any	526	121	86	50	365	365	0	0	0	0
	Surface	Any	938	406	220	2	19,000	365	35	0	218	2
	Subtotal		1,464	527	306	2	19,000	365	35	0	218	2
More than 50,000	Ground	Conventional Filtration	14	4	[CBI Redacted]				[CBI Redacted]			
		Membrane	19	2	0	-	-	-	0	-	-	-
		Other	2	2	[CBI Redacted]				[CBI Redacted]			
		Softening	66	31	27	21	1,500	1,000	2	0	0	0
		Ion Exchange	8	0	--				--			
		None	2	0	--				--			
		Subtotal [a]	111	40	29	21	1,500	1,000	2	0	0	0
	Surface	Conventional Filtration	383	167	76	2	70,810	455	15	0	6	0
		Membrane	19	4	0	-	-	-	0	-	-	-
		Other	4	2	[CBI Redacted]				[CBI Redacted]			
		Softening	168	90	45	1	36,000	1,095	8	0	12	0
		None	2	2	[CBI Redacted]				[CBI Redacted]			
		Subtotal [a]	576	266	123	1	70,810	589	25	0	12	0
	Subtotal [a]		688	305	152	1	70,810	848	27	0	12	0
Total [a]			**2,151**	**832**	**458**	**1**	**70,810**	**365**	**62**	**0**	**218**	**1**

a – CBI redacted WTP estimates are included in subtotal and total rows.

Table 3-17. Estimated Numbers of WTPs Directly Discharging to Various Types of Receiving Waters (National Estimates Based on Responses to Question 2k)

Classification			Estimated Number of WTPs in Classification	Estimated Number of Direct Dischargers	Estimated Number of WTPs Directly Discharging to Receiving Waters					
Size of Population Served	**Primary Water Source**	**Treatment Method**			**River**	**Creek**	**Wetland**	**Ocean**	**Lake**	**Other**
10,001-50,000	Ground	Any	526	121	57	55	0	2	0	6
	Surface	Any	938	406	167	157	0	8	67	0
	Subtotal		1,464	527	224	212	0	10	67	6
More than 50,000	Ground	Conventional Filtration	14	4	[CBI Redacted]					
		Membrane	19	2	0	0	0	0	2	0
		Other	2	2	[CBI Redacted]					
		Softening	66	31	23	8	0	0	0	0
		Ion Exchange	8	0	--					
		None	2	0	--					
		Subtotal [a]	111	40	28	8	0	0	2	2
	Surface	Conventional Filtration	383	167	61	60	0	0	39	8
		Membrane	19	4	0	2	0	0	0	0
		Other	4	2	[CBI Redacted]					
		Softening	168	90	47	25	0	0	12	2
		None	2	2	[CBI Redacted]					
		Subtotal [a]	576	266	109	87	0	0	51	13
	Subtotal [a]		688	305	137	95	0	0	53	15
Total [a]			**2,151**	**832**	**361**	**307**	**0**	**10**	**119**	**21**

a – CBI redacted WTP estimates are included in subtotal and total rows.

Table 3-18. Estimated Number of WTPs with Indirect Discharge and Release Volumes for Continuous Discharges (National Estimates Based on Responses to Question 2k)

Classification			Estimated Number of WTPs in Classification	Estimated Number of Indirect Dischargers	Continuous			
						Gallons/Day		
Size of Population Served	**Primary Water Source**	**Treatment Method**			**Est # WTPs**	**Min.**	**Max.**	**Median**
10,001-50,000	Ground	Any	526	307	44	720	1,000,000	50,000
	Surface	Any	938	405	129	5000	610,000	80,000
	Subtotal		1,464	711	173	720	1,000,000	1,000,000
More than 50,000	Ground	Conventional Filtration	14	4	[CBI Redacted]			
		Membrane	19	6	6	122,200	997,000	260,000
		Other	2	0	0	-	-	-
		Softening	66	2	0	-	-	-
		Ion Exchange	8	8	[CBI Redacted]			
		None	2	0	0	-	-	-
		Subtotal [a]	111	20	7	122,020	997,000	260,000
	Surface	Conventional Filtration	383	142	48	6,375	1,404,000	173,337
		Membrane	19	12	6	111,233	341,000	226,117
		Other	4	2	[CBI Redacted]			
		Softening	168	55	24	3,562	1,056,960	300,000
		None	2	0	0	-	-	-
		Subtotal [a]	576	211	78	3,562	1,404,000	200,000
	Subtotal [a]		688	231	85	3,562	1,000,000	1,404,000
Total [a]			**2,151**	**943**	**258**	**720**	**1,000,000**	**99,800**

a – CBI redacted WTP estimates are included in subtotal and total rows.

Table 3-19. Estimated Number of WTPs with Indirect Discharge and Release Volumes for Batch Discharges (National Estimates Based on Responses to Question 2k)

Classification			**Estimated Number of WTPs in Classification**	**Estimated Number of Indirect Dischargers**	**Batch**			
						Gallons/Day		
Size of Population Served	**Primary Water Source**	**Treatment Method**			**Est # WTPs**	**Min.**	**Max.**	**Median**
10,001-50,000	Ground	Any	526	307	265	157	700,000	15,000
	Surface	Any	938	405	271	110	1,234,000	60,000
	Subtotal		1,464	711	537	110	1,234,000	16,000
More than 50,000	Ground	Conventional Filtration	14	4	[CBI Redacted]			
		Membrane	19	6	0	-	-	-
		Other	2	0	0	-	-	-
		Softening	66	2	2	270,000	270,000	270,000
		Ion Exchange	8	8	[CBI Redacted]			
		None	2	0	0	-	-	-
		Subtotal [a]	111	20	13	1,600	270,000	51,305
	Surface	Conventional Filtration	383	142	102	246	730,000	45,000
		Membrane	19	12	7	8,000	2,265,900	8,000
		Other	4	2	[CBI Redacted]			
		Softening	168	55	31	26,000	1,000,000	350,000
		None	2	0	0	-	-	-
		Subtotal [a]	576	211	141	246	2,265,900	70,000
	Subtotal [a]		688	231	154	246	2,265,900	67,641
Total [a]			**2,151**	**943**	**691**	**110**	**2,265,900**	**25,000**

a – CBI redacted WTP estimates are included in subtotal and total rows.

Table 3-20. Estimated Number of WTPs Employing Various Zero Discharge Disposal Methods (National Estimates Based on Responses to Question 2k)

Classification			**Estimated Number of WTPs in Classification**	**Estimated Number of WTPs using Zero Discharge Methods [a]**	**Estimated Number of WTPs Using Zero Discharge Methods [a]:**							
Size of Population Served	**Primary Water Source**	**Treatment Method**			**Recycle**	**Evaporation**	**Compost**	**Landfill**	**Spray Irrigation**	**Underground Injection**	**Land Application**	**Other**
10,001-50,000	Ground	Any	526	273	151	74	0	143	0	3	52	48
	Surface	Any	938	666	284	141	12	388	14	0	166	25
	Subtotal		1,464	939	434	216	12	531	14	3	218	73
More than 50,000	Ground	Conventional Filtration	14	11	[CBI Redacted]							
		Membrane	19	13	6	0	0	6	0	11	2	0
		Other	2	2	[CBI Redacted]							
		Softening	66	64	36	7	0	16	0	0	48	4
		Ion Exchange	8	8	[CBI Redacted]							
		None	2	2	[CBI Redacted]							
		Subtotal [b]	111	100	59	12	0	37	0	11	50	13
	Surface	Conventional Filtration	383	318	211	69	10	165	8	0	74	17
		Membrane	19	13	7	0	0	9	0	0	6	2
		Other	4	2	[CBI Redacted]							
		Softening	168	129	77	20	8	46	0	0	48	15
		None	2	2	[CBI Redacted]							
		Subtotal [b]	576	463	297	88	18	224	8	0	130	33
	Subtotal [b]		688	563	356	101	18	261	8	11	180	46
Total [a,b]			**2,151**	**1,502**	**790**	**316**	**29**	**792**	**21**	**14**	**399**	**119**

a – Number of WTPs using one or more zero discharge method (e.g., landfill disposal, recycling). WTP may also discharge some residuals directly or indirectly.
b – CBI redacted WTP estimates are included in subtotal and total rows.

3.2.2.5 Copper Usage (Question 3)

This subsection summarizes the responses to question 3 about the WTP's usage of copper-based chemicals to treat source water. For example, WTPs might use copper-based chemicals to control nuisance algae in reservoirs. Tables 3-21 through 3-24 estimate copper usage by the target population based upon the responses to the question shown in Figure 3-16. If the respondent did not check a particular box, EPA assumed that the answer was 'no.'

Tables 3-21 and 3-22 estimate the application rate of the copper sulfate and chelated copper complexes for WTPs in the target population that use copper. The application rate is expressed in pounds per acre-foot and was calculated as:

$$\text{Rate} = \frac{\text{Annual amount}}{\text{Reservoir volume}} \qquad \text{(Eq. 3-1)}$$

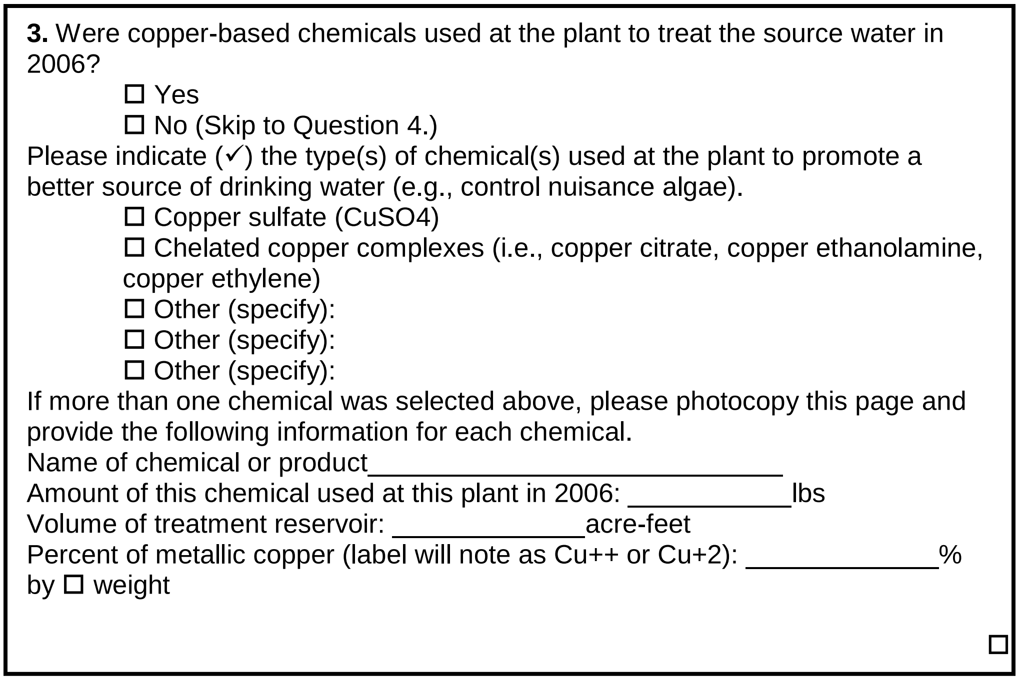
Tables 3-23 and 3-24 estimate the metallic copper content of the treatments based upon the responses from WTPs using copper. For each response, EPA calculated the amount of metallic copper in one of two ways, depending upon whether the metallic content of the copper was expressed by weight or by volume. For weight-based metallic copper, the metallic copper was calculated as follows:

$$W_m = W_c \cdot \frac{P_W}{100} \qquad \text{(Eq. 3-2)}$$

where W_m is the weight of metallic copper (lbs), W_c is the total weight of chemical (lbs), and P_W is the percentage of metallic copper by weight. For volume-based metallic copper, the weight of metallic copper was calculated as follows:

$$W_m = W_c \cdot \frac{P_V \cdot 8.92/100}{\left(P_V \cdot 8.92/100\right) + \left(1 - P_V/100\right)} \qquad \text{(Eq. 3-3)}$$

where P_V is the percentage of metallic copper by volume.



3. Were copper-based chemicals used at the plant to treat the source water in 2006?

☐ Yes
☐ No (Skip to Question 4.)

Please indicate (✓) the type(s) of chemical(s) used at the plant to promote a better source of drinking water (e.g., control nuisance algae).

☐ Copper sulfate (CuSO4)
☐ Chelated copper complexes (i.e., copper citrate, copper ethanolamine, copper ethylene)
☐ Other (specify):
☐ Other (specify):
☐ Other (specify):

If more than one chemical was selected above, please photocopy this page and provide the following information for each chemical.

Name of chemical or product_____________________________
Amount of this chemical used at this plant in 2006: ___________lbs
Volume of treatment reservoir: _____________acre-feet
Percent of metallic copper (label will note as Cu++ or Cu+2): _____________% by ☐ weight

☐

Figure 3-16. Question 3: Use of Copper-Based Chemicals to Treat Source Water

Table 3-21. Estimated Number of WTPs Using Copper Sulfate and Application Rate (National Estimates Based on Responses to Question 3)

Classification			Estimated Number of WTPs in Classification	Estimated Number of WTPs Using Copper-based Chemicals	Copper Sulfate				
Size of Population Served	Primary Water Source	Treatment Method			Estimated Number of WTPs	Application Rate (lbs/acre-ft)			
						Min.	Max.	Est. Mean	Std Err of Mean
10,001-50,000	Ground	Any	526	0	0	-	-	-	-
	Surface	Any	938	95	87	0.02	1,000	102.89	88.61
	Subtotal		1,464	95	87	0.02	1,000	102.89	88.64
More than 50,000	Ground	Conventional Filtration	14	[CBI Redacted]	[CBI Redacted]				
		Membrane	19						
		Other	2						
		Softening	66						
		Ion Exchange	8						
		None	2						
		Subtotal [a]	111	5	5	0.46	4.11	2.18	1.25
	Surface	Conventional Filtration	383	[CBI Redacted]	[CBI Redacted]				
		Membrane	19						
		Other	4						
		Softening	168						
		None	2						
		Subtotal [a]	576	92	64	0	50,000	2,355.9	2,195.4
	Subtotal [a]		688	96	69	0	50,000	2,167.9	2,021.4
Total [a]			**2,151**	**191**	**156**	**0**	**50,000**	**978.12**	**8,81.43**

a – CBI redacted WTP estimates are included in subtotal and total rows.

Table 3-22. Estimated Number of WTPs Using Chelated Copper Complexes and Application Rate (National Estimates Based on Responses to Question 3)

Classification			**Estimated Number of WTPs in Classification**	**Estimated Number of WTPs Using Copper-based Chemicals**	**Chelated copper complexes**				
Size of Population Served	**Primary Water Source**	**Treatment Method**			**Estimated Number of WTPs**	**Application Rate (lbs/acre-ft)**			
						Min	**Max**	**Est. Mean**	**Std Err of Mean**
10,001-50,000	Ground	Any	526	0	0	-	-	-	-
	Surface	Any	938	95	18	0	0.03	0.01	0.01
	Subtotal		1,464	95	18	0	0.03	0.01	0.01
More than 50,000	Ground	Conventional Filtration	14	[CBI Redacted]	[CBI Redacted]				
		Membrane	19						
		Other	2						
		Softening	66						
		Ion Exchange	8						
		None	2						
		Subtotal [a]	111	5	2	0	0	0	0
	Surface	Conventional Filtration	383	[CBI Redacted]	[CBI Redacted]				
		Membrane	19						
		Other	4						
		Softening	168						
		None	2						
		Subtotal [a]	576	92	29	0	25.25	2.6	1.93
	Subtotal [a]		688	96	32	0	25.25	2.37	1.77
Total [a]			**2,151**	**191**	**50**	**0**	**25.25**	**1.45**	**1.19**

a – CBI redacted WTP estimates are included in subtotal and total rows.

Table 3-23. Estimated Number of WTPs Using Copper Sulfate and Amount of Metallic Copper Used in Pounds (National Estimates Based on Responses to Question 3)

Classification			**Estimated Number of WTPs in Classification**	**Estimated Number of WTPs Using Copper-based Chemicals**	**Copper Sulfate**				
Size of Population Served	**Primary Water Source**	**Treatment Method**			**Estimated Number of WTPs**	**Amount of metallic copper (lbs/yr)**			
						Minimum	**Maximum**	**Estimated Mean**	**Std err of mean**
10,001-50,000	Ground	Any	526	0	0	-	-	-	-
	Surface	Any	938	95	87	1	2,000	515	164
	Subtotal		1,464	95	87	1	2,000	515	164
More than 50,000	Ground	Conventional Filtration	14	[CBI Redacted]	[CBI Redacted]				
		Membrane	19						
		Other	2						
		Softening	66						
		Ion Exchange	8						
		None	2						
		Subtotal [a]	111	5	5	1,969	3,465	2,674	512
	Surface	Conventional Filtration	383	[CBI Redacted]	[CBI Redacted]				
		Membrane	19						
		Other	4						
		Softening	168						
		None	2						
		Subtotal [a]	576	92	64	21	34,520	3,322	1,558
	Subtotal [a]		688	96	69	21	34,520	3,269	1,431
Total [a]			**2,151**	**191**	**156**	**1**	**34,520**	**1,666**	**655**

a – CBI redacted WTP estimates are included in subtotal and total rows.

Table 3-24. Estimated Number of WTPs Using Chelated Copper Complexes and Amount of Metallic Copper Used in Pounds (National Estimates Based on Responses to Question 3)

Classification					**Chelated copper complexes**				
						Amount of metallic copper (lbs/yr)			
Size of Population Served	**Primary Water Source**	**Treatment Method**	**Estimated Number of WTPs in Classification**	**Estimated Number of WTPs Using Copper-based Chemicals**	**Estimated Number of WTPs**	**Minimum**	**Maximum**	**Estimated. Mean**	**Std Err of Mean**
10,001-50,000	Ground	Any	526	0	0	-	-	-	-
	Surface	Any	938	95	18	0	24	12	8
	Subtotal		1,464	95	18	0	24	12	8
More than 50,000	Ground	Conventional Filtration	14	[CBI Redacted]	[CBI Redacted]				
		Membrane	19						
		Other	2						
		Softening	66						
		Ion Exchange	8						
		None	2						
		Subtotal [a]	111	5	2	0	0	0	0
	Surface	Conventional Filtration	383	[CBI Redacted]	[CBI Redacted]				
		Membrane	19						
		Other	4						
		Softening	168						
		None	2						
		Subtotal [a]	576	92	29	0	5,533	1,298	580
	Subtotal [a]		688	96	32	0	5,533	1,165	534
Total [a]			**2,151**	**191**	**50**	**0**	**5,533**	**717**	**398**

a – CBI redacted WTP estimates are included in subtotal and total rows.

3.3 DRINKING WATER INDUSTRY ECONOMIC OVERVIEW

This economic overview compiles and analyzes economic and operational data for public water systems (PWSs) and provides a general overview of the types and characteristics of public drinking water systems. The purpose of this section is to provide an overview of the financial characteristics of PWSs that operate WTPs serving at least 10,000 people, as well as the variability of financial strength across drinking water systems. The remainder of this section is organized as follows:

- Section 3.3.1 describes the major data sources used for this profile.
- Section 3.3.2 presents a general overview of PWSs, including population served, ownership type, water source, and discharge characteristics.
- Section 3.3.3 reviews financial characteristics of PWSs.
- Section 3.3.4 provides an overview of water system customers, with focus on water consumption and rate payments by residential customers.

3.3.1 Major Sources of Information

EPA used three primary sources of data to characterize the universe of PWSs: the Safe Drinking Water Information System (SDWIS), the Community Water System Survey (CWSS), and the responses to the EPA DWT Industry Questionnaire.

3.3.1.1 Safe Drinking Water Information System

As discussed in Section 2.3.1, the SDWIS is a database compiled and maintained by EPA. It contains data on all PWSs including system location, system type (such as community or non-community water systems), primary raw water source (ground water or surface water), and violations. Optional reporting fields include type of treatment and ownership type. Because providing some data is discretionary, EPA does not have complete data on every system for these parameters. This is particularly common for non-community water systems (NCWSs).

Because SDWIS is continuously being updated, EPA used 155,693 records of active PWSs from the third quarter of 2007 for this economic profile (U.S. EPA, 2007).

3.3.1.2 Community Water System Survey

The second source of information, the CWSS, is a periodically updated detailed EPA survey of surface and ground water community water systems (CWSs). The most recent survey was conducted in 2000 and published in 2002 (U.S. EPA, 2002). See Section 2.3.2 for more details. Since there is no survey equivalent to CWSS for non-community water systems, the operational and financial information presented later in this profile is only available for CWSs (U.S. EPA, 2002).

3.3.1.3 EPA DWT Industry Questionnaire

The EPA DWT Industry Questionnaire, conducted in 2007, is a survey of WTPs specifically created for this study to gather data on the operation, financial characteristics, and residuals discharges from the industry. The technical operations questions were posed at the water treatment plant level. The financial portion of the survey (questions 4 through 13) asked for system or utility level data depending on whether the costs for a treatment technology would be spread amongst consumers at the system level or across all the customers of the larger utility. For the purpose of determining the financial strength of the larger corporate entity which owns the individual drinking water treatment plant being surveyed in the engineering portion of the survey and the impacts to the large corporate entity's customer base EPA must look to the level of the system. It is at the system level that the costs of technology improvements are financed and it is the system that can spread the costs of upgrades to a specific plant or plants across its total customer base. In some instances a larger utility may own more than one system and spreads the cost of technology improvements across those systems. In this case the proper level of financial assessment is at the level of the utility.[10] See Section 2.2 for further details.

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[10] In the EPA DWT Industry Questionnaire respondents were instructed to give either system or utility level information in their financial survey responses depending on which characterization was most appropriate. The competed responses to the financial portion of the survey are all at the system level. They may also be referred to as single system utility level data.

3.3.2 Public Water System Characteristics

As discussed in Section 3.1, there are two major types of PWSs: community and non-community water systems (CWSs and NCWSs). This section discusses the different types of PWSs and the major characteristics used to classify them. Basic characteristics such as population served, ownership, and water source are discussed first, followed by operational characteristics such as water treatment and residual management. The purpose of this section is to provide a snapshot of the public water system industry. Table 3-25 provides a breakdown of PWSs by system type, according to SDWIS.

Table 3-25. Number of PWSs and Total Population Served by System Type, SDWIS

System Type	Systems		Population Served	
CWS	52,110	33%	286,451,204	93%
NCWS	103,583	67%	20,086,152	7%
Total [a]	**155,693**	**100%**	**306,537,356**	**100%**

Source: U.S. EPA, 2007.
a – Four systems of an "unspecified" system type are included in these totals.

3.3.2.1 Population Served

Table 3-26 presents the number of systems by type and by the number of people (as a range) served by each system, according to SDWIS. The table shows that the vast majority of both community and non-community water systems are fairly small, serving a population of less than 3,000 people. Only 8 percent of CWSs and 0.04 percent of NCWSs are large (serve more than 10,000 people).

Table 3-26. Summary of the Number of PWSs by System Type and Size, SDWIS

System Type	System Size (Population Served)						
	<100	**101 - 500**	**501 - 3k**	**3k - 10k**	**10k - 50k**	**>50k**	**Total [a]**
CWS	13,270	16,012	13,906	4,822	3,175	925	52,110
NCWS	71,170	26,737	5,413	222	33	8	103,583
Total	**84,440**	**42,749**	**19,319**	**5,044**	**3,208**	**933**	**155,693**

Source: U.S. EPA, 2007.
a – components may not add up to totals due to rounding.

Table 3-27 shows the number of systems, by source water and population served , reporting water sales for each customer category. This data is from the EPA DWT Industry Questionnaire; the total number of systems listed , 285, is a subset of the SDWIS systems .[11]) This table shows that 95 percent of systems serve residential customers, 89 percent of systems serve non-residential customers, and 65 percent of systems sell water to other systems.

Table 3-27. Number of Systems that Report Water Sales to Different Customer Categories, DWT Industry Questionnaire

Primary Source*	Population Served	Sold to Other Systems	Residential Customers	Non-Residential Customers	Other
Surface	10,000-50,000	48	73	67	59
	More than 50,000	123	155	151	142
Ground	10,000-50,000	4	17	15	14
	More than 50,000	10	25	21	22
Total		185	270	254	237

Note: Systems serve more than one customer type—totals are not of unique systems. All systems report at least one customer type.
*Systems that use purchased water as their primary source are not presented in this table because of the potential for revealing Confidential Business Information Source: Appendix A.

3.3.2.2 Ownership

PWSs are owned by a variety of public and private entities. Public PWSs may be owned by a federal, state, or local entity, or by a Native American tribe. Private PWSs may be owned by non-profit or for-profit firms, or may be operated as ancillary businesses to other enterprises. Some PWSs are also co-owned by public and private entities.

Table 3-28 summarizes the number of PWSs by ownership type and size of the population served, according to SDWIS. Public entities such as federal, state, and local government agencies and Native American tribes own approximately 27 percent of all PWSs in the U.S. Privately-owned PWSs make up approximately 69 percent of all PWSs. The majority of privately-owned PWSs, however, are small with over 71 percent serving fewer than 10,000 people. They make up only 15 percent of PWSs serving over 50,000 people. In total, privately

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[11] 285 is the number of completed system responses to the financial portion of the EPA DWT Industry Questionnaire without those systems that primarily resell water that is purchased from other systems. The purchased water source category has been omitted from the results presented in this section because of the potential for revealing Confidential Business Information.

owned PWSs provide water to only 18 percent of the population served by PWSs, while publicly-owned systems serve about 80 percent (U.S. EPA, 2007).

Table 3-28. Number of Water Systems by Ownership Type and Size, SDWIS

Type of Ownership	System Size (Population Served)				Population Served
	<10k	**10k - 50k**	**>50k**	**Total**	
Public	38,601	2,722	789	42,112	245,085,282
Federal Government	3,736	66	5	3,807	3,038,437
State Government	5,370	40	6	5,416	5,957,549
Local Government	28,560	2,604	778	31,942	235,112,533
Native American	935	12	0	673	976,763
Private	106,899	437	134	107,470	56,238,197
Mixed public/private	6,052	49	10	6,111	5,213,877
Total	**151,552**	**3,208**	**933**	**155,693**	**306,537,356**

Source: U.S. EPA, 2007.

Table 3-28 does not present systems according to the type of population served, but groups these systems together. In general, a larger percentage of NCWSs than CWSs are privately owned. Privately-owned PWSs account for approximately 82 percent of TNCWSs and 69 percent of NTNCWSs, as compared to only 48 percent of CWSs.

3.3.2.3 Water Source

In addition to the type and size of population served and the type of ownership, water systems can be classified by their primary water source. PWSs may rely on ground water, surface water, or water purchased from other water systems. Table 3-29 presents the number of PWSs that draw water from each type of water source, by the size of the population served according to SDWIS.[12] The table also presents the total number of people that receive water from each type of water source. The vast majority of PWSs draw water from ground sources. The percent of PWSs utilizing ground water decreases significantly, however, as the size of the population served increases. The percentage of PWSs utilizing surface water, on the other hand, increases with the increase in the population served. In total, about 92 percent of PWSs draw water from ground sources. These systems, however, distribute water to only 36 percent of the

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[12] SDWIS classifies a water system as relying on surface water if any of its water comes from surface water sources.

total populations served by PWSs. Sixty-four percent of PWSs' customers receive water drawn from surface sources.

Table 3-29 does not present PWSs according to the type of population served, but groups these systems together. PWSs that draw from ground water account for approximately 74 percent of CWSs, as compared to only 13 percent of NCWSs. PWSs that draw from surface water account for approximately 97 percent of CWS, as compared to only 2 percent of NCWSs.

Table 3-29. Number of Water Systems by Water Source and System Size, SDWIS

Type of Source Water	**System Size (Population Served)**				**Population Served**
	<10k	**10k - 50k**	**>50k**	**Total**	
Ground water	137,371	1,344	231	138,946	105,598,776
Surface water	4,043	938	455	5,436	137,577,368
Purchased	10,100	925	247	11,272	63,298,151
Ground water	3,669	60	7	3,736	4,676,746
Surface water	6,431	865	240	7,536	58,621,405
Total [a]	**151,552**	**3,208**	**933**	**155,693**	**306,537,356**

Source: U.S. EPA, 2007.

a – Totals include 12 systems in the "< 10k" category that use an "unspecified" water type.

As identified in Table 3-27 within the EPA DWT Industry Questionnaire in the 10,000 to 50,000 population category, approximately 17 percent of the systems draw from ground water and 83 percent draw from surface water. Within the greater than 50,000 population category, approximately 14 percent of the respondent systems draw from ground water and 86 percent draw from surface water.

3.3.2.4 Operational Characteristics: Water Treatment and Direct Discharge to Surface Water

This section presents CWSS data on two characteristics: water treatment and residuals management. Because SDWIS does not provide data on either treatment practices or residuals management, this information is not available for NCWSs. This section also does not present the characteristics for systems surveyed by the EPA DWT Industry Questionnaire; national estimates for WTPs are presented in Section 3.2.

- Water Treatment: Not all CWSs treat water prior to distributing it to their customers. Some CWSs purchase water that has already been treated from other drinking water systems while other CWSs draw their water from sources that are pure enough to satisfy federal drinking water guidelines, eliminating the need for treatment. Systems that do not treat water are assumed not to discharge to surface water. CWSS asks respondents to report whether or not they treat water and several detailed questions regarding the treatment technology used. Overall, 75 percent of ground water systems, 99.6 percent of surface water systems, and 17 percent of systems purchasing water provide treatment (U.S. EPA, 2002).

- Residual Management: CWSs use a variety of technologies to dispose of water treatment residuals such as sludge, sediment, and chemicals. Some of the residual management techniques used by water systems include mechanical dewatering, land application, deep well injection, and direct discharge to surface water. Overall, 3 percent of ground water systems, 10 percent of surface water systems, and 6 percent of systems purchasing water perform residuals treatment (U.S. EPA, 2002).

Table 3-30 presents the number of large CWSs (serving more than 10,000 people) that provide treatment and the number of CWSs that discharge directly to surface water, according to CWSS. The information is presented for all systems and by water source.

Table 3-30. Summary of CWSs by Water Source and Population Served, CWSS

	System Size (Population Served)		
	10k-50k	**>50k**	**Total >10k**
Ground Water			
All Systems	1,340	307	1,647
Provide Treatment	983	233	1,216
Discharger	217	50	267
Surface Water			
All Systems	988	440	1,428
Provide Treatment	977	434	1,411
Discharger	387	142	529
Purchased Water			
All Systems	685	238	923
Provide Treatment	385	100	485
Discharger	27	19	46
Total			
All Systems	3,013	985	3,998
Provide Treatment	2,345	767	3,112
Discharger	631	211	842

Source: U.S. EPA, 2002.

Table 3-31 presents the 2006 water quantity sold, in million gallons per year (MGY), per system, reported at the 25th, 50th, and 75th quartiles, according to the EPA DWT Industry Questionnaire responses. The median quantity sold in 2006 across all respondent surface and ground water source systems was 4,297 million gallons.

3.3.3 Financial Characteristics of Drinking Water Treatment Systems

In order to gauge the ability of PWSs to comply with environmental regulations, EPA conducts analyses that assess the financial health of the industry. This section provides a snapshot of the financial state of large CWSs (serving over 10,000 people).

Basic data on revenue, expenses, capital expenditures, and funding sources available to water systems was obtained from CWSS and responses to the EPA DWT Industry Questionnaire questions 4 through 13. Because SDWIS does not provide any data on finances of the encompassed systems, no such information was available for non-community systems. This section first presents system revenues and revenue sources, followed by system expenses and funding availability.

3.3.3.1 Water System Revenues

Water sales are the primary source of revenue for the vast majority of water systems.[13] CWSs supply water to private homes, businesses, agricultural and other non-residential customers. A portion of CWS revenues also comes from connection fees, inspections, penalties and fines, and other non-consumption based charges.

Total CWS revenues came to $39 billion in 2000 (2000$). Revenues of publicly-owned systems accounted for 88 percent of this total. Water sales revenues contributed $33 billion (85 percent) of total CWS revenues, and residential water sales accounted for about 60 percent of total water sales for CWSs of all sizes. Overall, residential revenues have increased slightly since 1995 (U.S. EPA, 2002).

Table 3-32 presents the 25th percentile. median, and 75th percentile values for revenue by ownership type and system size, according to CWSS. The table shows that private systems earn slightly higher revenues than public systems.

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[13] Although some smaller systems may be run as ancillary businesses, this was not true for any of the systems with a population of greater than 10,000 served.

Table 3-31. Reported 2006 Water Quantity Sold (MGY), per System, DWT Industry Questionnaire

Primary Source [a]	Population Group	Number of Systems	Water Quantity Sold (MGY) 25th Percentile	50th Percentile	75th Percentile
Surface	10,000-50,000	74	657	1,351	2,274
	More than 50,000	166	4,403	8,488	17,333
Ground	10,000-50,000	18	594	758	1,435
	More than 50,000	27	2,026	3,700	5,871
Total Systems/Quantity Across All Categories		285	1,664	4,297	11,242

Source: Appendix A.

a – Systems that use purchased water as their primary source are not presented in this table because of the potential for revealing Confidential Business Information.

Table 3-32. Summary of Annual CWS Revenues by Ownership Type ($1,000), CWSS

System Size (Population Served)	Ownership Type								
	Public			Private			All Systems		
	P25	P50	P75	P25	P50	P75	P25	P50	P75
10k-50k	$1,566	$2,302	$3,373	$1,454	$2,465	$4,100	$1,566	$2,313	$3,386
50k-100k	$5,344	$7,126	$11,254	$8,086	$10,133	$14,830	$5,440	$7,313	$11,802
100k-500k	$9,674	$16,444	$27,767	$15,217	$15,970	$36,579	$9,885	$16,187	$27,811
>500k	$61,899	$89,897	$193,345	$121,339	$122,075	$171,568	$62,103	$99,807	$188,013

Source: U.S. EPA, 2002.
P25 – 25th percentile.
P50 – 50th percentile (median).
P75 – 75the percentile.

Table 3-33 presents the median revenue per 1,000 gallons (and the 25th and 75th percentiles), also by ownership type and system size, for those CWSs identified as discharging, according to CWSS. Similar to annual revenue, private systems also earn significantly more per gallon than their public counterparts. This discrepancy decreases with system size. For both private and public systems, revenue per 1,000 gallons generally declines as system size grows.

Table 3-33. Summary of Total Revenues of CWSs that Discharge ($/1,000 gallons)

System Size (Population Served)	Ownership Type								
	Public			Private			All Systems		
	P25	P50	P75	P25	P50	P75	P25	P50	P75
10k-50k	$1.40	$1.93	$2.83	$3.16	$3.26	$3.36	$1.41	$2.51	$3.07
50k-100k	$1.12	$1.58	$1.71	$0.93	$2.42	$4.24	$1.12	$1.71	$1.74
100k-500k	$1.36	$1.82	$2.24	$2.17	$2.18	$2.58	$1.45	$1.95	$2.25
>500k	$1.37	$1.69	$1.71	N/A	N/A	N/A	$1.37	$1.69	$1.71

Source: U.S. EPA, 2002.
P25 – 25th percentile.
P50 – 50th percentile (median).
P75 – 75the percentile.

Table 3-34 presents the 2006 total revenue per system (in millions), reported at the 25th, 50th, and 75th quartiles, according to responses to the EPA DWT Industry Questionnaire. Median total annual revenue across all source water and population size categories was $14 million. Surface source water systems serving both populations between 10,000 and 50,000, and those serving greater than 50,000 people reported higher median revenues, $4.5 and $25.3 million respectively, than their ground water counterparts. Table 3-35 presents 2006 revenues per volume (dollars per million gallons) from the EPA questionnaire. Unlike the total revenue values in Table 3-34 the per unit water sales median values show that ground water systems receive higher per unit revenues than surface water systems. Ground water systems serving between 10,000 and 50,000 people sell water at a median price of $4,021 per million gallons while surface water systems serving the same number of people receive a median sale value of $3,379. Systems serving more people and dealing in greater amounts of delivered water generally sell water at lower per unit prices. The median 2006 revenue per million gallons across all systems that responded to the DWT Industry Questionnaire was $3,082.

Table 3-34. Reported 2006 Revenues by Population Served and Primary Water Source, per System, DWT Industry Questionnaire

Primary Source [a]	Population Group	Number of Systems	Revenues ($ Millions)		
			25th Percentile	50th Percentile	75th Percentile
Surface	10,000-50,000	74	$3.2	$4.5	$6.8
	More than 50,000	166	$13.8	$25.3	$49.5
Ground	10,000-50,000	18	$2.4	$3.2	$3.8
	More than 50,000	27	$9.9	$14.9	$23.3
Total Systems/ Revenues Across All Categories		285	$6.2	$14	$32.7

Source: Appendix A.

a – Systems that use purchased water as their primary source are not presented in this table because of the potential for revealing Confidential Business Information.

Table 3-35. Reported 2006 Water Sales Revenue per Volume, per System, DWT Industry Questionnaire

Primary Source [a]	Population Group	Number of Systems	Water Sales Revenue per Volume ($/MGY)		
			25th Percentile	50th Percentile	75th Percentile
Surface	10,000-50,000	74	$2,230	$3,379	$5,216
	More than 50,000	166	$2,043	$2,826	$3,765
Ground	10,000-50,000	18	$2,202	$4,021	$5,893
	More than 50,000	27	$2,655	$3,867	$6,723
Total Systems/ Sales Revenue Across All Categories		285	$2,199	$3,082	$4,599

Source: Appendix A.

a – Systems that use purchased water as their primary source are not presented in this table because of the potential for revealing Confidential Business Information.

3.3.3.2 Expenses

CWSs spent a total of $32 billion in 2000 on routine operating expenses, including water treatment, water distribution, and residuals management. Expenses of systems with a population of greater than 10,000 served totaled $13.3 billion (U.S. EPA, 2002).

According to CWSS employee compensation – including salary, benefits, and contractor payments – accounts for about 31 percent of total system expenditures. Other routine operating and maintenance expenses account for another 45 percent. In total, operating expenses (employee expenses and other operating and maintenance expenditures) account for about 75 percent of total system expenditures. Debt service payments and other expenses, contribute another 19 percent (U.S. EPA, 2002).

Table 3-36 presents average total system expenditures by ownership type and system size, according to CWSS. The table also presents a breakdown of expenses by major category (employee, routine operating, debt service expenditures, and other expenses).

Table 3-36. Average System Expenses and Expense Breakdown by Major Category, CWSS

	System Size (Population Served)				
	10k- 50k	**50k-100k**	**100k –500k**	**> 500k**	**Total Across All[a]**
All Systems					
Average System Expenses ($000)	**$2,673**	**$7,617**	**$18,561**	**$129,320**	**$7,539**
Employeeb	*28%*	*30%*	*32%*	*34%*	***31%***
Routine Operating	*70%*	*62%*	*52%*	*48%*	***45%***
Debt Service	*2%*	*6%*	*12%*	*14%*	***19%***
Other Expenses	*1%*	*3%*	*4%*	*5%*	***6%***
Public Systems					
Average System Expenses ($000)	**$2,675**	**$7,630**	**$18,408**	**$131,490**	**$7,805**
Employeeb	*34%*	*32%*	*32%*	*33%*	***30%***
Routine Operating	*45%*	*52%*	*52%*	*46%*	***44%***
Debt Service	*16%*	*11%*	*12%*	*16%*	***20%***
Other Expenses	*5%*	*6%*	*3%*	*5%*	***6%***
Private Systems					
Average System Expenses ($000)	**$2,664**	**$7,470**	**$20,466**	**$94,419**	**$5,355**
Employeeb	*28%*	*29%*	*32%*	*40%*	***34%***
Routine Operating	*72%*	*69%*	*53%*	*56%*	***51%***
Debt Service	*1%*	*3%*	*10%*	*4%*	***9%***
Other Expenses	*1%*	*1%*	*6%*	*3%*	***8%***

Source: U.S. EPA, 2002.
a – Components may not add up to 100% due to rounding.
b – Employee expenses include contractor expenses.

Table 3-37 presents the median and bounding quartiles for total expenses per 1,000 gallons of water produced by ownership type and system size for CWSs, according to CWSS.

Table 3-37. Summary of Total Expenses by System Size and Ownership Type ($/1,000 gallons produced), CWSS

System Size (Population Served)	**Ownership Type**								
	Public			**Private**			**Across All Systems**		
	P25	**P50**	**P75**	**P25**	**P50**	**P75**	**P25**	**P50**	**P75**
10k-50k	$1.27	$2.05	$2.95	$1.99	$2.30	$2.68	$1.29	$2.11	$2.79
50k-100k	$1.16	$1.67	$2.32	$1.66	$2.11	$2.99	$1.16	$1.67	$2.41
100k-500k	$1.20	$1.93	$2.48	$1.42	$2.09	$2.85	$1.22	$1.93	$2.48
>500k	$1.09	$1.70	$2.06	$1.49	$2.05	$2.17	$1.21	$1.71	$2.10

Source: U.S. EPA, 2002.
P25 – 25th percentile. P50 – 50th percentile (median). P75 – 75the percentile.

Table 3-38, Table 3-39, and Table 3-40 report the 25th, 50th, and 75th quartiles for 2006 total expenses per system, total and routine operating expenses per million gallons a year for each system, and total employee wages per system, respectively from the DWT Industry Questionnaire.

Based on the EPA DWT Industry Questionnaire responses representing 285 systems, median total annual expenses equaled $15.6 million. Seventy-five percent of systems reported total costs of operation below $39.6 million. Median total expenses per million gallons of produced water ranged from $3,272 to $4,815 across the source water and population served categories. Routine per unit operating expenses were highest for ground water systems serving more than 50,000 people, at $3,268. Surface water systems serving more than 50,000 people had the lowest per unit routine expenditures, $1,897. Across all respondent categories median total per unit expenses equaled $3,522. Median routine operating expenses across all respondents was $2,034 or about 58% of the total median expenditures value.

Table 3-40 shows that the median hourly wage rate paid in 2006 among EPA's survey responders equals $26. The median hourly wage rate ranged from $23 an hour paid by surface water producers serving between 10,000 and 50,000 residents, and $27 an hour paid by surface water suppliers serving greater than 50,000 people. Median total annual wages paid by the surveyed drinking water systems in 2006 was $1,447,000. Fifty percent of the 251 respondents to this question paid between $616,000 and $3,535,000 in wages for the year 2006.

Table 3-38. Reported 2006 Total Expenses, per System, DWT Industry Questionnaire

Primary Source [a]	**Population Group**	**Number of Systems**	**Total Expenses ($in millions)**		
			25th Percentile	**50th Percentile**	**75th Percentile**
Surface	10,000-50,000	74	$2.8	$4.7	$7.5
	More than 50,000	166	$14.5	$30.2	$58.1
Ground	10,000-50,000	18	$2.0	$3.0	$4.6
	More than 50,000	27	$12.0	$16.8	$36.3
Total Systems/ Expenses Across All Categories		285	$6.4	$15.6	$39.6

Source: Appendix A.

a – Systems that use purchased water as their primary source are not presented in this table because of the potential for revealing Confidential Business Information.

Table 3-39. Reported 2006 Expenses per MGY, Total and Operating, per System, DWT Industry Questionnaire

Primary Source [a]	**Population Group**	**Number of Systems**	**Total Expenses ($/MGY)**			**Routine Operating Expenses ($/MGY)**		
			25th Percentile	**50th Percentile**	**75th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**
Surface	10,000-50,000	74	$2,186	$3,272	$5,653	$1,342	$2,105	$3,244
	More than 50,000	166	$2,377	$3,406	$4,906	$1,324	$1,897	$2,847
Ground	10,000-50,000	18	$2,196	$3,900	$6,762	$1,267	$2,516	$3,407
	More than 50,000	27	$3,231	$4,815	$10,489	$2,046	$3,268	$4,810
Total Systems/ Expenses Across All Categories		285	$2,357	$3,522	$5,474	$1,378	$2,034	$3,186

Source: Appendix A.

a – Systems that use purchased water as their primary source are not presented in this table because of the potential for revealing Confidential Business Information

Table 3-40. Reported 2006 Hourly and Total Wages for All Employees, per System, DWT Industry Questionnaire

Primary Source [a]	**Population Group**	**Number of Systems [b]**	**Number of Employees**	**Hourly Wage ($)**			**Total Wages Annually ($ in thousands)**		
				25th Percentile	**50th Percentile**	**75th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**
Surface	10,000-50,000	69	1,249	$20	$23	$26	$398	$579	$1,088
	More than 50,000	139	15,433	$22	$27	$33	$1,441	$2,694	$5,142
Ground	10,000-50,000	18	249	$19	$25	$27	$323	$543	$645
	More than 50,000	26	1,126	$23	$26	$30	$765	$1,454	$1,927
Total Systems/ Wages Across All Categories		251	18,579	$22	$26	$30	$616	$1,447	$3,535

Source: Appendix A.

a – Systems that use purchased water as their primary source are not presented in this table because of the potential for revealing Confidential Business Information.

b – There is a smaller number of systems in this table as some systems did not report wages, or reported them in an unclear manner.

3.3.4 Customer Profile

Most CWSs, especially the ones serving the larger populations, are expected to be able to pass on any technology costs to their customers through rate increases. As a result, it is important to conduct an assessment of the likely burden on households served by CWSs.

This section provides information on the customers of regulated CWSs, including customer types and water deliveries, revenues, and water rates by customer type. For residential customers, this section also discusses average annual water bills per household, information on the billing structures utilized, the availability of subsidized rates for low income families, and the average annual income of households served by regulated CWSs.

3.3.4.1 Customer Types

CWSs serve three primary customer types: (1) other water suppliers, who resell water to the final customers, (2) residential customers, and (3) non-residential customers. Non-residential customers can be further divided into commercial, industrial, agricultural, and other customers (e.g., hospitals and schools, prisons, or governments).

According to the CWSS, of the systems with a population of greater than 10,000 served, 1,680 (or 43 percent) sell water to other water suppliers, 3,242 (or 83 percent) serve residential customers, and 3,024 (or 77 percent) serve non-residential customers. Of the systems that serve non-residential customers, 91 percent serve commercial/industrial customers, 10 percent serve agricultural customers, and 32 percent serve other non-residential customers. Table 3-41 presents the number and percentage of systems with a population of greater than 10,000 that serve the different types of customers, by system size, according to CWSS. The majority of all systems, irrespective of size, serve residential and non-residential customers, while the largest systems (serving 500,000 people and more) are more likely to sell water to other water systems than the smaller-sized systems.

Table 3-41. Number and Percentage of CWSs Serving Different Customer Types, CWSS

	System Size (Population Served)									
	10k - 50k		50k - 100k		100k - 500k		> 500k		Total[a]	
Sold to Other PWS	1,107	37%	247	53%	251	60%	75	88%	**1,680**	**43%**
Residential	2,478	84%	384	82%	314	75%	66	78%	**3,242**	**83%**
Non-Residential	2,282	77%	371	79%	302	72%	69	82%	**3,024**	**77%**
Commercial/Industrial	*2,112*	*93%*	*346*	*93%*	*232*	*77%*	*52*	*75%*	***2,742***	***91%***
Agricultural	*214*	*9%*	*38*	*10%*	*48*	*16%*	*9*	*12%*	***309***	***10%***
Other	*603*	*26%*	*143*	*39%*	*173*	*57%*	*37*	*53%*	***956***	***32%***
Total	**2,952**	**100%**	**470**	**100%**	**421**	**100%**	**85**	**100%**	**3,928**	**100%**

Source: U.S. EPA, 2002.
a – Fifteen of the 2,283 systems with a population of greater than 10,000 served are excluded from these numbers because of removal of outliers in the CWSS data.

3.3.4.2 Water Deliveries, Revenues, and Rates by Customer Type

In 2000, the CWSs with a population of greater than 10,000 served supplied over 17,317 billion gallons of water to their customers.[14] Thirty-eight percent of this amount was delivered to residential customers, 22 percent was delivered to non-residential customers, 23 percent was sold to another CWS, and 7 percent of the water was unaccounted for. Systems serving over 500,000 people accounted for the largest share of total water deliveries, with 40 percent, followed by systems serving 100,000 to 500,000 people, with 26 percent.

Table 3-42 presents year 2000 water deliveries by population served and customer type, according to CWSS. The table also distinguishes between systems owned by private and public entities. Based on ownership type, private systems deliver 49 percent of all water to residential customers, compared to 37 percent for public systems. This difference is especially pronounced in the largest size category (more than 500,000 people served). Conversely, public systems deliver 25 percent of their water to other CWSs, compared to only 6 percent for private systems.

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[14] These numbers are based on 2,268 of the 2,283 regulated systems, that provided information on water deliveries.

Table 3-42. Amount of Water Delivered by Customer and Ownership Type and System Size (billion gallons; 2000), CWSS

	System Size (Population Served)									
	10k - 50k		**50k - 100k**		**100k - 500k**		**> 500k**		**Total**	
All Systems										
Sold to Other PWS	468	12%	180	9%	638	14%	2,774	40%	4,061	23%
Residential	1,700	43%	878	45%	1,762	40%	2,191	31%	6,530	38%
Non-Residential	893	23%	542	28%	1,004	23%	1,377	20%	3,816	22%
Unaccounted for	290	7%	187	10%	320	7%	480	7%	1,278	7%
Totala	**3,930**	**100%**	**1,960**	**100%**	**4,436**	**100%**	**6,991**	**100%**	**17,317**	**100%**
Public Systems										
Sold to Other PWS	443	13%	165	9%	610	15%	2,759	42%	3,976	25%
Residential	1,440	42%	762	43%	1,616	40%	1,989	30%	5,807	37%
Non-Residential	832	24%	487	28%	899	22%	1,313	20%	3,531	22%
Unaccounted for	245	7%	166	9%	283	7%	461	7%	1,155	7%
Totala	**3,402**	**100%**	**1,753**	**100%**	**4,072**	**100%**	**6,623**	**100%**	**15,850**	**100%**
Private Systems										
Sold to Other PWS	25	5%	16	8%	29	8%	15	4%	85	6%
Residential	260	49%	116	56%	146	40%	202	55%	724	49%
Non-Residential	61	11%	54	26%	105	29%	64	18%	285	19%
Unaccounted for	45	9%	21	10%	37	10%	19	5%	122	8%
Totala	**529**	**100%**	**207**	**100%**	**364**	**100%**	**367**	**100%**	**1,467**	**100%**

Source: U.S. EPA, 2002.
a – Sum of individual components may not add up to total due to missing data in some of the subaccounts.

Table 3-43 presents the 25th percentile, median, and 75th percentile values for water sales for residential customers, in millions of gallons per year, according to the EPA DWT Industry Questionnaire respondents.

Table 3-43. Reported 2006 Water Sales to Residential Customers, by System, DWT Industry Questionnaire

Primary Source[a]	Population Group	Number of Systems[b]	Estimated Water Sold (MGY)		
			25th Percentile	50th Percentile	75th Percentile
Surface	10,000-50,000	73	332	654	1,090
	More than 50,000	155	2,094	3,800	7,889
Ground	10,000-50,000	17	273	331	484
	More than 50,000	25	1,601	2,819	4,113
Total		270	740	2,187	4,933

Source: Appendix A.

a – Systems that use purchased water as their primary source are not presented in this table because of the potential for revealing Confidential Business Information.

b – There are fewer systems in this table than in the others as only systems with residential sales are reported.

Table 3-44 presents 2000 water sales revenue of CWSs, by population served and customer type, according to CWSS.[15] The table also distinguishes between systems owned by private and public entities. In 2000, these large CWSs received $27.2 billion in water sales revenue. Public systems accounted for almost 89 percent of this total. Similar to water deliveries discussed above, residential customers account for the largest share of water sales revenues. However, while residential customers accounted for 38 percent of water deliveries in 2000, they accounted for 48 percent of revenues, indicating higher average rates for this customer group.

Table 3-44. Revenues by Customer Type (in million $), CWSS

	10k - 50k		50k - 100k		100k - 500k		> 500k		Total	
All Systems										
Sold to Other PWS	$403	6%	$212	7%	$852	12%	$2,922	29%	$4,388	16%
Residential	$3,796	57%	$1,795	55%	$3,719	52%	$3,894	38%	$13,204	48%
Non-Residential	$1,601	24%	$761	23%	$1,973	28%	$2,348	23%	$6,683	25%
Total[a]	**$6,715**	**100%**	**$3,250**	**100%**	**$7,150**	**100%**	**$10,127**	**100%**	**$27,242**	**100%**
Public Systems										
Sold to Other PWS	$351	6%	$192	7%	$822	13%	$2,911	32%	$4,277	18%
Residential	$3,235	56%	$1,506	53%	$3,283	51%	$3,389	37%	$11,413	47%
Non-Residential	$1,525	26%	$694	24%	$1,715	27%	$2,148	23%	$6,082	25%
Total[a]	**$5,774**	**100%**	**$2,840**	**100%**	**$6,411**	**100%**	**$9,176**	**100%**	**$24,202**	**100%**
Private Systems										
Sold to Other PWS	$51	5%	$20	5%	$30	4%	$10	1%	$111	4%
Residential	$561	60%	$289	71%	$436	59%	$504	53%	$1,790	59%
Non-Residential	$76	8%	$67	16%	$258	35%	$199	21%	$601	20%
Total[a]	**$941**	**100%**	**$409**	**100%**	**$738**	**100%**	**$951**	**100%**	**$3,040**	**100%**

Source: U.S. EPA, 2002.
a – Sum of individual components may not add up to total due to missing data in some of the subaccounts.

Table 3-45 presents median revenue (per 1,000 gallons of water delivered) of CWSs, by population served and customer type, according to CWSS.[16] Similar to Table 3-44 above, Table 3-45 also distinguishes between systems owned by private and public entities. The table shows that non-residential customers served by privately-owned CWSs have the highest

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[15] These numbers are based on 2,063 of the 2,283 regulated systems that provided information on water sales revenues.
[16] These numbers are based on 2,014 of the 2,283 regulated systems that provided information on water sales revenues and water deliveries.

median water rates of $4.27 per 1,000 gallons. For all customer groups, private systems charge higher rates than public systems.

Table 3-45. Median Revenue per 1000 Gallons of Water Delivered by Customer Type, Ownership Type, and System Size ($/1000 gallons), CWSS

	System Size (Population Served)				
	10k-50k	**50k-100k**	**100k-500k**	**>500k**	**Total**
		All Systems			
Sold to Other PWS	$1.54	$1.61	$1.09	$1.09	**$1.57**
Residential	$2.80	$2.61	$2.05	$1.89	**$3.20**
Non-Residential	$2.10	$2.14	$1.86	$1.74	**$1.75**
Total[a]	**$2.02**	**$1.65**	**$1.79**	**$1.62**	**$2.73**
		Public Systems			
Sold to Other PWS	$1.32	$1.43	$1.09	$1.02	**$1.57**
Residential	$2.72	$2.49	$2.02	$1.85	**$3.03**
Non-Residential	$2.09	$1.93	$1.79	$1.66	**$1.73**
Total[a]	**$1.86**	**$1.61**	**$1.73**	**$1.56**	**$2.48**
		Private Systems			
Sold to Other PWS	$2.30	$2.00	$1.28	$1.16	**$1.44**
Residential	$2.87	$3.45	$3.26	$2.60	**$3.55**
Non-Residential	$2.96	$2.91	$2.36	$3.06	**$4.27**
Total[a]	**$2.47**	**$3.09**	**$2.47**	**$2.66**	**$3.22**

Source: U.S. EPA, 2002.

a – Total quantity (denominator) includes unaccounted for water for which no revenues were received.

3.3.4.3 Households

CWSs derive approximately 50 percent of their water sales revenue from residential customers, with smaller CWSs depending more heavily on this customer class than the larger CWSs. The average annual residential water bill for systems of every size, ownership type, and water source category is $266 in the year 2000. Based on this average annual residential water bill, and the national median household income of $42,151, most households spend less than 1 percent of their annual income on water services (U.S. EPA, 2002).

Table 3-46 presents the median annual water bill for systems with a population of greater than 10,000 served, by system size, ownership type, and water source, according to the CWSS. In general, the median annual residential water bill is higher for privately-owned systems than for publicly-owned systems, at $280 and $240, respectively. Additionally, across all population size categories systems using ground water have the lowest median annual water bills, followed closely by surface water systems, with purchased water systems having significantly higher median annual residential water bills. These generalizations do not hold for the 50,000 to 100,000 and the greater than 500,000 categories where surface water systems have lower median residential water bills than ground water systems.

Table 3-46. Summary of Median Annual Residential Water Bill, CWSS

	System Size (Population Served)				
	10k-50k	**50k-100k**	**100k-500k**	**>500k**	**Total**
Overall	**$269**	**$267**	**$224**	**$236**	**$266**
By Ownership Type					
Public	$240	$260	$211	$223	**$240**
Private	$260	$395	$350	$350	**$280**
By Water Source					
Ground Water	$211	$262	$144	$251	**$211**
Surface Water	$264	$240	$234	$211	**$249**
Purchased Water	$360	$300	$299	$255	**$338**

Source: U.S. EPA, 2002.

Table 3-47 shows the estimated number of systems using various billing methods for all customers, according to the EPA DWT Industry Questionnaire. Seventy-five percent of systems use rates based on metered water usage. Approximately 50 percent of the systems that reported a billing method have uniform rates. Peak seasonal rates are not common. Smaller systems are more likely to use declining block rates than increasing block rates. As for larger systems serving more than 50,000 people the story is mixed with surface water systems tending towards declining block rates and ground water systems strongly skewed to the use of increasing block rates.

Some of the variance in median annual residential water bills may be attributed to the fact that some CWSs provide reduced rates to low- and fixed-income households (i.e., lifeline rates). Table 3-48 presents the number and percentage of systems that offer reduced rates to low- and fixed-income households, according to CWSS. Overall, 3 percent of CWSs offer reduced rates to qualifying household, while 69 percent do not (28 percent did not provide this information). By ownership type, publicly-owned systems are more likely to offer lifeline rates than privately-owned CWSs: 1,503 of 25,510 publicly-owned systems (6 percent) offer reduced rates compared to only 18 of 26,675 privately-owned systems.

Table 3-47. Number of Systems Using Various Billing Methods for All Customers, 2006, DWT Industry Questionnaire

Primary Source[a]	Population Group	Metered Charges					Unmetered Charges				Other
		Declining Block rate	Increasing Block Rate	Peak Season Rate	Uniform Rate	Total Metered	Annual Connection Fee	Combined Flat Fee for Water and Other Services	Separate Flat Fee for Water	Total Unmetered	
Surface	10,000-50,000	26	20	2	36	84	5	2	23	30	10
	More than 50,000	58	50	9	93	210	8	1	35	44	32
Ground	10,000-50,000	7	4	0	10	21	0	1	6	7	2
	More than 50,000	5	17	3	13	38	2	0	6	8	2
Total		96	91	14	152	353	15	4	70	89	46

Source: Appendix A.

Note: Systems utilize more than one billing method—totals are not of unique systems. All systems report at least one billing method.

a – Systems that use purchased water as their primary source are not presented in this table because of the potential for revealing Confidential Business Information.

Table 3-48. Number and Percentage of Systems with Lower Rates for Low- or Fixed-Income Households, CWSS

	System Size (Population Served)									
	10k - 50k		50k - 100k		100k - 500k		> 500k		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
All Systems										
Lower Rates Available	244	8%	43	9%	30	7%	18	22%	1,521	3%
Lower Rates Not Available	2,552	85%	377	80%	360	84%	49	58%	35,958	69%
Did Not Report	217	7%	50	11%	41	9%	17	20%	14,707	28%
Total	**3,013**	**100%**	**470**	**100%**	**430**	**100%**	**85**	**100%**	**52,186**	**100%**
Public Systems										
Lower Rates Available	232	9%	40	10%	30	8%	16	20%	1,503	6%
Lower Rates Not Available	2,144	84%	328	79%	326	83%	45	59%	19,563	77%
Did Not Report	166	7%	47	11%	37	9%	16	21%	4,444	17%
Total	**2,542**	**100%**	**415**	**100%**	**393**	**100%**	**76**	**100%**	**25,510**	**100%**
Private Systems										
Lower Rates Available	12	3%	3	6%	-	0%	3	33%	18	0%
Lower Rates Not Available	408	87%	49	89%	34	91%	4	51%	16,395	61%
Did Not Report	51	11%	3	6%	3	9%	1	16%	10,263	38%
Total	**471**	**100%**	**55**	**100%**	**37**	**100%**	**8**	**100%**	**26,675**	**100%**

Source: U.S. EPA, 2002.

Table 3-49 shows the number of systems in 2006 that had a low income assistance program, the 25th, 50th, and 75th quartiles for the number of low-income households qualifying for the program, and the mean highest annual qualifying income for these programs (if the system supplied the number), according to the EPA DWT Industry Questionnaire respondents. Nearly 13 percent of systems offer some type of assistance program.

As shown in Table 3-50 according to the CWSS data, approximately 411,000 households were eligible for reduced rates in 2000, with qualifying household incomes ranging from $0 to $54,000. Table 3-50 summarizes the number of households with reduced rates and the qualifying income ranges by system size and ownership type. The table shows that most of the households that qualify for the reduced rates receive their water from CWSs that serve greater than 500,000 people or 10,000 to 50,000 people, with 189,770 households and 56,962 households in each group, respectively.

Table 3-49. Reported 2006 Household Participation in System Assistance Programs and Income Requirements, DWT Industry Questionnaire

Primary Source [a]	Population Group	Number of Households				Highest Annual Income Requirement	
		Number of Systems	25th Percentile	50th Percentile	75th Percentile	Number of Systems	Median (50th Percentile)
Surface	10,000-50,000	8	75	291	1,000	1	$25,000
	More than 50,000	24	467	1,500	3,100	11	$35,000
Ground	10,000-50,000	1	9	9	9	0	NA
	More than 50,000	3	146	150	779	2	$18,800
Total		36	148	704	2,567	14	$25,200

Source: Appendix A.
Note: Non-responses to this question were assumed to indicate that the system had no assistance program.
a – Systems that use purchased water as their primary source are not presented in this table because of the potential for revealing Confidential Business Information.

Table 3-50. Number of Households with Lower Rates and Range of Qualifying Household Incomes, CWSS

	System Size (Population Served)									
	10k - 50k		50k - 100k		100k - 500k		> 500k		Total	
	# of Households	Min. - Max. Inccome	# of Households	Min. - Max. Inccome	# of Households	Min. - Max. Inccome	# of Households	Min. - Max. Inccome	# of Households	Min. - Max. Inccome
Public	**56,962**	**$0-29k**	**26,985**	**$10-54k**	**41,959**	**$15-33k**	**189,770**	**$17-29k**	**411,155**	**$0-54k**
Private	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**a**	**a**	**a**	**a**
All Systems	**56,962**	**$0-29k**	**26,985**	**$10-54k**	**41,959**	**$15-33k**	**189,770**	**$17-29k**	**411,155**	**$0-54k**

Source: U.S. EPA, 2002.
a – Data not provided.

3.4 REFERENCES

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SECTION 4

CURRENT STATE NPDES PERMIT REQUIREMENTS FOR WATER TREATMENT PLANT RESIDUALS

This section presents the current wastewater discharge requirements for drinking water treatment plant (WTP) residuals. Currently, there are no *national* effluent limitation guidelines and standards, direct or indirect, to regulate discharges of residuals to waters of the United States. Therefore, regulation of pollutants being discharged in residuals is decided by the state (or other permitting authority) for direct dischargers and by the publicly-owned treatment works (POTW) for indirect dischargers. Topics discussed in this section include an overview of the state and federal National Pollutant Discharge Elimination System (NPDES) permit program for WTPs (Section 4.1) and a summary of current pollutant limitations in NPDES permits for WTPs (Section 4.2).

4.1 OVERVIEW OF STATE AND FEDERAL NPDES REGULATORY REQUIREMENTS FOR WATER TREATMENT PLANTS

The NPDES permit program regulates residuals discharged directly to waters of the United States. The permits are issued by EPA regional offices or authorized states (permitting authority). WTPs may be authorized to discharge process wastewater (i.e., residuals) under an individual or general NPDES permit. Individual NPDES permits are developed and issued on a site-specific basis to manage the discharges at individual plants. General NPDES permits are developed and issued for multiple plants with similar activities or effluent characteristics. For both permit types, states apply water quality-based pollutant limitations where required and develop technology-based best professional judgment (BPJ) limitations for other pollutants.

EPA reviewed the 2004 Permit Compliance System (PCS) database to determine how states are permitting discharges from WTPs. As discussed in Section 2.4.2, larger facilities are more likely to appear in the PCS system as they are expected to impact surface waters to a greater extent. Information on smaller facilities with less likelihood to impact surface waters is not consistently tracked in PCS. Also, information might not be available for facilities with discharges covered under a general permit.

The 2004 PCS database included 20 WTPs identified as major dischargers and 2,806 WTPs identified as minor dischargers. Of the 2,826 permit identification numbers in PCS, 971 WTPs (34%) have general permits and 1,855 WTPs (66%) have individual permits (ERG, 2005). Table 4-1 presents a summary of the PCS database (http://www.epa.gov/enviro/html/pcs/pcs_subj.html) review by state.

Table 4-1. Summary of Permit Information in the 2004 Permit Compliance System

	WTPs in EPA's Permit Compliance System [a]		
State	**General Permits**	**Individual Permits**	**General Permits for WTP Discharges**
Alabama	0	85	No general permit.
Alaska	0	3	No general permit.
Arizona	0	11	No general permit.
Arkansas	107	9	ARG640000: Water Treatment Plants
California	None listed in PCS	33	Desalination concentrates covered under: CAG9930001: Dewatering and Other Low Threat Discharges (Central Coast Region)
Colorado	72 (COG64) 4 (COG38)	10	COG640000: General Permit for Water Treatment Plants COG380000: Treated Water Distribution Systems
Connecticut	None listed in PCS	1	GP-002: General Permit for the Discharge of Water Treatment Wastewater Into Waters of the State of Connecticut
Delaware	0	None listed in PCS	No general permit.
DC (Region 3)	0	1	No general permit.
Florida	1 (FLG07)[b]	32	No general permit.
Georgia	0	1	No general permit.
Hawaii	0	1	No general permit.
Idaho (Region 10)	0	10	No general permit.
Indiana	0	101	No general permit.
Illinois	48	175	ILG640000: General Permit for Public Water Supply Wastewaters
Iowa	0	14	No general permit.
Kansas	0	9	No general permit.
Kentucky	138 (KYG64) 2 (KYG20)[b]	15	KYG64: General Permit for Wastewater Discharges Associated with Drinking Water Plant Activities

Table 4-1. Summary of Permit Information in the 2004 Permit Compliance System

State	WTPs in EPA's Permit Compliance System [a]		General Permits for WTP Discharges
	General Permits	Individual Permits	
Louisiana	2 (LAG38) 1 (LAG53)	12	LAG380000: Potable Water Treatment Plant LAG530000: Waste Water Treatment Plant
Maine	0	12	No general permit.
Maryland	9	26	MDG670000: General Permit for Tanks and Pipes, and Other Liquid Containment Structures at Facilities other than Oil Terminals
Massachusetts	55 (MAG64) 8 (MAG07)	6	MAG640000: Water Treatment Facility Discharges MAG070000: Construction Dewatering
Michigan	34	8	MIG640000: Wastewater Discharge from Potable Water Supply
Minnesota	38 (MNG64) 1 (MNG82) [b]	22	MNG640000: Treated Filter Backwash Water from Water Treatment Facilities
Mississippi	0	19	No general permit.
Missouri	142 (MOG640) 7 (MOG641) 1 (MOG25) [b]	37	MOG640000 - Water Treatment Plant Filter Backwash MOG641000 - Backwash Water from Water Softening Units
Montana	1	15	MTG770000: Disinfected Water Discharges
Nebraska	0	27	No general permit.
Nevada	0	3	No general permit.
New Hampshire	3	None listed in PCS	NHG640000: Water Treatment Facility Discharges
New Jersey	0	33	No general permit.
New Mexico	0	7	No general permit.
New York	0	52	No general permit.
North Carolina	0	170	No general permit.
North Dakota	0	26	No general permit.
Ohio	0	142	No general permit.
Oklahoma	4	31	OKG38: Filter Backwash Discharges from Potable Water Treatment Plants
Oregon	63 (ORG38) 1 (ORG75) [b]	5	OR38 (OR-200-J on website): Discharge/Land Application of Filter Backwash, Settling Basin, and Reservoir Cleaning Water
Pennsylvania	0	139	No general permit.
Puerto Rico	0	109	No general permit.
Rhode Island	0	5	No general permit.
South Carolina	58 (SCG64) 1 (SCG25)	11	SCG641000: Water Treatment Plant Discharges With Maximum Total Residual Chlorine (TRC) Limits SCG643000: Water Treatment Plant Discharges With Median TRC Limits SCG645000: Water Treatment Plant Discharges With the Lowest TRC Limits SCG250000: Utility Water Discharge
South Dakota	21	9	SDG07: Temporary Dewatering Activities

Table 4-1. Summary of Permit Information in the 2004 Permit Compliance System

State	WTPs in EPA's Permit Compliance System [a]		General Permits for WTP Discharges
	General Permits	Individual Permits	
Tennessee	None listed in PCS	111	TNG640000: Filter Backwash and Sedimentation Basin Washwater from Water Treatment Plants
Texas	0	126	No general permit.
Utah	31	1	UTG640000: General Permit for Drinking Water Treatment Plants
Vermont	0	2	No general permit.
Virginia	0	128	No general permit.
Virgin Islands	0	14	No general permit.
Washington	30	None listed in PCS	WAG-64: Water Treatment Plant General Permit
West Virginia	86 (WVG64) 1 (WVG55) [b]	24	WVG64 (WV0115754 on website): Water Treatment Plant Wastewater Disposal Systems
Wisconsin	None listed in PCS	None listed in PCS	WI-0046540-4 (Process wastewater discharges): Potable Water Treatment and Conditioning
Wyoming	1	12	WYG71: General Permit for Temporary Discharges
Total	**971**	**1,855**	

Source: ERG, 2005.

a – Additional WTPs included in PCS, but omitted from table because of low flow or not applicable activities (by state):

Arkansas: Eight additional plants have discharge coverage under general permit ARG550000 - Individual Treatment Facilities with maximum design flow of ≤ 1,000 gallons/day.

Colorado: 12 additional plants have discharges covered under COG60 - Minimal Discharges (not specific to drinking water treatment).

Massachusetts: One plant had discharges covered under a general permit for noncontact cooling water (MAG25)

Minnesota: One plant had discharges covered under a general permit for noncontact cooling water (MNG25)

Missouri: One plant had discharges covered under a general permit for noncontact cooling water (MOG35)

North Carolina: Four additional plants discharge under general permit NCG510000, Groundwater Remediation

b – Permit not found on-line; discharge coverage unknown.

States commonly issue general permits for certain waste streams discharged by WTPs. The most common waste stream covered by general permits is filter backwash water. Residuals from solids settling (e.g., clarifiers, lagoons) are the second most common waste stream covered. Residuals less commonly covered by general permits include water softening discharges, membrane desalination concentrates, and ion exchange regeneration waste. Sections 6 and 7 of this document discuss the source water treatment operations and residuals generated in more detail.

Table 4-2 lists the process wastewater discharges covered by drinking water treatment industry-specific general permits identified in Table 4-1. In addition to the information presented in the table, the Louisiana General Permit (LAG380000) also covers wastewater from disinfection of source water, the South Carolina (SCG641000, SCG643000, and SCG645000) and Tennessee (TNG640000) general permits also cover wash water from sedimentation basins. Some general permits specifically prohibit discharges (or exclude them from permit coverage). For example, the Oklahoma general permit (OKG38) requires no residual disinfectant in the discharge (i.e., completely diluted in the backwash water during storage in detention ponds).

General permits may further limit applicability beyond type of WTP discharge. Applicability requirements include providing general permit coverage for existing plants only (MAG640000 and NHG640000) and limiting coverage to smaller dischargers using discharge flow rate limits or production limits. General permits that limit coverage based on discharge quantities, include the following:

- The Oklahoma general permit (OKG38) requires discharge of no more than one million gallons per day;
- The California Central Coast general permit (CAG993001) requires continuous maximum discharges to be specified in the permit, including limiting desalination concentrate to 50,000 gallons per day; and
- The Washington general permit (WAG-64) requires a maximum production capacity of 50,000 gallons per day (peak output based on 24-hour production).

Other applicability requirements are also used to protect the receiving water. For example, the Wisconsin general permit (WI-0046540-4) does not cover discharges containing radium and arsenic (present in water supply). Additionally, a number of general permits do not cover discharges to certain receiving streams (e.g., impaired waters); in those cases, WTPs need to apply for an individual permit.

If the WTP does not meet the applicability of the general permit, an individual permit must be obtained prior to discharge. The types of waste streams and pollutants covered by an individual permit depend on the source water treatment operations, treatment chemicals, and source water contaminants at a particular plant.

Table 4-2. Wastewater Discharges from WTPs Covered by General Permits

		Wastewater Discharges Covered by General Permit					
State	**NPDES Permit Number**	**Filter Backwash**	**Solids Removal**[a]	**Water Softening**[b]	**Ion Exchange Regeneration**	**Reverse Osmosis Concentrate**	**Wastewater from Sludge Dewatering**
AR	ARG640000	**X**	**X**				
CA	CAG9930001					**X**[c]	
CO	COG640000	**X**	**X**				
CT	GP-002	**X**	**X**		**X**	**X**	**X**
IL	ILG64	**X**	**X**	**X**			
KY	KYG640000	**X**					
LA	LAG380000	**X**	**X**	**X**			
MA	MAG640000	**X**					**X**[d]
MD	MD670000	Overflow, flushing, disinfection, mechanical cleaning, or dewatering discharges					
MI	MIG640000	**X**	**X**	[e]			
MN	MNG640000	**X**					
MO	MO-G640000	**X**					
	MO-G641000	**X**[f]		**X**[f]			
MT	MTG770000	Disinfected water discharges					
NH	NHG640000	**X**					**X**[d]
OK	OKG38	**X**					
OR	OR-200-J	**X**					
SC	SCG641000, SCG643000, and SCG645000	**X**	**X**				
SD	SD070000						**X**[g]
TN	TN640000	**X**					
UT	UTG640000	Not specified					
WA	WAG-64	**X**	**X**				
WV	WV0115754	**X**[h]	**X**[h]				
WI	WI-0046540-4		**X**[i]	**X**[i]		**X**[i]	
WY	WYG710000	Not specified (temporary discharges)					

Source: ERG, 2005.

a – Residuals from solids removal include sludge/blowdown from clarifiers, lagoons, etc. and filter sludge. The filter sludge may be part of iron and/or manganese removal operations.

b – Water softening residuals may include ion exchange wash/rinse concentrates and sludge from sedimentation basins or filters.

c – The California Central Coast Regional general permit covers discharges of desalination concentrate up to 50,000 gallons per day to ocean waters. This general permit does not cover discharges of desalination concentrate to inland surface waters.

d – The Massachusetts and New Hampshire general permits cover the discharge of treated presedimentation underflow and treated underflow from coagulation/settling processes using aluminum compounds or polymers as coagulants.
e – The Michigan general permit No. 649000 (expires April 1, 2005) includes water softening discharges, except from batch regenerated potassium permanganate iron removal and sodium zeolite softening. The general permit effective April 1, 2005 does not cover any discharges from water softening.
f – The Missouri general permit (G641000) covers discharges of backwash water from water softening.
g – South Dakota general permit covers discharges from temporary dewatering activities. The discharges "must be relatively uncontaminated and must not contribute nonconventional or toxic pollutant loadings to the receiving stream."
h – The West Virginia general permit covers treatment wastewater discharges and describes minimum treatment requirements for sediment removal and total residual chlorine removal.
i – Discharges covered by the Wisconsin general permit (WI-0046540-4) include those from iron removal filters (excluding batch regeneration by potassium permanganate (KMnO4) to surface water), demineralizers (excluding sodium or potassium cycle ion exchange softeners), lime softeners, alum coagulation units, granular media filters, reverse osmosis units, and other systems with similar discharges.

4.2 SUMMARY OF CURRENT POLLUTANT LIMITATIONS AND REQUIREMENTS FOR WATER TREATMENT PLANTS: GENERAL AND INDIVIDUAL PERMITS

The most common pollutants regulated in general permits include aluminum, iron, manganese, pH, settleable solids, total residual chlorine (TRC), and total suspended solids (TSS). In addition, NPDES permits for membrane desalination and ion exchange plants may also require limits or monitoring of chlorides and total dissolved solids (TDS) (ERG, 2005).

WTPs not covered under a general discharge permit must apply for an individual NPDES permit. EPA reviewed individual permits from the following states:

- Alabama;
- Alaska;
- Arizona;
- California;
- Florida;
- Illinois;
- Indiana;
- Iowa;
- Kansas;
- Massachusetts;
- Missouri;
- Montana;
- Nebraska;
- Nevada;
- North Carolina;
- Ohio;
- Pennsylvania;
- Puerto Rico;
- Texas;
- Washington, DC; and
- Wisconsin.

The common pollutants regulated in individual permits include aluminum, copper, dissolved oxygen, iron, lead, pH, temperature, TRC, TSS, and turbidity. Other pollutants that may be included in WTP permits based on source water characteristics or treatment chemicals used include ammonia, arsenic, biochemical oxygen demand (BOD), cadmium, manganese, oil and grease, settleable solids, total phosphorus, and zinc. In addition, NPDES permits for membrane desalination and ion exchange plants may also require limits or monitoring of chlorides and TDS. Table 4-3 lists the range of pollutant limitations in general and individual NPDES permits reviewed by EPA as part of the industry review (ERG, 2005 and ERG, 2008).

Table 4-3. Range of Pollutant Limitations From a Sample of General and Individual NPDES Permits

	General NPDES Permits			**Individual NPDES Permits**		
Pollutant	**States with Limitations or Reporting Requirements**	**Monthly Average Limitation** [a]	**Daily Maximum Limitation** [a]	**States with Limitations or Reporting Requirements**	**Monthly Average Limitation** [b]	**Daily Maximum Limitation** [b]
Aluminum	*Majority of state general permits*	0.75 to 1 mg/L	1.5 to 10 mg/L	California Missouri Montana Pennsylvania Washington, DC	1 to 4 mg/L	1.5 to 8 mg/L
Ammonia	Colorado	Report only		California Puerto Rico	Report only	1 mg/L
Arsenic	Michigan	0.150 mg/L	0.680 mg/L	Alaska Arizona California Puerto Rico	0.036 mg/L	0.00018 to 0.080 mg/L
Biochemical oxygen demand (BOD)	*None*	—	—	California Florida Illinois Puerto Rico	10 to 20 mg/L	5 to 30 mg/L
Cadmium	*None*	—	—	California Florida Missouri	0.002 to 0.0093 mg/L	0.004 to 0.042 mg/L
Chlorides	Illinois Louisiana Missouri	—	250 to 1,000 mg/L	California Florida	—	150 mg/L
Copper	Connecticut Wisconsin	—	<1.09 mg/L	Arizona California Florida Massachusetts Puerto Rico	0.0031 to 0.007 mg/L	0.0029 to 0.500 mg/L
Dissolved oxygen	*None*	—	—	Alaska California Florida Puerto Rico	Minimum: 2.0 to 7.0 mg/L	

Table 4-3. Range of Pollutant Limitations From a Sample of General and Individual NPDES Permits

Pollutant	**General NPDES Permits**			**Individual NPDES Permits**		
	States with Limitations or Reporting Requirements	**Monthly Average Limitation [a]**	**Daily Maximum Limitation [a]**	**States with Limitations or Reporting Requirements**	**Monthly Average Limitation [b]**	**Daily Maximum Limitation [b]**
Iron	*Majority of state general permits*	1 to 5 mg/L	2 to 10 mg/L	Alaska Florida Illinois Indiana North Carolina Pennsylvania Washington, DC	1.8 to 2 mg/L	0.3 to 4.1 mg/L
Lead	Wisconsin	—	—	Arizona California Missouri Puerto Rico	0.003 to 0.0081 mg/L	0.0044 to 0.210 mg/L
Manganese	*Majority of state general permits*	0.0043 to 1 mg/L	0.019 to 3 mg/L	Arizona Pennsylvania Puerto Rico	1 mg/L	0.05 to 2 mg/L
Oil and grease	California Colorado	25 mg/L	10 to 75 mg/L	California Massachusetts Puerto Rico	10 mg/L	10 to 15 mg/L
pH	*Majority of state general permits*	6.0 to 9.0 s.u.		*Majority of states reviewed*	6.0 to 11.0 s.u.	
Phosphorus	Michigan	1 mg/L	—	California Florida Missouri Puerto Rico	1 mg/L	1 mg/L
Settleable solids	California Missouri Oregon Tennessee Washington	0.1 to 2.0 mL/L	0.1 to 3.0 mL/L	California Missouri North Carolina	0.1 mL/L	0.2 to 0.3 mL/L
Temperature	*None*	—	—	California Massachusetts Nevada Puerto Rico	—	86 to 100°F ±5°F: effect on receiving stream
Total dissolved solids (TDS)	Colorado Connecticut Illinois	—	1,000 to 1,500 mg/L	Alaska California Illinois Nevada	80 to 800 mg/L	95 to 1,500 mg/L
Total residual chlorine (TRC)	*Majority of state general permits*	0.03 to 1 mg/L	<0.02 to 1 mg/L [c]	*Majority of states reviewed*	0.01 to 0.29 mg/L	0.002 to 1.3 mg/L
Total suspended solids (TSS)	*Majority of state general permits*	15 to 30 mg/L	20 to 60 mg/L	*Majority of states reviewed*	15 to 70 mg/L	5 to 150 mg/L

Table 4-3. Range of Pollutant Limitations From a Sample of General and Individual NPDES Permits

	General NPDES Permits			Individual NPDES Permits		
Pollutant	**States with Limitations or Reporting Requirements**	**Monthly Average Limitation [a]**	**Daily Maximum Limitation [a]**	**States with Limitations or Reporting Requirements**	**Monthly Average Limitation [b]**	**Daily Maximum Limitation [b]**
Turbidity	California	75 NTU	225 NTU	California Massachusetts Nevada Puerto Rico	6 to 50 NTU	5 to 150 NTU
Zinc	Connecticut Wisconsin	—	<2.0 mg/L	California Missouri Puerto Rico	0.061 to 0.093 mg/L	0.09 to 50 mg/L

Sources: ERG, 2005; ERG, 2008.
NTU—Nephelometric turbidity units
a – Limitations may be less than range presented for certain receiving streams (e.g., small streams, impaired waters).
b – Some states may only require monitoring and reporting (i.e., no numerical limitations).
c – One general permit allows up to 3.0 mg/L TRC discharge to ground water.

One of the trends in the drinking water treatment industry is the increased use of membrane desalination operations. Between 1992 and 1999, the number of desalination plants in the United States with production of 25,000 gallons per day or more increased from 103 to 203 plants (Mickley, 2001). Residuals from desalination include concentrates. Due to large volumes and high TDS concentrations, WTPs have difficulty disposing of concentrates unless discharge to surface water is an option. Most membrane desalination plants do not treat the concentrate prior to discharge. Other waste management options include indirect discharge, land application, landfill disposal, and underground injection (Malmrose, et al., 2004). These other waste management options often include certain regulations that must be met by the WTP.

Typical permit limitations for direct discharge of desalination concentrate include TDS, TSS, salinity, and contaminants specific to the source water such as nutrients (nitrogen and phosphorus), arsenic, barium, and radionuclides. If the discharge is potentially highly saline, WTPs may dilute the discharge with source water, wastewater treatment plant effluent, or cooling water. Also, concentrates for membrane systems treating ground water may contain low dissolved oxygen levels that can adversely impact the receiving stream (Malmrose, et al., 2004).

4.3 REFERENCES

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SECTION 5

SOURCE WATER QUALITY

Drinking water sources include ground water and surface water. Ground water comes from wells drilled into underground aquifers (geologic formations containing water). Surface water is obtained from rivers, lakes, and reservoirs open to the atmosphere.

Source water may contain undesirable contaminants that must be removed from the drinking water. These contaminants enter the water supply via natural sources or from human activities. Table 5-1 presents common source water contaminants and their environmental, agricultural, and industrial sources. Source water quality can also vary based on geographic region. This section discusses factors that influence source water quality (Section 5.1), compares ground water and surface water quality (Section 5.2), and discusses how the Safe Drinking Water Act (SDWA) addresses source water protection (Section 5.3).

Table 5-1. Common Source Water Contaminants and Sources

Contaminant	Sources
Naturally Occurring	
Microorganisms	Wildlife and soils; microorganism-containing wastes in runoff from nonpoint sources, including animal wastes; and other point source discharges which are not disinfected
Radionuclides: All except beta particles and photon emitters	Erosion of natural deposits
Metals (e.g., arsenic, cadmium, chromium, lead, and selenium)	Erosion of natural deposits
Nitrates and nitrites	Erosion of natural deposits
Fluoride	Erosion of natural deposits
From Human Activities	
Microorganisms	Human and animal wastes
Radionuclides: Beta particles and photon emitters	Decay of man-made deposits
Metals	Mining; construction; industrial discharges; runoff from orchards, croplands, and landfills; lead and copper from household plumbing materials
Nitrates and nitrites	Runoff from fertilizer use; leaching of septic tanks or sewage
Organics	Runoff from herbicide and pesticide use, industrial discharges; emissions from incineration or combustion; household wastes such as cleaning solvents

Source: U.S. EPA, 2008.

5.1 FACTORS THAT INFLUENCE SOURCE WATER QUALITY

The factors that influence the quality of source water—both ground water and surface water—include naturally-occurring attributes (climate, geology, soil type, land cover, hydrology, precipitation and runoff, and wildlife) and man-made attributes (land management practices and runoff or discharge from point and nonpoint sources). The Safe Drinking Water Act (SDWA) Amendments of 1996 required states to develop and implement source water assessment programs (SWAPs) to analyze existing and potential threats to the quality of the public drinking water throughout the state. Using these programs, most states have completed source water assessments for every public water system - from major metropolitan areas to the smallest towns (http://cfpub.epa.gov/safewater/sourcewater/sourcewater.cfm?action=Programs#swap). Using baseline water quality data, water treatment plants (WTPs) are designed with the treatment technologies necessary to produce potable water (U.S. EPA, 1999a). Source water quality impacts the design of the WTP, the treatment chemicals used, and the quantity and composition of the residuals generated.

Source water quality may vary over time or in seasonal cycles. Land uses, such as agriculture, urban development, and industrial sites, and the watershed management (i.e., the management of the land around a waterway) are the variables that most affect the source water quality conditions over time. For example, agricultural practices that affect source water quality include irrigation, field drainage, and chemical and biosolids application to crops and soil. Industrialization and urbanization within the watershed may affect source water quality due to changes in storm water runoff. As the land management practices change, WTPs adjust their operations and treatment chemical usage to meet drinking water quality standards. Changes in the source water quality (e.g., additional solids due to increased soil runoff; increased nutrient content in the source water due to fertilizer use) also affect the generation and composition of residuals. These land management practices are responsible for additional treatment over the baseline conditions of the source water.

Watershed management includes strategies and plans to assess and maintain a water resource within a specified drainage area. The overall strategy is to maintain or improve the quality of water (drinking, recreational, or industrial) that is derived from the watershed and to comply with the various statutes like the Clean Water Act (CWA), the SDWA, and state/local requirements.

The industrialization and urbanization of rural land increases the amount of runoff into source water (U.S. EPA, 2001). The increased runoff of silt and sediment increases the amount of solids that WTPs must remove from source water, and, ultimately, the amount of residual solids. To remove these additional solids from drinking water, WTPs may need to spend additional money on operations, treatment chemical usage, residuals treatment operations, and residuals disposal costs. One way to reduce these costs is to have a strong cooperative watershed management program that maintains the quality of the source water.

Some of the less obvious runoff effects are caused by landscaping chemicals from lawns and gardens, as well as oil and hydrocarbons from roadways. The increased impervious surfaces of urban and industrial areas do not retain runoff, and the quality and quantity of both surface and ground water are adversely impacted. Increased runoff can lead to other watershed related problems such as flow modifications, erosion, introduction of chemical and microbiological pollutants, accumulation of sediments, habitat loss, ecosystem disruption, and the possible introduction of invasive species. The additional pollutants present in the source water must be removed by WTPs to meet drinking water standards and customer demands.

Watershed protection can be a key pollution prevention option to reduce residuals from source water treatment. For example, New York City is investing $1.2 billion to safeguard its upstate reservoir system in hopes of reducing or eliminating the estimated $6 to 8 billion required for a filtration plant to treat an unprotected watershed. Also, New Jersey has a multiyear master plan for long-term funding and acquisition of watershed properties to protect source water quality (Ernst, 2004).

5.2 COMPARISON OF GROUND WATER AND SURFACE WATER QUALITY

Most ground water is naturally filtered as it passes through layers of the earth into underground reservoirs known as aquifers. Ground water generally contains less organic material than surface water and may not need to undergo as many treatment steps. Surface water collects a wide variety of contaminants from watershed drainage, agricultural practices, and urban sources. Thus, surface water has more variable and extensive treatment requirements.

EPA's Office of Ground Water and Drinking Water (OGWDW) completed a review of contaminant occurrences in the source water for drinking water systems (U.S. EPA, 1999b). The purpose of the review was to enhance the scientific understanding of the occurrence of chemical contaminants in public drinking water systems and to refine the basis for the monitoring of these contaminants. The review found the following occurrence results for ground water and surface water:

- Volatile organic compounds (VOCs) are more common in surface water; however, exceedances of the EPA MCLs are nearly equal for surface and ground water systems.
- Some VOCs are not geographically centralized (i.e., they are present in source water in all states[17] studied). These VOCs include ethylbenzene, cis-1,2-dichloroethane, tetrachloroethylene (PCE), trichloroethylene (TCE), vinyl chloride, 1,1,1-trichlorethane, and xylenes.
- Inorganic chemicals are common in both surface and ground water, but ground water concentrations tend to be higher.
- Synthetic organic chemicals (SOC) are more common in surface water.

Section 8 of this report discusses pollutants of concern for surface water and ground water.

5.3 SOURCE WATER PROTECTION UNDER THE SDWA

In addition to establishing drinking water requirements, the 1996 Amendments to the SDWA outlined measures to ensure the quality of drinking water by protecting the source water. The measures include source water assessments, providing information to the public (consumer confidence reports), and providing federal funds for source water assessments and protection.

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[17] The study included source water for drinking water systems in the following states: Alabama, California, Illinois, Indiana, Iowa, Massachusetts, Michigan, Montana, New Jersey, New Mexico, Ohio, and Oregon.

To give water systems and community members the information needed to decide how to protect their drinking water sources, the SDWA requires states to develop EPA-approved programs to carry out assessments of all source waters in the state. The source water assessment is a study that defines the land area contributing water to each public water system, identifies the major potential sources of contamination that could affect the drinking water supply, and then determines how susceptible the public water supply is to this potential contamination. Water systems and communities can then use the publicly-available study results to reduce potential sources of contamination and protect the source water.

Community water systems are also required to provide consumer confidence reports, or annual water quality reports, to the public each year. The report explains where the supplied drinking water comes from and what contaminants might be in the drinking water. The consumer confidence reports summarize information regarding sources used (e.g., rivers, lakes, reservoirs, or aquifers), any detected contaminants, compliance, and educational information.

EPA provides funding to states through the Drinking Water State Revolving Fund (DWSRF) for source water assessment and protection activities. Source water protection approaches are tailored to each unique local situation. Although most source water protection efforts are primarily led by the system (or utility), state, or locality, a variety of federal tools can be used, such as those available through the CWA, Underground Injection Control Program, and various agricultural programs. In addition, a number of national nongovernmental organizations, such as the American Water Works Association (AWWA), the National Rural Water Association (NRWA), the National Association of Counties (NACo), and the Trust for Public Lands (TPL), are active in the realm of source water protection. One of EPA's roles is to encourage partnerships and provide information to those directly involved in source water protection.

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SECTION 6

SOURCE WATER TREATMENT TECHNOLOGIES

Treatment of source water removes contaminants that are unhealthy or undesirable for consumption. The type of treatment operation performed at a drinking water treatment plant (WTP) and treatment chemicals used depend on the contaminants present in the source water. The removed contaminants and treatment chemical composition impact the content and quantity of residuals generated. This section discusses the source water treatment operations and treatment chemicals used that impact the content and quantity of residuals generated.

WTPs strive to add sufficient treatment chemicals to source water to remove contaminants without adding excessive levels of additional pollutants (i.e., treatment chemical active ingredients and impurities). AWWA began assembling consensus standards for different aspects of drinking water production about 100 years ago and updates them periodically. Included in those consensus standards are best engineering judgments for the different chemicals added to drinking water.

About 20 years ago, the National Sanitation Foundation (NSF) and a consortium of stakeholders established minimum human health effects requirements for any chemicals added directly to drinking water. The American National Standards Institute (ANSI)/NSF Standard 60 recommends, when available, that EPA MCLs (U.S. EPA, 2008b) be used to determine the acceptable level for a treatment chemical in the finished drinking water. If an MCL is not available, ANSI/NSF Standard 60 provides criteria to conduct a toxicological risk assessment for the chemical.

There are many different approaches to removing source water contaminants. In addition to the characteristics of the source water, the size of the system or plant may be a factor when selecting or implementing new source water treatment operations. For example, larger systems have in general a larger number of technology options to select from and can take advantage of economies of scale that can reduce both capital and operational expenses, allowing for a lower per unit of treated water cost. The larger systems can also spread the costs incurred to install and operate source water treatment over a larger customer base. Common treatment operations for all system sizes that affect residuals content and quantity generated are discussed in this section. The source water treatment operations discussed include the following:

- Conventional filtration, direct filtration, and filtration only (Section 6.1);
- Precipitative softening (Section 6.2);
- Membrane separation (Section 6.3);
- Ion exchange (Section 6.4);
- Activated carbon (Section 6.5);
- Disinfection (Section 6.6); and
- Other chemical additions (Section 6.7).

6.1 CONVENTIONAL FILTRATION, DIRECT FILTRATION, AND FILTRATION ONLY

Conventional filtration is the most common treatment train at WTPs and is the primary treatment used at 63 percent of WTPs. It is a series of processes including coagulation, flocculation, sedimentation, and filtration that result in substantial particulate removal from the source water. Figure 6-1 shows a typical conventional filtration treatment plant flow diagram.

Direct filtration is another treatment train operated at WTPs, where plants perform coagulation, flocculation, and filtration without sedimentation. Unlike conventional filtration, the floc is removed at the filter rather than at the sedimentation basin (National Drinking Water Clearinghouse, 1996b). Some treatment plants perform filtration without coagulation or flocculation, referred to as filtration only.

The types of processes used at the WTP depend on the characteristics of the source water. Source water with high solids content may require pretreatment, or presedimentation. The following subsections focus on the individual processes that WTPs use to remove particulates (or solids) from the source water either as stand-alone processes or in series.

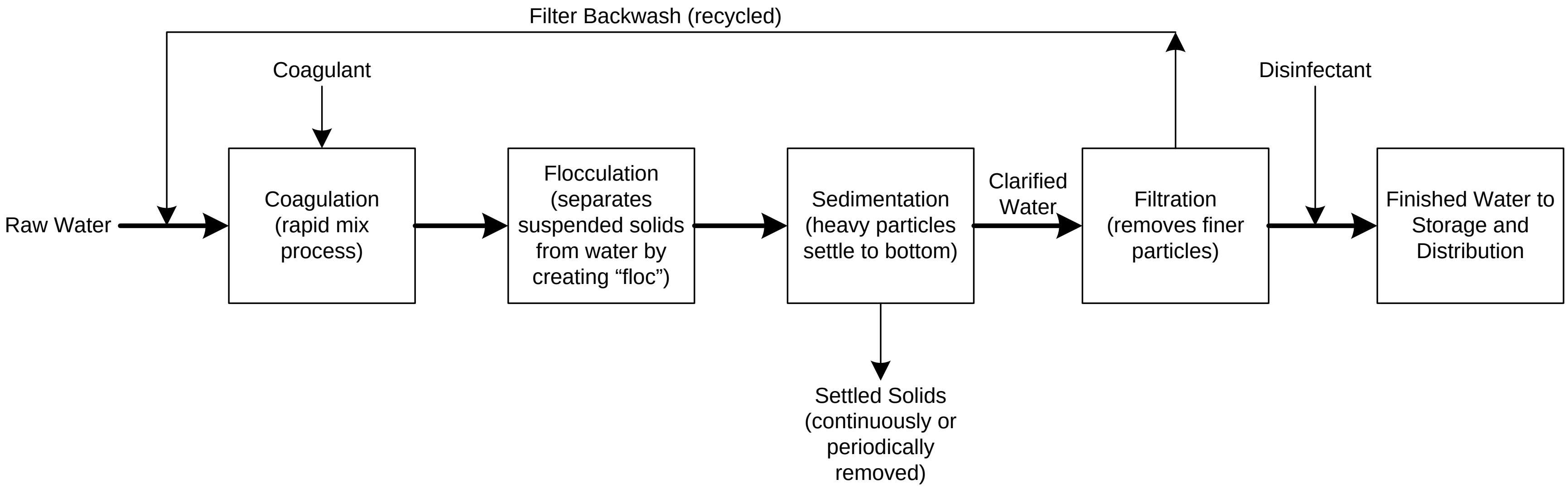

Figure 6-1. Typical Conventional Filtration Treatment Plant Flow Diagram (U.S. EPA, 2002a)

Residuals generated by solid removal processes include filter backwash water, filter-to-waste, and coagulation sludge (i.e., underflow streams removed from sedimentation or settling tanks). The residuals contain solids from the source water and chemicals added by the WTP to aid in solids removal. In addition, filter backwash and filter-to-waste streams may contain residual disinfectants.

6.1.1 Presedimentation

Presedimentation is a pretreatment process operated at the head of the WTP (e.g., in a sedimentation basin) or prior to intake (e.g., within a reservoir). Its primary purpose is to remove a significant amount of readily settleable and suspended solids and other contaminants in the source water prior to other water treatment operations (e.g., coagulation and filtration). WTPs might add treatment chemicals during presedimentation; however, the primary removal mechanism is gravity settling. The process removes relatively high concentrations of easily settled solids (e.g., sand and silt). By allowing adequate detention time in the basin, coarser and other easily settleable particles drop out of the source water. To aid settling, WTPs may add polymers and other coagulants. The settled solids are removed continuously (or in frequent batches) via an underflow pipe.

6.1.2 Coagulation, Flocculation, and Sedimentation

Coagulation, flocculation, and sedimentation are water treatment processes performed in mixing tanks and sedimentation basins. WTPs operate one or more of the processes to remove as much source water solid matter as possible. Most plants follow coagulation, flocculation, and sedimentation with filtration to remove finer solid particles such as suspended solids, colloids, and color (indicative of dissolved organic material).

At the clarification basins, coagulants and flocculants are added to the source water. Agitation of the water causes collisions between suspended particles, forming agglomerated solids. The solids settle to the bottom of the basin and are removed via an underflow pipe. An additional sedimentation basin may be used to allow further solids settling.

Coagulants and flocculants added to the raw water include metal salts (e.g., aluminum sulfate and ferrous sulfate) and polyelectrolytes. To optimize solids removal, plants may adjust the pH. Coagulant chemicals carry multivalent positive charges, which, when dissolved in water, tend to neutralize the negative charges on the surface of the particulate matter. This allows the small particles to approach each other, overcome electrostatic repulsion, and combine. As the particles grow larger, they become heavier and gravity aids their settling to the bottom of the tank.

Inorganic coagulants (e.g., aluminum sulfate, aluminum chloride, ferrous sulfate, and ferric chloride) are used by many WTPs. The trivalent forms of aluminum and iron (Al^{+++}, Fe^{+++}) are insoluble at normal drinking water treatment operating conditions so very little metal is carried into the finished product (Tchobanoglous, et al., 2003). In addition to inorganic chemicals, a large variety of organic-based polymers are employed as coagulant aids either independently or in concert with the inorganic coagulation aids. About 1,100 different formulations of polymer beads, polyacrylamide, polyamines, and polydimethylammonium chloride are listed in ANSI/NSF Standard 60 and used to promote the removal of turbidity from drinking water. Some of these chemicals are also referred to as filtration aids, but function the same way as coagulants.

Residuals are generated as underflow discharges from the sedimentation tanks. These residuals contain source water contaminants, as well as chemicals added to aid solid removal and formulation impurities in the added treatment chemicals.

6.1.3 Filtration

After solids settling, the source water passes through filters to remove finer particles and metals. Various types of filter media may be used by WTPs, including permeable fabric and porous beds. The types of filters used by WTPs include the following:

- Slow sand: consists of a bed of fine sand above a gravel layer and underdrain system. This type of filter is used for low-flow rates and might be performed without other solids removal treatment steps (i.e., filtration only). Slow sand filters are not suitable for high turbidity source waters. (National Drinking Water Clearinghouse, 1996b)

- Rapid sand: consists of a bed of sand above several layers of gravel in varying sizes.
- Pressure: similar to rapid sand filters but the operation is housed within a cylindrical tank and the water passes through the filter while under pressure generated by a pump rather than by gravity.
- Diatomaceous earth: consists of a layer of diatomaceous earth above a septum or filter element. Most suitable for low turbidity and low bacterial count source water. Coagulants and filter aids are required for effective virus removal. (National Drinking Water Clearinghouse, 1996b)
- Multimedia: consists of layers of various sizes of gravel, high-density garnet, sand, and anthracite coal.
- Membrane filters: include ultrafilters and microfilters. These membranes use pressure as the driving force and are designed to remove particulates smaller than 10 micrometers (discussed in Section 6.3).

The filtration process removes suspended solids by mechanical straining—trapping them between grains of the filter medium (e.g., bed of sand). Filtration also uses adhesion to remove solids; suspended solids stick (or adhere) to the surface of the filter material or previously deposited solids. In addition to mechanical removal, slow sand filters trap microorganisms that break down algae, bacteria, and other organic matter. (National Drinking Water Clearinghouse, 1996b)

Slow sand and diatomaceous earth filtration are older filtration techniques that are effective in removing suspended particles and some microbes. Many older systems abandoned the use of these filter media due to slower filtration rates and the larger required size of the slow sand and diatomaceous earth filter beds (about 10 times that of the newer systems). Low filtration rate and large filter size both translate into higher operating costs. As a result, WTPs have switched to other fine particle removal systems like membranes or multimedia filters.

WTPs may operate filtration systems without coagulation; these plants are typically smaller (less than 50,000 people served) and treat ground water (U.S. EPA, 2008a).

Smaller WTPs may also use adsorption (e.g., activated carbon), rather than filtration to remove certain contaminants (see Section 6.5).

Residuals from filtration operations include filter backwash (finished drinking water flushes out solids and contaminants trapped in the filter) and filter-to-waste (initial permeate after the filter has been brought on line). The residuals may contain source water contaminants (e.g., solids), treatment chemical active ingredients and impurities, and residual disinfectant added prior to filtration or in the finished water used to backwash the filter.

6.2 PRECIPITATIVE (LIME) SOFTENING

Drinking water that contains elevated levels of divalent cations, mostly calcium and magnesium, can produce customer complaints that revolve around appliance malfunctions (pipe scaling) and aesthetic concerns (water spots). These compounds present in the source water contribute to the water's "hardness." Plants remove these compounds from the water by precipitative, or chemical, softening.

Precipitative softening is the removal of divalent cations by increasing the pH and altering the bicarbonate equilibrium. As the pH increases to about 9.5, the increased alkalinity extracts a hydrogen atom from the bicarbonate and forces the equilibrium toward the carbonate species, resulting in a precipitate of insoluble calcium carbonate. The chemical reaction is shown in Equation 6-1 (Manahan, 1993).

$$Ca^{2+} + 2HCO_3^- + Ca(OH)_2 \rightarrow 2CaCO_3 \text{ (solid)} + 2H_2O \qquad \text{(Eq. 6-1)}$$

If the pH is increased to about 11, magnesium is precipitated as a hydroxide, as shown in Equation 6-2.

$$Mg^{2+} + 2OH^- \rightarrow Mg(OH)_2 \text{ (solid)} \qquad \text{(Eq. 6-2)}$$

The softening process increases pH and leaves excess calcium hydroxide in the water. After softening, pH is reduced by the conversion of excess calcium hydroxide to solid calcium carbonate using carbon dioxide, as shown in Equation 6-3.

$$CO_{2-} + Ca(OH)_2 \rightarrow CaCO_3 \text{ (solid)} + H_2O \qquad \text{(Eq. 6-3)}$$

Calcium oxide (lime) is usually the chemical of choice to affect the pH changes necessary for precipitative softening, but in some cases, sodium carbonate (soda ash) is used. Plants add lime to remove *carbonate hardness*—bicarbonates of calcium and magnesium, or plants add lime and soda ash to remove carbonate hardness and *non-carbonate hardness*—sulfates, chlorides, or nitrates of calcium and magnesium. The precipitative softening process is usually integrated with other treatment processes, particularly conventional or direct filtration (see Section 6.1). The precipitated solids are removed from the bottom of sedimentation or settling tanks (underflow), generating a residual waste stream—referred to as softening sludge.

Due to cost and operating concerns, not all of the hardness is removed. By a combination of pH control, treatment bypass, and blending, plants customize the precipitative softening operation to the initial water quality conditions and the customer demands. The hardness level in the drinking water typically ranges between 80 and 100 mg/L (ASCE/AWWA, 1997).

6.3 MEMBRANE SEPARATION

Membranes are used to separate components of a liquid stream into useable and waste products. Membrane systems are characterized by the driving force needed to effect separation (e.g., pressure-driven or electrical-driven separation). Membrane separation techniques used to treat source water include the following:

- High-pressure technologies, such as reverse osmosis (RO) and nanofiltration (NF);
- Low-pressure technologies, such as microfiltration (MF) and ultrafiltration (UF); and
- Electrical-driven technologies, such as electrodialysis (ED) and electrodialysis reversal (EDR).

WTPs using membrane separation are typically smaller plants (serving less than 50,000 people). From EPA’s 2007 industry questionnaire, all plants that operated membranes served less than 150,000 people (U.S. EPA, 2008a).

WTPs may use membrane operations to remove salt from saline or brackish water. Brackish water typically contains between one and 35 parts per thousand (ppt) salt. Seawater typically contains approximately 35 ppt of salt[18] (USGS, 2007). The removal of salt from source water is called *desalination*. Desalination processes include RO, NF, ED, and EDR.

Residuals from MF and UF include filter backwash and spent cleaning solutions. Residuals from membrane desalination include the concentrate or “reject” stream and spent cleaning solutions. The following subsections discuss the desalination processes and MF and UF processes in more detail.

6.3.1 Reverse Osmosis and Nanofiltration

Most membranes use pressure as the driving separation force. Generally the smaller the pore size in the membrane, the higher the driving force (pressure) required to accomplish separation. For source water treatment, the application determines the driving force and thus the type of membrane. If the treatment application is removal of dissolved contaminants (hardness, salinity, arsenic, radioactive cations), then WTPs use high pressure systems like NF or RO. These systems also can remove dissolved organic material, biological contaminants, and suspended solids.

Pretreatment is typically used to remove biological material and particulates. The use of NF or RO requires clean source water, with a significant amount of pretreatment to remove the majority of suspended solids so that the membrane will not quickly clog. The high pressure and additional pretreatment needed to operate RO and NF systems can translate into high operating and maintenance costs.

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[18] Fresh water contains less than one ppt (or 1,000 parts per million) salt (USGS, 2007).

NF and RO use semipermeable membranes to remove contaminants from the source water. These systems operate at pressures between 75 pounds per square inch gauge (psig) and 1,200 psig (Malmrose, et al., 2003). Figure 6-2 presents a cross-section of a reverse osmosis membrane.

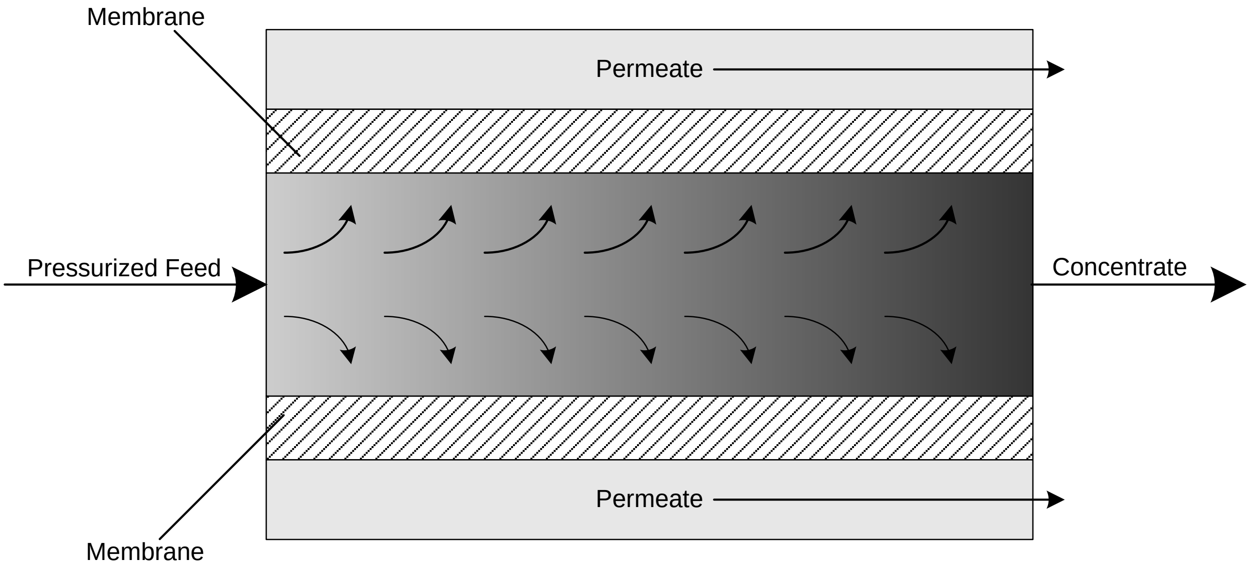

Figure 6-2. Reverse Osmosis Cross-Flow Membrane (The Merit Partnership, 2002)

6.3.2 Microfiltration and Ultrafiltration

If the treatment application is particulate and suspended solids removal, lower pressure membrane systems may be used. MF and UF systems can effectively remove turbidity, metals such as iron, manganese and arsenic, as well as protozoan like *Cryptosporidium*. Dissolved organics may be removed when assisted by an adsorption agent (e.g., powdered activated carbon). UF systems can also remove viruses from the source water without additional treatment (Malmrose, et al., 2003).

Pretreatment of source water is desirable but if the source is relatively clean, pretreatment may not be necessary. Applications of MF and UF systems are becoming more common as replacement for small, older conventional treatment systems. Lower capital costs, lower operating costs, and improved performance are reasons for their increased use.

MF and UF systems use porous, hollow-fiber membranes to remove source water contaminants. The membrane pore size for MF systems typically ranges between 0.1 and 10 micrometers (μm). UF pore size is smaller, ranging from 0.01 to 0.4 μm. These systems typically operate at pressures less than 40 psig (Malmrose, et al., 2003).

6.3.3 Electrodialysis and Electrodialysis Reversal

Dissolved contaminants in the source water may be removed using electrodialysis membranes, which are ion exchange membranes that use electrical current to separate the contaminants from the water (Malmrose, et al., 2004). This operation is primarily used to desalt brackish water. Electrodialysis is not effective in removing non-charged solutes, such as silica, pathogens, and dissolved organics.

Electrodialysis uses alternating pairs of cation (positively charged) and anion (negatively charged) membranes positioned between two oppositely charged electrodes. Channeled spacers between the membranes create parallel flow streams across the membrane surface. The source water is pumped into the flow channels. When voltage is applied, the electrical current causes ions from the source water to migrate toward the oppositely charged electrodes, where the ions become restrained in the polarized membranes. Cations are attracted to the negatively charged electrodes, pass through the positively charged membranes, and become restrained by the negatively charged membrane. Anions are attracted to the positively charged electrodes, pass through the negatively charged membranes, and become restrained by the positively charged membranes. (Malmrose, et al., 2004)

The EDR membrane system is constructed the same as the electrodialysis process, but the EDR system reverses direction of the charge and ion movement several times hourly. The direction of the charge is changed frequently to reverse the electrical polarity and flush fouling ions from the membrane. (Malmrose, et al., 2004)

The electricity cost to operate ED/ EDR may inhibit the use of this source water treatment technique. ED and EDR are not common to large WTPs—those serving more than 10,000 people (U.S. EPA, 2008a).

6.4 ION EXCHANGE

In ion exchange, ions are transferred between different substances with an exchange between solid and liquid being the most common. A precondition for using this process is that the substances must be ionized when exchanged. In drinking water applications, naturally occurring zeolites were first used for hardness removal, but modern ion exchange technology uses resin materials that can be customized to remove specific contaminants of interest. Ion exchange selectively removes a charged inorganic species (i.e., specific drinking water contaminant) from the source water using an ion-specific resin (U.S. EPA, 1998).

Resins act as a repository of loosely held ions (cation or anion) that are exchanged for like-charged ions that have a greater affinity for the resin than the currently held ions. Resins are categorized as anion exchange or cation exchange resins. Anion exchange resins selectively remove anionic species such as nitrate (NO_3^-) and fluoride (F^-). Cation exchange resins selectively remove cationic species such as radium from the water and replace with protons (H^+), sodium ions (Na^+), and potassium ions (K^+). This process continues until all of the exchange sites are used (i.e., saturated with the contaminant). (U.S. EPA, 1998)

Ion exchange often generates a backwash stream (or concentrate waste stream). After the exchanger has exhausted all of the exchange sites, it must be regenerated or replaced. Regeneration requires a reverse ion exchange and it is accomplished with a concentrated solution of a common ion, usually a salt, so that the pH of the water is not affected. The contaminated ions are exchanged for the concentrated salt common ions, and a waste stream requiring treatment and/or disposal is created. Anion exchange resins may be regenerated using sodium hydroxide or sodium chloride solutions by replacing the contaminant ions with a hydroxide (OH^-) or chloride (Cl^-) ion (U.S. EPA, 1998). Cation exchange resins may be regenerated using acid (i.e., replacing the contaminant with a proton, H^+).

Some WTPs may not operate their ion exchange systems year-round. For example, the Des Moines Water Works Fleur Drive Plant operates a lime softening system year-round and adds nitrate removal through ion exchange during spring and summer months, when nitrate concentrations are elevated in the river source water (U.S. EPA, 2006).

6.5 ADSORPTIVE MEDIA—ACTIVATED CARBON

While many adsorptive media are available, WTPs most commonly use activated carbon. Plants use activated carbon filtration systems primarily to remove organic compounds from source water. Organic compounds removed include those that may cause objectionable taste or odor and those that pose potential negative health effects (e.g., pesticides). The most common type of system is granular activated carbon (GAC), but WTPs also use powdered activated carbon (PAC).

Activated carbon can adsorb ions or molecules on its surface from any environmental media, with water and air being the most common. Activated carbon has a random structure that is highly porous and exhibits different types of intramolecular forces. Intramolecular attractions overcome the attractive forces of the liquid for the substance (i.e., source water contaminant), and the substance is deposited on the surface of the carbon. The large surface area of activated carbon (1 gram = 1,000 square meters) allows removal of trace quantities of contaminants from drinking water (ASCE/AWWA, 1997). Unlike filtration, activated carbon plants do not remove the contaminants by straining; the removal is based on adsorption rather than the size of the particulate. Detailed descriptions of the two activated carbon forms follow.

GAC is a more coarse material than PAC and is usually employed later in the treatment process to remove dissolved organic compounds as well as disinfection by-products. GAC is usually used in a fixed bed, which water passes through for treatment. The carbon bed is backwashed or surface washed to prevent buildup of solids and prevent fouling. As with other treatment technologies, there is a finite amount of surface material that can adsorb impurities, and when exceeded, “break through” occurs (i.e., contaminants are no longer removed from the source water). At this point, the spent GAC must be replaced; the spent material may be thermally reconditioned (regenerated) or discarded (U.S. EPA, 2000).

PAC is usually added early in the treatment process and is used to remove organic contaminants that are associated with taste and odor. On a limited basis, PAC is also used to remove seasonal contaminants like pesticides. PAC grains are 10 to 100 times smaller than GAC grains. Use of PAC is less efficient than GAC due to less carbon material per unit volume treated. The PAC is mixed with the water to create a suspension. The PAC continues along with the treated water to sedimentation or filtration and becomes part of the residuals. Care must be taken when using the small PAC particles so that they do not interfere with the application of other treatment chemicals and treatment processes. For example, PAC can adsorb free and combined chlorine, chlorine dioxide, and potassium permanganate, thereby reducing their effectiveness (U.S. EPA, 1998).

6.6 DISINFECTION

Both surface and ground water sources typically require disinfection to eliminate or inactivate microbiological populations. The application of disinfecting agents to a potable water supply has been practiced for over a century and is recognized as one of the most successful examples of public health protection. Historically, chlorine was the disinfectant used, but more recently other chemicals such as chlorine dioxide, chloramines, and ozone have been used to purify water. Non-chemical methods of disinfection include heat and radiation (e.g., ultraviolet light). The general disinfection reaction mechanism is chemical or physical interference with the microorganism structure and cell membrane function.

If the microorganism cell membrane is compromised or penetrated, the microorganism dies. Disinfection does not totally destroy pathogens, but eliminates the ability to cause disease or interfere with normal body functions. The original disinfection theory, proposed by Harriet Chick over 100 years ago, was that disinfection is a function of the concentration of the treatment chemicals and the length of time they stay in contact with the pathogen (Chick, 1908). This concept of "CT values[19]" as a way to evaluate disinfection effectiveness continues today. The lower the CT value, the more effective the disinfecting agent.

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[19] CT is the product of disinfectant residual concentration "C" in milligrams per liter (mg/L) and contact time "T" in minutes to achieve a 3 log reduction of Giardia and a 4 log reduction of viruses (Chick, 1908).

WTPs perform two kinds of disinfection: 1) primary disinfection, and 2) secondary disinfection. Primary disinfection achieves the desired level of microorganism kill or inactivation. Secondary disinfection maintains a disinfectant residual in the finished drinking water to prevent regrowth of microorganisms as water passes through the distribution system. WTPs may use different chemicals for the two kinds of disinfection. Both kinds of disinfection might affect chemicals in the residuals.

Primary disinfection occurs early in the source water treatment, prior to sedimentation or filtration. Although no residuals are generated during this treatment step, the disinfectant used (e.g., chlorine) or disinfection by-products may be present in the WTP residual waste streams (e.g., filter backwash). Chlorine, ozone with another secondary disinfectant, and UV light with another secondary disinfectant are effective primary disinfectants (National Drinking Water Clearinghouse, 1996a).

Secondary disinfection occurs at the end of source water treatment, either at the finished drinking water clear well or at various points in the distribution system. This disinfection step is used to maintain a disinfectant residual in the finished drinking water to prevent regrowth of microorganisms. The secondary disinfection process does not result in residuals generation; however, water from the clear well may be used to backwash filters. As a result, disinfectant added to the finished drinking water may become part of the filter backwash. Chlorine and chloramines are effective secondary disinfectants (National Drinking Water Clearinghouse, 1996a).

Almost all WTPs disinfect the source water prior to delivery—98 percent of the ground water plants and 99 percent of the surface water plants (U.S. EPA, 2002b). The common methods of disinfection are discussed in subsections below.

6.6.1 Disinfection with Chlorine (Chlorination)

When dissolved in water, chlorine gas quickly forms hypochlorous acid (HOCl), which in turn, dissociates into hypochlorite ion (OCl^-) (ASCE/AWWA, 1997). The hypochlorous acid form of chlorine is a more effective disinfectant that the dissociated form, hypochlorite ion.

Chlorine gas, however, is toxic and has a density greater than air, therefore gas leaks accumulate and present significant safety concerns. Properly engineered gas handling systems, continuous training, or switching to a non-gaseous chlorine form like calcium hypochlorite reduce safety concerns.

In the early 1970s, researchers discovered that the use of chlorine for disinfection of drinking water produced microgram per liter (µg/L) quantities of halogenated methane compounds (e.g., trihalomethane). The halogenated methane compounds, known as disinfection by-products, are suspected to be carcinogens (Chlorine Chemistry Council, 2003). EPA limits the amount of total trihalomethanes (TTHMs) in the drinking water to 0.08 mg/L (U.S. EPA, 2008b). The balance between producing microbiologically safe drinking water without long term health effect implications from disinfection by-products became a major problem for some systems. Alternatives to chlorine disinfection have been known for a long time, and the discovery of halogenated methane compounds in chlorine-treated drinking water increased the pressure to explore these alternatives.

6.6.2 Disinfection with Chlorine Dioxide

Chlorine dioxide has been used in some drinking water systems where an elevated pH (>7) of the processed water has reduced the effectiveness of chlorine. Chlorine dioxide is formed when chlorine (gaseous or liquid form) is mixed with sodium chlorite. As with chlorine, WTPs must safely handle chlorine dioxide: it must be generated when used because it can not be safely stored due to explosive characteristics. Also, reaction by-products or waste materials can be toxic, such as chlorite (ClO_2, MCL 1.0 mg/L) and chlorate (Cl_2O_2) ions (U.S. EPA, 2008b). On the positive side, chlorine dioxide does not dissociate or disproportionate under normal drinking water treatment conditions, is a strong oxidant, and does not form halogenated disinfection by-products. It is sometimes used in conjunction with ozone systems as a residual disinfectant.

6.6.3 Disinfection with Chloramines (Chloramination)

Chloramines (or combined residual chlorine) result when chlorine reacts with ammonia. The ammonia can be natural or added to ensure the production of chloramines. Chloramines have been demonstrated as disinfectants, but are not as effective as other germicidal agents. The combined residual from chloramines lasts longer than chlorine residuals; therefore, chloramines are typically used as secondary disinfectants. In addition, the use of chloramines for disinfection results in very few disinfection by-products; however WTPs may need to periodically switch to free chlorine for biofilm control in the water distribution system (U.S. EPA, 1999d).

From EPA national estimates (see Section 3.3), EPA determined that 2,002 WTPs perform primary disinfection. Approximately 80 percent of the WTPs disinfect with free chlorine. 318 WTPs (or 16 percent) use chloramines for primary disinfection (see Appendix A).

6.6.4 Ozone Disinfection

Ozone (O_3) is an energetic species generated by electrical discharge through dry air or pure oxygen and tends to oxidize anything it contacts. Ozone disinfects microbes effectively and can easily penetrate the sturdy cell membranes of protozoa like *Cryptosporidium* (Tchobanoglous, et al., 2003). In addition to the on-site generation safety concerns, the main concern with using ozone as a disinfectant is that its “half life” in water is only 30 minutes (Lenntech, 2006). If ozone alone is used as the disinfectant in large distribution systems (characterized by a residence time of 2 to 3 days), this residual concentration “half life” is insufficient to maintain the microbiological integrity of the finished water. Use of ozone disinfection at large drinking water systems requires booster ozone additions or supplemental disinfection. Ozone disinfection is more commonly used to disinfect wastewater. EPA estimated that 65 WTPs (only three percent) use ozone for primary disinfection (see Appendix A). Figure 6-3 shows an ozone disinfection process flow diagram.

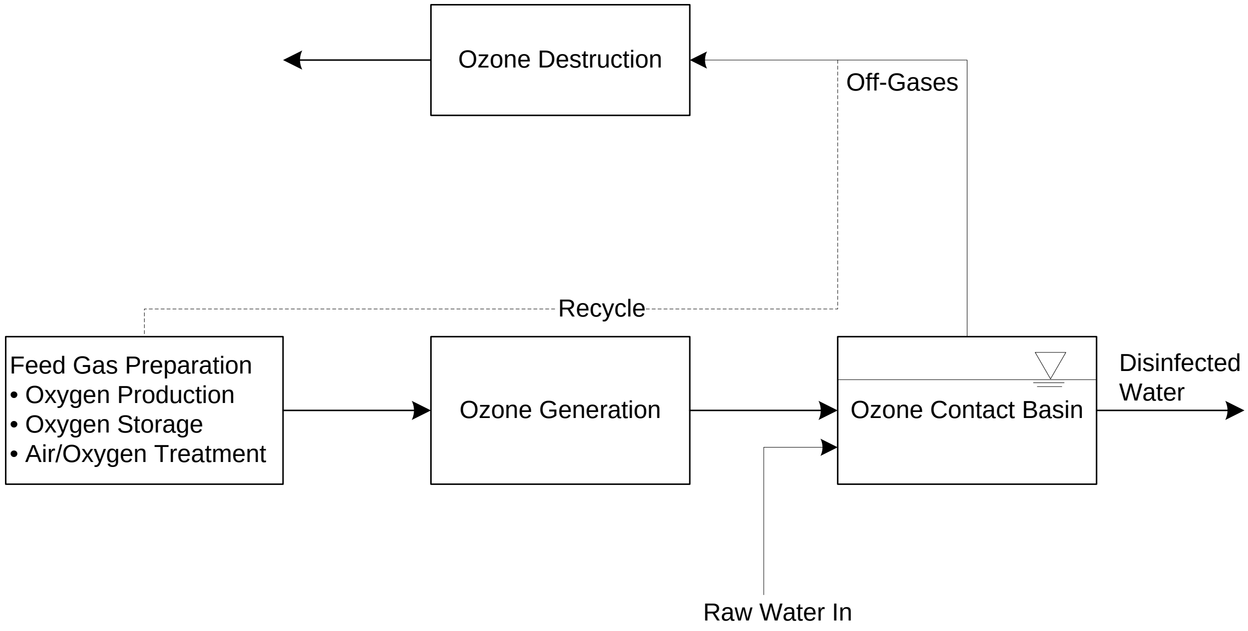

Figure 6-3. Ozone Disinfection Process Flow Diagram (U.S. EPA, 1986)

6.6.5 Ultraviolet Light Disinfection

In ultraviolet (UV) disinfection, electromagnetic energy (UV radiation) is transferred from a mercury arc lamp to an organism's genetic material. The UV radiation penetrates microorganism cell membranes and destroys the microorganisms' ability to reproduce. The application of UV disinfection for source water treatment is limited because turbidity and suspended solids can render UV disinfection ineffective (U.S. EPA, 1999c). As with ozone disinfection, UV disinfection requires large drinking water systems to add a secondary disinfectant to maintain the microbiological integrity of the finished water.

6.7 OTHER CHEMICAL ADDITIONS

In addition to disinfection, coagulation, and precipitative softening chemicals, drinking water systems add other chemicals to drinking water to control corrosion and scaling, facilitate solids removal, adjust pH, and impart properties to the drinking water. The process of adding the chemicals does not generate residuals; however, portions of the chemicals may become part of the residuals at a downstream operation (e.g., sedimentation tank underflow).

6.7.1 Corrosion and Scale Control

To maintain pipes and tanks in the drinking water distribution system, systems add chemicals to control corrosion (i.e., deterioration of material) and scale (i.e., film build-up). Systems use chemicals such as phosphates and zinc for the control of scaling and corrosion. Corrosion and scale control occurs at 26 percent of the ground water plants and 58 percent of the surface water plants (U.S. EPA, 2002b).

Selected chemicals minimize scaling and corrosion by forming a protective film that reduces the electrochemical reactions between the plumbing material and the water. pH control with lime or strong bases, such as sodium hydroxide (NaOH) and potassium hydroxide (KOH) contribute to the stability of the water and assist in reducing corrosion. About 45 different blended phosphate chemicals listed in ANSI/NSF Standard 60 can be used for corrosion control and 12 miscellaneous zinc products can be custom blended to serve different water quality conditions. Zinc does not have a primary standard (no MCL), but does have a secondary standard of 5 mg/L (U.S. EPA, 2008b). ANSI/NSF Standard 60 recommends that zinc not exceed 2 mg/L in the finished water.

6.7.2 Solids Removal Using Sequestering Agents

Iron and manganese are metals found in many drinking water supplies, especially ground water. EPA has secondary standards for iron (0.3 mg/L) and manganese (0.05 mg/L) (U.S. EPA, 2008b) and both metals can cause off-tastes and staining of customer sinks. If iron and manganese concentrations are low, the aesthetic problems can be addressed by adding a sequestering agent that will tie up the soluble form of the metal and inhibit precipitation (staining). Blended phosphates, sodium silicate, and sodium polyphosphate are sequestering agents listed in ASNI/NSF Standard 60.

The use of sequestering agents occurs at 45 percent of the ground water plants and 32 percent of the surface water plants (U.S. EPA, 2002b).

6.7.3 pH Adjustment

Adjusting the pH of a drinking water treatment process is often necessary to ensure the proper interactions between chemicals and contaminants. WTPs add lime or a strong base such as sodium hydroxide or potassium hydroxide to raise the pH. Sodium hydroxide is listed in ANSI/NSF Standard 60. In cases where the pH must be lowered, plants use carbon dioxide or purified mineral acids, such as hydrochloric acid (HCl).

6.7.4 Water Additives

Small amounts of fluoride (~1.0 mg/L) in the drinking water can play a significant role in reducing tooth decay. Sodium fluoride, sodium fluorosilicate, and fluorosilicic acid are used by the drinking water systems and all three are covered by AWWA Standards. Fluoridation is used by 21 percent of the ground water plants and 49 percent of the surface water plants (U.S. EPA, 2002b).

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SECTION 7

TYPES OF RESIDUALS PRODUCED BY SOURCE WATER TREATMENT

The previous section discusses the treatment processes and common treatment trains that are used at water treatment plants (WTPs) to produce drinking water. The treatment processes used to produce drinking water may generate waste streams (or residuals) that the WTP must manage. Two of the treatment processes presented in the previous section, disinfection and other chemical addition, may contribute chemicals to the residuals, but do not generate waste streams themselves. Therefore these two processes are not specifically discussed in this section. This section discusses residuals generated by the following water treatment processes:

- Presedimentation (Section 7.1);
- Coagulation, flocculation, and sedimentation (Section 7.2);
- Precipitative softening (Section 7.3);
- Filtration, microfiltration, and ultrafiltration (Section 7.4);
- Membrane desalination (Section 7.5);
- Ion exchange (Section 7.6); and
- Activated carbon (adsorption process) (Section 7.7).

Water treatment plants (WTPs) may use more than one of the treatment processes listed above and may generate multiple types of residuals. The volume and characterization of the residuals generated depends on the quality of the source water, the drinking water production rate, efficiency of the source water treatment system, the amount of treatment chemical used, and type of source water treatment. The residuals volume at a WTP may vary seasonally or monthly (U.S. EPA, 1993). EPA collected data through literature searches, EPA and state sources, and the 2006 industry questionnaire to quantify residuals generation rates and composition before residuals treatment. An overview of the data sources is presented in Section 2 of this document.

7.1 PRESEDIMENTATION

As discussed in Section 6, presedimentation is a sedimentation basin operated at the head of the WTP. Presedimentation uses gravity to remove suspended solids from source water. The residence time, which depends on the WTP design, capacity, and production rate, is an important factor in the efficiency of solids separation and removal. Clay and organics settle slowly and are not removed during presedimentation; these contaminants require coagulants to assist settling. Silt also has a slow settling velocity; 2-micron silt particles settle at a rate of 10 millimeters per hour (0.4 inches per hour). Sand and grit settle more rapidly; 600-micron sand particles settle at a rate of 900 meters per hour (50 feet per minute) (New Zealand Ministry of Health, 2005). If the presedimentation basin has a residence time of two days, then all of the sand and grit will be in the sludge, but very little of the clay and silt. The composition of the solids in the sludge is site-specific. Depending on the composition, settling basins can remove between 50 and 90 percent of the influent solids (U.S. EPA, 1999). Following presedimentation, WTPs remove smaller particles during the coagulation, flocculation, sedimentation, and filtration processes, as shown in Figure 7-1.

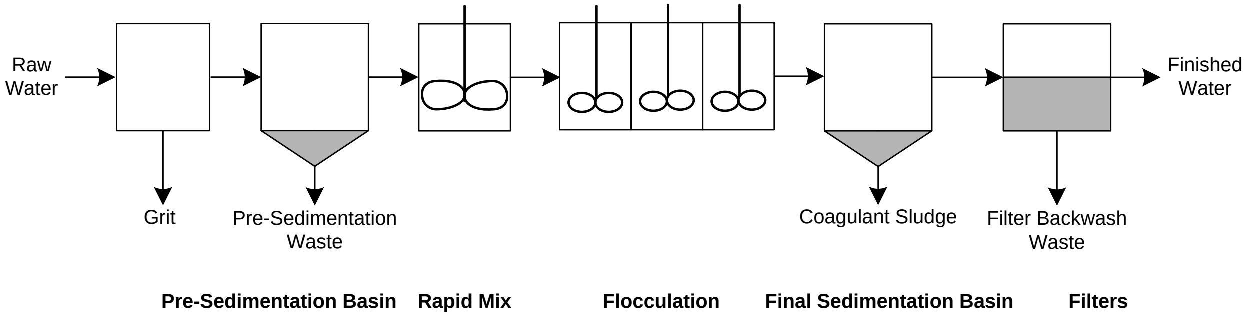

Figure 7-1. Residuals from Source Water Solids Removal (U.S. EPA/ACSE/AWWA, 1996)

7.2 RESIDUALS FROM COAGULATION, FLOCCULATION, AND SEDIMENTATION

During coagulation, flocculation, and sedimentation, solids settle to the bottom of clarifiers and sedimentation basins. Coagulation is the addition of chemical agent(s) to the solids settling process to reduce the negative surface charges by introducing positive ions, which allows the particulates to agglomerate and settle. Aluminum and iron salts are common coagulant aids whose positive trivalent forms are insoluble at normal conditions for drinking water treatment and precipitate along with the neutralized suspended solids (Tchobanoglous, et al., 2003). The charge neutralization reactions begin immediately, necessitating a rapid mix chamber.

The term flocculation is the agglomeration of small finely separated particles into larger particles that become heavier than water. Optimum floc formation is best carried out under conditions of gradually reducing energy: turbulent rapid mix is reduced to gentle agitation, which is further reduced to quiescent deposition.

Within sedimentation basins, solids settle by gravity to the bottom. The underflow sludge is removed from the basin on either a continuous or batch basis. In continuous sludge removal, rakes or blades push the sludge along the bottom of the settling basin to an outlet. In batch removal, basins are drained and the sludge is removed with the remaining basin water and cleaning water. Batch removal occurs when the settling volume in the basin is no longer effective (i.e., sludge displaces too much settling volume). The time between batch removals varies from a few weeks to over a year.

The volume of coagulation sludge generated depends on the plant production, amount of coagulant or other treatment chemical added (dose), and amount of suspended solids in the source water. Table 7-1 presents typical coagulation sludge volumes generated (U.S. EPA, 1993). The characteristics of coagulation sludge vary depending on initial water quality and the amount and type of coagulant used (e.g., higher aluminum concentration in the sludge using aluminum-based coagulant). Coagulation sludge predominately contains the coagulant metal hydroxides along with source water natural organic matter, suspended solids, microorganisms, radionuclides, and other organic and inorganic constituents. The metals found in coagulation sludge include aluminum, arsenic, and occasionally cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc (Cornwell, 1999).

Table 7-1. Typical Chemical Coagulation Sludge Volumes

Population Served Range	Average Water Treatment Plant Flow (MGD)	Water Treatment Plant Design Flow (MGD)	Typical Sludge Volume Range (GPD)	Average Sludge Volume (GPD)
1,001 to 3,300	0.23	0.7	7 – 2,600	770
3,301 to 10,000	0.7	1.8	18 – 6,700	2,000
10,001 to 25,000	2.1	4.8	48 – 17,800	5,300
25,001 to 50,000	5	11	110 – 40,900	12,100
50,001 to 75,000	8.8	18	180 – 66,800	19,800
75,001 to 100,000	13	26	260 – 96,600	28,600
100,001 to 500,000	27	51	510 – 189,400	56,200
500,001 to 1,000,000	120	210	2,100 – 779,900	231,300
Greater than 1,000,000	270	430	4,300 – 1,596,900	473,500

Source: U.S. EPA, 1993.
MGD – Million gallons per day.
GPD – Gallons per day.

If the source water has a high concentration of total suspended solids (TSS), then the coagulant sludge will contain a high percentage of gelatinous, hydroxide precipitates. The alum and ferric (or iron) sludge exhibit poor compaction traits, ranging from 0.5 to 2 percent solids (ASCE/AWWA, 1997). Consequently, coagulation sludge usually requires additional processing such as thickening, dewatering, or drying prior to disposal. Because of their low solids content, these sludges are difficult to dewater. They are also biologically inert with little organic content and have little value as a fertilizer or soil conditioner. Section 11 discusses residuals treatment and management practices.

7.3 RESIDUALS FROM PRECIPITATIVE (LIME) SOFTENING

WTPs use precipitative softening to remove divalent ions in water, particularly calcium and magnesium, by the addition of lime. The concentration of the divalent ions in the water is often referred to as the water’s “hardness.” The lime increases the pH and reacts with the ions to form a precipitate of insoluble calcium carbonate and magnesium hydroxide. Softening sludge (or carbonate residuals) settles to a solids content ranging from 2 to 15 percent (ASCE/AWWA, 1997). Softening sludge is easier to dewater and compact than coagulation sludge (see Section 7.2). Table 7-2 presents typical lime softening sludge volumes produced by WTPs (U.S. EPA, 1993).

Table 7-2. Typical Lime Softening Sludge Volumes

Population Served Range	Average Water Treatment Plant Flow (MGD)	Water Treatment Plant Design Flow (MGD)	Typical Sludge Volume Range (GPD)	Average Sludge Volume (GPD)
1,001 to 3,300	0.23	0.7	2,800 – 10,700	8,500
3,301 to 10,000	0.7	1.8	7,200 – 27,400	21,900
10,001 to 25,000	2.1	4.8	19,300 – 73,100	58,300
25,001 to 50,000	5	11	44,200 – 167,500	133,600
50,001 to 75,000	8.8	18	72,300 – 274,100	218,600
75,001 to 100,000	13	26	104,400 – 395,900	315,800
100,001 to 500,000	27	51	204,800 – 776,600	619,400
500,001 to 1,000,000	120	210	843,400 – 3,198,000	2,550,600
Greater than 1,000,000	270	430	1,726,900 – 6,548,200	5,222,700

Source: U.S. EPA, 1993.
MGD – Million gallons per day.
GPD – Gallons per day.

Softening sludge is biologically inert and has a high pH (typically greater than 10.5) due to unreacted lime and high alkalinity. The sludge contains calcium carbonate, magnesium hydroxide, other divalent ions, natural organic matter from the source water, inorganics, suspended solids, microorganisms, and radionuclides. Metals found in the softening sludges include calcium, magnesium, arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver (Cornwell, 1999).

In lime softening, sludge generation rates depend on the ratio of calcium carbonate to magnesium hydroxide and the type of clarifier/sedimentation basin. Conventional gravity sedimentation basins generate sludge with solids concentrations of only 2 to 4 percent, whereas, sludge blanket clarifiers generate sludge with solids concentrations up to 30 percent (U.S. EPA/ASCE/AWWA, 1996).

Softening sludges are generally dense, stable, and inert materials that dewater easily to a solids content up to 50 to 60 percent. However, if the hardness is due to magnesium, the hydroxide sludge is more difficult to handle and dewater (Cornwell, 1999). Figure 7-2 presents the sources of residuals from a typical precipitative softening plant.

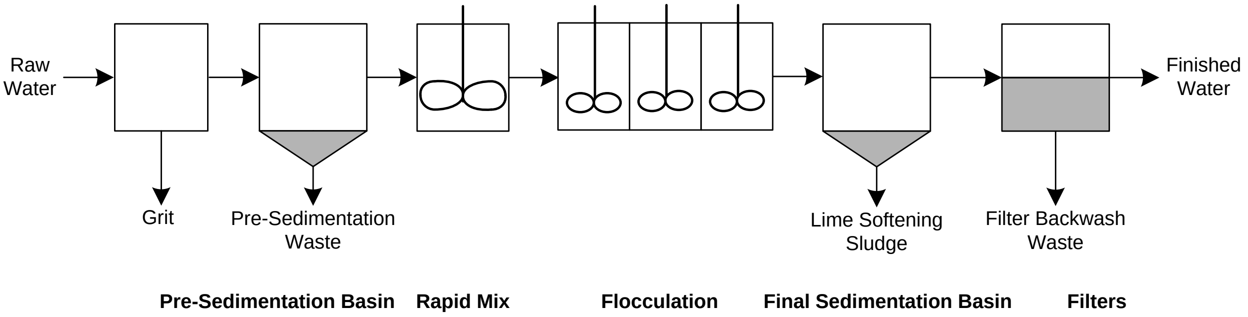

Figure 7-2. Residuals from Precipitative Softening WTP

7.4 RESIDUALS FROM FILTRATION

WTPs use filtration to remove finer particles and metals. At some WTPs, filtration is the only solids removal step. Filter types include non-membrane filters such as multi-media, slow sand, and diatomaceous earth and low-pressure membranes such as microfiltration (MF) and ultrafiltration (UF).

7.4.1 Filters (non-membrane)

Filtration removes suspended material in the source water by allowing water to pass through the filter media while suspended solids accumulate in the interstices of the filter media. As the filter run continues and more particles are removed, it becomes more difficult for the inlet water to easily make its way through the filter. This condition is called filter head loss and is an indication of waning filter performance. At a predetermined filter head loss value, the filter is taken out of service for backwash.

Backwashing is the process of using finished water to reversely expel the particles collected on the filter media. The plant collects the filter backwash water (containing the particles) in an area separated from the filter inlet. Due to the relatively low level of filtered particles and the relatively large volume of water necessary to clean the filter, the resulting backwash residuals water is dilute (50 to 400 mg/L of suspended solids) and difficult to dewater (U.S. EPA/ASCE/AWWA, 1996).

Filter backwash contains particulates including clay and silt particles, microorganisms (bacteria, viruses, and protozoan cysts), colloidal and precipitated humic substances, and other natural organic particulates from the decay of vegetation. At conventional and direct filtration plants, filter backwash also contains precipitates of aluminum or iron used in coagulation (Cornwell, 1999).

The volume of filter backwash wastewater generated depends on the number of filters, frequency of backwash, and duration of backwash events. The volume is typically between 2 and 5 percent of the finished water produced (U.S. EPA/ASCE/AWWA, 1996). This is a sizeable residuals volume. Consequently, many WTPs employ a flow equalization system to settle and remove some of the solids and recycle the backwash water to the head of the source water treatment plant.

After backwashing, WTPs may wash the filter to ensure adequate filter performance. The spent wash water is called “filter-to-waste.” By generating the filter-to-waste stream, WTPs can check the effluent quality from the filter prior to bringing the filter back on-line. Filter-to-waste is the filter effluent for the first 15 to 60 minutes after startup (following backwash). The filter-to-waste stream is equalized and returned to the head of the treatment plant, rather than distributed to customers (U.S. EPA/ASCE/AWWA, 1996).

7.4.2 Low-Pressure Membranes

Low-pressure membranes (MF/UF) generate filter backwash waste streams, similar to other filtration processes, and spent chemical cleaning solutions. MF and UF systems remove suspended solids, turbidity, inorganic and organic colloids, microorganisms (protozoan cysts and bacteria), viruses (UF only), and some organic fractions (UF only) from the source water. The volume of backwash generated is typically between 2 and 15 percent of the plant flow rate. The backwash stream represents the majority of residuals generated from MF/UF treatment process (95 to 99 percent of the total volume of residuals). The remaining 1 to 5 percent of membrane residuals is generated by chemical cleaning procedures (Malmrose, et al., 2003).

Table 7-3 presents typical characteristics of low-pressure membrane backwash residuals. These characteristics vary with feed flow rate and backwash frequency. (Malmrose, et al., 2003)

Table 7-3. Typical Characteristics of Low-Pressure Membrane Backwash Residuals

Frequency of application	Every 10 to 60 minutes.
Volume of backwash residuals generated/ waste produced	2 to 15% of plant feed flow rate for recoveries of 85 to 98%. (Daily chemically-enhanced backwash (CEBW) wastes might be 0.2 to 0.4% of plant feed flow rate.)
Characteristics of backwash residuals	Algae, precipitated solids, possible chemical residues if using CEBW
	Total organic carbon (TOC) concentration of 1 to 2 times the feed water concentration (if no coagulant or absorbent is used). If coagulant is used, the TOC could be 5 times the feed water concentration.
	For recoveries of 85 to 98%, backwash will have a concentration factor of 7 to 50 times the feed water for total suspended solids (TSS) and Cryptosporidium.
	If using CEBW (with chlorine, acid, or base), pH may be <6 or >9, and chlorine residual may be up to 1,000 mg/L as Cl_2.

Source: Malmrose, et al., 2003.

Some systems use coagulants, powdered activated carbon (PAC), or other chemicals (e.g., potassium permanganate) as pretreatment to membrane filtration to remove some solids prior to the membrane. This pretreatment helps to reduce fouling of the membrane and reduce the backwash frequency. The characteristics of the resulting residuals from these pretreatment operations closely resemble those of coagulation sludge (Malmrose, et al., 2003).

MF/UF systems also generate spent chemical cleaning solution residuals during the membrane cleaning processes used to control fouling (CEBW and clean in place (CIP)). Cleaning solution residuals reflect the chemicals used in the cleaning process. Only a portion of the active chemical ingredient is consumed during the cleaning process, so the resulting chemical cleaning waste includes some remaining active chemical ingredient, as well as salts from chemical reactions between the chemicals and foulants, dissolved organic materials, and suspended solids. While some plants refresh the active ingredient in spent cleaning solutions and reuse it to minimize waste quantities, this practice can result in more concentrated waste cleaning solutions. Table 7-4 summarizes the characteristics of some typical waste chemical cleaning solutions (Malmrose, et al., 2003).

Table 7-4. Typical Characteristics of Spent Low-Pressure Membrane Chemical Cleaning Solutions

Frequency of application	Daily to once every 3 or 4 months.
Volume of residuals generated	Monthly CIP wastes normally <0.05% of plant feed flow rate. Daily CEBW wastes might be 0.2 to 0.4% of plant feed flow rate.
Chemicals commonly used	Sodium hypochlorite – 500 to 1,000 mg/L as Cl_2.
	Citric or hydrochloric acid – pH 1 to 2.
	Caustic soda – pH 12 to 13.
	Surfactant – 0.1% by weight.
Characteristics of spent cleaning solutions	pH from 2 to 14.
	Chlorine residual up to 1,000 mg/L as Cl_2.
	Low concentrations of surfactants.
	TSS up to 500 mg/L (neutralization may precipitate additional solids).
	TOC 10 to 30 times the feed water concentration.
	5-day biochemical oxygen demand (BOD_5) up to 5,000 or 10,000 mg/L (if citric acid is used).

Source: Malmrose, et al., 2003.

7.5 RESIDUALS FROM MEMBRANE DESALINATION

As discussed in Section 6 of this document, membrane desalination technologies include reverse osmosis (RO), nanofiltration (NF), electrodialysis (ED), and electrodialysis reversal (EDR). Membranes are typically used to remove dissolved solids and ions. In addition to dissolved solids and ions, membranes can also remove dissolved organics, dissolved gases, biological contaminants, and suspended solids (U.S. EPA/ASCE/AWWA, 1996). However, industry practice is to remove biological material and particulates via pretreatment. Plants typically pretreat the source water prior to membrane desalination to protect and extend the life of the membrane. Pretreatment steps commonly include:

- Acid addition – lowering pH to between 5.5 and 7.0.
- Anti-scalant addition – to prevent membrane fouling.
- Filtration – remove suspended particles.

The filtration step generates a backwash waste stream. Figure 7-3 presents typical residuals generated from membrane desalination plants.

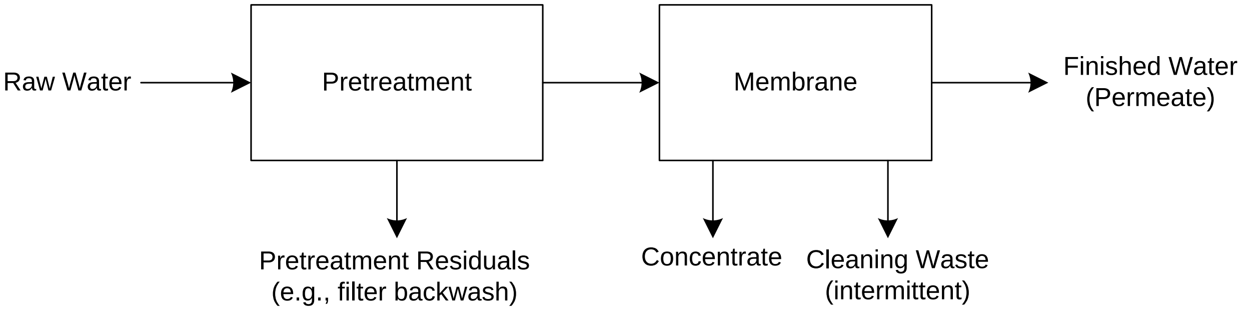

Figure 7-3. Residuals from Membrane Desalination

Membrane desalination systems generate a clean permeate stream that passes through the membranes and a reject stream (or concentrate) containing the contaminants that are retained by the membranes for separate disposal. The types of contaminants in the concentrate are generally the same as those in the source water (i.e., very few process-added chemicals).

Contaminant concentrations in the concentrate are typically 4 to 10 times feed water concentrations and depend upon the rejection characteristics of the membrane and finished drinking water (i.e., permeate) production. If pretreatment is used, then the feed water to the desalting membranes will have lower levels of certain constituents and particles; however, feed water levels of other constituents may increase. For example, coagulation pretreatment will increase the inorganic ions, such as sulfate, iron, and aluminum, and polymer or sulfuric acid pretreatment may increase residual organics. Table 7-5 lists the target contaminants typically removed by membrane desalination (Malmrose, et al., 2004).

The rejection rate for a contaminant is the percentage of the contaminant in the source water that does not pass through the membrane, but becomes part of the concentrate stream. The rejection rate depends on the contaminant size and interaction with the membrane. In general, the larger the pore size of the membrane, the lower the rejection rate. RO systems have rejection rates from 90 to 99.8 percent for monovalent ions and from 98 to 99.9 percent for divalent ions (e.g., hardness) (Malmrose, et al., 2004). NF membranes have rejection rates from 40 to 90 percent for monovalent ions and from 80 to 98 percent for divalent ions (Malmrose, et al., 2004). The ED/EDR process can reject more than 90 percent of dissolved ions (U.S. EPA/ASCE/AWWA, 1996).

Table 7-5. Membrane Desalination: Typical Target Contaminants by Source Water

Source Water	Typical Target Contaminants
Surface water	Total Organic Carbon (TOC)
	Disinfection By-product (DBP) Precursors
	Microorganisms (or pathogens)
	Pesticides / Synthetic Organic Compounds (SOCs)
	Taste & Odor Compounds
Ground water	Hardness
	Color (indicative of dissolved organic material)
	TOC
	Inorganic and organic compounds / chemicals
Brackish surface water and ground water	Total Dissolved Solids (TDS)
	Hardness
	Chloride and sodium
Seawater	TDS
	Chloride and Sodium
	Bromide
	Boron

Source: Malmrose, et al., 2004.

Table 7-6 presents typical design parameters for RO and NF membrane desalination treatment plants (Malmrose, et al., 2004). The water recovery rate for a membrane is the percentage of the feed water that passes through the membrane as permeate (finished water).

Table 7-6. Typical Membrane Desalination System (RO and NF) Design Parameters

Parameter	Surface Water	Fresh Ground Water	Brackish Ground Water	Seawater
Feed total dissolved solids (TDS) (mg/L)	200-400	400-500	500-10,000	30,000-40,000
Water recovery (% of feed)	80-90	80-90	65-85	40-60
Concentrate quantity (% of feed)	10-20	10-20	15-35	40-60
Concentrate TDS (mg/L) (at example recovery)	1,330-2,660 (85%)	2,660-3,330 (85%)	2,000-40,000 (75%)	60,000-80,000 (50%)
Concentration factor [a]	5-10	5-10	2.9-6.7	1.7-2.5

Source: Malmrose, et al., 2004.
a – Ratio of total dissolved solids in concentrate to total dissolved solids in feed, assuming 100 percent salt rejection.
mg/L – Milligrams per liter.

Membrane desalination plants also clean the equipment and generate spent cleaning solutions every three to 12 months. Typically, the waste cleaning solution volume generated during a clean in place of NF and RO is about 3 gallons per 100 square feet (1.2 liters/square meter). Typical waste cleaning solution volume is estimated by adding the total empty vessel volume and pipe volume. In addition to spent cleaning solution, the plant may generate one to two volumes of rinse water. Typical cleaning solutions, which may be diluted with rinse water (feed or permeate), for NF and RO systems include acid (mineral or citric) to remove inorganic contaminants and alkaline solutions (e.g., caustic soda with detergents or surfactants) to remove organic contaminants and biofilms.[20] ED/EDR system cleaning solutions typically include concentrated hydrochloric acid and sodium chlorine solutions. Occasionally, chlorine solutions may be used to clean ED/EDR systems for organic contaminant and biofilm removal. The waste cleaning solution volume is extremely small compared to treated flow (<0.1 percent) (Malmrose, et. al., 2004).

ED/EDR systems also produce a low flow waste stream called "electrode waste," which contains significant levels of hydrogen and chlorine gases that are typically stripped from the electrode waste stream using a degasifier (which is part of the EDR system) (Malmrose, et al., 2004).

7.6 RESIDUALS FROM ION EXCHANGE

Ion exchange may be used by WTPs to reduce hardness by replacing calcium and magnesium ions in source water with sodium ions that are contained in the ion exchange resin. Ion exchange can also remove nitrates, barium, radium, arsenate, selenate, excess levels of fluoride, lead, and chromate (U.S. EPA/ASCE/AWWA, 1996). Once all the ion exchange sites reach capacity, the plant must regenerate the ion exchange material, thus producing waste concentrate that contains the source water contaminants. In addition to the waste concentrate, the ion exchange process also generates backwash water and rinse water that is used before and after the regeneration of the ion exchange resin, respectively. Waste concentrate generation rates from ion exchange for water softening ranges from 1.5 to 10 percent of the water softened (U.S.

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[20] Biofilms are an accumulated mixture of microorganisms, organic contaminants, and inorganic contaminants.

EPA/ASCE/AWWA, 1996). Table 7-7 presents typical ion exchange concentrate generation rates for WTPs (U.S. EPA, 1993).

Table 7-7. Typical Ion Exchange Concentrate Volumes

Population Served Range	Average Water Treatment Plant Flow (MGD)	Water Treatment Plant Design Flow (MGD)	Range of Typical Concentrate Generation Rates (GPD)
1,001 to 3,300	0.23	0.7	12,300 – 63,200
3,301 to 10,000	0.7	1.8	31,500 – 162,500
10,001 to 25,000	2.1	4.8	84,000 – 433,300
25,001 to 50,000	5	11	192,500 – 993,000
50,001 to 75,000	8.8	18	315,000 – 1,624,900
75,001 to 100,000	13	26	455,000 – 2,347,100
100,001 to 500,000	27	51	892,600 – 4,604,000
500,001 to 1,000,000	120	210	3,675,200 – 18,957,700
Greater than 1,000,000	270	430	7,525,400 – 38,818,100

Source: U.S. EPA, 1993.
MGD – Million gallons per day.
GPD – Gallons per day.

Table 7-8 lists typical concentrations of ions in ion exchange waste concentrate (U.S. EPA/ASCE/AWWA, 1996).

Table 7-8. Typical Chemical Concentrations in Ion Exchange Waste Concentrate

Constituent	Average Concentration Range (mg/L)
Total dissolved solids	15,000 – 35,000
Calcium (Ca++)	3,000 – 6,000
Magnesium (Mg++)	1,000 – 2,000
Hardness (as CaCO3)	11,600 – 23,000
Sodium (Na+)	2,000 – 5,000
Chlorine (Cl-)	9,000 – 22,000

Source: U.S. EPA, ASCE, AWWA, 1996.

7.7 RESIDUALS FROM ADSORPTION (ACTIVATED CARBON)

Adsorption removes ions or molecules from the source water by adsorbing the chemicals in the source water onto the treatment media. Adsorption is used to remove naturally occurring organic materials, taste, odor, synthetic organic compounds, as well as disinfection by-products. Adsorption can use different types of adsorptive media, and the most common is granular activated carbon (GAC). Residuals generated by GAC include backwash water (or surface wash water) and spent media.

As the treatment process goes on, adsorption sites become filled. Once all the adsorption sites are filled, breakthrough of the contaminant occurs (i.e., pollutants are no longer removed from the influent but continue through to the GAC filter effluent). WTPs then perform backwashing of the GAC filter bed. The time it takes for breakthrough to occur depends on the concentration of the pollutant contaminants being removed.

Plants perform backwashing to disengage solids that have been entrapped in the filter bed. Backwashing of GAC filter-adsorbers is essential to remove solids and to maintain the desired hydraulic properties of the bed. Backwash water generally contains the removed contaminants such as suspended solids, biological films, organics, and some filter media. The volume and quantity of the GAC backwash stream depends on the influent source water quality.

The spent media (or carbon) is sent off site for regeneration or disposal. Regeneration of the spent carbon is accomplished by thermal means (e.g., rotary kiln, hearth furnace) and does not generate a wastewater stream.

7.8 REFERENCES

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SECTION 8

POLLUTANTS IN WATER TREATMENT PLANT RESIDUALS

This section identifies and discusses the pollutants present in WTP residuals including the source of these pollutants. Section 9 presents pollutant loadings estimate for discharges of these residuals and Section 10 discusses the environmental impacts of the pollutants on discharge receiving streams.

EPA reviewed data sources to determine the presence of priority, conventional, and nonconventional pollutant parameters in water treatment plant (WTP) residuals. EPA defines priority pollutant parameters in Section 307(a)(1) of the Clean Water Act (CWA). Table 8-1 lists the 126 specific priority pollutants listed in 40 CFR Part 423, Appendix A. For this industry review, most of the priority pollutants listed in Table 8-1 were not identified as significant contributors to WTP residuals. Section 304(a)(4) of the CWA defines conventional pollutant parameters to include biochemical oxygen demand (BOD), total suspended solids (TSS), oil and grease, pH, and fecal coliform bacteria. Nonconventional pollutant parameters are those that are neither priority nor conventional pollutant parameters. This group includes nonconventional metal pollutants, nonconventional organic pollutants, and other nonconventional pollutant parameters such as chemical oxygen demand (COD).

EPA gathered data on pollutants from literature sources, including composition of source water treatment chemicals (Cornwell, 2002) and pollutants identified by EPA's Drinking Water Program as a contaminant in finished drinking water (U.S. EPA, 2008), and discharge monitoring reports (DMRs) from effluent discharges (U.S. EPA, 2007). Pollutants in WTP residuals come from two sources: 1) treatment chemical addition (including by-product formation); and 2) source water. The following subsections identify the pollutants commonly found in residuals and wastewater discharged from WTPs.

Table 8-1. Priority Pollutant List [a]

1 Acenaphthene
2 Acrolein
3 Acrylonitrile
4 Benzene
5 Benzidine
6 Carbon tetrachloride (tetrachloromethane)
7 Chlorobenzene
8 1,2,4-Trichlorobenzene
9 Hexachlorobenzene
10 1,2-Dichloroethane
11 1,1,1-Trichloroethane
12 Hexachloroethane
13 1,1-Dichloroethane
14 1,1,2-Trichloroethane
15 1,1,2,2-Tetrachloroethane
16 Chloroethane
17 *Removed*
18 Bis(2-chloroethyl) ether
19 2-Chloroethyl vinyl ether (mixed)
20 2-Chloronaphthalene
21 2,4,6-Trichlorophenol
22 Parachlorometa cresol (4-chloro-3-methylphenol)
23 Chloroform (trichloromethane)
24 2-Chlorophenol
25 1,2-Dichlorobenzene
26 1,3-Dichlorobenzene
27 1,4-Dichlorobenzene
28 3,3'-Dichlorobenzidine
29 1,1-Dichloroethylene
30 1,2-Trans-Dichloroethylene
31 2,4-Dichlorophenol
32 1,2-Dichloropropane
33 1,3-Dichloropropylene (trans-1,3-dichloropropene)
34 2,4-Dimethylphenol
35 2,4-Dinitrotoluene
36 2,6-Dinitrotoluene
37 1,2-Diphenylhydrazine
38 Ethylbenzene
39 Fluoranthene
40 4-Chlorophenyl phenyl ether
41 4-Bromophenyl phenyl ether
42 Bis(2-Chloroisopropyl) ether
43 Bis(2-Chloroethoxy) methane
44 Methylene chloride (dichloromethane)
45 Methyl chloride (chloromethane)
46 Methyl bromide (bromomethane)
47 Bromoform (tribromomethane)
48 Dichlorobromomethane (bromodichloromethane)
49 *Removed*
50 *Removed*
51 Chlorodibromomethane (dibromochloromethane)
52 Hexachlorobutadiene
53 Hexachlorocyclopentadiene
54 Isophorone
55 Naphthalene
56 Nitrobenzene
57 2-Nitrophenol
58 4-Nitrophenol
59 2,4-Dinitrophenol
60 4,6-Dinitro-o-cresol (phenol, 2-methyl-4,6-dinitro)
61 N-Nitrosodimethylamine
62 N-Nitrosodiphenylamine
63 N-Nitrosodi-n-propylamine (di-npropylnitrosamine)
64 Pentachlorophenol
65 Phenol
66 Bis(2-ethylhexyl) phthalate
67 Butyl benzyl phthalate
68 Di-n-butyl phthalate
69 Di-n-octyl phthalate
70 Diethyl phthalate
71 Dimethyl phthalate
72 Benzo(a)anthracene (1,2-benzanthracene)
73 Benzo(a)pyrene (3,4-benzopyrene)
74 Benzo(b)fluoranthene (3,4-benzo fluoranthene)
75 Benzo(k)fluoranthene (11,12-benzofluoranthene)
76 Chrysene
77 Acenaphthylene
78 Anthracene
79 Benzo(ghi)perylene (1,12-benzoperylene)
80 Fluorene
81 Phenanthrene
82 Dibenzo(a,h)anthracene (1,2,5,6-dibenzanthracene)
83 Indeno(1,2,3-cd)pyrene (2,3-o-phenylenepyrene)
84 Pyrene
85 Tetrachloroethylene (tetrachloroethene)
86 Toluene
87 Trichloroethylene (trichloroethene)
88 Vinyl chloride (chloroethylene)
89 Aldrin
90 Dieldrin
91 Chlordane (technical mixture & metabolites)
92 4,4'-DDT (p,p'-DDT)
93 4,4'-DDE (p,p'-DDX)
94 4,4'-DDD (p,p'-TDE)
95 Alpha-endosulfan
96 Beta-endosulfan
97 Endosulfan sulfate
98 Endrin
99 Endrin aldehyde
100 Heptachlor
101 Heptachlor epoxide
102 Alpha-BHC
103 Beta-BHC
104 Gamma-BHC (lindane)
105 Delta-BHC
106 PCB-1242 (Arochlor 1242)
107 PCB-1254 (Arochlor 1254)
108 PCB-1221 (Arochlor 1221)
109 PCB-1232 (Arochlor 1232)
110 PCB-1248 (Arochlor 1248)
111 PCB-1260 (Arochlor 1260)
112 PCB-1016 (Arochlor 1016)
113 Toxaphene
114 Antimony (total)
115 Arsenic (total)
116 Asbestos (fibrous)
117 Beryllium (total)
118 Cadmium (total)
119 Chromium (total)
120 Copper (total)
121 Cyanide (total)
122 Lead (total)
123 Mercury (total)
124 Nickel (total)
125 Selenium (total)
126 Silver (total)
127 Thallium (total)
128 Zinc (total)
129 2,3,7,8-Tetrachloro-dibenzo-p-dioxin (TCDD)

Source: 40 CFR Part 423, Appendix A.

a – Priority pollutants are numbered 1 through 129 but include 126 pollutants, because EPA removed three pollutants (17, 49, and 50) from the list.

8.1 OVERVIEW OF POLLUTANTS IN WATER TREATMENT PLANT RESIDUALS

WTP residuals contain pollutants from the source water (concentrated when removed from drinking water) and from treatment chemicals (including impurities and disinfection by-products). Source water pollutants removed from potable drinking water include solids, metals, and microorganisms. Pollutants from treatment chemical formulations include active treatment chemical ingredients such as aluminum, calcium, and ammonia compounds, and formulation impurities. Water treatment chemical impurities can concentrate into detectable levels in residuals and recycle streams over time (Cornwell, 2002). Disinfection by-products include bromate, chlorite, haloacetic acids, and trihalomethanes.

Common treatment chemicals listed in responses to the 2006 industry questionnaire include the following (U.S. EPA, 2009):

- Chlorine (disinfection);
- Chlorine and ammonia (disinfection with chloramines);
- Conventional treatment:
  - Aluminum chlorohydrate/polyaluminum chloride (PACl),
  - Aluminum sulfate (alum),
  - Iron-based coagulants (ferric chloride and ferric sulfide),
  - Potassium permanganate,
  - Polymer coagulants.
- Lime (precipitative) softening:
  - Hydrated lime ($Ca(OH)_2$),
  - Caustic soda/sodium hydroxide (NaOH),
  - Quick lime (CaO),
  - Sodium carbonate/soda ash (Na_2CO_3).
- Powdered activated carbon;
- Granular activated carbon; and
- Fluoride.

Appendix B lists the compositions for some of the common treatment chemical formulations.

8.2 SOLIDS IN WATER TREATMENT PLANT RESIDUALS

Solids are the most common pollutant in WTP residuals. WTP residuals contain both suspended and dissolved solids, which are also known as filterable and nonfilterable residue. Suspended and dissolved solids concentrations are determined by filtering the solids with a standard glass fiber filter and then drying them to a constant weight. The solids retained on the filter are considered suspended solids, and the solids passing through the filter are considered dissolved solids. Total solids are the sum of suspended and dissolved solids.

Suspended solids in WTP residuals include inorganic (e.g., silt, sand, clay, and insoluble hydrated metal oxides) and organic matter (e.g., flocculated colloids and compounds that contribute to color). Suspended solids may be measured using the parameters total suspended solids or turbidity. Dissolved solids consist primarily of dissolved inorganic compounds and can be found in ion exchange and membrane desalination concentrate waste streams at high concentrations. One of the primary functions of WTPs is to remove solids from the source water.

Solids in WTP residuals primarily come from the source water, but the addition of treatment chemicals can add to the measured value (e.g., metals present in coagulants). Solids from the source water may be concentrated in the residuals resulting in a higher solids concentration than the source water solids concentration.

DMR data collected with the 2007 industry questionnaire includes TSS concentrations for precipitative softening, conventional filtration (i.e., coagulation/filtration), filtration only (includes microfiltration and ultrafiltration), membrane desalination, and ion exchange plants. DMR data includes total dissolved solids (TDS) concentrations for ion exchange plants. EPA included TSS and TDS in the pollutant loadings analysis (see Section 9). A portion of the solids in WTP residuals are metals.

8.3 PRIORITY AND NONCONVENTIONAL METALS IN WATER TREATMENT PLANT RESIDUALS

A number of metals may be present in WTP residuals from the source water and from source water treatment chemicals (and their impurities). Table 8-2 summarizes EPA's evaluation of the presence of priority metals and nonconventional metals in WTP residuals. Metals, including iron, manganese, and mercury, listed in Table 8-2, may be present in source water from natural erosion, land runoff, and industrial discharges. Aluminum salts, iron salts, and polymers are commonly used as coagulants. Potassium permanganate is added to control taste and odors, remove contaminants that cause color, control biological growth in treatment plants, and remove iron and manganese. Lime products and caustic soda are added to reduce hardness. Depending on the formulation, these treatment chemicals may contain metal impurities as listed in Table 8-2.

WTPs remove metals from the source water to meet maximum contaminant levels (MCLs) in the finished drinking water. The removed metals and metal constituents of treatment chemicals become part of the residual waste streams. Permit writers select the appropriate pollutants of concern when issuing discharge permits based on the pollutants in the source water and type of treatment chemicals being added at the plant.

The following subsections discuss the active ingredient metals and other metals in more detail.

Table 8-2. Evaluation of Priority and Nonconventional Metals in Water Treatment Plant Residuals

Pollutant	Source Water Contaminant Removed from Drinking Water [a]	Present in Treatment Chemicals? [b]					
		Aluminum-Based Coagulant	Iron-Based Coagulant	Potassium Permanganate	Organic Polymers	Lime Products	Caustic Soda
Priority Metals							
Antimony, total	Yes	No	Yes—Treatment chemical impurity	No	No	No	No
Arsenic, total	Yes	No—Not present.					
Beryllium, total	Yes	No—No data.					
Cadmium, total	Yes	No	Yes—Treatment chemical impurity	No	No	Yes—Treatment chemical impurity	No
Chromium, total	Yes	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	No	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity
Copper, total	Yes	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	No	No	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity
Cyanide, total	Yes	No—No data.					
Lead, total	Yes	No	Yes—Treatment chemical impurity	No	No	No	No
Mercury, total	Yes	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	No	No	No
Nickel, total	No [e]	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	No	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity
Selenium, total	Yes	No	No	Yes—Treatment chemical impurity	No	No	No
Silver, total	Yes	No	No	Yes—Treatment chemical impurity	No	No	No
Thallium	Yes	No—No data.					
Zinc, total	Yes	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity

Table 8-2. Evaluation of Priority and Nonconventional Metals in Water Treatment Plant Residuals

Pollutant	Source Water Contaminant Removed from Drinking Water [a]	Present in Treatment Chemicals? [b]					
		Aluminum-Based Coagulant	**Iron-Based Coagulant**	**Potassium Permanganate**	**Organic Polymers**	**Lime Products**	**Caustic Soda**
Nonconventional Metals (Limited to those potentially in DWT Residuals)							
Aluminum, total	Yes	Yes—Treatment chemical addition (active ingredient)	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity
Barium, total	Yes	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	No	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity
Calcium, total [c]	No [f]	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical addition (active ingredient)	Yes—Treatment chemical impurity
Cobalt, total	No [e]	No	Yes—Treatment chemical impurity	No	No	Yes—Treatment chemical impurity	No
Fluoride, total	Yes	No—No data					
Iron, total	Yes	Yes—Treatment chemical impurity	Yes—Treatment chemical addition (active ingredient)	Yes—Treatment chemical impurity	No	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity
Magnesium, total	No [f]	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	No	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity
Manganese, total	Yes	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical addition (active ingredient)	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity
Molybdenum	No [e]	No	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	No	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity
Potassium, total	No [e]	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical addition (active ingredient)	No	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity
Silicon	No [e]	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity
Sodium, total [d]	No (but may be present in source water)	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical addition (active ingredient)

Table 8-2. Evaluation of Priority and Nonconventional Metals in Water Treatment Plant Residuals

Pollutant	**Source Water Contaminant Removed from Drinking Water** [a]	**Present in Treatment Chemicals?** [b]					
		Aluminum-Based Coagulant	**Iron-Based Coagulant**	**Potassium Permanganate**	**Organic Polymers**	**Lime Products**	**Caustic Soda**
Strontium, total	No [e]	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	No	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity
Tin, total	No [e]	No	Yes—Treatment chemical impurity	No	No	No	No
Titanium, total	No [e]	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity
Vanadium, total	Yes	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	No	No	Yes—Treatment chemical impurity	No
Yttrium, total	No [e]	No	No	Yes—Treatment chemical impurity	No	Yes—Treatment chemical impurity	No
Zirconium, total	No [e]	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	Yes—Treatment chemical impurity	No

Sources: U.S. EPA, 2008 and Cornwell, 2002.

a – Identified by EPA as a contaminant in drinking water.

b – “Yes” indicates that the metal was detected in at least one formulation sample. Specific formulation details are included in Appendix B.

c – Also an active ingredient in calcium hypochlorite (may be used for chlorination).

d – Also an active ingredient in sodium hypochlorite (may be used for chlorination).

e – Although not identified by EPA as a drinking water contaminant, metal may be present in certain source waters from natural materials (e.g., ores) or industrial discharges.

f – Calcium and magnesium ions may be present in source water and removed via lime softening.

8.3.1 Aluminum and Iron

As discussed in Section 6, WTPs use aluminum and iron salts as coagulants. These metals are active ingredients in coagulants; and their use occurs at precipitative softening and conventional filtration plants. These metals, along with coagulant impurities, become part of the residual waste stream. In addition, the metals can be found in some source waters. Also, DMR data collected with the 2007 industry questionnaire demonstrate the presence of aluminum and iron in WTP discharges. As a result, EPA included aluminum and iron in the pollutant loadings analysis (see Section 9).

8.3.2 Arsenic

Arsenic may be present at potentially high levels in the source water, especially ground water sources. Sources of arsenic include natural sources (e.g., rocks, soil) and industrial sources (e.g., use as a wood preservative). Higher concentrations of arsenic are typically found in ground water compared to surface water. States in the western part of the United States tend to have more public water systems with arsenic levels exceeding the MCL of 10 parts per billion (ppb) for finished drinking water. Most of the systems in the Midwest and Northeast have arsenic levels between 2 and 10 ppb (U.S. EPA, 2006a). Most systems with high levels of arsenic are small systems (serving less than 10,000 people).

Of the systems affected by the OGWDW final arsenic rule (66 FR 6976, January 22, 2001), 97 percent were small systems. EPA’s 2007 industry questionnaire focused on large WTPs and the DMR data collected did demonstrated that arsenic was not present at measurable concentrations. Therefore, EPA did not include arsenic in the pollutant loadings analysis (see Section 9).

8.3.3 Calcium and Sodium

Calcium and sodium are active ingredients in lime products and caustic soda, respectively. Lime products and caustic soda are added to reduce hardness (i.e., remove calcium and magnesium from the source water). EPA has not set MCLs for these two pollutants in drinking water. DMR data collected with the 2007 industry questionnaire demonstrated the presence of calcium, but no sodium. Therefore, EPA included only calcium in its pollutant loadings analysis (see Section 9).

8.3.4 Fluoride

Fluoride occurs naturally in source water. WTPs may add fluoride to the drinking water to promote healthy teeth; however, fluoride addition typically occurs at the end of the source water treatment process. WTPs use finished drinking water to backwash filters; fluoride may be present in residuals if added prior to finished water use as backwash. At the majority of WTPs, the concentration of the fluoride in the wastewater is similar to the concentration in the finished drinking water. DMR data collected with the 2007 industry questionnaire demonstrated the presence of fluoride in discharges. EPA included fluoride in its pollutant loadings analysis (see Section 9).

8.3.5 Manganese and Potassium

Manganese and potassium are active ingredients in potassium permanganate. Potassium permanganate is added to control taste and odors, remove contaminants that cause color, control biological growth in treatment plants, and remove iron and manganese from the source water. EPA set secondary standards for manganese at 0.05 mg/L for drinking water. DMR data collected with the 2007 industry questionnaire demonstrated the presence of manganese, but not potassium. Therefore, EPA included only manganese in its pollutant loadings analysis (see Section 9).

8.3.6 Additional Metals with DMR Data

As summarized in Table 8-2, metals may be present in the source water (and concentrated in the WTP residuals) or in the treatment chemicals. The following metals are trace contaminants in common WTP treatment chemicals and monitored by WTPs in the DMR data collected by EPA:

- Barium;
- Cadmium;

- Copper;
- Lead;
- Magnesium;
- Nickel; and
- Zinc.

EPA included these metals in its pollutant loadings analysis (see Section 9).

8.4 WTP POLLUTANTS FROM DISINFECTION

As discussed in Section 6.6, WTPs add disinfecting agents during source water treatment to eliminate or inactivate microbiological populations. Primary disinfection occurs at the front of the source water treatment process; disinfecting chemicals and any resulting by-products might be found in WTP residuals generated later in the treatment process. Secondary disinfection occurs at the clear well or in the distribution system to prevent microbiological regrowth. If secondary disinfection occurs at the clear well, disinfecting chemicals and any resulting by-products might be found in wastewaters where finished water is used for washing or cleaning (e.g., filter backwash).

Chlorine is the most commonly used disinfectant. To disinfect with chlorine (or chlorination), WTPs can use gaseous chlorine; calcium hypochlorite ($Ca(OCl)_2$), an easily dissolved solid containing 65 percent available chlorine; or sodium hypochlorite (NaOCl), a solution with 5 to 15 percent chlorine. Other disinfectant chemicals include chloramines (chlorine gas and ammonia), chlorine dioxide, and ozone. Most U.S. WTPs use gaseous chlorine to disinfect drinking water (U.S. EPA, 2009).

Disinfection by-products (DBPs) form when disinfectants react with substances in the source water, such as bromide and/or natural organic matter. EPA promulgated maximum contaminant levels (MCLs) in drinking water for DBPs because they are potentially carcinogenic (71 FR 478).

The DMR data collected with the 2007 industry questionnaire includes concentrations for total residual chlorine and four DBPs: 1) bromodichloromethane, 2) chloroform, 3) dibromochloromethane, and 4) trihalomethane. EPA did not have DMR data for chloramines discharges, but did have DMR data for ammonia concentrations in the effluent. EPA included ammonia, total residual chlorine, the four DBPs listed above, and two additional DBPs, bromoform and haloaectic acids, in the pollutant loadings analysis (see Section 9).

8.4.1 Chemistry of Chlorine Disinfection

Depending on the chemistry of the source water and wastewater, various forms of chlorine and disinfection by-products may be present in WTP residuals. Figure 8-1 shows the chemistry of how chlorine reacts when added during source water for disinfection (primary or secondary) purposes (CDC, 2006; Block, 2000).

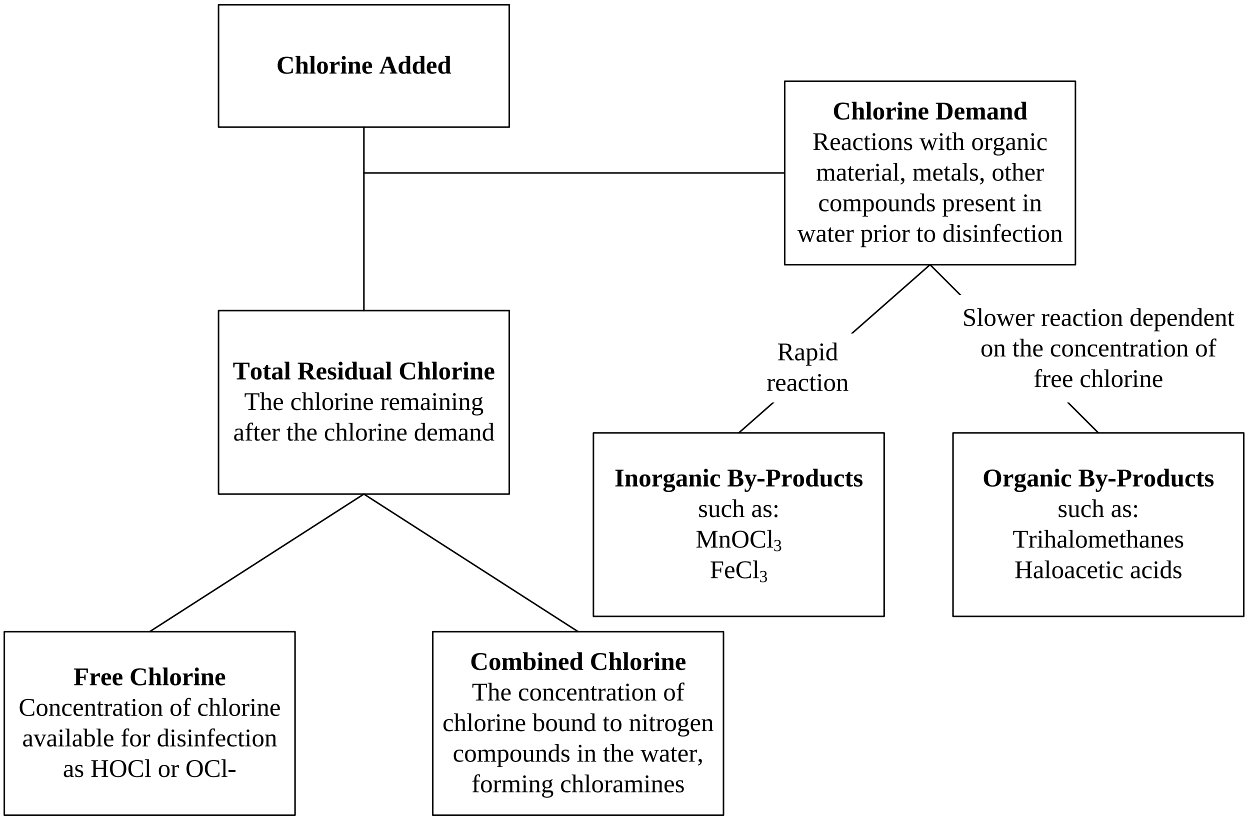

Figure 8-1. Chemistry of Compounds Resulting from Chlorine Disinfection (CDC, 2006; Block, 2000)

The chlorine chemistry shown above includes the following three components: 1) chlorine added; 2) chlorine demand; and 3) total residual chlorine.

8.4.1.1 Chlorine Added

As discussed above, chlorine may be added at several points during source water treatment for disinfection. Primary disinfection is the addition of a disinfectant before sedimentation or filtration to achieve desired inactivation of microorganisms. Secondary disinfection is the addition of a disinfectant at the clear well and/or various points in the distribution system to maintain a disinfectant residual in the finished water, preventing regrowth of microorganisms.

8.4.1.2 Chlorine Demand

Chlorine demand is the chlorine consumed by inorganic and organic substances in the water, not including amines. Chlorine reacts rapidly with inorganic substances, such as metals (manganese and iron), hydrogen sulfide, and nitrites. Chlorine reacts more slowly with organic substances, and the reaction depends on the amount of free chlorine available (U.S. EPA, 1999a). By-products formed during chlorination include inorganic chlorine compounds, such as $FeCl_3$ and $MnOCl_3$ and organic chlorine compounds, such as trihalomethanes and haloacetic acids.

8.4.1.3 Total Residual Chlorine

Total residual chlorine (TRC) is the amount of chlorine remaining after chlorine demand. TRC includes combined chlorine and free chlorine. Combined chlorine is the chlorine that has combined with amines to form chloramines. Although chloramines are a weaker disinfectant than chlorine, some WTPs use them for secondary disinfection. To perform disinfection with chloramines, WTPs inject chlorine, followed by ammonia into the distribution main. Chloramines are more stable than free chlorine in distribution systems and therefore more effective in controlling microorganism regrowth.

There are three chloramine compounds, formed in the following conditions:

1. Monochloramine (NH_2Cl): $NH_3 + HOCl \rightarrow NH_2Cl + H_2O$; pH near 6
2. Dichloramine ($NHCl_2$): $NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$; pH near 5
3. Nitrogen trichloride (NCl_3) : $NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$; Uncommon; undesirable

Free chlorine is the chlorine that is available for disinfection after other chlorine compounds are formed, found as HOCl or OCl-, depending on pH.

8.4.2 Residual Disinfectants in Finished Drinking Water

Under the Safe Drinking Water Act (SDWA), EPA set requirements for drinking water systems to ensure safe levels of disinfectants in the finished drinking water. The Total Coliform Rule requires a minimum residual disinfectant level of 0.2 mg/L of total residual chlorine for treated water entering the distribution system. Drinking water systems maintain residual disinfectants in the finished water to ensure disinfection throughout the distribution system.

EPA also set primary standards for the finished drinking water including the maximum residual disinfectant levels (MRDLs) allowed. The MRDLs are:

- Chlorine: 4.0 mg/L;
- Chloramines (as chlorine): 4.0 mg/L; and
- Chlorine dioxide: 0.8 mg/L.

8.4.3 Disinfection By-Products

EPA identified four parameters in its DBP rules: chlorite, bromate, haloacetic acids, and trihalomethanes (71 FR 478). EPA set standards for these because they are good indicators of DBPs in disinfected drinking water, and because they are usually found at measurable concentrations (71 FR 478). Haloacetic acids include monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid. Trihalomethanes include chloroform ($CHCl_2$, trichloromethane), bromodichloromethane ($CHCl_2Br$), bromoform (tribromomethane), and dibromochloromethane ($CHClBr_2$).

Chlorite is a by-product from disinfection with chlorine dioxide. Bromate is a by-product from disinfection with ozone. Trihalomethanes and haloacetic acids by-products form primarily from disinfection with chlorine, but also form when other disinfectants are used (71 FR 478).

WTPs can control DBPs by three methods: 1) removal of DBP precursors (i.e., natural organic matter), 2) modifying chlorination strategy, or 3) removing DBPs after formation, where the last of these is the most difficult process. Most plants typically focus on removing DBP precursors prior to chlorination. In general, aggregate DBP formation will decrease as the removal of total organic carbons (TOCs) increases. Studies have found that adding chlorine later (downstream) in the source water treatment process (e.g., adding after sedimentation) results in a reduction of DBP formation. However, some plants use the addition of chlorine to promote other pollutant removals prior to sedimentation (e.g., iron removal, manganese removal, taste/odor control, and color removal). Plants may also decrease DBP formation by the use of enhanced coagulation (U.S. EPA, 1999b).[21]

8.5 PARAMETERS MEASURING ORGANIC MATTER AND OXYGEN IN THE WATER IN WTP RESIDUALS

Plants can measure organic matter and oxygen content in the wastewater using various parameters. Permit writers select which parameter works best for their NPDES permitting program.

8.5.1 Biochemical Oxygen Demand

BOD is an estimate of the oxygen-consuming requirements of organic matter decomposition under aerobic conditions. When WTP wastewaters are discharged to surface waters, the microorganisms present in the naturally occurring microbial ecosystem decompose

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[21] "Enhanced coagulation" is the term used to define the process of improving removal of DBP precursors (natural organic matter) by conventional filtration. "Enhanced softening" is the term used to define the process of improving removal of DBP precursors by precipitative softening.

the organic matter contained in the wastewater. The decomposition process consumes oxygen and reduces the amount available for aquatic animals.

BOD determinations include estimates of the amount of oxygen required for the degradation of both particulate and dissolved organic matter. Separation of these estimates is accomplished by first filtering the sample to remove particulate organic matter and then determining the BOD of the filtrate and dissolved BOD. The difference between BOD and dissolved BOD (DBOD) is an estimate of the contribution of particulate matter to total BOD. Also, BOD_5 typically measures carbonaceous oxygen demanding organic material in the wastewater (CBOD). Nitrogenous oxygen demanding material (NBOD or NOD) is not likely to be a major concern for WTP wastewaters, as it is for certain nitrogen-containing industrial and municipal wastewaters and associated treatment systems.

DMR data collected with the 2007 industry questionnaire includes concentration of BOD in effluent discharges from conventional filtration plants. The data also includes CBOD concentrations in effluent discharges from membrane desalination and ion exchange plants. EPA included BOD and CBOD in the pollutant loadings estimate (see Section 9).

8.5.2 Dissolved Oxygen

Dissolved oxygen (DO) measures the amount of oxygen in the water. Water bodies both produce and consume oxygen. A water body gains oxygen from the atmosphere and from plants as a result of photosynthesis. Running water, because of its churning, dissolves more oxygen than still water. Respiration by aquatic animals, decomposition, and various chemical reactions consume oxygen.

WTP residuals may contain organic materials that are decomposed by microorganisms, using oxygen in the process. The amount of oxygen used is measured as BOD (discussed above). If more oxygen is consumed than produced, DO levels decline and some sensitive animals may move away, weaken, or die.

DO levels fluctuate seasonally and over a 24-hour period. The level also varies with water temperature and altitude. Cold water holds more oxygen than warm water, and water holds less oxygen at higher altitudes.

EPA received DO data with the DMR data collected with the 2007 industry questionnaire. Because DO requirements are to maintain a minimum level, EPA did not include this pollutant in the pollutant loadings estimate (see Section 9).

8.6 OTHER POLLUTANTS IN WTP

Other pollutant parameters found in residuals are primarily contaminants removed from the source water to produce finished drinking water. The pollutants discussed in this section include chloride, nitrogen, pH, phosphorous, and radionuclides.

8.6.1 Chloride

Chloride (Cl-) is a common anion in wastewaters and natural waters. Excessively high chloride concentrations in surface waters can impair their use as source waters for potable water supplies. If sodium is the predominant cation present, the water will have an unpleasant taste due to the corrosive action of chloride ions. Chloride is a constituent of TDS; dissolved solids are removed using membrane desalination and ion exchange processes. DMR data collected with the 2007 industry questionnaire includes concentrations of chlorides in effluent discharges from membrane desalination and ion exchange plants. EPA used these concentrations in its pollutant loadings analysis (see Section 9).

8.6.2 Nitrogen

Nitrogen may be present in WTP residuals (removed from the source water). WTPs are required to meet primary drinking water standards for nitrate (measured as nitrogen) and nitrite (measured as nitrogen). There are several parameters to measure forms of nitrogen, including total nitrogen, total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH4-N), and nitrite plus nitrate nitrogen (NO2 + NO3-N). TKN is defined as the sum of organic nitrogen and free ammonia. DMR data collected with the 2007 industry questionnaire includes total nitrogen concentrations and ammonia concentrations. EPA used these concentrations in its pollutant loadings analysis (see Section 9).

8.6.3 pH

WTPs adjust the pH to optimize source water treatment, and the addition of lime for softening raises the pH of the water. The hydrogen-ion concentration in an aqueous solution is represented by the pH, which is defined as the negative logarithm of the hydrogen-ion concentration in a solution. On the pH scale ranging from zero to 14, a value of seven represents neutral conditions—the concentrations of hydrogen (H+) and hydroxyl ions (OH-) are equal. pH values less than seven indicate acidic conditions and values greater than seven represent basic conditions.

EPA received pH data with the DMR data collected with the 2007 industry questionnaire. Because pH cannot be expressed as pounds in the discharge, EPA did not include this pollutant in the pollutant loadings estimate (see Section 9).

8.6.4 Phosphorus

The sources of phosphorus in WTP residuals and wastewater discharges include the source water and treatment chemicals for scale and corrosion control. In marine waters, phosphorus is not as much of a concern because of relatively high naturally occurring phosphorus concentrations. The impact of phosphorus in wastewater discharges into estuaries varies—in general, impacts decrease as salinity levels increase. DMR data collected with the 2007 industry questionnaire includes phosphorus concentrations in effluent discharges. EPA used these concentrations in its pollutant loadings analysis (see Section 9).

8.6.5 Radionuclides

Low levels of radioactive contaminants, or radionuclides, occur in most drinking water sources and do not pose a public health risk. However, some drinking water sources have elevated radionuclide levels, usually occurring naturally (from certain rock types). Radionuclides regulated by EPA include the following:

- Combined radium -226/-228: occurs naturally in some drinking water sources.
- (Adjusted) Gross alpha: occurs naturally in some drinking water sources.
- Beta particle and photon radioactivity: contamination from facilities using or producing radioactive materials.
- Uranium: occurs naturally in some drinking water sources.

Some drinking water sources located in the Midwest have elevated levels of radium -226/-228, while some sources in the West have elevated uranium levels (U.S. EPA, 2006c). DMR data collected with the 2007 industry questionnaire includes concentration for radionuclides at some WTPs. However, since the presence of radionuclides is dependent on the source water, EPA did not use the DMR data to estimate pollutant loadings for the industry (see Section 9).

8.7 REFERENCES

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SECTION 9

WATER TREATMENT PLANT POLLUTANT DISCHARGE ESTIMATES

As part of its effluent guidelines review process, EPA developed a variety of tools and methodologies to evaluate effluent discharges from various industrial categories. One of the main tools EPA used is an estimate of pollutant loadings being discharged from facilities within an industry sector. This section discusses how EPA estimated pollutant loadings for the drinking water treatment (DWT) industry.

Pollutant loadings are the estimated amount of pollutants in water treatment plant (WTP) residuals currently being discharged to surface waters, whether directly from the plant or indirectly from publicly owned treatment works (POTWs) after taking POTW treatment effectiveness into account (i.e., pollutants that pass through the POTW). As part of the drinking water industry review, EPA estimated pollutant loadings from water treatment plants (WTPs) in the U.S. that serve more than 10,000 people. These loadings include contaminants in the source water that are removed to produce drinking water, and ingredients present in treatment chemicals added by the WTP. EPA did not have data to quantify the pollutant discharges attributed to source water contaminants and those attributed to treatment chemical addition.

EPA estimated discharges for bulk parameters and chemical-specific parameters. Bulk parameters for the DWT pollutant loadings analysis include biochemical oxygen demand (BOD), carbonaceous BOD (CBOD), total nitrogen, total dissolved solids (TDS) and total suspended solids. The pollutant loadings estimated for bulk parameters may include the chemical-specific pollutant loading (e.g., TSS loadings include metals such as aluminum loadings). Because some portion of the chemical-specific pollutants are included in the bulk pollutant estimates, the two estimates should never be summed as this would constitute double counting of pollutants and result in an overestimate of the total pollutant loadings from DWT. EPA presents both bulk and chemical-specific parameters in this report since they offer different types of information but these estimates will always be presented separately to emphasize the non-additive nature of the data.

Overall, EPA estimated that the discharges from the industry are 574 million pounds of bulk parameters per year and 352 million pounds per year of chemical-specific parameters, including metals and pollutants from disinfection with chlorine (chlorination). The majority of the bulk parameter loadings (over 98 percent) are TSS: 314 million pounds per year, primarily from precipitative softening plants, and TDS: 252 million pounds per year, primarily from ion exchange/adsorption plants. In EPA's loadings analysis most of the chemical-specific parameter releases (over 98 percent) are due to the following five pollutants:

1. Chlorides: 326 million pounds per year from membrane desalination and ion exchange/adsorption plants;

2. Calcium: 14.4 million pounds per year from precipitative softening and coagulation/filtration plants;

3. Magnesium: 4.2 million pounds per year from precipitative softening and coagulation/filtration plants;

4. Lead: 1.97 million pounds per year, primarily from coagulation/filtration plants; and

5. Aluminum: 1.48 million pounds per year, primarily from coagulation/filtration plants.

In addition to the pounds per year, EPA also estimated the toxic-weighted pound equivalent (TWPE) for the loadings parameters to determine the relative toxicity of DWT discharges[22]. EPA used toxic weighting factors (TWFs) that are specific to each chemical. EPA estimated 415,000 toxic-weighted pounds per year. Most of the TWPE (85 percent) is due to five pollutants:

1. Total Residual Chlorine: 120,000 pound equivalents per year (lb-eq/yr);
2. Aluminum: 88,600 lb-eq/yr;
3. Copper: 60,700 lb-eq/yr;
4. Manganese: 41,800 lb-eq/yr; and

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[22] The DWT discharges include both the source water contaminants removed to produce drinking water and ingredients in treatment chemicals added by the WTP. EPA does not have sufficient source water characteristic data to determine the proportion of the total discharge loadings that come from source water contaminates versus material added by the WTP facilities as part of the drinking water treatment process.

5. Fluoride: 41,100 lb-eq/yr.

This section describes EPA's pollutant loadings analysis in the following subsections:

- Section 9.1: Data sources used for the pollutant loadings analysis;
- Section 9.2: Methodology to estimate pollutant loadings using model plants;
- Section 9.3: Selection of pollutants to include in the loadings estimates;
- Section 9.4: Development of long-term averages for pollutants;
- Section 9.5: Pollutant loadings estimate for model plants; and
- Section 9.6: National discharge estimate of pollutants from WTPs serving more than 10,000 people.

9.1 DATA SOURCES FOR THE POLLUTANT LOADINGS ANALYSIS

For this analysis, EPA estimated pollutant loadings discharged in the base year of the questionnaire (2006). EPA used the following data sources as part of the pollutant loadings analysis:

- **Discharge monitoring report (DMR) data from WTPs (U.S. EPA, 2007):** These data were used to calculate average pollutant concentrations in the discharges for model plants by source water treatment type and type of residuals treatment. EPA also used the flow rates reported to calculate average direct discharge flow rates for model plants by source water treatment type. EPA used data from 108 WTPs (direct dischargers with completed survey responses and submitted DMR data). EPA supplemented pollutant concentration data for pollutants resulting from chlorination using four additional WTPs with DMR data.

- **2006 WTP Questionnaire Response Database – Technical Data** (U.S. EPA, 2009a): EPA used the survey responses to classify WTPs with DMR data into the four characteristics used to define model plants (see below). EPA also used the flow rates for indirectly-discharging plants to calculate average indirect discharge flow rates for model plants by source water treatment type.

- **EPA published maximum contaminant levels (MCLs)** (U.S. EPA, 2008b)**:** MCLs are the maximum amount of a source water contaminant allowed in the finished drinking water. For one pollutant without DMR data (haloacetic acids), EPA used the MCL to estimate the average concentration discharged by model plants.

- **EPA National Estimates: WTP Counts for Pollutant Loadings** (see Appendix A) EPA used the survey responses to classify all WTPs in the sample frame into the four characteristics used to define model plants (see below).

9.2 METHODOLOGY TO ESTIMATE POLLUTANT LOADINGS USING MODEL PLANTS

EPA used a model plant approach to estimate pollutant loadings from the drinking water treatment industry. EPA estimated the pollutant loadings being discharged from each of the model plants and then calculated national discharges by multiplying the model treatment plant loadings by the number of WTPs represented by that model plant. A WTP may represent multiple types of source water treatment, but was counted only one time in the totals.

9.2.1 Model Plant Development

EPA used four factors representing the different types of WTPs in the U.S. to develop the model plants. EPA selected these four major factors because they govern the amount of pollutants discharged in residuals. The four factors are:

- Type of WTP (such as coagulation and filtration or precipitative softening);
- Type of residuals treatment in place;
- WTP size; and
- Discharge status (i.e., direct or indirect).

Applying these four factors led to the development of distinct model plants. Each of the factors is described in detail below.

9.2.1.1 Type of WTP

Based on data collected for the industry review, EPA determined that pollutant concentrations in residuals would vary by source water treatment type and type of residuals treatment in place. The five source water treatment types that EPA included in its analysis are the following:

- Precipitative (i.e., lime) softening: includes all plants performing precipitative softening.
- Coagulation & filtration: includes conventional filtration plants, direct filtration plants, microfiltration (MF) plants also performing coagulation; and ultrafiltration (UF) plants also performing coagulation.
- Filtration only: includes plants performing filtration, MF, and UF without coagulation.
- Membrane desalination: includes reverse osmosis (RO), nanofiltration (NF), electrodialysis (ED), and electrodialysis reversal (EDR) plants.
- Ion exchange & adsorption: includes plants performing ion exchange or adsorption (e.g., granular activated carbon).

9.2.1.2 Type of Residuals Treatment

EPA identified two groups of residuals treatment that would affect the pollutant concentration in the effluent: 1) solid/water separation and 2) dechlorination. For most pollutants, WTPs use solid/water separation to treat residuals. For pollutants resulting from disinfection with chlorine, WTPs use dechlorination to treat the residuals. EPA determined that pollutant concentrations in residuals would vary by the type of residuals treatment in place. For pollutants other than those from disinfection with chlorine, EPA used two residuals treatment types for model plants: 1) solid/water separation or 2) no solid/water separation. For pollutants resulting from disinfection with chlorine, EPA also used two residuals treatment types for model plants: 1) dechlorination; and 2) no dechlorination.

9.2.1.3 WTP Size/Flow Rate

In addition to the two characteristics affecting pollutant concentrations in discharges (source water treatment and residuals treatment), pollutant loadings are based on the volume of wastewater residuals generated. EPA determined that the discharge flow rate would vary by source water treatment type, plant size (correlated to population served), and discharge status (direct or indirect). EPA used the following population served size categories for the model plants:

- Population served between 10,001 and 50,000 people;
- Population served between 50,001 and 100,000 people;
- Population served between 100,001 and 500,000 people; and
- Population served greater than 500,000 people.

9.2.1.4 Discharge Status

In addition to using the discharge status (direct or indirect) to determine model plant effluent flow rates, EPA also used the discharge status when calculating pollutant loadings. For model plants discharging indirectly (i.e., wastewater treated by a POTW prior to discharge in waters of the U.S.), EPA accounted for the pollutants removed by the POTW (i.e., loadings are for pollutants that pass through the POTW).

9.2.2 Estimation of Model Plant Pollutant Loadings

EPA estimated pollutant loadings for each model plant and pollutant parameter for the base year of 2006 using the equations below:

$$\text{Model Plant Load} = (\text{Concentration} \times \text{Flow} \times \text{Conversion Factor}) \qquad \text{(Eq. 9-1)}$$

where:

Model Plant Load = Pollutant loadings, in pounds per year (lbs/year).
Concentration = Annual average pollutant concentration, in milligrams per liter (mg/L).
Flow = Production-based discharge flow rate, in million gallons per day.
Conversion factor = 8.345 (to convert the loadings into lbs/year; derived from 3.784 L/gal × 2.2 lbs/kg) x 365 days per year.

EPA estimates the pollutant loadings from indirect dischargers to account for pollutant discharges that pass through the POTW to surface waters. Indirect discharges are treated at POTWs prior to discharge and EPA takes that treatment into account when calculating pollutant loadings. For indirect dischargers, EPA uses the results from Equation 9-1 and accounts for treatment at the POTW prior to discharge to surface waters using Equation 9-2:

$$\text{Load}_{\text{POTW}} = (1 - \text{POTW \% Removal}) \times \text{Model Plant Load} \qquad \text{(Eq. 9-2)}$$

where:

$\text{Load}_{\text{POTW}}$ = Pollutant loadings discharged to surface water after treatment at the POTW, in pounds per year (lb/year).
Model Plant Load = Pollutant loadings discharged to the POTW from Equation 9-1 for each indirect discharger, in pounds per year (lb/year).
POTW % Removal = Percent removal at the POTW, shown in Appendix C

Most of the POTW percent removal values are based on data from the Fate of Priority Pollutants in Publicly Owned Treatment Works and National Risk Management Research Laboratory (NRMRL) Treatability Database (U.S. EPA, 1982 and U.S. EPA, 1994) and are presented in Appendix C. The pollutant loadings and associated removals for indirect dischargers presented in this report represent pass through discharge from POTWs to receiving streams using the above equation.

EPA also estimated toxic-weighted pound equivalent (TWPE) pollutant loadings. To calculate TWPE, EPA multiplied the annual load (lb/yr) by a toxic weighting factor (TWF). TWFs account for differences in toxicity across pollutants and provide the means to compare mass loadings of different pollutants on the basis of their toxic potential. EPA multiplies a mass loading of a pollutant in pounds per year (lb/yr) by a pollutant-specific weighting factor to derive a "toxic-equivalent" loading (lb-equivalent/yr), or TWPE. EPA has developed TWFs for more than 1,900 pollutants based on aquatic life and human health toxicity data, as well as physical/chemical property data. EPA calculated TWPE using Equation 9-3. TWPEs do not apply to conventional pollutants or bulk parameters.

$$\text{TWPE (lb-eq-yr)} = \text{Annual Load (lb/yr)} \times \text{TWF} \qquad \text{(Eq. 9-3)}$$

The TWFs used for the pollutant loading estimates are presented in Appendix D (U.S. EPA, 2006).

9.3 MODEL PLANT CONCENTRATION ESTIMATION

To estimate model plant loadings, Equation 9-1 lists two variables: concentration and flow rate. This section discusses how EPA estimated pollutant concentrations in the model plant effluent discharges and Section 9.4 discusses how EPA estimated effluent discharge flow rates for the model plants.

9.3.1 Selection of Pollutant Parameters for Pollutant Loadings Analysis

EPA identified two groups of pollutant parameters for the loadings analysis based on type of residual treatment that affects the pollutant discharges: 1) pollutants resulting from the disinfection with chlorine (chlorination); and 2) all other pollutants. Chlorination pollutants include: total trihalomethanes, chloroform, bromodichloromethane, bromoform, dibromochloromethane, haloacetic acids, chloramines, and total residuals chlorine. To treat chemicals resulting from disinfection with chlorine, WTPs perform dechlorination. To treat all other pollutants, WTPs perform solid/water separation.

EPA selected a subset of pollutants for the model plant loadings estimates based on three main factors: 1) ability to estimate pollutant loadings in pounds per year (lbs/yr), 2) availability of concentration data from the DMR submittals, and 3) presence of the pollutant in the residuals for the source water treatment type.[23]

EPA included three pollutants without DMR data in the pollutant loadings analysis. Bromoform, haloacetic acids, and chloramines are by-products of disinfection with chlorine. EPA estimated loadings for bromoform and haloacetic acids using a mass balance approach, which allows the estimation of pollutant loadings without DMR data. For bromoform,

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[23] The memorandum entitled *Pollutant Loadings Estimates for Drinking Water Treatment Plants: Model Plants and National Estimates* (ERG, 2009) details the selection of pollutants for the loadings analysis.

EPA transferred the effluent concentration from chloroform. For haloacetic acids, EPA used the drinking water MCL to estimate pollutant loadings. For chloramines, EPA performed a qualitative review of the discharges of chloramines from WTPs.

EPA selected 27 pollutants to include in the loadings analysis. For pollutants resulting from chlorination, EPA estimated discharge concentrations based on two factors: 1) whether the WTP disinfects with chlorine and 2) whether residuals are treated using dechlorination prior to discharge). If the WTP does not use chlorine for disinfection, EPA set the loadings for the chlorination pollutants equal to zero. EPA assumed that WTPs that do not disinfect with chlorine would not discharge pollutants resulting from chlorination. EPA did not differentiate between source water treatment types (e.g., assumed concentrations would be the same for precipitative softening plants as for plants with only filtration). Table 9-1 presents the pollutants selected for the loadings estimates for each source water treatment type.

Table 9-1. Pollutants Included in the Loadings Estimates

Parameter	Precipitative Softening	Coagulation and Filtration	Filtration Only	Membrane Desalination	Ion Exchange and Adsorption
Conventionals					
BOD	X [a]	X	X [a]		
CBOD5				X	X
TSS	X	X	X	X	X
Other Solids					
TDS [c]					X
Chlorides				X	X
Nitrogen					
Nitrogen, Total [c]	X [a]	X	X [a]	X	X
Ammonia	X [a]	X	X [a]	X	X
Metals					
Aluminum	X	X	X		
Barium	X [a]	X			
Cadmium				X	X
Calcium	X [a]	X			
Copper	X [a]	X		X	X
Fluoride	X	X	X	X	X
Iron	X	X	X	X	X
Lead	X [a]	X	X [a]		X
Magnesium	X [a]	X			
Manganese	X	X	X		X

Table 9-1. Pollutants Included in the Loadings Estimates

Parameter	Precipitative Softening	Coagulation and Filtration	Filtration Only	Membrane Desalination	Ion Exchange and Adsorption
Nickel	X[a]	X			
Phosphorus	X[a]	X	X[a]	X	X
Zinc	X[a]	X			X
Pollutants from Chlorination and Disinfection By-Products					
Bromodichloromethane	X[b]				
Bromoform	X[b]				
Chlorine, Total Residual	X[b]				
Chloroform	X[b]				
Dibromochloromethane	X[b]				
Haloacetic acids	X[b]				
Trihalomethane	X[b]				

a – Transfer concentrations from coagulation/filtration source water treatment type. Note that all but three of the survey respondents that perform precipitative softening also perform coagulation and filtration (U.S. EPA, 2009a); therefore EPA included the same pollutants in the loadings analysis for each model plant type. For filtration only, EPA transferred pollutant concentrations from coagulation and filtration for source water contaminant pollutants that may be concentrated in the residuals.

b – Pollutant discharges expected only from WTPs that disinfect with chlorine. For pollutant loading estimates, EPA did not group chlorination chemical concentrations by source water treatment type.

c – Bulk parameters represent more than one pollutant. For example, Total Nitrogen includes ammonia nitrogen (NH_3) as well as organic nitrogen, nitrate, and nitrite. EPA estimated loads for total nitrogen in lbs/yr. EPA estimated loads for ammonia nitrogen in lbs/yr and TWPE/yr. EPA does not estimate TWPE for bulk parameters, because TWFs apply to specific chemicals. TDS is also a bulk parameter that includes chlorides.

In addition to grouping DMR data by source water treatment type, EPA used the survey response database (U.S. EPA, 2009a) to determine whether the WTP performed residuals treatment prior to discharge. WTPs use solid/water separation to remove most pollutants from the residuals. Three of the plants fell under two source water treatment types. EPA used the plant's DMR data to characterize discharges from both source water treatment types. Table 9-2 summarizes the WTPs with DMR data and whether solid separation is used to treat residuals.

Table 9-2. Type of Source Water Treatment and Residuals in Place (Solid/Water Separation) for WTPs with DMR Data

Source Water Treatment Type	Total Number of Plants	Number of Plants without Solid/Water Separation (Untreated)	Number of Plants with Solid/Water Separation (Treated)
Precipitative softening	24	6	18
Coagulation/filtration	76	6	70
Filtration only (including MF and UF)	5	1	4
Membrane desalination [a]	2	2	0
Ion exchange and adsorption [b]	4	1	3
Total [c]	**108**	**15**	**93**

Source: U.S. EPA, 2009a and U.S. EPA, 2007.

a – DMR data available for high pressure membrane (reverse osmosis and nanofiltration) plants. Data were not available for electrodialysis and electrodialysis reverse plants; assume discharge similar pollutants and at similar concentrations to high pressure membrane plants. Desalination membrane plants typically do not treat the concentrate prior to discharge (Malmrose, et al., 2004).

b – DMR data available for ion exchange plants. Data were not available for adsorption plants; assume discharge similar pollutants and at similar concentrations to ion exchange plants.

c – A WTP may represent multiple types of source water treatment, but was counted only one time in the totals.

To remove pollutants resulting from disinfection with chlorine, WTPs use dechlorination to treat residuals. Table 9-3 summarizes the WTPs with DMR data including whether the WTP uses chlorine for disinfection and whether dechlorination is used to treat residuals.

Table 9-3. Type of Source Water Treatment and Residuals in Place (Dechlorination) for WTPs with DMR Data

Source Water Treatment Type	Total Number of Plants	Number of Plants Performing Chlorination	Number of Plants without Dechlorination (Untreated)	Number of Plants with Dechlorination (Treated)
Lime softening	24	22	17	5
Coagulation/filtration	76	69	47	22
Filtration only (including MF and UF)	5	4	3	1
Membrane desalination [a]	2	2	1	1
Ion exchange and adsorption [b]	4	4	2	2
Total [c]	**108 [d]**	**98**	**68**	**30**

Source: U.S. EPA, 2009a and U.S. EPA, 2007.
a – DMR data available for high pressure membrane (reverse osmosis and nanofiltration) plants. Data were not available for electrodialysis and electrodialysis reverse plants; assume discharge similar pollutants and at similar concentrations to high pressure membrane plants.
b – DMR data available for ion exchange plants. Data were not available for adsorption plants; assume discharge similar pollutants and at similar concentrations to ion exchange plants.
c – A WTP may represent multiple types of source water treatment, but was counted only one time in the totals.
d – EPA used DMR data collected with the 2007 industry questionnaire from an additional four WTPs to characterize discharge of disinfection by-products (U.S. EPA, 2007). These four WTPs are not included in the above total because a complete survey review was not completed for the four WTPs; therefore, these four WTPs are not included in the technical survey response database (U.S. EPA, 2009a).

9.3.2 Development of Long-Term Average Concentrations for Pollutants

EPA estimated the annual average pollutant concentrations (long-term averages) for each model plant, based on source water treatment type and residuals treatment in place. EPA does not expect WTP size or discharge status to affect the concentration in the effluent discharge. EPA used DMR data from WTPs in the survey database with matching source water treatment type and residuals treatment in place to estimate long-term average concentrations. EPA used alternate approaches for two pollutants without DMR data:

1. Bromoform (tribromomethane): Transfer from similar trihalomethane (chloroform); and
2. Haloacetic acids (5HAA’s): Use MCL as concentration.

EPA used the DMR data supplied with the 2007 industry questionnaire response to estimate annual averages for each WTP and pollutant. To calculate the annual average pollutant concentration, EPA took the arithmetic mean of the samples taken in 2006. For samples showing presence of a chemical but at concentrations below detection limits, EPA used one-half of the method detection limit value to estimate pollutant loadings. For chemicals never detected in the effluent, EPA used a concentration of zero for the loadings estimates.

EPA averaged the DMR pollutant concentrations for each source water treatment type and residuals treatment in place (i.e., model plant). For most pollutants, EPA calculated annual average pollutant concentrations by the source water treatment type and whether the WTP treated residuals using solid/water separation. For pollutants resulting from disinfection with chlorine, EPA differentiated the average pollutant concentration only by whether or not the plant used chlorine for disinfection and performed dechlorination. EPA describes the long-term average calculations in more detail in the memorandum entitled, *Pollutant Loadings Estimates for Drinking Water Treatment Plants* (ERG, 2009).

Table 9-4 presents the model plant long-term average concentrations for all pollutants except those resulting from chlorination. These are grouped by source water treatment type and residuals treatment in place. EPA did not apply any toxic weighting factors (TWFs) to the long-term averages; TWFs are applied to the pounds per year loadings.

Table 9-5 presents the long-term average concentrations for pollutants resulting from chlorination. These are grouped only by the presence of dechlorination as part of residuals treatment. EPA did not apply any toxic weighting factors (TWFs) to the long-term averages; TWFs are applied to the pounds per year loadings.

Table 9-4. Long-Term Average Concentrations from DMR Data by Source Water Treatment Type and Residuals Treatment (mg/L)

Pollutant	**Precipitative Softening**		**Coagulation and Filtration**		**Filtration only**		**Membrane Desalination**		**Ion Exchange and Adsorption**	
	Solids Separation	**No Solids Separation**	**Solids Separation**	**No Solids Separation**	**Solids Separation**	**No Solids Separation**	**Solids Separation**	**No Solids Separation**	**Solids Separation**	**No Solids Separation**
Conventionals										
BOD	1.44 (b)	1.44 (b)	1.44	1.44 (e)	1.44 (b)	1.44 (b)	(d)	(d)	(d)	(d)
CBOD5	(d)	(d)	(d)	(d)	(d)	(d)	1.00 (f)	1.00	1.00 (f)	1.00
TSS	5.89	1,430	54.5	135	2.62	22.5	2.86 (f)	2.86	6.38 (a)	
Other Solids										
TDS	(d)	(d)	(d)	(d)	(d)	(d)	(d)	(d)	8,570	8,570 (e)
Chlorides	(c)	(c)	(c)	(c)	(c)	(c)	7,120 (f)	7,120	2,930	7,120
Nitrogen										
Nitrogen, Total	3.64 (b)	3.64	3.64	3.64 (e)	3.64 (b)	3.64 (b)	2.95 (f)	2.95	0.472	0.908
Ammonia	0.482 (b)	0.482 (b)	0.482	0.482 (e)	0.482 (b)	0.482 (b)	1.55 (f)	1.55	0.0894	0.0894 (e)
Metals										
Aluminum	0.177 (a)		2.16 (a)		0.919	0.919 (e)	(d)	(d)	(d)	(d)
Barium	0.0100 (b)	0.0100 (b)	0.0100	0.0100 (e)	(d)	(d)	(d)	(d)	(d)	(d)
Cadmium	(d)	(d)	(d)	(d)	(d)	(d)	0.00104 (f)	0.00104	0.00104 (f)	0.00104
Calcium	8.73 (b)	8.73 (b)	8.73	8.73 (e)	(d)	(d)	(d)	(d)	(d)	(d)
Copper (g)	0.0693 (b)	0.0693 (b)	0.0693	0.0693 (e)	(d)	(d)	0.000891(f)	0.000891	0.00149 (a)	
Fluoride	0.665	1.14	0.684	0.684 (e)	0.183	0.183 (e)	2.11 (f)	2.11	2.11 (f)	2.11
Iron	0.115	0.115 (e)	2.73	4.31	0.128	0.128 (e)	1.46 (f)	1.46	0.361 (a)	
Lead (g)	0.00569 (b)	0.00569 (b)	0.00569	0.00569 (e)	0.00569 (b)	0.00569 (b)	(d)	(d)	0.00	0.00
Magnesium	2.58 (b)	2.58 (b)	2.58	2.58 (e)	(d)	(d)	(d)	(d)	(d)	(d)
Manganese	0.346	0.346 (e)	0.442 (a)		0.0574	0.0574 (e)	(d)	(d)	0.368	0.368 (e)
Nickel (g)	0.00 (b)	0.00 (b)	0.00	0.00 (e)	(d)	(d)	(d)	(d)	(d)	(d)

Table 9-4. Long-Term Average Concentrations from DMR Data by Source Water Treatment Type and Residuals Treatment (mg/L)

Pollutant	**Precipitative Softening**		**Coagulation and Filtration**		**Filtration only**		**Membrane Desalination**		**Ion Exchange and Adsorption**	
	Solids Separation	**No Solids Separation**	**Solids Separation**	**No Solids Separation**	**Solids Separation**	**No Solids Separation**	**Solids Separation**	**No Solids Separation**	**Solids Separation**	**No Solids Separation**
Phosphorus, Total	0.423 (b)	0.423 (b)	0.423	0.423 (e)	0.423 (b)	0.423 (b)	0.0678 (f)	0.0678	0.0965 (a)	
Zinc (g)	0.316 (b)	0.316 (b)	0.316	0.316 (e)	(d)	(d)	(d)	(d)	0.00473	0.00473 (e)

Source: U.S. EPA, 2007

a – EPA calculated average concentration using all plants within the source water treatment type group regardless of residuals treatment in place. The average concentration for WTPs without solid/water separation was less than the average concentration for WTPs with solid/water separation.

b – Transferred pollutant concentration from coagulation and filtration because no other data were available.

c – DMR data available for ion exchange/membrane desalination plants only. Note that one plant with data also listed coagulation and filtration; however the chlorides load is expected to be due to ion exchange.

d – No DMR data were available for this pollutant and model plant. EPA did not estimate loadings for this pollutant and model plant.

e – DMR data available only for WTPs that perform solid/water separation. EPA used the treated concentration to estimate untreated pollutant loadings.

f – DMR data available only for WTPs that do not perform solid/water separation. EPA used the untreated concentration to estimate treated pollutant loadings.

g – Percent of non-detect samples in DMR databases exceeds 10 percent. Nickel was not detected above the detection limit for any sample; therefore EPA set the LTA equal to zero (0).

Table 9-5. Long-Term Average Concentrations for Pollutants Resulting from Disinfection with Chlorine

Pollutant	Dechlorination Performed	No Dechlorination Performed	Source for Concentration
Total trihalomethanes	0 mg/L (a)	0.00223 mg/L	DMR Data
Chloroform ($CHCl_2$)	0 mg/L (a)	0.050 mg/L	DMR Data
Bromodichloromethane ($CHCl_2Br$, Dichlorobromomethane)	0 mg/L (a)	0.010 mg/L	DMR Data
Bromoform (tribromomethane)	0 mg/L (a)	0.050 mg/L	Transfer from Chloroform
Dibromochloromethane (CDBM; Chlorodibromomethane)	0 mg/L (a)	0.002 mg/L	DMR Data
Haloacetic acids (5HAA's)	0 mg/L (a)	0.060 mg/L	MCL
Total residual chlorine (b)	0.144 mg/L	0.192 mg/L	DMR Data

a – No DMR data were available. EPA assumed that, in WTPs that perform dechlorination, the effluent concentrations of these parameters are not present (i.e., are zero).
b – Percent of non-detect samples in DMR databases exceeds 10 percent.

9.3.3 DMR Data Limitations

The DMR data received as part of the industry questionnaire includes limitations which affected the calculation of pollutant loadings estimates. In these cases, EPA used its best engineering judgment to calculate loadings. The primary data limitation is that there was no standard list of pollutants monitored by all WTPs. The DMR data submitted by each WTP includes data for only those pollutants listed in the plant's NPDES permit. For example, a state may have a core set of pollutants that WTPs need to monitor; however, additional pollutant monitoring might be more random and dependent on the watershed characteristics of the source water. Furthermore, it is not known why pollutants are monitored at specific facilities, that is, whether the monitoring is due to suspected problems so that these facilities are more likely to be representative of high loading plants than not. On the other hand, it may be the case that facilities with lower loading levels were more likely to report their DMR data with the 2007 industry questionnaire In the absence of additional information, it's not possible to describe the potential magnitude and direction of bias, if any. Where appropriate, EPA transferred pollutant concentrations from another model plant group.

EPA also found that some model plants had more data than others. For example, EPA had DMR data for 24 precipitative softening plants and for 76 coagulation/filtration plants.

Whereas, EPA had a limited number of WTPs with DMR data for the three other source water treatment types: filtration only (5 WTPs), membrane desalination (2 WTPs), and ion exchange/adsorption (4 WTPs). For the filtration only WTPs, 4 WTPs represented discharges following solid/water separation and only one WTP represented untreated discharges. For the ion exchange/adsorption, 3 WTPs represented discharges following solid/water separation and only one WTP represented untreated discharges. Neither membrane desalination plants treated the discharge using solid/water separation prior to discharge. In some cases, only a single WTP had DMR data for a pollutant in a certain model plant group. EPA used these data to estimate the pollutant concentration, however, EPA does not have the data available to determine whether the concentration reported is representative of a majority of discharges for the model plant group.

Membrane desalination plants typically do not treat the concentrate prior to discharge (Malmrose, et al., 2004). Therefore, EPA used the same pollutant concentration to represent WTPs treating residuals via solid/water separation as those WTPs not treating residuals prior to discharge. EPA's survey database included only two membrane desalination plants that performed solid/water separation. Both of these WTPs are zero discharge plants (U.S. EPA, 2009a).

Where appropriate, EPA transferred concentrations or modified the calculation of average pollutant concentrations to use for the pollutant loading estimates. The memorandum entitled, *Pollutant Loadings Estimates for Drinking Water Treatment Plants* (ERG, 2009), provides details.

9.4 MODEL PLANT FLOW RATE ESTIMATION

As noted above, EPA determined that the effluent flow rate would vary based on three of the four model plant characteristics: 1) source water treatment; 2) population served size; and 3) discharge type. EPA did not distinguish flow rates by residuals treatment type; EPA assumed that the flow rate would not be significantly altered by solid/water separation or dechlorination. Solid/water separation results in removal of certain parameters from the wastewater (e.g., TSS, metals); however EPA does not believe this will result in a significant difference in the wastewater volume discharged. The dechlorination process is the addition of sulfur chemicals (e.g., sodium metabisulfite) to react with chlorine in the wastewater and remove free chlorine and total combined chlorine residual. The addition of the sulfur chemicals is not expected to significantly impact the wastewater volume discharged.

EPA estimated the model plant flow rates using reported flow data from DMRs submitted with the 2007 industry questionnaire and the responses to the survey (U.S. EPA, 2007; U.S. EPA, 2009a). As such, the loadings estimate will be reflective of actual flow rather than design flow. An additional data limitation for this analysis is that the flow rates from 2006 (either in response to the 2007 industry questionnaire or included with the 2006 DMR data) might not be typical.

9.4.1 Review of DMR and Survey Data

EPA categorized each of the 108 WTPs that submitted survey responses and DMR data into a model plant type to calculate flow rate. EPA used the DMR data to estimate direct discharge flow rates and survey responses to estimate indirect discharge flow rates and population served. EPA then used the DMR and survey data to estimate model plant effluent flow rates. For direct discharging WTPs, EPA assumed continuous discharge (i.e., discharge occurs 365 days per year).

For indirect dischargers, EPA reviewed responses to the questionnaire to determine whether the discharge was continuous, batch, or an emergency discharge. For continuous indirect discharges, EPA assumed the discharge occurred 365 days per year. For batch discharges, EPA multiplied the volume discharged by the number of batches per year and then normalized the flow rate to 365 days per year. For example, if a WTP discharged 1,000,000 gallons (1 MG) for 20 days of the year, then the flow rate normalized for the year was calculated as follows:

$$(1\text{ MG} \times 20\text{ DPY})/365 = 0.055\text{ MGD} \qquad \text{(Eq. 9-4)}$$

If the number of batch discharges was greater than 365 days per year, EPA assumed the discharge occurred 365 days per year, for the purpose of estimating the average daily discharge rate. For example, if a WTP reported 1,100 batch discharges annually and each batch was 1 MG, EPA calculated the discharge as follows:

$$(1 \text{ MG} \times 1{,}100 \text{ Batches})/365 = 3.0 \text{ MGD} \qquad \text{(Eq. 9-5)}$$

For indirect dischargers reporting both continuous and batch flow rates, EPA summed the two quantities to estimate total daily flow rate from the WTP. EPA excluded emergency discharge volumes unless no other discharges (i.e., continuous or batch) were reported.

9.4.2 Model Plant Effluent Flow Rate Results

For each model plant group, EPA calculated an average effluent flow rate using the data from individual WTPs. Table 9-6 presents the model plant flow rates (range of individual WTP flow rates and average) estimated for each source water treatment type, population served, and discharge type.

Table 9-6. Model Plant Effluent Flow Rates

Treatment Plant Type	Population Served	Direct Discharge Effluent Flow Rate Range (MGD)	Direct Discharge Average Effluent (MGD)	Indirect Discharge Effluent Flow Rate Range (MGD) (a)	Indirect Discharge Average Effluent (MGD) (a)
Precipitative Softening	10,001 to 50,000	0.04175 to 0.432	0.235	0.00021 to 0.469	0.144
	50,001 to 100,000	0.062 to 0.512	0.312	0.00082 to 0.830	0.297
	100,001 to 500,000	0.067 to 20.1	3.79	0.00091 to 1.057	0.339
	>500,000	3.56 to 7.79	5.68	(b)	0.339
Coagulation & Filtration	10,001 to 50,000	0.0114 to 0.903	0.209	4.5E-7 to 0.61	0.089
	50,001 to 100,000	0.003 to 1.26	0.376	4.5E-6 to 1.1	0.168
	100,001 to 500,000	0.0046 to 3.5	1.22	0.000146 to 3.13	0.276
	>500,000	0.502 to 7.04	3.47	0.0142 to 0.985	0.291
Filtration Only	10,001 to 50,000	0.0656 to 0.337	0.179	8.6E-7 to 0.18	0.040
	50,001 to 100,000	(b)	0.179	0.00063 to 0.341(d)	0.171(d)
	100,001 to 500,000	0.734 to 1.36	1.05	0.00063 to 0.341(d)	0.171(d)
	>500,000	(b)	1.05	(b)	0.171

Table 9-6. Model Plant Effluent Flow Rates

Treatment Plant Type	Population Served	Direct Discharge Effluent Flow Rate Range (MGD)	Direct Discharge Average Effluent (MGD)	Indirect Discharge Effluent Flow Rate Range (MGD) (a)	Indirect Discharge Average Effluent (MGD) (a)
Membrane Desalination	10,001 to 50,000	(c)	0.627	1.5E-5 to 0.00274	0.002
	50,001 to 100,000	(c)	1.15	(c)	0.26
	100,001 to 500,000	(b)	1.15	0.122 to 0.997	0.560
	>500,000	(f)	Not applicable	(f)	Not applicable
Ion Exchange & Adsorption	10,001 to 50,000	0.0576 to 0.185	0.120	2.8E-6 to 0.7(e)	0.110(e)
	50,001 to 100,000	(c)	1.15	2.8E-6 to 0.7(e)	0.110(e)
	100,001 to 500,000	(f)	Not applicable	(b)	0.110
	>500,000	(f)	Not applicable	(f)	Not applicable

Sources: U.S. EPA, 2007; U.S. EPA, 2009a
MGD – Million Gallons per Day
a – EPA calculated annual normalized flow rates using indirect discharge data from the survey response database for the 2006 industry questionnaire (U.S. EPA, 2008a). EPA multiplied the gallons per day by the number of days per year reported in the survey; and then divided by 365 days per year.
b – No flow rate data were available for this population category. For pollutant loadings analysis, EPA transferred the average flow rate from the next smallest population group with the same treatment plant type.
c – Not applicable: only one WTP falls into this characteristic group.
d – For the indirect discharge effluent flow rate, EPA combined the flow rate averages for plants serving 50,001 to 100,000 people with the flow rate averages for plants serving between 100,001 and 500,000. The average flow rate for the larger population group is smaller than the average flow rate for the smaller population group suggesting that this size distinction is not adequately represented or less meaningful.
e – For the indirect discharge effluent flow rate, EPA combined the flow rate averages for plants serving 10,001 to 50,000 people with the flow rate averages for plants serving between 50,001 and 100,000. The average flow rate for the larger population group is smaller than the average flow rate for the smaller population group suggesting that this size distinction is not adequately represented or less meaningful.
f – The national estimates do not include any WTPs in this population category.

9.5 RESULTS OF THE POLLUTANT LOADINGS ESTIMATE FOR MODEL PLANTS

EPA calculated the pollutant loadings and TWPE for each model plant as described above. EPA did not have data to quantify the pollutant discharges attributed to source water contaminants and those attributed to treatment chemical addition. The portion from source water contaminants would be site-specific; WTPs did not submit source water quality data to pair with the effluent discharge data. However, WTPs might collect source water quality data to help optimize addition of treatment chemicals. These data can be used by permit writers when developing best professional judgment (BPJ) permit limitations. From literature data, membrane concentrate has very few process-added chemicals and the pollutants are primarily from the source water (U.S. EPA, ASCE, AWWA, 1996).

Tables 9-7 through 9-10 each show the pollutant loading estimate for model plants by the five source water treatment types and by residuals treatment type (with or without solid/water separation) for direct and indirect dischargers. Each table is for a different population served size category.

Table 9-7. Model Plant Pollutant Loadings by Source Water Treatment Type and Residuals Treatment Type (With and Without Solid/Water Separation) for Direct and Indirect (Pass Through) Discharges: Population Served of 10,001 to 50,000 People

Source Water Treatment Type and Pollutant	Pollutant Loadings for Model Plants Serving 10,001 to 50,000 People							
	With Solid/Water Separation				Without Solid/Water Separation			
	Direct Discharge		Indirect Discharge		Direct Discharge		Indirect Discharge	
	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)
Precipitative Softening								
Bulk Parameters								
BOD	1030		68.8		1030		68.8	
Nitrogen, Total	2610		679		2610		679	
TSS	4220		270		1030000		65600	
Total Bulk Parameters (Precipitative Softening)	**7860**		**1017.8**		**1033640**		**66347.8**	
Specific Parameters								
Aluminum	127	8.2	6.98	0.452	127	8.2	6.98	0.452
Ammonia	345	0.383	129	0.143	345	0.383	129	0.143
Barium	7.16	0.0143	1.96	0.00391	7.16	0.0143	1.96	0.00391
Calcium	6250	0.175	3500	0.0979	6250	0.175	3500	0.0979
Copper	49.6	31.5	4.8	3.04	49.6	31.5	4.8	3.04
Fluoride	476	16.7	113	3.94	814	28.5	192	6.74
Iron	82.3	0.461	9.07	0.0508	82.3	0.461	9.07	0.0508
Lead	4.07	9.12	0.562	1.26	4.07	9.12	0.562	1.26
Magnesium	1840	1.6	968	0.838	1840	1.6	968	0.838
Manganese	248	17.5	90.1	6.34	248	17.5	90.1	6.34
Nickel	0	0	0	0	0	0	0	0
Phosphorus, Total	303		57.4		303		57.4	
Zinc	226	10.6	28.9	1.35	226	10.6	28.9	1.35
Total Specific Parameters (Precipitative Softening)	**9,958**	**96**	**4,910**	**18**	**10,296**	**108**	**4,989**	**20**

Table 9-7. Model Plant Pollutant Loadings by Source Water Treatment Type and Residuals Treatment Type (With and Without Solid/Water Separation) for Direct and Indirect (Pass Through) Discharges: Population Served of 10,001 to 50,000 People

Source Water Treatment Type and Pollutant	**Pollutant Loadings for Model Plants Serving 10,001 to 50,000 People**							
	With Solid/Water Separation				**Without Solid/Water Separation**			
	Direct Discharge		**Indirect Discharge**		**Direct Discharge**		**Indirect Discharge**	
	Lb/yr	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**
Coagulation & Filtration								
Bulk Parameters								
BOD	921		42.8		921		42.8	
Nitrogen, Total	2320		422		2320		422	
TSS	34700		1550		85800		3830	
Total Bulk Parameters (Coagulation & Filtration)	**37941**		**2014.8**		**89041**		**4294.8**	
Specific Parameters								
Aluminum	1380	89	52.9	3.42	1380	89	52.9	3.42
Ammonia	308	0.341	80.2	0.089	308	0.341	80.2	0.089
Barium	6.38	0.0127	1.22	0.00243	6.38	0.0127	1.22	0.00243
Calcium	5570	0.156	2170	0.0609	5570	0.156	2170	0.0609
Copper	44.2	28.1	2.98	1.89	44.2	28.1	2.98	1.89
Fluoride	436	15.3	72.1	2.52	436	15.3	72.1	2.52
Iron	1740	9.76	134	0.751	2750	15.4	211	1.18
Lead	3.63	8.13	0.349	0.783	3.63	8.13	0.349	0.783
Magnesium	1640	1.42	602	0.521	1640	1.42	602	0.521
Manganese	282	19.8	71.5	5.03	282	19.8	71.5	5.03
Nickel	0	0	0	0	0	0	0	0
Phosphorus, Total	270		35.7		270		35.7	
Zinc	201	9.45	18	0.842	201	9.45	18	0.842
Total Specific Parameters (Coagulation & Filtration)	**11,881**	**181**	**3,241**	**16**	**12,891**	**187**	**3,318**	**16**
Filtration Only								
Bulk Parameters								
BOD	788		19.1		788		19.1	
Nitrogen, Total	1990		188		1990		188	
TSS	1430		33.2		12200		285	
Total Bulk Parameters (Filtration Only)	**4208**		**240.3**		**14978**		**492.1**	

Table 9-7. Model Plant Pollutant Loadings by Source Water Treatment Type and Residuals Treatment Type (With and Without Solid/Water Separation) for Direct and Indirect (Pass Through) Discharges: Population Served of 10,001 to 50,000 People

Source Water Treatment Type and Pollutant	**Pollutant Loadings for Model Plants Serving 10,001 to 50,000 People**							
	With Solid/Water Separation				**Without Solid/Water Separation**			
	Direct Discharge		**Indirect Discharge**		**Direct Discharge**		**Indirect Discharge**	
	Lb/yr	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**
Specific Parameters								
Aluminum	501	32.4	10	0.649	501	32.4	10	0.649
Ammonia	263	0.292	35.7	0.0396	263	0.292	35.7	0.0396
Fluoride	100	3.5	8.59	0.301	100	3.5	8.59	0.301
Iron	69.9	0.392	2.8	0.0157	69.9	0.392	2.8	0.0157
Lead	3.1	6.95	0.156	0.348	3.1	6.95	0.156	0.348
Manganese	31.3	2.2	4.13	0.291	31.3	2.2	4.13	0.291
Phosphorus, Total	231		15.9		231		15.9	
Total Specific Parameters (Filtration Only)	**1,199**	**46**	**77**	**2**	**1,199**	**46**	**77**	**2**
Membrane Desalination								
Bulk Parameters								
CBOD5	1910		0.52		1910		0.52	
Nitrogen, Total	5640		6.01		5640		6.01	
TSS	5460		1.43		5460		1.43	
Total Bulk Parameters (Membrane Desalination)	**13010**		**7.96**		**13010**		**7.96**	
Specific Parameters								
Ammonia	2960	3.29	4.52	0.00501	2960	3.29	4.52	0.00501
Cadmium	1.98	45.7	0.000492	0.0114	1.98	45.7	0.000492	0.0114
Chlorides	13600000	331	14500	0.353	13600000	331	14500	0.353
Copper	1.7	1.08	0.000673	0.000427	1.7	1.08	0.000673	0.000427
Fluoride	4030	141	3.89	0.136	4030	141	3.89	0.136
Iron	2800	15.7	1.26	0.00705	2800	15.7	1.26	0.00705
Phosphorus, Total	129		0.1		129		0.1	
Total Specific Parameters (Membrane Desalination)	**13,609,923**	**538**	**14,510**	**1**	**13,609,923**	**538**	**14,510**	**1**
Ion Exchange and Adsorption								
Bulk Parameters								
CBOD5	366		36.4		366		36.4	
Nitrogen, Total	172		67.2		332		129	
TDS	3130000		2640000		3130000		2640000	
TSS	2330		223		2330		223	
Total Bulk Parameters (Ion Exchange & Adsorption)	**3132868**		**2640326.6**		**3133028**		**2640388.4**	

Table 9-7. Model Plant Pollutant Loadings by Source Water Treatment Type and Residuals Treatment Type (With and Without Solid/Water Separation) for Direct and Indirect (Pass Through) Discharges: Population Served of 10,001 to 50,000 People

Source Water Treatment Type and Pollutant	**Pollutant Loadings for Model Plants Serving 10,001 to 50,000 People**							
	With Solid/Water Separation				**Without Solid/Water Separation**			
	Direct Discharge		**Indirect Discharge**		**Direct Discharge**		**Indirect Discharge**	
	Lb/yr	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**
Specific Parameters								
Ammonia	32.7	0.0363	18.2	0.0203	32.7	0.0363	18.2	0.0203
Cadmium	0.378	8.75	0.0345	0.797	0.378	8.75	0.0345	0.797
Chlorides	1070000	26	417000	10.2	2600000	63.3	1010000	24.7
Copper	0.544	0.345	0.0787	0.0499	0.544	0.345	0.0787	0.0499
Fluoride	771	27	273	9.55	771	27	273	9.55
Iron	132	0.74	21.8	0.122	132	0.74	21.8	0.122
Lead	0	0	0	0	0	0	0	0
Manganese	134	9.47	73.1	5.15	134	9.47	73.1	5.15
Phosphorus, Total	35.3		10		35.3		10	
Zinc	1.73	0.081	0.33	0.0155	1.73	0.081	0.33	0.0155
Total Specific Parameters (Ion Exchange & Adsorption)	**1,071,108**	**72**	**417,397**	**26**	**2,601,108**	**110**	**1,010,397**	**40**

Source: U.S. EPA, 2008a; U.S. EPA, 2009b

Blanks indicate that for this pollutant, no TWF is available and therefore, no TWPE were calculated. EPA does not derive TWFs for conventional pollutants.

Zero indicates that EPA estimates the load for this pollutant at zero lbs/yr.

Table 9-8. Model Plant Pollutant Loadings by Source Water Treatment Type and Residuals Treatment Type (With and Without Solid/Water Separation) for Direct and Indirect (Pass Through) Discharges: Population Served of 50,001 to 100,000 People

Source Water Treatment Type and Pollutant	**Pollutant Loadings for Model Plants Serving 50,001 to 100,000 People**							
	With Solid/Water Separation				**Without Solid/Water Separation**			
	Direct Discharge		**Indirect Discharge**		**Direct Discharge**		**Indirect Discharge**	
	Lb/yr	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**
Precipitative Softening								
Bulk Parameters								
BOD	1370		142		1370		142	
Nitrogen, Total	3460		1400		3460		1400	
TSS	5610		556		1360000		135000	
Total Bulk Parameters (Precipitative Softening)	**10440**		**2098**		**1364830**		**136542**	

Table 9-8. Model Plant Pollutant Loadings by Source Water Treatment Type and Residuals Treatment Type (With and Without Solid/Water Separation) for Direct and Indirect (Pass Through) Discharges: Population Served of 50,001 to 100,000 People

Source Water Treatment Type and Pollutant	**Pollutant Loadings for Model Plants Serving 50,001 to 100,000 People**							
	With Solid/Water Separation				**Without Solid/Water Separation**			
	Direct Discharge		**Indirect Discharge**		**Direct Discharge**		**Indirect Discharge**	
	Lb/yr	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**
Specific Parameters								
Aluminum	168	10.9	14.4	0.932	168	10.9	14.4	0.932
Ammonia	459	0.509	266	0.295	459	0.509	266	0.295
Barium	9.52	0.0189	4.05	0.00807	9.52	0.0189	4.05	0.00807
Calcium	8300	0.232	7210	0.202	8300	0.232	7210	0.202
Copper	65.9	41.8	9.89	6.28	65.9	41.8	9.89	6.28
Fluoride	633	22.1	232	8.13	1080	37.9	397	13.9
Iron	109	0.613	18.7	0.105	109	0.613	18.7	0.105
Lead	5.41	12.1	1.16	2.6	5.41	12.1	1.16	2.6
Magnesium	2450	2.12	2000	1.73	2450	2.12	2000	1.73
Manganese	329	23.2	186	13.1	329	23.2	186	13.1
Nickel	0	0	0	0	0	0	0	0
Phosphorus, Total	402		119		402		119	
Zinc	301	14.1	59.5	2.79	301	14.1	59.5	2.79
Total Specific Parameters (Precipitative Softening)	**13,232**	**128**	**10,121**	**36**	**13,679**	**143**	**10,286**	**42**
Coagulation and Filtration								
Bulk Parameters								
BOD	1650		80.3		1650		80.3	
Nitrogen, Total	4170		792		4170		792	
TSS	62400		2910		154000		7180	
Total Bulk Parameters (Coagulation and Filtration)	**68220**		**3782.3**		**159820**		**8052.3**	
Specific Parameters								
Aluminum	2470	160	99.2	6.41	2470	160	99.2	6.41
Ammonia	553	0.613	150	0.167	553	0.613	150	0.167
Barium	11.5	0.0228	2.29	0.00456	11.5	0.0228	2.29	0.00456
Calcium	10000	0.28	4080	0.114	10000	0.28	4080	0.114
Copper	79.4	50.4	5.59	3.55	79.4	50.4	5.59	3.55
Fluoride	784	27.4	135	4.73	784	27.4	135	4.73
Iron	3130	17.5	251	1.41	4940	27.6	396	2.22
Lead	6.52	14.6	0.655	1.47	6.52	14.6	0.655	1.47
Magnesium	2950	2.55	1130	0.978	2950	2.55	1130	0.978

Table 9-8. Model Plant Pollutant Loadings by Source Water Treatment Type and Residuals Treatment Type (With and Without Solid/Water Separation) for Direct and Indirect (Pass Through) Discharges: Population Served of 50,001 to 100,000 People

Source Water Treatment Type and Pollutant	**Pollutant Loadings for Model Plants Serving 50,001 to 100,000 People**							
	With Solid/Water Separation				**Without Solid/Water Separation**			
	Direct Discharge		**Indirect Discharge**		**Direct Discharge**		**Indirect Discharge**	
	Lb/yr	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**
Manganese	506	35.6	134	9.44	506	35.6	134	9.44
Nickel	0	0	0	0	0	0	0	0
Phosphorus, Total	485		67		485		67	
Zinc	362	17	33.7	1.58	362	17	33.7	1.58
Total Specific Parameters (Coagulation & Filtration)	**21,337**	**326**	**6,088**	**30**	**23,147**	**336**	**6,233**	**31**
Filtration Only								
Bulk Parameters								
BOD	788		81.8		788		81.8	
Nitrogen, Total	1990		807		1990		807	
TSS	1430		142		12200		1220	
Total Bulk Parameters (Filtration Only)	**4208**		**1030.8**		**14978**		**2108.8**	
Specific Parameters								
Aluminum	501	32.4	43	2.78	501	32.4	43	2.78
Ammonia	263	0.292	153	0.17	263	0.292	153	0.17
Fluoride	100	3.5	36.9	1.29	100	3.5	36.9	1.29
Iron	69.9	0.392	12	0.0673	69.9	0.392	12	0.0673
Lead	3.1	6.95	0.667	1.49	3.1	6.95	0.667	1.49
Manganese	31.3	2.2	17.7	1.25	31.3	2.2	17.7	1.25
Phosphorus, Total	231		68.2		231		68.2	
Total Specific Parameters (Filtration Only)	**1,199**	**46**	**331**	**7**	**1,199**	**46**	**331**	**7**
Membrane Desalination								
Bulk Parameters								
CBOD5	3500		86.2		3500		86.2	
Nitrogen, Total	10300		996		10300		996	
TSS	10000		237		10000		237	
Total Bulk Parameters (Membrane Desalination)	**23800**		**1319.2**		**23800**		**1319.2**	

Table 9-8. Model Plant Pollutant Loadings by Source Water Treatment Type and Residuals Treatment Type (With and Without Solid/Water Separation) for Direct and Indirect (Pass Through) Discharges: Population Served of 50,001 to 100,000 People

Source Water Treatment Type and Pollutant	**Pollutant Loadings for Model Plants Serving 50,001 to 100,000 People**							
	With Solid/Water Separation				**Without Solid/Water Separation**			
	Direct Discharge		**Indirect Discharge**		**Direct Discharge**		**Indirect Discharge**	
	Lb/yr	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**
Specific Parameters								
Ammonia	5430	6.03	749	0.831	5430	6.03	749	0.831
Cadmium	3.63	83.8	0.0816	1.89	3.63	83.8	0.0816	1.89
Chlorides	24900000	607	2400000	58.4	24900000	607	2400000	58.4
Copper	3.12	1.98	0.111	0.0708	3.12	1.98	0.111	0.0708
Fluoride	7390	259	646	22.6	7390	259	646	22.6
Iron	5130	28.7	209	1.17	5130	28.7	209	1.17
Phosphorus, Total	237		16.6		237		16.6	
Total Specific Parameters (Membrane Desalination)	**24,918,194**	**987**	**2,401,621**	**85**	**24,918,194**	**987**	**2,401,621**	**85**
Ion Exchange & Adsorption								
Bulk Parameters								
CBOD5	3500		36.4		3500		36.4	
Nitrogen, Total	1650		67.2		3180		129	
TDS	30000000		2640000		30000000		2640000	
TSS	22300		223		22300		223	
Total Bulk Parameters (Ion Exchange & Adsorption)	**30027450**		**2640326.6**		**30028980**		**2640388.4**	
Specific Parameters								
Ammonia	313	0.348	18.2	0.0203	313	0.348	18.2	0.0203
Cadmium	3.63	83.8	0.0345	0.797	3.63	83.8	0.0345	0.797
Chlorides	10200000	250	417000	10.2	24900000	607	1010000	24.7
Copper	5.21	3.31	0.0787	0.0499	5.21	3.31	0.0787	0.0499
Fluoride	7390	259	273	9.55	7390	259	273	9.55
Iron	1270	7.09	21.8	0.122	1270	7.09	21.8	0.122
Lead	0	0	0	0	0	0	0	0
Manganese	1290	90.7	73.1	5.15	1290	90.7	73.1	5.15
Phosphorus, Total	338		10		338		10	
Zinc	16.6	0.777	0.33	0.0155	16.6	0.777	0.33	0.0155
Total Specific Parameters (Ion Exchange & Adsorption)	**10,210,626**	**695**	**417,397**	**26**	**24,910,626**	**1,052**	**1,010,397**	**40**

Source: U.S. EPA, 2008a; U.S. EPA, 2009b

Blanks indicate that for this pollutant, no TWF is available and therefore, no TWPE were calculated. EPA does not derive TWFs for conventional pollutants.

Zero indicates that EPA estimates the load for this pollutant at zero lbs/yr.

a – Excluded from total: chlorides is a constituent of TDS.

Table 9-9. Model Plant Pollutant Loadings by Source Water Treatment Type and Residuals Treatment Type (With and Without Solid/Water Separation) for Direct and Indirect (Pass Through) Discharges: Population Served of 100,001 to 500,000 People

	Pollutant Loadings for Model Plants Serving 100,001 to 500,000 People							
	With Solid/Water Separation				**Without Solid/Water Separation**			
	Direct Discharge		**Indirect Discharge**		**Direct Discharge**		**Indirect Discharge**	
Source Water Treatment Type and Pollutant	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**
Precipitative Softening								
Bulk Parameters								
BOD	16,700		162		16,700		162	
Nitrogen, Total	42,100		1,600		42,100		1,600	
TSS	68,100		636		16,600,000		155,000	
Total Bulk Parameters (Precipitative Softening)	**126,900**		**2,398**		**16,658,800**		**156,762**	
Specific Parameters								
Aluminum	2,050	132	16.4	1.06	2,050	132	16.4	1.06
Ammonia	5,570	6.19	304	0.337	5,570	6.19	304	0.337
Barium	116	0.23	4.63	0.00922	116	0.23	4.63	0.00922
Calcium	101,000	2.82	8240	0.231	101,000	2.82	8,240	0.231
Copper	801	508	11.3	7.17	801	508	11.3	7.17
Fluoride	7,690	269	265	9.29	13,100	460	454	15.9
Iron	1,330	7.44	21.4	0.12	1,330	7.44	21.4	0.12
Lead	65.7	147	1.32	2.97	65.7	147	1.32	2.97
Magnesium	29,800	25.8	2280	1.98	29,800	25.8	2,280	1.98
Manganese	4,000	282	212	15	4,000	282	212	15
Nickel	0	0	0	0	0	0	0	0
Phosphorus, Total	4,890		135		4,890		135	
Zinc	3,650	171	68	3.19	3,650	171	68	3.19
Total Specific Parameters (Precipitative Softening)	**160,963**	**1,551**	**11,559**	**41**	**166,373**	**1,742**	**11,748**	**48**
Coagulation & Filtration								
Bulk Parameters								
BOD	5,350		132		5,350		132	
Nitrogen, Total	13,500		1,300		13,500		1,300	
TSS	202,000		4,790		498,000		11,800	
Total Bulk Parameters (Coagulation & Filtration)	**220,850**		**6,222**		**516,850**		**13,232**	

Table 9-9. Model Plant Pollutant Loadings by Source Water Treatment Type and Residuals Treatment Type (With and Without Solid/Water Separation) for Direct and Indirect (Pass Through) Discharges: Population Served of 100,001 to 500,000 People

Source Water Treatment Type and Pollutant	Pollutant Loadings for Model Plants Serving 100,001 to 500,000 People							
	With Solid/Water Separation				Without Solid/Water Separation			
	Direct Discharge		Indirect Discharge		Direct Discharge		Indirect Discharge	
	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)
Specific Parameters								
Aluminum	7,980	516	163	10.6	7,980	516	163	10.6
Ammonia	1,780	1.98	248	0.275	1,780	1.98	248	0.275
Barium	37	0.0737	3.77	0.00751	37	0.0737	3.77	0.00751
Calcium	32,300	0.904	6,720	0.188	32,300	0.904	6,720	0.188
Copper	256	163	9.21	5.85	256	163	9.21	5.85
Fluoride	2,530	88.6	223	7.79	2,530	88.6	223	7.79
Iron	10,100	56.6	414	2.32	15,900	89.3	653	3.66
Lead	21.1	47.2	1.08	2.42	21.1	47.2	1.08	2.42
Magnesium	9,530	8.25	1,860	1.61	9,530	8.25	1,860	1.61
Manganese	1,630	115	221	15.5	1,630	115	221	15.5
Nickel	0	0	0	0	0	0	0	0
Phosphorus, Total	1,570		110		1,570		110	
Zinc	1,170	54.8	55.5	2.6	1,170	54.8	55.5	2.6
Total Specific Parameters (Coagulation & Filtration)	**68,904**	**1,052**	**10,029**	**49**	**74,704**	**1,085**	**10,268**	**51**
Filtration Only								
Bulk Parameters								
BOD	4,610		81.8		4,610		81.8	
Nitrogen, Total	11,600		807		11,600		807	
TSS	8,360		142		71,700		1,220	
Total Bulk Parameters (Filtration Only)	**24,570**		**1,031**		**87,910**		**2,109**	
Specific Parameters								
Aluminum	2,930	190	43	2.78	2,930	190	43	2.78
Ammonia	1,540	1.71	153	0.17	1,540	1.71	153	0.17
Fluoride	585	20.5	36.9	1.29	585	20.5	36.9	1.29
Iron	409	2.29	12	0.0673	409	2.29	12	0.0673
Lead	18.2	40.7	0.667	1.49	18.2	40.7	0.667	1.49
Manganese	183	12.9	17.7	1.25	183	12.9	17.7	1.25
Phosphorus, Total	1,350		68.2		1,350		68.2	
Total Specific Parameters (Filtration Only)	**7,015**	**268**	**331**	**7**	**7,015**	**268**	**331**	**7**

Table 9-9. Model Plant Pollutant Loadings by Source Water Treatment Type and Residuals Treatment Type (With and Without Solid/Water Separation) for Direct and Indirect (Pass Through) Discharges: Population Served of 100,001 to 500,000 People

Source Water Treatment Type and Pollutant	Pollutant Loadings for Model Plants Serving 100,001 to 500,000 People							
	With Solid/Water Separation				Without Solid/Water Separation			
	Direct Discharge		Indirect Discharge		Direct Discharge		Indirect Discharge	
	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)
Membrane Desalination								
Bulk Parameters								
CBOD5	3,500		185		3,500		185	
Nitrogen, Total	10,300		2,140		10,300		2,140	
TSS	10,000		509		10,000		509	
Total Bulk Parameters (Membrane Desalination)	**23,800**		**2,834**		**23,800**		**2,834**	
Specific Parameters								
Ammonia	5,430	6.03	1,610	1.79	5,430	6.03	1,610	1.79
Cadmium	3.63	83.8	0.176	4.06	3.63	83.8	0.176	4.06
Chlorides	24,900,000	607	5,170,000	126	24,900,000	607	5,170,000	126
Copper	3.12	1.98	0.24	0.152	3.12	1.98	0.24	0.152
Fluoride	7,390	259	1,390	48.6	7,390	259	1,390	48.6
Iron	5,130	28.7	449	2.52	5,130	28.7	449	2.52
Phosphorus, Total	237		35.8		237		35.8	
Total Specific Parameters (Membrane Desalination)	**24,918,194**	**987**	**5,173,485**	**183**	**24,918,194**	**987**	**5,173,485**	**183**
Ion Exchange & Adsorption								
Bulk Parameters								
CBOD5	Not applicable. No plants in this model plant group.		36.4		Not applicable. No plants in this model plant group.			
Nitrogen, Total			67.2					
TDS			2,640,000					
TSS			223					
Total Bulk Parameters (Ion Exchange & Adsorption)			**2,640,327**					
Specific Parameters								
Ammonia	Not applicable. No plants in this model plant group.		18.2	0.0203	Not applicable. No plants in this model plant group.			
Cadmium			0.0345	0.797				
Chlorides			417,000	10.2				
Copper			0.0787	0.0499				
Fluoride			273	9.55				
Iron			21.8	0.122				
Lead			0	0				
Manganese			73.1	5.15				
Phosphorus, Total			10					
Zinc			0.33	0.0155				
Total Specific Parameters (Ion Exchange & Adsorption)			**417,397**	**26**				

Source: U.S. EPA, 2008a; U.S. EPA, 2009b
Blanks indicate that for this pollutant, no TWF is available and therefore, no TWPE were calculated. EPA does not derive TWFs for conventional pollutants.
Zero indicates that EPA estimates the load for this pollutant at zero lbs/yr.

Table 9-10. Model Plant Pollutant Loadings by Source Water Treatment Type and Residuals Treatment Type (With and Without Solid/Water Separation) for Direct and Indirect (Pass Through) Discharges: Population Served of More than 500,000 People

Source Water Treatment Type and Pollutant	**Pollutant Loadings for Model Plants Serving >500,000 People**							
	With Solid/Water Separation				**Without Solid/Water Separation**			
	Direct Discharge		**Indirect Discharge**		**Direct Discharge**		**Indirect Discharge**	
	Lb/yr	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**
Precipitative Softening								
Bulk Parameters								
BOD	25,000		162		25,000		Not applicable. No plants in this model plant group.	
Nitrogen, Total	62,900		1,600		62,900			
TSS	102,000		636		24,800,000			
Total Bulk Parameters (Precipitative Softening)	**189,900**		**2,398**		**24,887,900**			
Specific Parameters								
Aluminum	3,060	198	16.4	1.06	3,060	198	Not applicable. No plants in this model plant group.	
Ammonia	8,340	9.25	304	0.337	8,340	9.25		
Barium	173	0.344	4.63	0.00922	173	0.344		
Calcium	151,000	4.22	8240	0.231	151,000	4.22		
Copper	1,200	760	11.3	7.17	1,200	760		
Fluoride	11,500	402	265	9.29	19,600	688		
Iron	1,990	11.1	21.4	0.12	1,990	11.1		
Lead	98.3	220	1.32	2.97	98.3	220		
Magnesium	44,500	38.5	2280	1.98	44,500	38.5		
Manganese	5,980	421	212	15	5,980	421		
Nickel	0	0	0	0	0	0		
Phosphorus, Total	7,310		135		7,310			
Zinc	5,460	256	68	3.19	5,460	256		
Total Specific Parameters (Precipitative Softening)	**240,611**	**2,320**	**11,559**	**41**	**248,711**	**2,606**		
Coagulation & Filtration								
Bulk Parameters								
BOD	15,200		139		15,200		139	
Nitrogen, Total	38,400		1,370		38,400		1,370	
TSS	575,000		5,040		1,420,000		12,400	
Total Bulk Parameters (Coagulation & Filtration)	**628,600**		**6,549**		**1,473,600**		**13,909**	

Table 9-10. Model Plant Pollutant Loadings by Source Water Treatment Type and Residuals Treatment Type (With and Without Solid/Water Separation) for Direct and Indirect (Pass Through) Discharges: Population Served of More than 500,000 People

	Pollutant Loadings for Model Plants Serving >500,000 People							
	With Solid/Water Separation				**Without Solid/Water Separation**			
	Direct Discharge		**Indirect Discharge**		**Direct Discharge**		**Indirect Discharge**	
Source Water Treatment Type and Pollutant	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**
Specific Parameters								
Aluminum	22,800	1470	172	11.1	22,800	1,470	172	11.1
Ammonia	5,090	5.65	260	0.289	5,090	5.65	260	0.289
Barium	106	0.21	4	0.0079	106	0.21	3.97	0.0079
Calcium	92,100	2.58	7,070	0.198	92,100	2.58	7,070	0.198
Copper	731	464	9.69	6.15	731	464	9.69	6.15
Fluoride	7,220	253	234	8.19	7,220	253	234	8.19
Iron	28,900	162	436	2.44	45,500	255	687	3.85
Lead	60	135	1.14	2.54	60	135	1.14	2.54
Magnesium	27,200	23.5	1,960	1.69	27,200	23.5	1,960	1.69
Manganese	4,660	328	232	16.4	4,660	328	232	16.4
Nickel	0	0	0	0	0	0	0	0
Phosphorus, Total	4,470		116		4,470		116	
Zinc	3,330	156	58.3	2.73	3,330	156	58.3	2.73
Total Specific Parameters (Coagulation & Filtration)	**196,667**	**3,000**	**10,553**	**52**	**213,267**	**3,093**	**10,804**	**53**
Filtration Only								
Bulk Parameters								
BOD	4,610		81.8		4,610		Not applicable. No plants in this model plant group.	
Nitrogen, Total	11,600		807		11,600			
TSS	8,360		142		71,700			
Total Bulk Parameters (Filtration Only)	**24,570**		**1,031**		**87,910**			
Specific Parameters								
Aluminum	2,930	190	43	2.78	2,930	190	Not applicable. No plants in this model plant group.	
Ammonia	1,540	1.71	153	0.17	1,540	1.71		
Fluoride	585	20.5	36.9	1.29	585	20.5		
Iron	409	2.29	12	0.0673	409	2.29		
Lead	18.2	40.7	0.667	1.49	18.2	40.7		
Manganese	183	12.9	17.7	1.25	183	12.9		
Phosphorus, Total	1,350		68.2		1,350			
Total Specific Parameters (Filtration Only)	**7,015**	**268**	**331**	**7**	**7,015**	**268**		

Table 9-10. Model Plant Pollutant Loadings by Source Water Treatment Type and Residuals Treatment Type (With and Without Solid/Water Separation) for Direct and Indirect (Pass Through) Discharges: Population Served of More than 500,000 People

Source Water Treatment Type and Pollutant	Pollutant Loadings for Model Plants Serving >500,000 People							
	With Solid/Water Separation				Without Solid/Water Separation			
	Direct Discharge		Indirect Discharge		Direct Discharge		Indirect Discharge	
	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)
Membrane Desalination								
Not applicable. No plants in this model plant group.								
Ion Exchange & Adsorption								
Not applicable. No plants in this model plant group.								

Source: U.S. EPA, 2008a; U.S. EPA, 2009b
Blanks indicate that for this pollutant, no TWF is available and therefore, no TWPE were calculated. EPA does not derive TWFs for conventional pollutants.
Zero indicates that EPA estimates the load for this pollutant at zero lbs/yr.

Tables 9-11 and 9-12 each show the pollutant loading estimate for model plants that disinfect using chlorine by the five source water treatment types and by residuals treatment type (with or without dechlorination) for direct and indirect dischargers. Table 9-12 shows the estimate for the population served size categories *10,001 to 50,000* and *50,001 to 100,000*. Table 9-13 shows the estimate for the population served size categories *100,001 to 500,000* and *greater than 500,000*. EPA did not include any bulk parameters (i.e., parameters that measure more than one chemical) in the list of pollutants in wastewaters from WTPs that disinfect using chlorine.

Table 9-11. Model Plant Pollutant Loadings for WTPs Performing Chlorination by Source Water Treatment Type and Residuals Treatment Type (With and Without Dechlorination) for Direct and Indirect (Pass Through) Discharges: Population Served of 10,001 to 100,000 People

Source Water Treatment Type and Pollutant	Pollutant Loadings for Model Plants Serving 10,001 to 50,000 People								Pollutant Loadings for Model Plants Serving 50,001 to 100,000 People							
	With Dechlorination				Without Dechlorination				With Dechlorination				Without Dechlorination			
	Direct Discharge		Indirect Discharge		Direct Discharge		Indirect Discharge		Direct Discharge		Indirect Discharge		Direct Discharge		Indirect Discharge	
	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)
Precipitative Softening																
Total trihalomethanes	0		0		1.6		0.264		0		0		2.12		0.545	
Chloroform	0	0	0	0	36.1	0.0751	5.96	0.0124	0	0	0	0	48	0.0997	12.3	0.0256
Bromodichloromethane	0	0	0	0	7.29	0.24	1.59	0.0525	0	0	0	0	9.69	0.319	3.29	0.108
Bromoform	0		0		36.1		5.96		0		0		48		12.3	
Dibromochloromethane	0	0	0	0	1.57	0.0699	0.955	0.0425	0	0	0	0	2.09	0.0929	1.97	0.0876
Haloacetic acids (5HAA’s)	0		0		43		26.3		0		0		57.1		54.2	
Total residual chlorine	103	52.6	0	0	137	70	0	0	137	69.9	0	0	183	93	0	0
Total (Precipitative Softening) (a)	**103**	**52.6**	**0**	**0**	**261.06**	**70.385**	**40.765**	**0.1074**	**137**	**69.9**	**0**	**0**	**347.88**	**93.5116**	**84.06**	**0.2212**
Coagulation and Filtration																
Total trihalomethanes	0		0		1.42		0.164		0		0		2.56		0.308	
Chloroform	0	0	0	0	32.2	0.0669	3.71	0.00771	0	0	0	0	57.8	0.12	6.95	0.0145
Bromodichloromethane	0	0	0	0	6.49	0.214	0.992	0.0327	0	0	0	0	11.7	0.384	1.86	0.0612
Bromoform	0		0		32.2		3.71		0		0		57.8		6.95	
Dibromochloromethane	0	0	0	0	1.4	0.0623	0.594	0.0264	0	0	0	0	2.52	0.112	1.11	0.0495
Haloacetic acids (5HAA’s)	0		0		38.3		16.3		0		0		68.7		30.6	
Total residual chlorine	92	46.9	0	0	122	62.3	0	0	165	84.2	0	0	220	112	0	0
Total (Coagulation & Filtration) (a)	**92**	**46.9**	**0**	**0**	**232.59**	**62.6432**	**25.306**	**0.06681**	**165**	**84.2**	**0**	**0**	**418.52**	**112.616**	**47.47**	**0.1252**

Table 9-11. Model Plant Pollutant Loadings for WTPs Performing Chlorination by Source Water Treatment Type and Residuals Treatment Type (With and Without Dechlorination) for Direct and Indirect (Pass Through) Discharges: Population Served of 10,001 to 100,000 People

Source Water Treatment Type and Pollutant	Pollutant Loadings for Model Plants Serving 10,001 to 50,000 People								Pollutant Loadings for Model Plants Serving 50,001 to 100,000 People							
	With Dechlorination				Without Dechlorination				With Dechlorination				Without Dechlorination			
	Direct Discharge		Indirect Discharge		Direct Discharge		Indirect Discharge		Direct Discharge		Indirect Discharge		Direct Discharge		Indirect Discharge	
	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)
Filtration Only																
Total trihalomethanes	0		0		1.22		0.0731		0		0		1.22		0.314	
Chloroform	0	0	0	0	27.5	0.0572	1.65	0.00343	0	0	0	0	27.5	0.0572	7.08	0.0147
Bromodichloromethane	0	0	0	0	5.55	0.183	0.442	0.0145	0	0	0	0	5.55	0.183	1.89	0.0624
Bromoform	0		0		27.5		1.65		0		0		27.5		7.08	
Dibromochloromethane	0	0	0	0	1.2	0.0533	0.264	0.0118	0	0	0	0	1.2	0.0533	1.13	0.0504
Haloacetic acids (5HAA's)	0		0		32.7		7.28		0		0		32.7		31.2	
Total residual chlorine	78.7	40.1	0	0	105	53.3	0	0	78.7	40.1	0	0	105	53.3	0	0
Total (Filtration Only) (a)	**78.7**	**40.1**	**0**	**0**	**199.45**	**53.5935**	**11.286**	**0.02973**	**78.7**	**40.1**	**0**	**0**	**199.45**	**53.5935**	**48.38**	**0.1275**
Membrane Desalination																
Total trihalomethanes	0		0		4.26		0.00288		0		0		7.82		0.477	
Chloroform	0	0	0	0	96.3	0.2	0.065	0.000135	0	0	0	0	177	0.367	10.8	0.0224
Bromodichloromethane	0	0	0	0	19.5	0.64	0.0174	0.000573	0	0	0	0	35.7	1.17	2.88	0.0949
Bromoform	0		0		96.3		0.065		0		0		177		10.8	
Dibromochloromethane	0	0	0	0	4.19	0.187	0.0104	0.000463	0	0	0	0	7.69	0.342	1.73	0.0768
Haloacetic acids (5HAA's)	0		0		115		0.287		0		0		210		47.5	
Total residual chlorine	276	140	0	0	367	187	0	0	505	257	0	0	672	342	0	0
Total (Membrane Desalination) (a)	**276**	**140**	**0**	**0**	**698.29**	**188.027**	**0.4448**	**0.001171**	**505**	**257**	**0**	**0**	**1279.39**	**343.879**	**73.71**	**0.1941**

Table 9-11. Model Plant Pollutant Loadings for WTPs Performing Chlorination by Source Water Treatment Type and Residuals Treatment Type (With and Without Dechlorination) for Direct and Indirect (Pass Through) Discharges: Population Served of 10,001 to 100,000 People

Source Water Treatment Type and Pollutant	Pollutant Loadings for Model Plants Serving 10,001 to 50,000 People								Pollutant Loadings for Model Plants Serving 50,001 to 100,000 People							
	With Dechlorination				Without Dechlorination				With Dechlorination				Without Dechlorination			
	Direct Discharge		Indirect Discharge		Direct Discharge		Indirect Discharge		Direct Discharge		Indirect Discharge		Direct Discharge		Indirect Discharge	
	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)
Ion Exchange and Adsorption																
Total trihalomethanes	0		0		0.816		0.202		0		0		7.82		0.202	
Chloroform	0	0	0	0	18.4	0.0383	4.56	0.00947	0	0	0	0	177	0.367	4.56	0.00947
Bromodichloromethane	0	0	0	0	3.72	0.122	1.22	0.0401	0	0	0	0	35.7	1.17	1.22	0.0401
Bromoform	0		0		18.4		4.56		0		0		177		4.56	
Dibromochloromethane	0	0	0	0	0.802	0.0357	0.729	0.0324	0	0	0	0	7.69	0.342	0.729	0.0324
Haloacetic acids (5HAA's)	0		0		21.9		20.1		0		0		210		20.1	
Total residual chlorine	52.7	26.8	0	0	70.1	35.7	0	0	505	257	0	0	672	342	0	0
Total (Ion Exchange & Adsorption) (a)	**52.7**	**26.8**	**0**	**0**	**133.322**	**35.896**	**31.169**	**0.08197**	**505**	**257**	**0**	**0**	**1279.39**	**343.879**	**31.169**	**0.08197**

Source: U.S. EPA, 2008a; U.S. EPA, 2009b.
Blanks indicate that for this pollutant, no TWF is available and therefore, no TWPE were calculated. EPA does not derive TWFs for conventional pollutants.
Zero indicates that EPA estimates the load for this pollutant at zero lbs/yr.
a – Excluded total trihalomethanes from totals to prevent double counting; individual trihalomethane compounds are included in the total.

Table 9-12. Model Plant Pollutant Loadings for WTPs Performing Chlorination by Source Water Treatment Type and Residuals Treatment Type (With and Without Dechlorination) for Direct and Indirect (Pass Through) Discharges: Population Served Greater than 100,000 People

Source Water Treatment Type and Pollutant	Pollutant Loadings for Model Plants Serving 100,001 to 500,000 People								Pollutant Loadings for Model Plants Serving >500,000 People							
	With Dechlorination				Without Dechlorination				With Dechlorination				Without Dechlorination			
	Direct Discharge		Indirect Discharge		Direct Discharge		Indirect Discharge		Direct Discharge		Indirect Discharge		Direct Discharge		Indirect Discharge	
	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)
Precipitative Softening																
Total trihalomethanes	0		0		25.8		0.622		0		Not applicable. No plants in this model plant group (based on plant size).		38.6		0.622	
Chloroform	0	0	0	0	583	1.21	14.1	0.0292	0	0			872	1.81	14.1	0.0292
Bromodichloromethane	0	0	0	0	118	3.87	3.76	0.124	0	0			176	5.79	3.76	0.124
Bromoform	0		0		583		14.1		0				872		14.1	
Dibromochloromethane	0	0	0	0	25.4	1.13	2.25	0.1	0	0			37.9	1.69	2.25	0.1
Haloacetic acids (5HAA's)	0		0		694		61.9		0				1040		61.9	
Total residual chlorine	1,670	849	0	0	2,220	1,130	0	0	2,490	1,270			3,320	1,690	0	0
Total (Precipitative Softening) (a)	**1,670**	**849**	**0**	**0**	**4,223**	**1,136**	**96**	**0**	**2,490**	**1,270**			**6,318**	**1,699**	**96**	**0**
Coagulation & Filtration																
Total trihalomethanes	0		0		8.26		0.507		0		0		23.6		0.534	
Chloroform	0	0	0	0	187	0.388	11.5	0.0238	0	0	0	0	532	1.11	12.1	0.0251
Bromodichloromethane	0	0	0	0	37.7	1.24	3.06	0.101	0	0	0	0	107	3.54	3.22	0.106
Bromoform	0		0		187		11.5		0		0		532		12.1	
Dibromochloromethane	0	0	0	0	8.13	0.361	1.83	0.0816	0	0	0	0	23.2	1.03	1.93	0.0858
Haloacetic acids (5HAA's)	0		0		222		50.5		0		0		633		53.1	
Total residual chlorine	534	272	0	0	710	362	0	0	1520	776	0	0	2,030	1,030	0	0
Total (Coagulation & Filtration) (a)	**534**	**272**	**0**	**0**	**1,352**	**364**	**78**	**0**	**1,520**	**776**	**0**	**0**	**3,857**	**1,036**	**82**	**0.22**

Table 9-12. Model Plant Pollutant Loadings for WTPs Performing Chlorination by Source Water Treatment Type and Residuals Treatment Type (With and Without Dechlorination) for Direct and Indirect (Pass Through) Discharges: Population Served Greater than 100,000 People

Source Water Treatment Type and Pollutant	**Pollutant Loadings for Model Plants Serving 100,001 to 500,000 People**								**Pollutant Loadings for Model Plants Serving >500,000 People**							
	With Dechlorination				**Without Dechlorination**				**With Dechlorination**				**Without Dechlorination**			
	Direct Discharge		**Indirect Discharge**		**Direct Discharge**		**Indirect Discharge**		**Direct Discharge**		**Indirect Discharge**		**Direct Discharge**		**Indirect Discharge**	
	Lb/yr	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**
Filtration Only																
Total trihalomethanes	0		0		7.13		0.314		0		Not applicable. No plants in this model plant group (based on plant size).		7.13		0.314	
Chloroform	0	0	0	0	161	0.335	7.08	0.0147	0	0			161	0.335	7.08	0.0147
Bromodichloromethane	0	0	0	0	32.5	1.07	1.89	0.0624	0	0			32.5	1.07	1.89	0.0624
Bromoform	0		0		161		7.08		0				161		7.08	
Dibromochloromethane	0	0	0	0	7.01	0.312	1.13	0.0504	0	0			7.01	0.312	1.13	0.0504
Haloacetic acids (5HAA's)	0		0		192		31.2		0				192		31.2	
Total residual chlorine	461	235	0	0	613	312	0	0	461	235			613	312	0	0
Total (Filtration Only) (a)	**461**	**235**	**0**	**0**	**1166.51**	**313.717**	**48.38**	**0.1275**	**461**	**235**			**1166.51**	**313.717**	**48.38**	**0.1275**
Membrane Desalination																
Total trihalomethanes	0		0		7.82		1.03		Not applicable. No plants in this model plant group (based on plant size).							
Chloroform	0	0	0	0	177	0.367	23.2	0.0482								
Bromodichloromethane	0	0	0	0	35.7	1.17	6.21	0.204								
Bromoform	0		0		177		23.2									
Dibromochloromethane	0	0	0	0	7.69	0.342	3.71	0.165								
Haloacetic acids (5HAA's)	0		0		210		102									
Total residual chlorine	505	257	0	0	672	342	0	0								
Total (Membrane Desalination) (a)	**505**	**257**	**0**	**0**	**1,279**	**344**	**158**	**0**								
Ion Exchange & Adsorption																
	Not applicable. No plants in this model plant group (based on plant size).															

Source: U.S. EPA, 2008a; U.S. EPA, 2009b.
Blanks indicate that for this pollutant, no TWF is available and therefore, no TWPE were calculated. EPA does not derive TWFs for conventional pollutants.
Zero indicates that EPA estimates the load for this pollutant at zero lbs/yr.
a – Excluded total trihalomethanes from totals to prevent double counting; individual trihalomethane compounds are included in the total.

9.6 NATIONAL POLLUTANT DISCHARGE ESTIMATES

EPA estimated the national discharges of pollutants from WTPs serving more than 10,000 people (all four size categories) using the model plant loadings presented in Section 9.5 and national estimates of WTP counts (see Appendix E). For WTPs classified as both direct and indirect dischargers, EPA assumed that half would discharge pollutant loadings similar to direct dischargers and half would discharge pollutant loadings similar to indirect dischargers (i.e., pass through the POTW). For example, national estimates list a total of 49 coagulation and filtration plants, performing dechlorination, and serving between 10,001 and 50,000 people. Of these 49 plants, 39 are direct dischargers, 2 are indirect discharges, and eight discharge both directly and indirectly. For the pollutant loadings calculations, EPA used the following WTP counts:

- 43 direct dischargers (39 direct + 4 both); and
- 6 indirect dischargers (2 indirect + 4 both).

EPA used Equation 9-6 and Equation 9-7 to estimate industry pollutant loadings.

$$\text{Load}_{\text{Industry}} = \Sigma\,(\text{Load}_{\text{Model Plant}} \times \text{WTP Count}_{\text{Model Plant}}) \qquad \text{(Eq. 9-6)}$$

where:

$\text{Load}_{\text{Industry}}$ = Total industry loadings, in pounds per year (lb/year), for the model plant group.
$\text{Load}_{\text{Model Plant}}$ = Pollutant loadings, in lb/year, taking into account any pollutant removals by the POTW for indirect dischargers.
$\text{WTP Count}_{\text{Model Plant}}$ = National estimate of total number of WTPs for the corresponding model plant group.

$$\text{TWPE}_{\text{Industry}} = \Sigma\,(\text{TWPE}_{\text{Model Plant}} \times \text{WTP Count}_{\text{Model Plant}}) \qquad \text{(Eq. 9-7)}$$

where:

$\text{TWPE}_{\text{Industry}}$ = Total industry loadings, in toxic weighted pound equivalents per year (lb-eq/yr), for the model plant group.
$\text{TWPE}_{\text{Model Plant}}$ = Pollutant loadings, in lb-eq/year, taking into account any pollutant removals by the POTW for indirect dischargers.
$\text{WTP Count}_{\text{Model Plant}}$ = National estimate of total number of WTPs for the corresponding model plant group.

Table 9-13 presents a summary of the industry pollutant discharges by source water treatment type and pollutant, including an estimate of pollutant loadings per facility for each of the five source water treatment types.

Table 9-14 presents the industry pollutant discharges without pollutant detail by source water treatment type and WTP size category. The total discharges from the industry are 352 million pounds per year (excluding bulk parameters to prevent double counting of pollutant loadings) and 415,000 toxic-weighted pound equivalents (TWPE) per year. Most of the TWPE (85 percent) is due to five pollutants:

1. Total Residual Chlorine: 120,000 lb-eq/yr;
2. Aluminum: 88,600 lb-eq/yr;
3. Copper: 60,700 lb-eq/yr;
4. Manganese: 41,800 lb-eq/yr; and
5. Fluoride: 41,100 lb-eq/yr.

Discharges of Chloramines

As discussed in Section 8, total residual chlorine (TRC) is the amount of chlorine remaining in the wastewater after chlorine demand. TRC is the summation of free chlorine and combined chlorine (chloramines). The industry discharges of TRC total 235,000 pounds per year and 120,000 toxic-weighted pound equivalents per year. EPA does not have data available to determine the portion of TRC that is chloramines versus free chlorine. Therefore, EPA cannot estimate the percent of TRC loadings attributed to chloramines. EPA did collect data in the industry questionnaire to estimate the number of WTPs using chloramines for primary disinfection. From national estimates, 318 of 2,002 WTPs performing primary disinfection and serving more than 10,000 people use chloramines as their primary disinfectant, or approximately 16 percent of plants that perform primary disinfection. Most of the plants (192 of 318 WTPs) serve less than 50,000 people. For the larger plants

- 83 are precipitative softening plants;
- 37 are conventional filtration plants; and
- 6 are membrane desalination, microfiltration, or ultrafiltration plants.

Table 9-13. Pollutant Loadings [a] for WTPs: National Estimates by Source Water Treatment Type and Pollutant

	Precipitative Softening		Coagulation and Filtration		Filtration Only		Membrane Desalination		Ion Exchange and Adsorption		INDUSTRY TOTAL	
Pollutants	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**	**Lb/yr**	**TWPE (lb-eq/yr)**
Bulk Parameters												
BOD	1,160,000		885,000		31,200						2,070,000	
CBOD							31,000		9,610		40,600	
Nitrogen, Total	3,020,000		2,460,000		90,000		97,800		12,300		5,680,000	
TDS									252,000,000		252,000,000	
TSS	275,000,000		38,700,000		65,800		88,500		60,500		314,000,000	
Total Bulk Parameters	**280,000,000**		**42,100,000**		**187,000**		**217,000**		**252,000,000**		**574,000,000**	
Specific Parameters												
Aluminum	142,000	9,130	1,320,000	78,200	19,700	1,270					1,480,000	88,600
Ammonia	408,000	453	344,000	356	12,800	14.2	53,300	59.2	1,950	2	820,000	884
Barium	8,330	16.5	6,810	12.6							15,100	29.1
Cadmium							32	740	9.7	224	41.8	964
Calcium	7,630,000	213	6,760,000	177							14,400,000	390
Chlorides							236,000,000	5,740	90,500,000	2,210	326,000,000	7,950
Copper	55,800	35,400	43,100	25,300			27.9	17.7	16.1	10.2	99,000	60,700
Fluoride	642,000	22,500	457,000	14,900	4,459	156	69,300	2,430	34,600	1,210	1,210,000	41,100
Iron	92,800	519	1,830,000	9,490	2,860	16	46,100	259	4,100	23	1,970,000	10,300
Lead	4,610	10,300	3,620	7,500	129	290			0	0	8,360	18,100
Magnesium	2,240,000	1,940	1,960,000	1,590							4,200,000	3,530
Manganese	292,000	20,600	313,000	20,600	1,511	106			7,880	556	615,000	41,800
Nickel	0	0	0	0							0	0
Phosphorus, Total	346,000		277,000		9,981		2,186		1,400		637,000	0
Zinc	256,000	12,000	200,000	8,660					57	2.67	456,000	20,600
Total Specific Parameters	**12,100,000**	**113,000**	**13,500,000**	**167,000**	**51,400**	**1,860**	**236,000,000**	**9,240**	**90,600,000**	**4,240**	**352,000,000**	**295,000**

Table 9-13. Pollutant Loadings [a] for WTPs: National Estimates by Source Water Treatment Type and Pollutant

Pollutants	Precipitative Softening		Coagulation and Filtration		Filtration Only		Membrane Desalination		Ion Exchange and Adsorption		INDUSTRY TOTAL	
	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)
Pollutants from Chlorination												
Total trihalomethanes	1,510	0	830	0	27.5	0	12.8	0	11.5	0	2,390	0
Chloroform	34,000	70.7	18,800	39	621	1.29	290	0.601	260	0.54	54,000	112
Bromodichloromethane	6,950	228	3,950	130	132	4.34	58.7	1.93	69.5	2.29	11,200	367
Bromoform	34,000	0	18,800	0	621	0	290	0	260	0	54,000	0
Dibromochloromethane	1,610	71.4	1,090	48.7	38.5	1.72	12.7	0.566	41.6	1.85	2,790	124
Haloacetic acids (5HAA's)	43,900	0	30,000	0	1,050	0	348	0	1,150	0	76,400	0
Total residual chlorine	139,000	70,600	91,600	46,700	2,620	1,330	1,100	561	1,000	509	235,000	120,000
Total From Chlorination (b)	**259,000**	**71,000**	**164,000**	**46,900**	**5,090**	**1,340**	**2,100**	**564**	**2,780**	**514**	**433,000**	**120,000**
Total Specific Pollutants plus Chlorination Pollutants	**12,400,000**	**184,000**	**13,700,000**	**214,000**	**56,500**	**3,200**	**236,000,000**	**9,800**	**90,600,000**	**4,750**	**352,000,000**	**415,000**
Number of WTPs (a)	349		1,010		97		41		92		1,620	
Loads per WTP -- Bulk Parameters	801,000		41,800		1,930		5,300		2,740,000		354,000	
Loads per WTP) -- Specific Pollutants	34,700	324	13,400	166	530	19.1	5,760,000	225	984,000	46.1	217,000	182
Loads per WTP -- Chlorination Pollutants	743	203	163	46.7	52.5	13.8	51.2	13.8	30.2	5.59	267	74.1
Loads per WTP – Specific Pollutants plus Chlorination Pollutants	35,400	527	13,600	213	583	32.9	5,760,000	239	984,000	51.7	217,000	256

Source: U.S. EPA, 2009b.

a – Loadings include only those pollutants included in the analysis (see Section 9.3).

b – Excluded total trihalomethanes from totals to prevent double counting; individual trihalomethane compounds are included in the total.

Table 9-14. Pollutant Loadings [a] for WTPs Serving More than 10,000 People: National Estimate by Source Water Treatment Type and WTP Size (as Population Served)

Source Water Treatment Type	WTPs Serving 10,001 to 50,000 People		WTPs Serving 50,001 to 100,000 People		WTPs Serving 100,001 to 500,000 People		WTPs Serving >500,000 People		Total
	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	Lb/yr	TWPE (lb-eq/yr)	
Precipitative Softening	1,380,000	16,700	1,040,000	13,400	7,950,000	124,000	2,000,000	30,300	12,400,000 lb/yr (184,000 lb-eq/yr)
Coagulation and Filtration	5,150,000	66,500	2,250,000	37,300	5,020,000	87,600	1,250,000	22,200	13,700,000 lb/yr (214,000 lb-eq/yr)
Filtration Only	41,000	2,630	663	14.1	14,000	536	760	14.3	56,500 lb/yr (3,200 lb-eq/yr)
Membrane Desalination	191,000,000	8,100	4,800,000	170	40,400,000	1,540	0	0	236,000,000 lb/yr (9,800 lb-eq/yr)
Ion Exchange and Adsorption	86,000,000	4,520	2,020,000	80.8	2,500,000	155	0	0	90,600,000 lb/yr (4,800 lb-eq/yr)
Total by WTP Size	**283,000,000**	**98,400**	**10,100,000**	**50,900**	**55,900,000**	**214,000**	**3,250,000**	**52,500**	**352,000,000 lb/yr (415,000 lb-eq/yr)**

Source: U.S. EPA, 2009b.

a – Loadings include only those pollutants included in the analysis. Totals exclude total trihalomethanes (individual trihalomethanes are included in the total) and bulk parameters to prevent double counting of pollutant loadings.

9.7 REFERENCES

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SECTION 10

POTENTIAL SCOPE OF ENVIRONMENTAL IMPACTS OF POLLUTANT DISCHARGES

As part of its review of the drinking water treatment industry, EPA assessed the potential scope of environmental impacts from surface water discharges of water treatment plant (WTP) residuals. The purpose of the assessment was to better understand, at the national level, the degree to which discharges of residuals may be causing environmental harm.

Due to incomplete data, EPA is unable to draw conclusions about the extent and magnitude of potential environmental impacts from WTP discharges. EPA did not conduct sampling of WTP discharges, so the analysis of environmental impacts typically performed for an effluent guidelines rulemaking was not performed. Instead, EPA reviewed publicly available information about potential environmental impacts.

10.1 REVIEW OF PUBLICLY AVAILABLE INFORMATION

EPA reviewed major on-line research services, together with a search of the websites of 18 drinking water treatment utilities and industry organizations. The search yielded 197 references and EPA reviewed 106 articles published between 1984 and 2005, including articles from U.S. regional newspapers and trade journals. The articles identified only a few environmental impact issues associated with WTP discharges. The majority of articles (26 articles) concern the disposal of desalination concentrate, particularly in Tampa Bay, Florida, and discharges from the Washington Aqueduct WTP to the Potomac River in Washington, DC. Other articles about specific plants include reporting of a treatment chemical spill in North Carolina, an unpermitted WTP discharge in Massachusetts, alum discharge issues at a WTP in Arkansas, and a permit application in Virginia involving desalination concentrate discharges.

Key points about potential environmental impacts found in studies and journal articles include:

- Alum and lime sludge discharges pose a threat to aquatic life through benthic smothering downstream of outfalls.

- Aluminum and other metals present in alum sludge can be toxic to aquatic organisms (AWWARF, 1987; George, 1995; Sotero-Santos et al., 2005; Tumeo, 1992).

- WTPs that accumulate sludge in settling basins for several months and then discharge in batches periodically, increase the magnitude of potential environmental impacts.

- The flow and volume of the receiving waterbody is a factor in the degree of impacts from alum and lime sludge. If the flow is low, then sludge will more readily fall out of suspension in the water column and coat the bottom (U.S. EPA/ASCE/AWWA, 1996).

10.2 SUMMARY OF ENVIRONMENTAL IMPACT OF WTP RESIDUALS BY POLLUTANT

This section provides details on the pollutants highlighted in the review of readily available information for the environmental impacts and common pollutants found in WTP residuals (see Section 8). The information in this section is not specific to WTP discharges.

10.2.1 Environmental Impact of Solids

Suspended solids discharged by WTPs may settle to form bottom deposits in the receiving water, creating anaerobic conditions because of the oxygen demand exerted by microbial decomposition. Suspended solids also increase turbidity in receiving waters and reduce light penetration through the water column, thereby limiting the growth of rooted aquatic vegetation that serves as a critical habitat for fish, shellfish, and other aquatic organisms. Suspended solids also provide a medium for the transport of other sorbed pollutants, including nutrients, pathogens, metals, and toxic organic compounds, which accumulate in settled deposits. Settled suspended solids and other associated pollutants often have extended interaction with the water column through cycles of deposition, resuspension, and redeposition.

In addition, suspended solids in wastewater discharges can clog fish gills. In severe situations, clogging of fish gills can result in asphyxiation; in less severe situations, it can result in an increase in susceptibility to infection.

Dissolved solids can have a potential impact on the subsequent use of receiving waters that serve as source waters for public and industrial water supplies. Dissolved solids also have the potential to alter the chemistry of natural waters to a degree that adversely affects indigenous aquatic biota, especially in the immediate vicinity of the effluent discharge. An example is a possible influence on the toxicity of heavy metals and organic compounds to fish and other aquatic organisms, primarily because of the antagonistic effect of hardness.

10.2.2 Environmental Impact of Metals

Metals are potentially toxic to phytoplankton and zooplankton and to higher aquatic plant and animal species, including fish. They also have the potential for bioaccumulation and biomagnification in aquatic food chains and presence downstream in effluent receiving waters used as source waters for potable water supplies.

Aluminum is toxic in the aquatic environment. The direct effect of WTP residuals on the aquatic environment is difficult to isolate from the effect of naturally-occurring aluminum. The aluminum species concentration causing toxicity depends on water chemistry, aquatic organism affected, and the effect being monitored. Studies on the toxic effects of aluminum in the aquatic environment have shown that inorganic aluminum can be toxic to several fresh-water species of fish, invertebrates, bacteria, and algae at pH conditions less than 6 (U.S. EPA, ASCE, AWWA, 1996).

10.2.3 Environmental Impact of Chlorine and Chloramines

WTPs commonly use chlorine and chloramines to disinfect drinking water. These chemicals may become part of residuals waste streams either by addition prior to residuals generation (primary disinfection) or by using finished drinking water as backwash (disinfection at the clear well is secondary disinfection).

Free chlorine is directly toxic to aquatic organisms and can react with naturally occurring organic compounds in receiving waters to form toxic compounds such as trihalomethane. Chloramines can remain chemically stable in water from hours to days. They are highly toxic to fish and other organisms which live in water. These substances are not found to be bioaccumulative, or to transfer up the food chain (Environment Canada, 2002).

10.2.4 Environmental Impact of Oxygen Demand

When WTP wastewaters are discharged to surface waters, the microorganisms present in the naturally occurring microbial ecosystem decompose the organic matter contained in the wastewater. The decomposition process consumes oxygen and reduces the amount available for aquatic animals. Severe reductions in dissolved oxygen concentrations can lead to fish kills. Even moderate decreases in dissolved oxygen concentrations can adversely affect waterbodies through decreases in biodiversity, as manifested by the loss of some species of fish and other aquatic animals. Loss of biodiversity in aquatic plant communities due to anoxic (i.e., insufficient oxygen) conditions can also occur.

10.2.5 Environmental Impact of Chlorides

Chloride (Cl-) is a common anion in wastewaters and natural waters. For the protection of freshwater fish and aquatic life, EPA recommends the following for chloride: criteria maximum concentration of 860 mg/L (acute effects) and criterion continuous concentration of 230 mg/L (chronic effects) (U.S. EPA, 2006). Exceeding these chloride levels in wastewater discharges can be harmful to animals and plants in non-marine surface waters and can disrupt ecosystem structure. It can also adversely affect biological wastewater treatment processes. Furthermore, excessively high chloride concentrations in surface waters can impair their use as source waters for potable water supplies. If sodium is the predominant cation present, the water will have an unpleasant taste due to the corrosive action of chloride ions.

10.2.6 Environmental Impact of Nitrogen

Under both anaerobic and aerobic conditions, the readily biodegradable fraction of organic nitrogen is mineralized readily by microbial activity. The nitrogen not used for cell synthesis accumulates as ammonia nitrogen. The water quality impacts associated with organic nitrogen are related to this process of mineralization to ammonia nitrogen in natural waters and are discussed below.

Both ammonia nitrogen and ammonium nitrogen can be directly toxic to fish and other aquatic organisms; ammonia nitrogen is the more toxic. In addition, discharges of ammonia nitrogen can reduce ambient dissolved oxygen concentrations in receiving surface waters because of the microbially mediated oxidation of ammonia nitrogen to nitrite plus nitrate nitrogen. This demand is known as nitrogenous oxygen demand (NOD).

Ammonia nitrogen in wastewater discharges can also be responsible for the development of eutrophic conditions in the receiving water. Eutrophic waters are rich in mineral and organic nutrients. These nutrients promote the growth of plant life, especially algae. Plants reduce the dissolved oxygen content. These adverse impacts on ambient dissolved oxygen concentrations occur if nitrogen is the nutrient limiting primary productivity. Although phosphorus is typically the nutrient limiting primary productivity in fresh surface waters, nitrogen is typically the limiting nutrient in marine waters and the more saline segments of estuaries. Algae blooms from eutrophic conditions cause shifts in ambient dissolved oxygen concentrations from supersaturation on sunny days to substantial deficits at night and on cloudy days, when photosynthesis does not occur. The decay of the biomass generated by excessive primary productivity also exerts a demand on ambient dissolved oxygen concentrations. With the depression of ambient dissolved oxygen concentrations, populations of fish and other aquatic organisms are adversely affected, possibly causing a change in ecosystem composition and a loss of biodiversity.

Although nitrite plus nitrate nitrogen exerts an NOD in surface waters, the principal concern about oxidized forms of nitrogen in wastewater discharges is related to their role in the development of eutrophic conditions. The impacts of such conditions on fish populations, biodiversity, recreation, and potable water supply are discussed above. An additional concern is their potential for increasing ambient surface water nitrate (as nitrogen) and nitrite (as nitrogen) concentrations above the national maximum contaminant levels in source waters used for public drinking water supplies.

10.2.7 Environmental Impact of pH Changes

The hydrogen-ion concentration in an aqueous solution is represented by the pH, which is defined as the negative logarithm of the hydrogen-ion concentration in a solution. On the pH scale ranging from zero to 14, a value of seven represents neutral conditions—the concentrations of hydrogen (H+) and hydroxyl ions (OH-) are equal. pH values less than seven indicate acidic conditions and values greater than seven represent basic conditions.

WTPs adjust the pH to optimize source water treatment, and the addition of lime for softening raises the pH of the water. pH varies in WTP wastewaters and can have negative impacts on receiving water. Wastewaters with pH values markedly different from the receiving stream pH can have a detrimental effect on the environment. Sudden pH changes can kill aquatic life.

10.2.8 Environmental Impact of Phosphorus

Phosphorus is the nutrient typically limiting primary productivity in freshwater ecosystems. In such aquatic ecosystems, an increase in ambient phosphorus concentration due to wastewater discharges above naturally occurring levels results in the excessive growth of algae and other phytoplankton, with the development of eutrophic conditions as the consequence. In turn, eutrophic conditions can cause fish kills, disruption of natural aquatic ecosystem structure, and loss of biodiversity. In marine waters, phosphorus is not as much of a concern because of relatively high naturally occurring phosphorus concentrations. The impact of phosphorus in wastewater discharges into estuaries varies—in general, impacts decrease as salinity levels increase.

10.2.9 Environmental Impact of Radionuclides

Radionuclides regulated in drinking water include combined radium -226/-228, (adjusted) gross alpha, beta particle and photon radioactivity, and uranium. Exposure to radionuclides from drinking water results in the increased risk of cancer. Exposure to elevated uranium levels in drinking water has been shown to lead to changes in kidney function that are indicators of potential future kidney failure (U.S. EPA, 2000).

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SECTION 11

TECHNOLOGIES AND PRACTICES FOR PREVENTING, TREATING, DISPOSING OF, AND DISCHARGING SOURCE WATER TREATMENT RESIDUALS

Water treatment plants (WTPs) use control technologies and management practices to improve the prevention, treatment, disposal, and discharge of source water treatment residuals. Adoption of certain control technologies and management practices may significantly help WTPs meet permit limits. Other benefits of control technologies and management practices include improved water quality, reduced treatment system operation costs, avoidance of NPDES permitting costs, and energy savings.

The Clean Water Act (CWA) authorizes EPA to require WTPs to implement best management practices (BMPs) as part of their National Pollutant Discharge Elimination System (NPDES) permits. EPA has the flexibility to include BMPs in addition to pollutant concentration limits or in lieu of pollutant limits. Examples of BMPs in permits include establishing schedules of activities; prohibitions of practices; maintenance procedures; treatment requirements; and operating procedures and practices to control plant site runoff, leaks and spills, sludge or waste disposal, and drainage from raw material storage areas.

When applied to WTPs, the Pollution Prevention Act of 1990 and EPA's national pollution prevention policy[24], provide a framework for determining BMPs, beginning with pollution prevention at the source, followed by recycling of filter backwash, efficient treatment of residuals, land disposal of solids and certain waste streams, and practices to minimize the potential aquatic impacts of the discharge of residuals. This chapter discusses a range of BMPs, organized according to their placement in the hierarchy:

- Pollution prevention and waste reduction (Section 11.1);
- Residuals treatment (Section 11.2);

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[24] See http://www.epa.gov/p2/pubs/p2policy/definitions.htm#national for a description of EPA's national pollution prevention policy.

- Disposal of wastes (Section 11.3); and
- Discharge of wastes (Section 11.4).

WTPs that do not discharge treatment residuals to surface water or to POTWs are not required to obtain a NPDES permit, and thus exemplify the most effective application of BMPs. Zero discharging WTPs that generate residuals but do not discharge, are not required to obtain a NPDES permit. Becoming a zero discharging WTP results in multiple benefits such as water conservation, environmental improvements, and cost reduction. Most plants achieve zero discharge status through a combination of pollution prevention/waste management and residuals treatment practices, such as recycling, evaporation, composting, landfill disposal, spray irrigation, underground injection, and land application. EPA’s 2006 survey found that 70 percent of WTPs perform one or more of these methods to reduce discharges to surface waters or POTWs and 25 percent have achieved zero discharge status (see Appendix A).

Ground water plants use primarily underground injection control, recycling, and landfill disposal to achieve zero discharge. Surface water plants use recycling, landfill disposal, and land application (see Appendix A).

11.1 POLLUTION PREVENTION AND WASTE REDUCTION

This section discusses pollution prevention (e.g., process modifications) and waste reduction (e.g., resource recovery) opportunities at WTPs to reduce the generation of residuals during source water treatment.[25] Pollution prevention and waste reduction practices may also benefit WTPs by reducing operating costs, reducing risk of liability, and improving system or plant image, without compromising the finished water quality.

As part of the 2006 industry survey, EPA collected data on pollution prevention and waste reduction practices at WTPs. Figure 11-1 presents the distribution of pollution prevention and waste reduction practices commonly found at WTPs serving more than 10,000 people.

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[25] Pollution prevention is the use of materials, processes, or practices that reduce or eliminate the creation of pollutants or waste at the source (U.S. EPA, 1992).

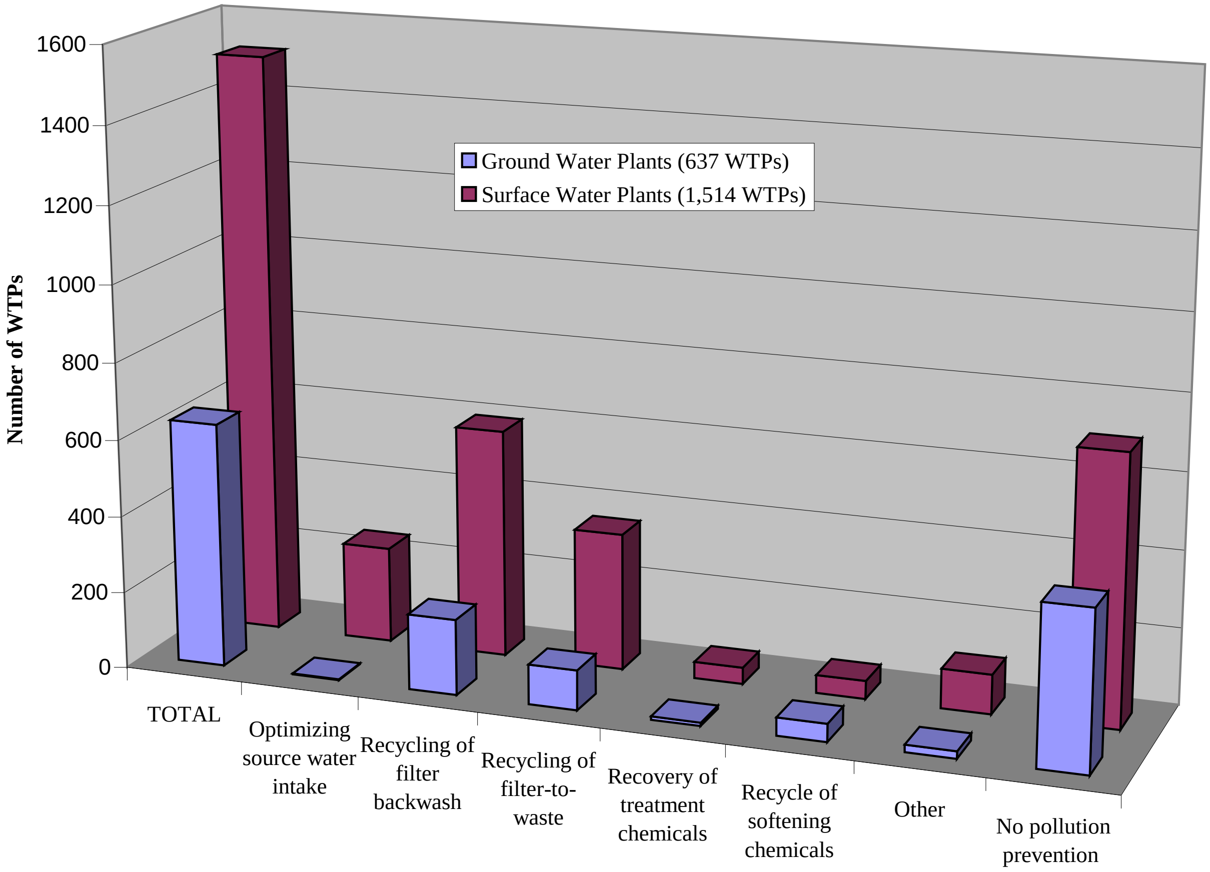

Figure 11-1. WTP Pollution Prevention and Waste Reduction Practices in the U.S. in 2006
Source: Appendix A.

WTP pollution prevention and waste reduction options discussed in this section include:

- Optimizing source water intake conditions to reduce suspended solids and thereby reduce source water treatment requirements.
- Optimizing filter media for finished water and residuals.
- Optimizing pH to reduce coagulant chemicals used.
- Reducing softening chemicals used by frequent monitoring of source water hardness.
- Returning backwash water and filter-to-waste to the head of the source water treatment plant for reuse.

- Reusing precipitative softening chemicals by recycling softening residuals.
- Recovering treatment chemicals.

11.1.1 Optimize Intake Water Conditions

When properly designed, situated, and instrumented, intake structures can play an important role in regulating the quality, volume, and composition of the source water presented for treatment. Intake features must be flexible to meet the current and future demands, yet be durable enough to withstand the rigors of time and nature. Careful placement of the intake structure (particularly in lakes or reservoirs) allows the WTP to draw water that has lower levels of total suspended solids, which in turn requires less coagulant to be added and generates a smaller volume of solid residuals.

An example of a facility that is currently optimizing intake water conditions is the James J. Corbalis Water Treatment Plant in Fairfax, Virginia. Fairfax Water constructed an extension that moved the intake structure away from the edge of the river. The new intake location improved the quality of the source water by decreasing turbidity and total organic carbon levels, and provided a more consistent day-to-day source that is less influenced by local runoff. The new intake location resulted in approximately 30 percent lower consumption of treatment chemicals and a corresponding reduction in residuals generation (U.S. EPA, 2005).

The relocation of the intake pipe in the example above might be an option for WTPs with high total suspended solids (TSS) and turbidity levels in the source water. While relocating the intake pipe requires an investment of capital, plants might be able to recoup these costs over a reasonably cost-effective time frame through savings on operation and maintenance.

11.1.2 Optimize Filter Media

By optimizing filter media, WTPs might be able to maintain or improve finished water quality, while reducing the quantity of backwash residuals. For example, in 1996, the Philadelphia Suburban Water Company replaced the support gravel and media in four of the dual media filters at the Pickering West Water Treatment Plant in Phoenixville, Pennsylvania. The

Philadelphia Suburban Water Company replaced the support gravel and sand with the same size and quality media in all of the filters. The water company also replaced the anthracite with the same effective size and quality in all of the filters, but with different uniformity coefficients (UC)[26] (one at 1.6 UC, one at 1.5 UC, one at 1.4 UC, and one at 1.3 UC). Data gathered over a one-year period indicated substantial differences in the filter run times and water quality. The lower anthracite uniformity coefficient showed the following benefits:

- Longer filter run times: up to 50 percent longer;
- Fewer backwashes—up to 33 percent less;
- Increased drinking water production—2 percent higher; and
- Improved water quality—up to 38 percent lower 2-5 micron particle counts (*Cryptosporidium* falls into this particle size range) (Yohe, 2006).

Reducing the volume of backwash water residuals can reduce the costs associated with residuals management, as long as finished water quality is not compromised.

11.1.3 Optimize pH to Reduce Coagulant Chemicals

As water progresses through the source water treatment train at coagulation and filtration plants, operators add coagulants to enhance the efficiency of solids removal. The majority of coagulant chemicals settle, along with the removed contaminants, during source water treatment. The coagulant chemicals then become part of the residuals waste stream. When selecting a coagulant chemical, plants might consider waste generation along with their finished water quality goals.

Coagulants contain active ingredients (e.g., aluminum, iron) and impurities (e.g., chromium, mercury, nickel, zinc). By reducing the amount of coagulant needed to achieve solids removal, WTPs also reduce the amount of these coagulant chemicals in the residuals. To minimize the use of coagulants, WTPs can optimize solids settling using the pH in clarifiers and sedimentation tanks. The pH of the water affects the performance of alum and ferric coagulation

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[26] Measure of the particle size variations (ratio).

salts. Alum has a minimum solubility at pH 6, while ferric salts have a minimum solubility at pH 8 (Tchobanoglous, et al., 2003). Thus, the continuous adjusting of pH to keep optimal coagulation conditions might help to reduce waste products but still effectively treat the source water.

11.1.4 Reduce Softening Chemicals by Monitoring Source Water Hardness

Similar to coagulation, softening operations add chemicals to adjust the pH, adjust the bicarbonate equilibrium, and precipitate the calcium hardness as calcium carbonate. WTPs remove calcium hardness to a level that meets the aesthetic requirements of the customer. By monitoring the calcium content of the influent, WTPs might reduce the amount of chemicals needed to precipitate the required fraction of calcium hardness, thus resulting in a minimized amount of residuals requiring additional treatment or disposal.

11.1.5 Return Backwash Water and Filter-to-Waste to the Head of the Source Water Treatment Plant for Reuse

Filter backwash water and filter-to-waste are good examples of residuals suitable for reuse, provided finished drinking water quality is maintained. Usually, finished drinking water is used as the filter scouring agent to backwash (or clean) the filter. Filter-to-waste is the initial permeate production when a filter is brought back online following backwashing, and is part of the backwash waste stream.

The backwash process generates a significant volume of wastewater that can amount to 2 to 5 percent of plant capacity (U.S. EPA, ASCE, and AWWA, 1996). If allowed to settle for 24 hours, the majority of the suspended solids in the backwash separate and the effluent can be returned to the head of the treatment plant for reuse while the solids are managed as waste. This practice also helps WTPs supplement available source water, which might prove especially valuable during water shortages. WTPs can also use this approach for decanted effluents from sludge thickeners and other dewatering liquids, thereby reducing the amount of effluent discharged.

In 2001, EPA's Filter Backwash Recycle Rule (FBRR) established requirements to ensure that WTPs do not compromise the quality of finished drinking water when reusing water in this manner. The FBRR applies to WTPs that use surface water or ground water under the direct influence of surface water and operate conventional or direct filtration plants (i.e., perform coagulation, filtration, and possibly sedimentation of the intake water). The FBRR requires WTPs that reuse certain wastewater residuals (i.e., filter backwash, thickener supernatant, and dewatering process liquids) to return the water to a point in the source water treatment process where it will be treated by coagulation and filtration. Introduction of reused waters at any other location requires prior state approval.

The purpose of the FBRR is to reduce the risk of illness from microbial pathogens in drinking water. During reuse, contaminants might be reintroduced into the source water treatment plant. The introduction of the contaminants can impair treatment process performance if not done properly. This can result in contaminants passing through source water treatment and into the drinking water.

Depending on the source water quality and wastewater characteristics (i.e., contaminant levels), some plants might not be able to reuse water streams. For example, concentrate residuals from membrane systems can concentrate contaminants more than five times their original concentration in the source water. Returning concentrate to the head of the treatment plant without extensive pretreatment would put a significant strain on the efficiency of the membrane and reduce its effectiveness. If the concentrate volume is low, discharge to a sanitary sewer might be the more affordable alternative to pretreatment and reuse.

11.1.6 Reuse of Precipitative Softening Chemicals

WTPs might reuse precipitative softening chemicals (i.e., lime) to save costs on purchasing lime and disposing of softening residuals. Lime recovery from the residuals is accomplished using recalcination, in which the calcium carbonate in the lime softening sludge is converted to calcium oxide. WTPs perform dewatering and oxidation to complete the conversion. WTPs generally use centrifugal separators to dewater the calcium carbonate. The calcium carbonate is then dried and oxidized, usually in a furnace. The recovered lime is returned back to the source water treatment plant (U.S. EPA, ASCE, and AWWA, 1996).

11.1.7 Recovery of Treatment Chemicals

In addition to the lime recovery discussed above, WTPs might recover coagulants for reuse at the plant. Assuming recovered treatment chemicals meet purity standards, this process results in cost savings from reduced cost to dispose of solid waste residuals and reduced cost for purchasing new treatment chemicals. A second treatment recovery option available to WTPs is to recover salts from ion exchange concentrate residuals. The salt is a saleable resource.

11.1.7.1 Coagulant Recovery

Most coagulants are cationic (positively-charged) in nature and include the following chemicals: aluminum (alum), iron (ferric) salts, and a wide variety of organic polymers. The type and character of the source water, as well as plant choice, determines which chemicals are used and the degree of possible reuse.

Solubility diagrams for aluminum and iron show that both metals approach their minimum solubility in the pH range of 6 to 8 (Tchobanoglous, et al., 2003). Because this is the normal operating range for most utilities, nearly all of the insoluble coagulant components added are expected to be incorporated in the precipitated solids and to be available for recovery. Solubility diagrams also show that the solubility for both metals increases as the pH is made more acidic (less than 6).

The traditional approach for alum recovery has been acid extraction to convert the alum to a dissolved form for decanting and recycling. Aluminum recovery rates of 60 to 80 percent have been reported at the pH 3 level (ASCE, 1997). However, this approach can also carry over “native” metals in the source water and the recycled coagulant might be of lesser purity than American National Standards Institute (ANSI)/National Science Foundation (NSF) Standard 60. Ion exchange has also been successfully used to recover dissolved aluminum from acid extraction. Iron recovery can be accomplished in a way that is similar to alum recovery.

Acid extraction at a pH between 1.5 and 2 has produced iron recoveries at 60 to 70 percent (ASCE, 1997), but dewatering difficulties with the sludge have limited its commercial application.

Since aluminum and iron are amphoteric (i.e., exhibiting properties of both an acid and a base), a strong base can also dissolve the metal hydroxides. Treatment with sodium hydroxide produces a sodium aluminate compound that can be reused as a coagulant in water treatment. To date, few WTPs recover coagulants due to purity concerns and the low cost (market price)[27] of purchasing of new chemicals.

11.1.7.2 Salt Recovery Via Evaporation and Crystallization of Concentrate

The use of membrane and ion exchange technologies produces a clean permeate stream and a reject stream (or concentrate) containing the source water contaminants. Concentrate generated by membrane water treatment technologies contains sodium and potassium salts of 36,000 milligrams per liter (mg/L) or more (Tchobanoglous, et al., 2003). Concentrate generated by ion exchange plants contains sodium (Na+) at average concentrations between 2,000 and 5,000 mg/L (U.S. EPA, ASCE, and AWWA, 1996). By recovering these salts, plants can gain a saleable resource and prevent the discharge of the concentrate into surface waters.

WTPs can use drying beds to recover salts by evaporating the water. Drying beds are particularly effective in the southern and southwestern parts of the country with moderate to hot temperatures.

Crystallization of salts from concentrate involves removing enough water to exceed salt solubility limitations. Once the salt changes phase from dissolved to crystallized form, it can be readily removed. If the residuals contain mixtures of chemical components, then additional steps are required to refine the crystallized material prior to sale or reuse.

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[27] The market price of the coagulant does not include the costs incurred to mitigate any potential environmental damage that pollutants in coagulants cause the environment when released in the effluent stream of the WTP.

11.2 RESIDUALS TREATMENT

Residuals contain contaminants removed from the source water and treatment chemicals added by the WTP. Prior to final waste management (e.g., land application, disposal, or discharge), residuals from the source water treatment operations (e.g., filter backwash water, coagulation sludge) can be treated on site by the WTP. This subsection is organized by technologies used by WTPs to achieve the following:

- Separation of solids from water (Section 11.2.1);
- Precipitation of chemicals (Section 11.2.2);
- Increase in oxygen content (Section 11.2.3);
- Removal of chlorine (Section 11.2.4); and
- Adjustment of pH (Section 11.2.5).

Table 11-1 presents the distribution of residuals treatment practices commonly found at WTPs serving more than 10,000 people. Section 11.2.6 presents nonwater environmental quality impacts to consider when installing a residuals treatment system.

Table 11-1. Distribution of Residuals Treatment Technologies at Drinking Water Treatment Plants

Treatment Category	Treatment Unit	Number and Percent of WTPs With the Treatment Unit in Place (2,151 WTPs)
Solid/Water Separation	Equalization only	159 (7%)
	Clarification	*Included with non-mechanical dewatering*
	Lagoon	*Included with non-mechanical dewatering*
	Thickening	*Included with non-mechanical dewatering*
	Mechanical dewatering	195 (9%)
	Non-mechanical dewatering [a]	1,413 (66%)
	Drying or evaporation	*Included with non-mechanical dewatering*
Other Residuals Treatment	Chemical precipitation	*Not estimated*
	Aeration to increase oxygen content	*Not estimated*
	Dechlorination	230 (14% of 1,599 plants that disinfect with free chlorine)
	pH Adjustment	*Not estimated*
No Treatment	No treatment	522 (24%)

Source: Appendix A.
a – Might include equalization.

11.2.1 Solids Removal (Separation of Solids and Water)

The volume and characteristics of the residuals depend on the source water, drinking water production rate, efficiency of source water treatment, and type of source water treatment used. Treatment residuals contain naturally occurring suspended and dissolved solids, as well as precipitated solids generated by chemical treatment. Many WTPs treat residuals to separate solids from the wastewater.

WTPs can use one or more solids removal processes to treat WTP residuals. For example, WTPs can separate solids and water using an equalization basin, followed by a gravity thickener, and finally a centrifuge. At each process in the residual treatment train, additional separation occurs.

Decreasing the volume of water while increasing solids content is the principle objective of solids removal systems. The decreased volume reduces landfill requirements and reduces cost. (Landfills usually charge customers by weight.) “Thickening” and “dewatering” are solids removal terms that are often used interchangeably. Based on the applicable treatment techniques, these two practices have many common elements. The discussion that begins with Table 11-2 describes solid/water separation using the following terminology:

- **Thickening:** Solids separation by physical means without the significant application of mechanical devices. Sedimentation (gravity settling) and dissolved air flotation are examples of drinking water residuals thickening technologies.

- **Mechanical Dewatering:** Solids separation by mechanical means. Pressure filtration and centrifugation are examples of mechanical dewatering technologies.

- **Non-Mechanical Dewatering:** Solids concentration by evaporation of the water. Storage ponds, lagoons, and drying beds are examples of non-mechanical dewatering.

- **Thermal Treatment:** Solids concentration by evaporation of the water using mechanical drying processes.

Table 11-2 presents the range of solids concentrations that typically results from using various solids removal processes (U.S. EPA, ASCE, and AWWA, 1996).

Table 11-2. Comparison of Solids Removal Technologies: Solids Concentration After Treatment by Residuals Type

Solids Removal Treatment	Solids Concentration for Treated Lime Softening Residuals	Solids Concentration for Treated Coagulation Residuals
Thickening		
Gravity Thickening	15–30%	1–3% (low TSS) 5–30% (high TSS)
Flotation Thickening	Not available	2–4%
Gravity Belt	Not available	2.5–4.5%
Mechanical Dewatering		
Scroll Centrifuge	55–65%	20–30%
Belt Filter Press	50–60%	1 –20% (Alum) 4–50% (Alum, TSS)
Plate (or Pressure) Filter	55–70%	35–45%
Diaphragm Filter Press	50–70%	30–60% (Alum with lime conditioning)
Non-Mechanical Dewatering		
Storage Lagoon	50–60%	7–15%
Sand Drying Bed	50%	20–25%

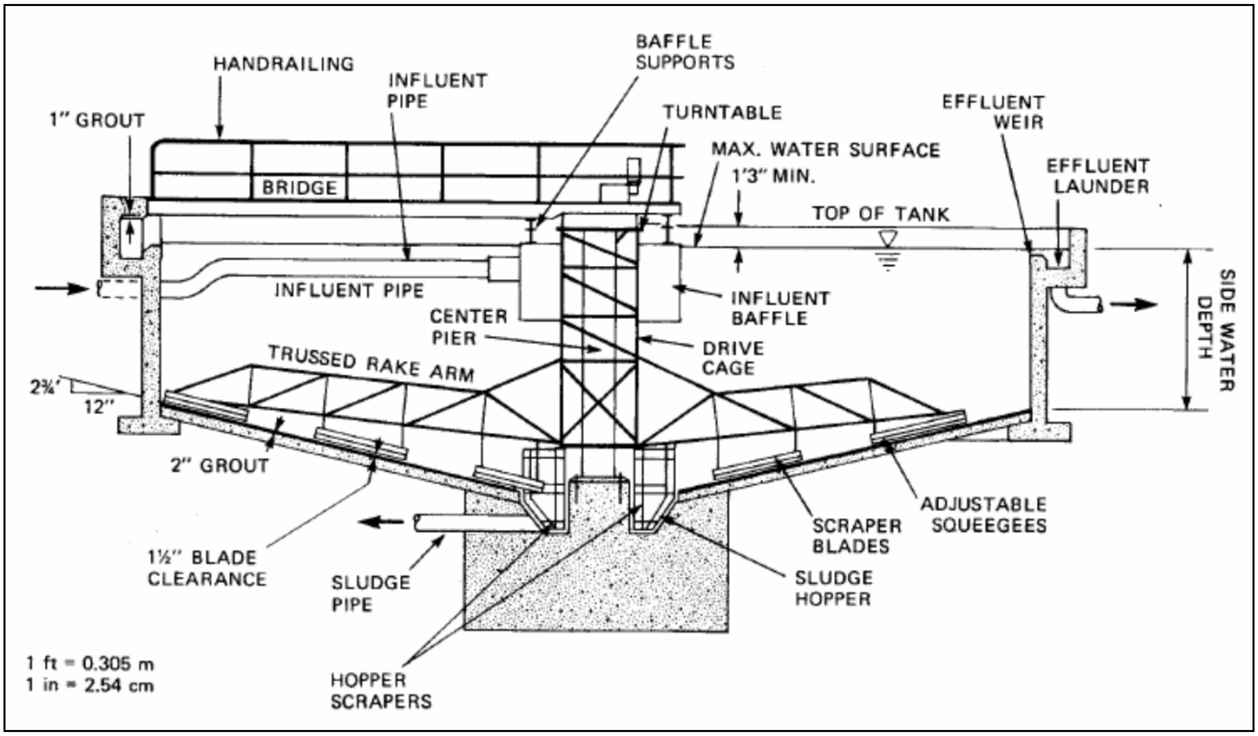
Source: U.S. EPA, ASCE, and AWWA, 1996.

11.2.1.1 Thickening

The objective of thickening is to increase the solids content of the residuals by removing a portion of the water. Gravity settling, dissolved air flotation, and gravity belt are the most common thickening technologies.

Thickening of residuals can take several paths, but the end result is to remove a portion of the influent water to concentrate the solids for resource recovery. The importance of having a higher concentration of solids progressing to the next treatment/recovery phase is reflected in the reduction of the capital and operating costs of the continuing treatment (e.g., an increase in solids from 3 to 6 percent results in a 50 percent volume reduction which in turn would reduce capital expenditures associated with the construction of greater wastewater handling capacity in this residuals treatment phase. An increase in solids concentration can also facilitate the design and reduce per unit cost associated with wastewater treatment and solids disposal.

Gravity settling is the term that describes using gravity to separate (thicken) solids from water. Initially, applications of this technology at WTPs consisted of long, narrow, and deep tanks with residence times of at least four hours. The industry has since shifted to use of circular units due to operational difficulties with removing residue from the long, narrow tanks and advances in engineering design. Figure 11-2 presents a diagram of a circular gravity thickener. New designs with the same thickening efficiencies have reduced the residence time to two hours or less (ASCE, 1997). Metal hydroxide (i.e., coagulation) residuals with low TSS concentrations can be thickened to up to 3 percent solids, while residuals with higher TSS concentrations can be thickened to as high as 30 percent solids. Lime softening residuals (carbonate residuals) can be thickened to the range of 15 to 30 percent solids (U.S. EPA, ASCE, and AWWA, 1996). The number of gravity settling tanks required for residuals treatment depends on the plant's treatment volume and the amount of redundancy required. For example, if the influent solids content is in the 1 to 3 percent range, and a design solids loading rate of 4.0 pounds/day/square foot is used (AWWARF, 1987), a sedimentation tank with a diameter of 30 feet is needed for each million gallons of waste treated.



Source: U.S. EPA, 1987. *Design Manual: Dewatering Municipal Wastewater Sludges.*

Figure 11-2. Gravity Thickener (U.S. EPA, 2003)

Dissolved air flotation (DAF) is the most common of several flotation separation technologies. Pressurized air is injected into recycled drinking water and added to the residuals feed. When the pressure on the injected water is released, it allows the super saturated air to escape into the residuals as small bubbles that cause turbulence. The small bubbles mix with the TSS in the residuals stream and adhere to the suspended particles, pushing them to the surface. The floating material (thickened solids) is then skimmed off. Flotation separation techniques for drinking water residuals are used more widely in Europe and can generate floating solid residuals with 3 to 4 percent solids reported (U.S. EPA, ASCE, and AWWA, 1996).

If space is a constraint, or if gravity settling or flotation do not provide the desired solids thickening, then plants can use a gravity belt thickener as an alternative. Gravity belt thickeners are constructed from a porous belt (metal mesh) that allows water to drain through the belt while retaining the solids. The recirculating belt travels through solids removal and wash sections before returning to service. The design of the belt material and the loading applied influence separation efficiencies, with solids concentrations for treated metal hydroxides residuals ranging from 2.5 to 4.5 percent (U.S. EPA, ASCE, and AWWA, 1996). Gravity belts are simple designs with minimal operator oversight; however, they generate another residuals stream (wash water), usually require use of a solids conditioner, and require maintenance.

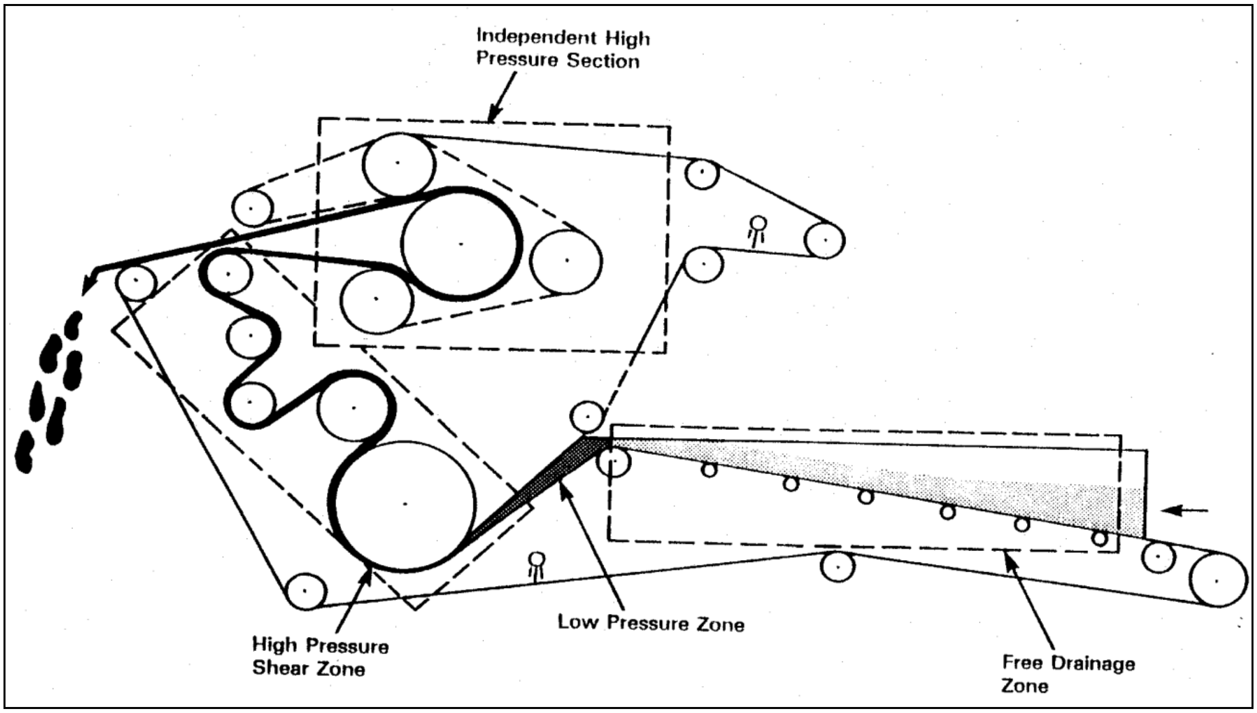
Following the thickening operation, the solids continue to the next solid/water separation step (i.e., mechanical dewatering). The supernatant from the thickening operation is recycled or discharged by the plant.

11.2.1.2 Mechanical Dewatering

WTPs commonly follow residuals thickening with mechanical dewatering for additional volume reduction and concentration of solids. Common mechanical dewatering technologies used by the WTPs are belt filter presses, plate and frame filter presses, and centrifuges.

Belt filter presses use pressure to force water out of the residuals through the porous belt while retaining the separated solids on the belt. Figure 11-3 shows the design of a belt filter press. Treatment residuals are placed on the dewatering belt and drained in the free drainage zone. The remaining solids/water are sandwiched between two porous belts and passed over/under a series of different diameter rollers. The different rollers impart low and high pressure on the belts, squeezing the additional water from the solids and through the porous belt. The more extensive the belt travel, the drier the filter cake. Lime softening residuals are good candidates for this system because their more granular structure can withstand higher pressures. Using this technology, plants have reported lime filter cake with 50 to 60 percent solids (U.S. EPA, ASCE, and AWWA, 1996).

Pressure filters (e.g., plate and frame filter press, diaphragm filter press) apply high pressure to a solid/liquid suspension and force the liquid out while retaining the solids. Plate and frame filters have a recessed area that receives the pumped influent waste material at elevated pressures. The filter fabric covering the plates allows the water to escape while retaining the solids. This is a continuous process until the pressure drop across the filter equals the pumping pressure and the unit is shut down. The filter is then broken down and manually cleaned and returned to service. A diaphragm filter press allows WTP operators to vary the volume in the receiving area. It employs a two-stage filtering process in which the diaphragm is expanded after initial filtering has been completed. Lime softening residuals have been dewatered to solids concentrations of 50 to 70 percent using this technique (U.S. EPA, ASCE, and AWWA, 1996).



Source: U.S. EPA, 1987. *Design Manual: Dewatering Municipal Wastewater Sludges*.

Figure 11-3. Belt Filter Press (U.S. EPA, 2000a)

Centrifugal separators use centrifugal force to separate suspended solids from water. The amount of force applied to the waste stream solids depends on the centrifuge's rotational speed. The force applied and the centrifuging time determine separation effectiveness. As the industrial application of centrifuges increases in size, so do the operational problems and energy costs. The solid bowl centrifuge is the principal type of centrifugal separator used to dewater treatment residuals. The bowl centrifuge has two moving parts: the bowl and the scroll. As centrifugal force pushes the solids to the edge of the spinning bowl, a rotating scroll moves the dewatered solids along a horizontal axis to a collection point. Centrifuges perform better with the addition of a conditioning agent, thus they are rarely operated without the addition of a polymer to the residual suspension (U.S. EPA, ASCE, and AWWA, 1996).

Table 11-3 lists example cake solids concentrations that have been achieved by mechanical dewatering operations performed in a laboratory (U.S. EPA, ASCE, and AWWA, 1996).

Table 11-3. Laboratory Results for Mechanical Dewatering Operations for Various Drinking Water Treatment Residuals

Residuals	Specific Gravity of Particles	Solids Concentration After Gravity Thickening	Solids Concentration After Mechanical Dewatering	
			Centrifuge	Pressure Filter
Lime Softening Sludge (low Magnesium [Mg])	1.19	28.5%	60.6%	69.5%
Iron Sludge	1.16	26.0%	55.6%	64.6%
Ferric Hydroxide	1.07	7.2%	28.2%	36.2%
Lime Sludge (high Mg)	1.05	5.6%	24.8%	34.6%
Aluminum Hydroxide	1.03	3.6%	19.0%	23.2%

Source: U.S. EPA, ASCE and AWWA, 1996.

11.2.1.3 Non-Mechanical Dewatering

Two types of non-mechanical dewatering are discussed in this section: storage lagoons and drying bed operations. Both are often used at the end of the residuals treatment train.

Storage Ponds and Lagoons

WTPs can collect and hold treatment residuals in settling ponds, tanks, or lagoons to separate solids. Plants can allow solids settling prior to further solids separation (e.g., thickening or mechanical dewatering) or discharge. In addition, lagoons and ponds can serve as long-term waste disposal. Since the separation occurs without physical means, the use of lagoons, ponds, and settling tanks is considered a non-mechanical dewatering process.

WTPs collect residuals in storage ponds and lagoons and allow long-term sedimentation and compaction to separate the solids from the water. For metal hydroxide residuals like aluminum and iron (from coagulation) that are retained in a pond or lagoon for a month, solids concentrations of 10 percent in the settled sludge are common. For lime softening sludges, solids concentrations of 20 percent in the settled sludge are common (ASCE, 1997).

Storage ponds and lagoons are long-term residuals treatment approaches that require periodic draining, cleaning, and maintenance. In addition, application of this residuals treatment method depends on the land available, evaporation rates (if no further discharge or recycling), and any ground water contamination concerns. This use of storage ponds might result in no discharge from the WTP; however, some WTPs perform intermittent discharges of overflows from the tanks.

Drying Beds

Drying bed technologies share a common design concept: the cover material (bed) is installed over an under-drain consisting of gravel and perforated pipe. Drying bed technologies differ in the type of supporting material used for the bed surface (e.g., sand) and in whether external forces such as vacuum are used to promote the separation of the solids (see Figure 11-4). Initially, water percolates through the bed and is collected by the under-drain and discharged. Additional dewatering then occurs via evaporation. The rate of evaporation depends on the local climate, the solids characterization in the residuals, and the extent of external drainage enhancement. Thin layers dry faster than thick layers, but result in higher operating costs.

The following non-thermal drying bed technologies are used to reduce the moisture content in WTP residual solids:

- **Sand drying beds** dewater residuals by gravity drainage, followed by evaporation. Water drains through the sand and exits through the under-drain.
- **Freeze-assisted sand beds** are sand drying beds where the residuals are applied and then allowed to freeze (either naturally or mechanically). By freezing and then thawing the residuals, the solids become compressed together, more granular, and easier to dewater. WTPs use this technique for alum residuals, which have a gelatinous consistency that makes them difficult to dewater without the added freezing step.
- **Vacuum-assisted** systems apply negative pressure to promote the percolation of the free water through the bed, thus speeding the drying process.

- **Solar drying beds** can be used in specific geographic locations where the climate is sufficiently hot and dry (e.g., southwestern United States) to quickly dry the residuals. "Greenhouse" solar drying beds can also be used in less sunny areas, but they are not currently widespread.

Lime solids concentrations as high as 50 percent have been achieved using drying beds. Alum residuals might require the addition of a chemical conditioner prior to drying. The solids content after the drying bed has been reported as high as 25 percent (U.S. EPA, ASCE, and AWWA, 1996).

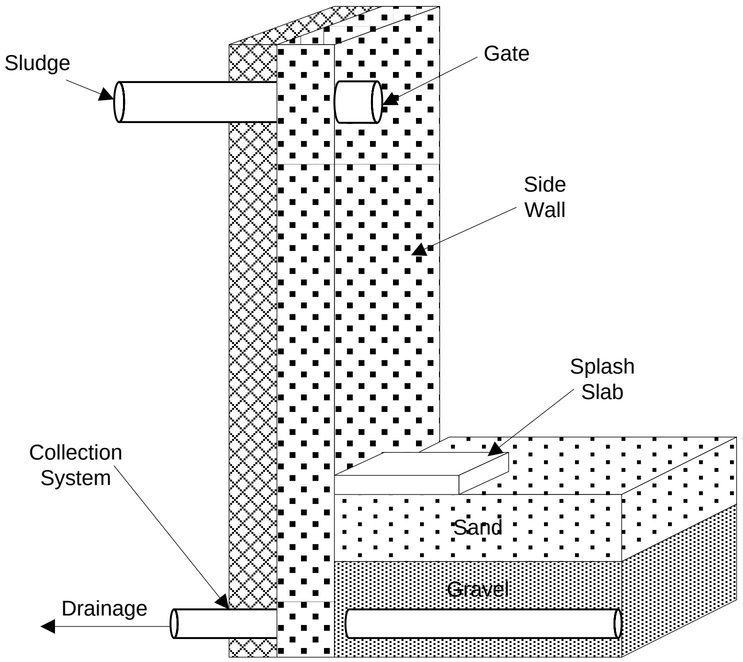


Figure 11-4. Sand Drying Bed Section (U.S. EPA, ASCE, and AWWA, 1996)

11.2.1.4 Thermal Drying

The final step in a residuals treatment train might be thermal drying. Thermal drying is not widely used by the industry because the costs of the technology are more than the costs savings that result from reduced residuals volume. In general, WTPs employ this technology to solve problems with pathogen control, odor control, and storage problems rather than to achieve solids/water separation alone. Thermal drying operations include direct fired systems (rotary kiln, fluidized bed, low temperature desorption), indirect fired (heated coils), and infrared radiation.

11.2.2 Chemical Precipitation

Chemical precipitation removes dissolved metals from wastewater by the addition of a precipitating reagent. The reagent reacts with the metal ions and creates insoluble forms of the metal. This type of residuals treatment is applicable to aqueous waste streams, such as filter ion exchange backwash and rinse and membrane desalination concentrates. The most common precipitating reagent is hydroxide; WTPs can add lime, quicklime, soda ash, or caustic soda to the residuals to introduce the hydroxide ions. Depending on the metals present in the residuals, sulfide and ferrous salt can also be used. Chemical precipitation of the residuals can be used to remove aluminum, antimony, arsenic, cadmium, chromium, copper, iron, lead, mercury, selenium, silver, thallium, or zinc. (U.S. EPA, 1993)

Equipment needed to perform chemical precipitation includes a stirred vessel reactor and clarifier. WTPs can add coagulants to aid solid settling. This treatment process results in: 1) a clean supernatant stream that is recycled or discharged, and 2) clarifier sludge. The clarifier sludge can be dewatered prior to disposal. (U.S. EPA, 1993)

11.2.3 Increased Oxygen Content by Aeration

Drinking water plants use aeration to treat both the source water and residuals streams. Aeration increases the oxygen content in the water. The dissolved oxygen concentration in the water indicates the amount of oxygen used by biological components and provides a qualitative measure to judge the relative purity of the residuals stream. To control biological oxygen demand discharges and increase dissolved oxygen levels, WTPs add oxygen to residuals prior to discharge.

11.2.4 Dechlorination

Residual chlorine in WTP discharges is toxic to many kinds of aquatic life and can react with organic materials in the receiving water to form carcinogenic trihalomethanes and organochlorines, including chloramines. Chloramines are highly toxic to fish and other organisms that live in water. Dechlorination removes the free or total combined chlorine residual remaining after disinfection through the addition of sulfur chemicals such as sulfur dioxide, sodium sulfite, sodium bisulfite, sodium metabisulfite, and sodium thiosulfite. Carbon adsorption can also be used for total dechlorination; however, this process is typically more expensive.

Dechlorination requires an adequate control system to reduce residual chlorine to near-zero levels of residual chlorine without overdosing with sulfite. Too much sulfite can result in sulfate formation, which suppresses oxygen content and lowers the pH of the treatment residuals (U.S. EPA, 2000b).

As presented in Section 3.3.2.2, EPA's survey found that 93 percent of WTPs in the target population perform primary disinfection (i.e., 2,002 of the 2,151 WTPs). Most WTPs (1,917 of 2,002) use free chlorine or chloramines for primary disinfection (1,599 and 318 plants respectively). EPA's survey found that only 230 WTPs perform dechlorination.

Costs for a dechlorination system depend on the particular conditions at the WTP. Cost considerations include capital costs (equipment, installation, and labor), operation and maintenance costs, and type of dechlorination chemical (U.S. EPA, 2000b).

11.2.5 pH Adjustment

As a result of treatment chemical addition, the source water pH is altered during treatment operations to improve treatment performance. Ecosystems are more vulnerable than humans to changes in pH—for example, small changes can affect reproductive patterns and longevity. NPDES permits typically require the pH of residuals discharges to range between 6 and 9. To adjust the pH, WTPs add acids to lower the pH and bases to raise the pH. Chemicals used by WTPs meet certified purity standards.

11.2.6 Nonwater Quality Environmental Impact Considerations

Eliminating or reducing one form of pollution may create or aggravate other environmental problems. When reviewing whether to install a residuals treatment system, WTPs and permit writers must look at the nonwater quality environmental impacts to determine any adverse effects on the environment.

11.2.6.1 Air Pollution and Control

The majority of impurities removed during source water treatment include suspended solids, metals, synthetic organic chemicals, and microbes. EPA does not expect suspended solids, metals, or microbes to escape and become air pollutants during residuals treatment. Air stripping of volatile organics is a residuals treatment option available to WTPs; however, the use of air stripping is infrequent. Materials handling operations may generate fugitive emissions, and these emissions can be managed by installing a proper ventilation system or dust suppression system.

Any increased air emissions as a result of installing residuals treatment would be primarily from the electric power generation facilities providing any additional energy and increased truck traffic due to additional sludge hauling.

11.2.6.2 Solid Waste Generation and Disposal

WTPs that treat large volumes of source water can generate large volumes of residuals. Plants have several options for handling the sludge/slurries produced by source water treatment. Options range from recycle/reuse to direct discharge. Recycling, discharging to a landfill, and performing land application are the most common approaches (U.S. EPA, 2008).

Residuals from WTPs are typically not hazardous and can be accepted by landfills or managed via land application. Treatment and disposal methods for residuals may vary among WTPs and are based on the characteristics of the waste. The volume and characteristics of the residuals generated by WTPs are discussed in Section 7 of this document.

11.2.6.3 Energy Requirements

The operation of the residuals treatment technology and operation of pumps to recycle residual streams would require additional energy. Total energy requirements for residuals treatment technologies are not expected to create a large impact. Incremental energy costs may be incurred by the installation of residuals treatment technology or other practices.

11.3 DISPOSAL PRACTICES FOR TREATMENT RESIDUALS

This subsection summarizes the typical disposal practices for residuals, including land application (Section 11.3.1) and land disposal via landfilling or deep well injection (Section 11.3.2). These disposal practices help reduce or eliminate discharges to surface water and POTWs. As such, they can be employed to help WTPs become zero discharging facilities.

11.3.1 Land Application of Residuals

After separating the solids from the wastewater and recovering usable materials, WTPs typically manage residual solids by land application or disposal in landfills (see Section 11.3.2). Land application involves spreading residuals on the land and cultivating it into the soil.

The application of residuals onto land depends on the crop being grown, chemistry of the soil, and sludge properties. Land application typically occurs with lime softening sludge, and to some extent coagulation sludge (e.g., alum sludge). Lime softening sludge can be used on farm land in place of commercial products to neutralize soil pH. Alum sludge does not benefit the soil and is used only for filler material. The ideal land application of WTP residuals occurs on non-food chain crops, mine reclamation areas, and forests (U.S. EPA, 1993).

Disadvantages of land application might exist depending on the properties of the residuals. For example, land application can result in increased concentration of metals in the soil (and possibly ground water). Application of aluminum and iron hydroxide sludge from coagulation can result in the adsorption of phosphorus from the soil to the applied residuals, resulting in less productive soil (U.S. EPA, 1993).

Land application requires large tracts of land and additional supporting infrastructure (tractor, pipes, lagoon, etc.). Further, ground water protection must also be addressed. If 1,000 (dry) pounds of residuals are produced daily, about 300 acres and about $50,000 in annual operating expenses are required (U.S. EPA, ASCE, and AWWA, 1996). WTPs can transport the residuals for offsite land application via tanker or truck.

Residuals managed by land application typically contain less than 15 percent solids. There must be sufficient liquid in the residuals to form pumpable slurry. Land application methods include spraying from trucks or a sprinkler system, injecting into the subsurface, or discharging the slurry onto a selected field. Dewatered residual sludge can be spread on the land (U.S. EPA, 1993).

Land application of membrane desalination concentrates is not as common as application of residual sludge. However, if desalination concentrates are applied to land, WTPs use percolation ponds, rapid infiltration basins, or landscape/crop irrigation (Malmrose, et al., 2004).

11.3.2 Disposal of Residuals to Landfills or Deep Injection Wells

Landfills for residuals can be either monofills (which contain one kind of waste) or municipal sanitary landfills (which contain many different kinds of waste). Disposal fees are usually based on weight of material presented for disposal and vary with different locations around the country. EPA regulates landfill disposal under the Resource Conservation and Recovery Act (RCRA).

In addition to landfills, WTPs can dispose of residuals using subsurface, or deep well, injection. Concentrates from membrane desalination can be disposed of through this practice, which is commonly performed by plants in Florida (Malmrose, et al., 2004). EPA regulates deep well injection disposal under its Underground Injection Control (UIC) program.

11.4 WASTEWATER DISCHARGES OF TREATMENT RESIDUALS

Wastewater from WTPs, such as filter backwash water, can be recycled to the head of the source water treatment plant or evaporated from residual solids. Solids (or slurries) from WTPs, such as lime softening sludge and coagulation sludge, can be dewatered and disposed of in a landfill or managed by land application. In some cases, WTPs opt to discharge treatment residuals either directly to waters of the United States or indirectly through publicly owned treatment works (POTWs).

Direct discharge to surface waters is the most common waste management method for conventional filtration and precipitative softening plants. Some of these WTPs are also able to achieve zero discharge using recycling, land application, and landfill disposal.

Indirect discharge is common for WTPs co-located with POTWs (i.e., operated by a local municipality) (U.S. EPA, 1993). Most membrane desalination plants are indirect dischargers or zero dischargers.

Some of the best discharge practices that might be included in NPDES permits or implemented by WTPs include the following:

- Limiting discharge flow rate. Rather than allowing batch discharges, NPDES permits can require WTPs to slowly discharge residuals into the receiving stream. Slowly discharging the residuals allows dilution in the receiving stream and minimizes the impacts of the pollutant discharge.

- Prohibiting discharges of solid residuals unless land-based use/disposal options are not feasible and/or WTPs demonstrate discharge does not degrade receiving water quality.

- Requiring that solids disposal from periodic cleaning of settling basins be land-based to avoid large batch discharges to the receiving stream.

- Prohibiting discharges of chlorinated backwash (or other waste streams) unless the WTP demonstrates that the receiving water-quality standards can be met at all times.

- Equalizing[28] the residuals discharge to avoid large batch discharges of pollutants. The WTP collects residuals in a tank, basin, or other device and discharges at a controlled flow rate over time. This practice can be used for filter backwash water (generated at very high flow rates for short

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[28] Equalization is the practice of collecting residuals in a tank, basin, or other device for later treatment or discharge at a controlled flow rate.

periods of time) and ion exchange regeneration waste streams (also generated at intermittent times) (AWWARF, 1987).

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SECTION 12

TREATMENT TECHNOLOGY COST CONSIDERATIONS FOR RESIDUALS THICKENING AND DEWATERING

As part of the drinking water industry review, EPA investigated technologies available to reduce residual discharges from the most common types of water treatment plants (WTPs) that discharge to surface waters. EPA evaluated the factors that affect the cost of installing and operating residuals treatment systems from conventional filtration (i.e., coagulation and filtration) and precipitative softening plants since these plants are the most prevalent across the country. EPA did not analyze options for treating residuals from other types of plants (e.g., ion exchange, adsorption, or membrane desalination). This section summarizes EPA's findings on costs and provides references to assist permit writers in estimating the costs for technology options. An example of costing analysis performed for a conventional filtration WTP is contained in the report *Technical Analysis for Determination of Technology-Based Permit Limits for the Guaynabo Drinking Water Treatment Facility NPDES No. PR0022438* (U.S EPA, 2009).

Section 12.1 presents a typical residuals treatment system which EPA used as part of its costing review. Section 12.2 provides background on cost data sources including cost models reviewed by industry experts and recent data provided by an industry trade association. Sections 12.3 and 12.4 summarize the determination of system size requirements and estimation of approximate costs for specific elements of the residuals treatment system.

12.1 RESIDUALS THICKENING AND DEWATERING TREATMENT TRAIN

Residuals from softening and conventional filtration plants include sedimentation basin underflow and spent filter backwash (see Figure 6-1). These residuals may be treated by various dewatering processes. As described in Section 11.2, WTPs can use one or more solids removal processes to dewater WTP residuals. At each process in the residual treatment train, additional separation occurs.

This report identifies cost considerations for the typical residuals treatment train illustrated in Figure 12-1. The residuals treatment train includes the following processes: spent filter backwash (SFBW) equalization basins and clarifiers, thickeners that further dewater clarifier underflow and treat sedimentation basin underflow from the source water treatment plant, centrifuges to further dewater underflow from the thickener, and final sludge handling prior to disposal. The figure does not show the source water treatment operations, only the treatment of residuals.

WTPs produce finished drinking water and generate residuals during source water treatment. Residuals from lime softening, coagulation, and filtration processes include filter backwash and sedimentation basin sludge. In the typical residuals treatment train, SFBW is pumped to equalization basins followed by a clarifier. Clarifier overflow can be discharged or recycled, as shown by the dashed line. Clarifier underflow is pumped to a thickener.

The thickener receives the SFBW clarifier underflow, sludge from the WTP's sedimentation basin, and the water that is removed during the dewatering step. Thickener overflow can be either recycled or discharged, as shown by the dashed line. Thickener underflow is pumped to dewatering.

In Figure 12-1, dewatering is accomplished using centrifuges. Centrate, the water that is removed from sludge in the centrifuge is shown returning to the thickener. Dewatered solids are stored and ultimately disposed.

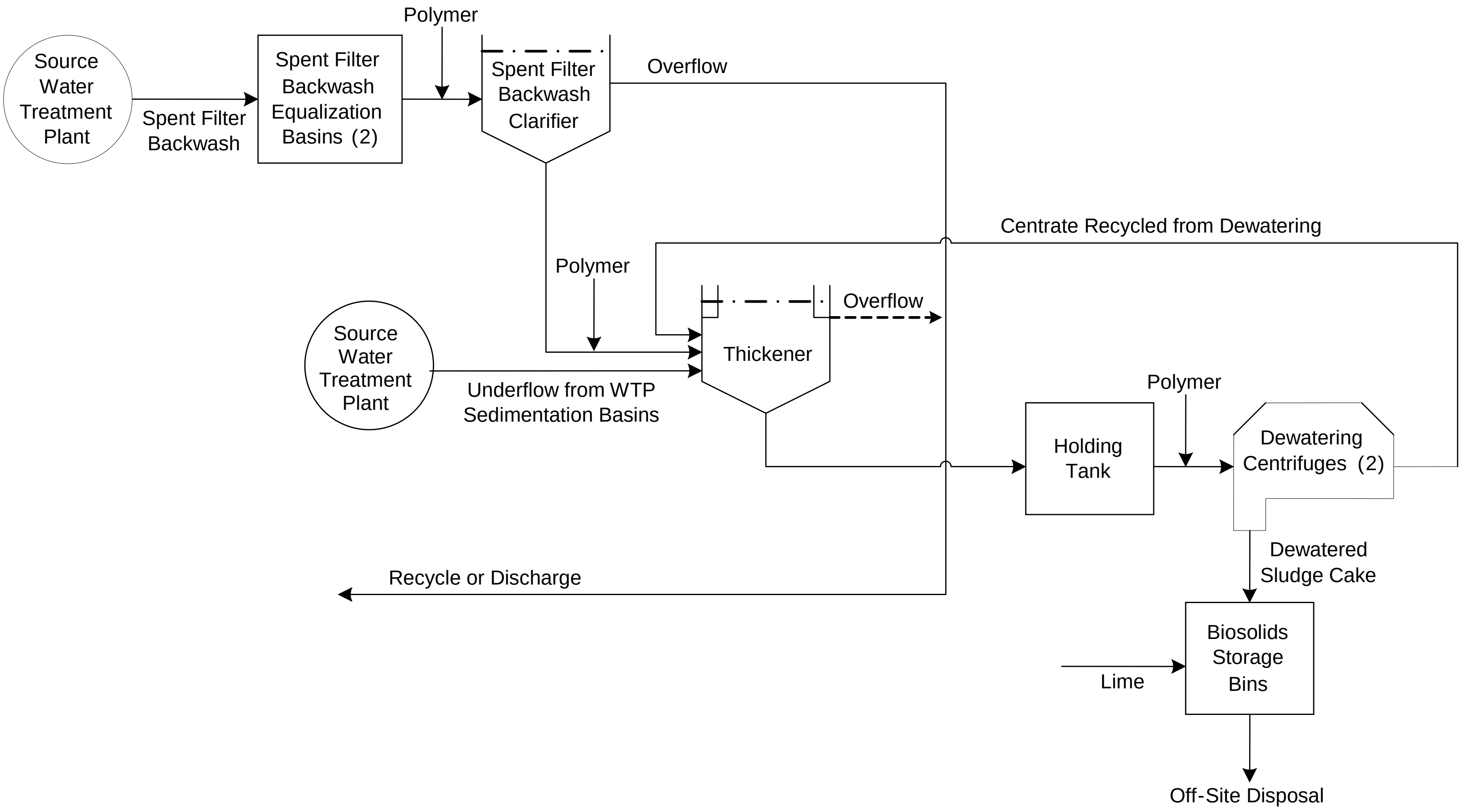

Figure 12-1. Residuals Treatment Technology Train

12.2 COST DATA SOURCES IDENTIFIED

EPA identified several primary sources of data to assess the cost of installing and operating residuals treatment systems. First, EPA sought the opinion of industry stakeholders and experts to review and characterize cost information (see Section 2.6). Second, EPA used data provided by the American Water Works Association (AWWA, 2008), an industry trade association. Third, EPA incorporated information on its forthcoming Work Breakdown Structure (WBS) cost models for drinking water treatment technologies.

12.2.1 Drinking Water Treatment Technology Review Group

EPA sought the opinion of a broad range of stakeholders to review documents that summarize the major technical and engineering issues related to the management of drinking water treatment residuals. Goals for this review included the following:

- Characterization of typical residuals;
- Identification of pollutants of concern;
- Identification of pollution prevention and treatment technologies for residuals;
- Evaluation of 1993 and 1987 cost estimates developed by EPA and AWWA, respectively, for these residuals treatment technologies; and
- Application of prevention and treatment technologies.

From 2005 through 2007, EPA held several meetings and provided stakeholders with various technical papers to review. EPA developed the document entitled, *Identification of Technology Options* (U.S. EPA, 2006), which included possible technology options to control residuals discharges and cost considerations for these options. EPA received comments on the technology options document and developed an input summary document (U.S. EPA, 2007).

The *Identification of Technology Options* document (U.S. EPA, 2006) included a comparison of costing data sources developed for WTP residuals. EPA reviewed the following costing data sources:

- **EPA, 1993:** EPA developed and presented drinking water residuals treatment costs in the *Large Water System Byproduct Treatment and Disposal Cost Document* (U.S. EPA, 1993). EPA also presented these costs in Chapter 11 of the Office of Research and Development (ORD) *Technology Transfer Handbook: Management of Water Treatment Residuals* (U.S. EPA, ASCE, AWWA, 1996). This source is referenced as EPA's 1993 costs.

- **ERG, 2006:** ERG, 2006 included a summary of information from early drafts of EPA's WBS cost models. This source has been superseded by up-to-date information provided directly by EPA (see Section 12.2.3).

- **AWWA 1987: AWWA** developed and presented residuals treatment costs in the handbook *Water Treatment Plant Waste Management* (AWWA, 1987).

Both EPA and AWWA estimated costs for several treatment technologies for residuals. Table 12-1 references specific sections for the residuals management cost equations that are available from EPA's 1993 document and AWWA's 1987 document. AWWA and EPA have also estimated lagoon costs and costs for evaporation ponds/sand drying beds. However, their use as a treatment option is highly dependent on weather/climate and the availability of land and their cost curves are highly dependent on land costs. Therefore, those options were not included in the costing review summarized in the *Identification of Technology Options* document.

Table 12-1. Available Residuals Management Cost Equations

Management Options	1993 EPA Section	1987 AWWA Section
Gravity Thickening	4.4	4.3.3
Chemical Precipitation	5.5	Not Included
Sludge Conditioning	Polymer feed system and feed included with filter press costs.	4.4.2
Sludge Pumping	Thickened sludge pumping costs to the filter press are included in the filter press costs. Assumes waste streams flow by gravity from the treatment plant to the settling tank.	4.5.2
Mechanical Dewatering – Pressure Filter Press	6.5	4.7.3
Mechanical Dewatering –Centrifuge (Scroll / Decanter)	6.10	4.6.3
Mechanical Dewatering – Belt Filter Press	Not included	4.9.3
Non-Mechanical Dewatering – Lagoon (lime softening sludge)	7.5	4.11.3
Non- Mechanical Dewatering – Lagoon (alum sludge)	7.6	4.11.3
Evaporation Ponds / Sand Drying Beds	8.5	4.10.3
POTW Discharge	9.5	Not included
Direct Discharge	10.5	Not included
Land Application – liquid sludge	11.5	Not included
Land Application – dewatered sludge	11.7	Not included
Non-hazardous Waste Landfill – off site	12.4	Not included
Non-hazardous Waste Landfill – on site	12.6	Not included
Hazardous Waste Landfill	13.4	Not included
Radioactive Waste Disposal	Not included	Not included
Deep Well Injection	Not included	Not included
Chemical Recovery	Not included	4.12

Source: U.S. EPA, 2006.
POTW—Publicly Owned Treatment Works.

12.2.2 AWWA 2008 Cost Estimates

AWWA sponsored a report entitled *Costing Analysis to Support National Drinking Water Treatment Plant Residuals Management Regulatory Options* (AWWA, 2008). AWWA estimated costs to install and operate a typical residuals treatment system at model plants and reviewed its estimates compared with actual installations. The resulting report presents a series of cost curves showing cost relative to population served, WTP type (conventional filtration or lime softening), and solids loading. By developing several of these cost estimates for a range of plant sizes, this study was able to capture the range of costs associated with implementing residuals management at WTPs plants across the country.

12.2.3 EPA's Work Breakdown Structure (WBS) Cost Models

EPA has developed its draft WBS cost estimating models for drinking water treatment technologies andanticipates public release of selected models in 2012.[29] The WBS models are spreadsheet-based engineering models for individual treatment technologies, linked to a central database of component unit costs. Under the WBS approach, a treatment technology is broken down into discrete components that can be measured for the purpose of estimating costs. The components include capital equipment (e.g., tanks, vessels, pipes, and instruments) and operational expenditures (e.g., annual expenditures on labor, chemicals, and energy).

By adopting a WBS-based approach to identify the components that should be included in a cost analysis, the models produce a transparent and comprehensive assessment of the capital and operating costs for a treatment system.

Instead of presenting a series of total cost curves, the WBS models estimate the cost of an individual treatment plant, including residuals management, at the level of line-item detail for individual pieces of equipment (e.g., clarifiers, piping, valves, instrumentation and system controls). Although the models estimate total cost for the entire treatment process, critical components of residuals management can easily be identified in the line-item output list. There are separate models for several conventional and emerging water treatment technologies.. The residuals management options available in each model are specific to the technology being modeled, driven by the types of residuals generated, their quantity, the frequency of generation (e.g., intermittent versus continuous), and their characteristics.

EPA subjected the individual models to a process of external peer review by nationally recognized technology experts. EPA also has conducted benchmarking, comparing the model results to actual capital and O&M costs for existing drinking water treatment systems.

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[29] For updates on the status of the WBS models, please check the EPA webpage at: http://water.epa.gov/scitech/wastetech/guide/treatment/index.cfm.

12.3 TREATMENT UNITS: DESCRIPTION AND CAPACITY

Many variables affect the cost of installing and operating a residuals treatment system, but the variable driving cost is capacity. The capacity requirements for treatment units determine how large they are and how many are required, which is by far the determining factor in the cost of residuals treatment. The factors that affect the capacity requirements are solids content and residuals flow rate (AWWA, 2008; U.S. EPA, ASCE, AWWA, 1996).

This section discusses how to estimate capacity requirements for the residuals treatment system shown in Figure 12-1, which includes the following treatment units:

- SFBW equalization tanks;
- SFBW clarifier(s);
- Gravity thickener(s);
- Dewatering holding tank(s);
- Dewatering centrifuges; and
- Ancillary equipment, including pumps, associated piping, control devices, and buildings to house equipment as necessary.

By estimating the flow of residuals from source water sedimentation, source water filtration, and residuals dewatering, the capacity requirements of a residuals treatment system can be determined and costs can then be estimated.

12.3.1 Typical Ranges of Solids Content and Flow in Residuals from Conventional Filtration and Softening Plants

As much as the capacity requirements of treatment units drive costs, it is the solids content and flow of residuals that drive the capacity requirements (AWWA, 2008; U.S. EPA, ASCE, AWWA, 1996). For example, if the source water for a treatment system is lake water, the residuals flow and solids content may be low. If the source water for a treatment system is from a river that receives large sediment loads, the residuals flow and solids content will be higher. The residuals treatment system would be smaller in capacity and less expensive to build and operate for the lake water WTP than for the river WTP, assuming their finished water productions are similar.

In its 2008 study, AWWA estimated a range of residuals production, based on population served. The study found that plant flow rate (finished drinking water) averages 150 gallons per capita per day (gpcpd) (AWWA, 2008). This corresponds well with results from EPA's data collection, as shown in Table 3-4 (on an annual basis). AWWA compiled ranges of residuals production for the various plant sizes using unit residuals production data from EPA's Information Collection Rule (ICR) database, shown in Table 12-2. These ranges can be used to help estimate capacity requirements for treatment units.

Table 12-2. Ranges of Residuals Production Estimated for AWWA 2008 Study

Population	Average Flow Rate for WTP (MGD)	Unit Residuals Production		Design Daily Residuals Production (dry)	
		Low [a] (lb/mg)	High [a] (lb/mg)	Low (lb/day)	High (lb/day)
Coagulation and Filtration					
13,000	2.0	120	539	351	1,577
30,000	4.5			810	3,638
70,000	10.5			1,890	8,489
110,000	16.5			2,970	13,340
175,000	26.3			4,725	21,223
265,000	39.8			7,155	32,138
400,000	60.0			10,800	48,510
650,000	97.5			17,550	78,829
1,000,000	150.0			27,000	121,275

Table 12-2. Ranges of Residuals Production Estimated for AWWA 2008 Study

Population	Average Flow Rate for WTP (MGD)	Unit Residuals Production		Design Daily Residuals Production (dry)	
		Low [a] (lb/mg)	High [a] (lb/mg)	Low (lb/day)	High (lb/day)
Precipitative Softening					
13,000	2.0	1,278	3,151	3,738	9,217
30,000	4.5			8,627	21,269
70,000	10.5			20,129	49,628
110,000	16.5			31,631	77,987
175,000	26.3			50,321	124,071
265,000	39.8			76,201	187,878
400,000	60.0			115,020	283,590
650,000	97.5			186,908	460,834
1,000,000	150.0			287,550	708,975

Source: AWWA, 2008.
MGD—million gallons per day.
lb - pound.
mg - milligram.
a - The AWWA used the median solids concentration from lake sources in the ICR database for the “low” unit residuals production and the 90th percentile solids concentrations from river sources in the ICR database for the “high” residuals production.

12.3.2 Spent Filter Backwash Equalization and Clarifier Capacity

As described in Section 7, WTPs typically backwash filters to clean them, generating SFBW, including filter-to-waste,[30] typically at a rate of 2 to 5 percent of the total plant production volume (U.S. EPA, ASCE, AWWA, 1996). For example, a WTP producing 1 MGD of finished water would generate approximately 20,000 to 50,000 gallons per day (GPD) of SFBW. Typically, WTPs backwash one filter at a time, which results in spikes of SFBW sent to residuals treatment. SFBW equalization tanks provide a consistent, lower flow through the residuals treatment system. The lower flow lowers the required treatment capacity, and the cost to install and operate the overall treatment system decreases (AWWA, 2008).

In their 2008 study, the AWWA found that WTPs could estimate the optimal capacity required for SFBW equalization based on a SFBW recycle flow rate of 6 percent of the

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[30] Filter-to-waste is the initial permeate production when a filter is brought back online following backwashing, and is part of the backwash waste stream.

total WTP flow rate (AWWA, 2008).[31] Also, the AWWA found that WTPs should install at least two equalization basins to provide redundancy. For a smaller plant, a single tank may meet capacity requirements; however, the plant would require an additional tank to provide backup. Table 12-3 summarizes optimal capacities for SFBW equalization tanks from AWWA's 2008 study. The table presents both average and peak flow rates for the WTP, which are used when sizing equipment and determining required volume capacity.

Table 12-3. SFBW Equalization Basin Capacity

Population Served	Plant Flow Rate		Optimal Capacity [b]		Number of Basins	Basin Diameter [a]
	Average (mgd)	Peak (mgd)	MGal	ft^3		
13,000	2.0	3.9	0.22	28,845	2	38
30,000	4.5	9.0	0.44	58,151	2	53
70,000	10.5	21.0	0.97	129,336	2	79
110,000	16.5	33.0	1.45	194,365	2	97
175,000	26.3	52.5	2.03	272,027	2	94
265,000	39.8	79.5	2.44	326,830	2	102
400,000	60.0	120.0	2.88	385,001	2	111
650,000	97.5	195.0	2.16	288,390	2	96
1,000,000	150.0	300.0	1.43	190,896	2	96

Source: AWWA, 2008.

a - Basin height was limited to less than 20 feet, and basin diameter was limited to 150 feet. AWWA's analysis was based on actual residuals treatment plant installations and standard assumptions used for engineering design.

b - Design capacity based on 6 percent of plant flow rate (peak capacity is used to set maximum size needed). As plant flow increases, required capacity decreases. That is, the backwash:plant flow ratio decreases as plant flow increases. AWWA's analysis was based on actual residuals treatment plant installations and standard assumptions used for engineering design.

As shown in Figure 12-1, water from the SFBW equalization basins can be treated through clarifiers to initially remove solids. The optimal capacity of SFBW clarifiers can be derived from the same flow rates shown in Table 12-3. The cost data sources discussed in this section provide further details on clarifier sizing, polymer feed rates, and design assumptions. After equalization and clarification, the treated SFBW overflow is either recycled or discharged. SFBW clarifier underflow typically contains 1 to 3 percent solids, and further dewatering is necessary, hence the thickener (U.S. EPA, ASCE, AWWA, 1996; Bosgraaf, 2005).

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[31] The general assumption of 6 percent is based on review of plant data that show recycle to be approximately 6 percent of spent filter backwash water and recommendations by The Partnership for Safe Water and EPA's Filter Backwash Recycling Rule (recycle no more than 5 to 10 percent of total plant flow).

12.3.3 Gravity Thickener Capacity

As shown in Figure 12-1, the typical gravity thickener receives clarified SFBW and sedimentation tank underflow from the WTP. Gravity thickeners increase the solids content of sludge and further remove solids from the residuals wastewater stream. The thickened sludge is pumped to the dewatering portion of the residuals treatment train, and the thickener overflow is either recycled or discharged.

In thickened lime sludge, the solids content ranges from 15 to 30 percent (U.S. EPA, ASCE, AWWA, 1996; AWWA, 2008); thickened coagulant sludge tends to have a solids content between 2 to 10 percent (U.S. EPA, ASCE, AWWA, 1996; AWWA, 2008).

Gravity thickener capacity requirements depend on many site specifics. Main design parameters include:

- **Solids Loading Rate (SLR) –** Thickener diameter and surface area are determined by the required SLR. Although generally recommended SLRs are available, WTPs can perform site-specific tests to determine the optimum design SLR. In general, the coagulant sludge SLR is between 2 and 3 lb/day/ft^2, and the lime softening sludge SLR is between 20 and 40 lb/day/ft^2 (U.S. EPA, ASCE, AWWA, 1996; AWWA, 2008).

- **Hydraulic Loading Rate (HLR) –** For WTP sludges, the HLR is not typically the limiting factor for thickener design (U.S. EPA, ASCE, AWWA, 1996). However, if large volumes of water will be pumped to the thickener, equalization may be required. For example, if sedimentation tanks are emptied periodically, the increased HLR from such a batch discharge may lead to poor solids removal. HLR is measured in gal/day/ft^2.

- **Residuals flow –** The flow of residuals to the gravity thickener can be calculated as the summation of the clarified SFBW, sedimentation tank underflow, and recycle from dewatering.

The cost data sources discussed in this section provide further details on gravity thickener capacity, and design assumptions.

12.3.4 Sludge Dewatering Centrifuges and Equalization Tanks

The most common type of WTP dewatering is evaporation through non-mechanical dewatering such as sludge drying beds, ponds, or lagoons, as shown in Table 3-11. However, these technologies are not universally available, and the feasibility and costs of lagoons and evaporation ponds depend on land availability. Therefore, EPA analyzed costs for mechanical dewatering. Specifically, EPA collected information on the costs to install and operate centrifuges, because this technology can be applied universally to precipitative softening and conventional filtration residuals treatment. For coagulation plants, WTPs may use belt filter presses for dewatering; however this application is not common for softening residuals. Precipitative softening plants may use plate and frame presses for dewatering; however this application is not commonly used for coagulation residuals due to high operation and maintenance costs (AWWA, 2008).

As shown in Figure 12-1, thickener sludge is pumped to the dewatering process. The sludge solids content will fluctuate, and a holding tank for equalization is needed to simplify the design and operation of dewatering centrifuges.

As with sludge thickening, the dewatering holding tank capacity requirements depend on SLR. However, these values are less complicated by site specifics than thickener SLR. The SLR can be calculated based on the influent solids load and holding tank dimensions.

The solids load entering the centrifuges can be calculated as:

$$\text{Solids Load (lbs/day)} = \text{Thickener Sludge (gpd)} \times \text{Sludge Density (lbs/gal)} \quad \text{(Eq. 12-1)}$$

where:

Thickened Sludge = Volume of sludge pumped from the thickener; and
Sludge Density = 65 lb/ft3, or 8.7 lb/gal (AWWA, 2008), by assumption.

The holding tank size will vary based on WTP requirements, such as capacity limitations. In its 2008 study, the AWWA estimated holding tank diameters between 10 to 100 feet (AWWA, 2008). Once holding tank surface area is determined, the SLR can be calculated as:

$$\text{SLR (lbs/day/ft}^2\text{)} = \text{Solids Load (lbs/day)} \div \text{Tank Surface Area (ft}^2\text{)} \qquad \text{(Eq. 12-2)}$$

The dewatering capacity of centrifuges can then be calculated from the solids loading rate and dewatering treatment duration. Treatment duration will vary by plant. Small WTPs may operate the centrifuges for less than eight hours per day, while larger plants may run multiple shifts daily. For example, treatment duration for a large plant operating two shifts will be 16 hours per day, or 112 hours per week. Treatment duration for a small plant operating one five-hour shift will be five hours per day, or only 35 hours per week for a seven-day work week.

12.3.5 Ancillary Equipment

Ancillary equipment includes pumps, piping, instrumentation, biosolids storage bins, and treatment system housing. In its 2008 study, AWWA estimated the costs for the ancillary equipment, except pumps, as indirect costs, using a percentage of the total direct capital cost (AWWA, 2008). Therefore, of the ancillary equipment, only pumps are not included in the AWWA cost estimate. When sizing and costing a pump, plants review the flow rate required, hydraulic properties (e.g., need to pump to a higher elevation vs. gravity flow, amount of solids in the waste stream), any potential corrosion issues, and the need for backup equipment.

In comparison, the EPA WBS cost models estimate the cost of ancillary equipment, including residuals pumps, piping, instrumentation, storage, and buildings, as direct line items, based on engineering requirments. In the WBS framework, indirect costs that are not directly related to the treatment technology used or the amount or quality of the treated water produced, but that are associated with the construction and installation of a treatment process. Section 12.4.2 further discusses indirect costs.

12.4 COSTS TO INSTALL AND OPERATE RESIDUALS TREATMENT SYSTEMS

The cost to install and operate a residuals treatment system includes:

- The capital costs to construct and install treatment units, such as an equalization tank and centrifuge;
- The indirect capital costs associated with construction and installation, such as project management;
- Annual costs, such as operations and maintenance requirements; and
- Additional, site-specific costs that vary between WTPs.

Upgrades to or retrofitting of an existing residuals treatment system may require additional costs that are not included in this section.

12.4.1 Capital Costs for Treatment Units

Estimates of capital costs to construct treatment units are available from sources including:

- AWWA, 1987: AWWA-developed residuals treatment costs.
- EPA-developed residuals treatment costs (U.S. EPA 1993 and U.S. EPA, ASCE, and AWWA, 1996).
- AWWA, 2008: AWWA-developed full cost estimates.
- EPA's forthcoming draft WBS Cost Models.

For certain treatment units, EPA compared estimated treatment unit costs. In general, the studies are not directly comparable due to differences in methodologies. The 2008 AWWA study built on the earlier two studies, and identified some additional costs that they did not include: the need for redundancy, differentiation by WTP type (coagulation versus softening), and trends in solids loads being higher than estimated in the earlier studies. Softening plants typically have higher costs than conventional filtration plants due to the larger amount of residuals generated (AWWA, 2008).

The EPA WBS cost models also differentiate by WTP type (including coagulation, softening, and more than a dozen other technologies) and address the need for redundancy. The specific capital equipment costs included in a WBS model depend on the WTP technology and the residuals management option chosen for that technology. The line-item capital costs in the WBS models for coagulation and softening, however, cover all of the components shown in the typical treatment train in Figure 12-1. The WBS models also include more ancillary equipment components as direct line items, instead of indirect costs, and include costs not covered in some of the previous costing studies, such as land and permitting cost.

12.4.2 Indirect Capital Costs

The magnitude of indirect cost multipliers depends greatly on which cost components are defined as indirect costs rather than direct capital costs (AWWA, 2008). Table 12-4 compares the indirect cost factors from the studies.

12.4.3 Annual Operating Costs

Annual operating costs for residuals treatment systems include chemical purchasing, labor to operate and maintain the treatment units, dewatered sludge disposal, electricity, and materials to maintain the treatment units. In the AWWA (2008) estimates, sludge disposal was the most expensive annual cost. AWWA estimated sludge disposal costs from previously published data. In 2007 dollars, the sludge disposal costs would be $0.37 per wet ton per mile for transportation and $36.32 per wet cubic ton for disposal (AWWA, 2008). In the EPA WBS models, the relative magnitude of various operating costs varies depending on a variety of factors. These factors include, but are not limited to: the WTP technology, the types of residuals generated, their quantity, the frequency of generation, residuals characteristics, the types of residuals treatment employed, the disposal or discharge options chosen, and the degree of automation of the process. Sludge transportation and disposal unit costs, however, are similar to those in the AWWA (2008) estimates. In 2010 dollars, the WBS unit costs are $0.468 per ton per mile for transportation and $59.99 per ton for non-hazardous waste disposal.

12.4.4 Additional Costs that Vary Between WTPs

Costs that differ by WTP were excluded from the costs presented in this section. These costs will vary because of WTP location, receiving stream, and other site-specific factors.

However, they will affect the overall residuals management costs. Additional costs include the following:

- **Sample Collection and Laboratory Analysis.** Costs for sample collection and analysis to determine solids content, free liquids (i.e., separate phase), toxicity characteristics, and other parameters. Depending on the residuals management method selected, sampling requirements could be minimal or extensive.

- **Permits and Other Regulatory Requirements.** Costs for permits and other regulatory requirements. Requirements vary considerably from state to state and for given management option. Permitting costs vary based on the capacity and complexity of a unit and the local governing jurisdiction. Management methods that may require permits include landfills, land application, evaporation ponds, and storage lagoons. In addition, generators of hazardous waste are required to comply with EPA Resource Conservation and Recovery Act (RCRA) generator regulations.

Table 12-4. Indirect Cost Factors and Selected Unit Costs for WTP Residuals Treatment System Planning

Component Factor	AWWA (1986 Cost)[c]	EPA (1992 Cost)[d]	AWWA (2008 Cost)[e]	EPA's Draft WBS Models (2010 Cost)[f]
Land	Not estimated as part of study	\$10,000/acre	Not estimated as part of study	\$13,000 to \$115,000 per acre (based on system size)
Buildings	\$75/ft^2 (1st floor); \$50/ft^2 (2nd floor)	\$33.00/ft^2	Included with treatment unit cost	\$39 to \$152/ ft^2 (based on quality; size; and heating, ventilating, and air conditioning (HVAC))
Piping	A percent of equipment costs and experience from authors	5% of installed equipment [a]	10% of installed equipment	Included in direct costs. Varies by material, diameter, length, process size; includes additional length to account for fittings cost
Pipe fittings		20% of piping costs [b]		
Electrical	Not estimated as part of study	1% of installed equipment	15% of installed equipment, piping, and general costs (see below)	10% of direct cost for outdoor lighting, yard wiring, switchgear, transformers, and miscellaneous wiring (General building electrical, such as building wiring and lighting fixtures, is included in the building cost. Certain other electrical costs are included in direct costs for system controls and pumps.)
Instrumentation	Not estimated as part of study	1–2% of installed equipment	15% of installed equipment, piping, and general costs	Technology- and site-specific instrumentation and system controls are included in direct costs
Engineering fee	Not estimated as part of study	15% of direct capital	Included as part of contractor's overhead and profit	Direct cost multipliers: 20% <1 mgd 12% 1–9.9 mgd 8% >= 10 mgd
Contingency, bonding, and mobilization	10% contingency applied to manufacturing furnished equipment costs. These costs cover site-specific requirements and extras normally encountered.	20% of direct capital	25% of installed equipment, piping, general costs, electrical, and instrumentation	Contingency: 0% to 13.4% of direct costs Mobilization/demobilization: 2% to 5% of direct costs Performance bonds: up to 2.5% of direct costs

Table 12-4. Indirect Cost Factors and Selected Unit Costs for WTP Residuals Treatment System Planning

Component Factor	**AWWA (1986 Cost)[c]**	**EPA (1992 Cost)[d]**	**AWWA (2008 Cost)[e]**	**EPA's Draft WBS Models (2010 Cost)[f]**
Contractor's overhead and profit (non-construction cost)	20% of construction cost subtotal	12% of direct capital	30% of total construction cost	General contractor overhead: 3.2% to 10% of direct costs (Includes construction management fee and builder's risk insurance. Installing contractor overhead and profit is included in direct costs for installed equipment.)
Additional add-on costs	Not estimated as part of study	Not estimated as part of study	Included as part of contractor's overhead and profit (non-construction cost)	Pilot study: equipment rental, analytical costs, labor cost Permits: vary by technology and site
Additional indirect cost categories	Not estimated as part of study	Not estimated as part of study	General costs: site work, yard piping, and final grading 30% of installed equipment and piping Indirect construction cost: 30% of installed equipment, piping, general costs, electrical, instrumentation, and contingency (i.e., total direct construction costs)	Architectural fee: 4.5% to 9% of building costs Sitework: \$10.90/ ft^2 Yard piping: varies by site Geotechnical: varies by site Standby power: varies by site Miscellaneous allowance: 10% of direct costs Financing during construction: 0% to 5% of direct costs Legal, fiscal, administrative: 2% of direct costs

a - Piping costs are calculated directly when piping is a significant cost (e.g., for direct discharge).
b - Factor is used when piping costs are calculated directly.
c - AWWA, 1986.
d - EPA, 1993.
e - AWWA, 2008.
f – For updates on the status of the WBS models, please check the EPA webpage at: http://water.epa.gov/scitech/wastetech/guide/treatment/index.cfm.

- **Additional Land Requirements.** Some WTPs will require additional land or have no adequate land adjacent. If land is not available, a residuals treatment system may not be possible, and alternate scenarios, such as piping residuals, would be necessary.

- **Power Capacity.** Depending on location, additional power capacity needed for residuals treatment may not be available or may require additional costs.

12.5 REFERENCES

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SECTION 13

ECONOMIC ACHIEVABILITY METHODOLOGY

13.1 INTRODUCTION

This section outlines a methodology for determining whether a proposed residuals management technology is economically achievable for a public water system (PWS) under their NPDES permit. Because drinking water systems are usually regulated monopolies or publicly owned entities, the way to evaluate economic achievability of technological requirements is different than the methods that would normally be used when evaluating impacts in a competitive industry.

In a competitive industry, the total cost of installing and operating pollution control technologies are often not passed on to the consumer. A firm that raises its price in a competitive industry risks losing sales or even customers. Therefore, companies operating in a competitive market will usually decide to raise their price by less than the amount of the additional production cost, lowering their operating profits as a result. In competition, it’s also possible that the price increase the market will bear would require a firm to lower its operating profits to the point where they are negative and the firm can’t stay in business.

Because public water systems are regulated monopolies or publicly owned entities, the rates (prices) they charge their customers are not set in an unregulated competitive marketplace. Instead, the rates are based on the costs the PWS incurs in delivering water to their customers. These costs include residuals management expenditures that are incurred as a result of NPDES permitting, as well as costs associated with complying with Safe Drinking Water Act regulations. Unless a PWS has access to funds not derived from water services, they are likely to completely pass on residuals management compliance costs to customers in the form of higher water rates. Therefore, the ability of the PWS to pay for residuals management technology is only limited by its ability to raise the water rates it charges its customers. Of course, there is a limit to how much customers can and will pay for their water services.

The economic analysis of improved residuals management for a PWS is focused on the impact of water rate increases on customers and, in particular, on their residential customers. Pollution abatement measures would be deemed economically achievable if the PWS's customer base is able to bear the impact of the water rate increases associated with the costs of the residuals management improvements. The analysis of customer impact could be extended to businesses; however, the impact to businesses of water rate increases is not likely to be substantial, except potentially in instances where effluent treatment costs for the PWS are very high and certain business customers rely heavily on publicly supplied water as an important factor in their production processes. But even these firms may be able to pass costs on to their customers.

13.2 A METHODOLOGY FOR DETERMINING THE ECONOMIC ACHIEVABILITY OF BEST PROFESSIONAL JUDGMENT EFFLUENT LIMITATIONS FOR A PUBLIC WATER SYSTEM

The approach to determining the economic achievability of residuals management technology improvements is conducted at the system or utility level, depending on whether the costs for a treatment technology would be spread amongst consumers at the system level or across all the customers of the larger utility. For the purpose of determining the financial strength of the larger corporate entity which owns the individual drinking water treatment plant implementing the NPDES residuals technology improvements and the impacts to the large corporate entity's customer base, EPA must look to the level of the system (the PWS). It is at the system level that the costs of technology improvements are financed, and it is the system that can spread the costs of upgrades to a specific plant or plants across its total customer base. In some instances a larger utility may own more than one system and spreads the cost of technology improvements across those systems. In these cases the proper level of financial assessment is at the level of the utility.

The assessment of economic achievability for NPDES residuals management technology at the PWS level consists of four steps, once the annualized costs associated with the technology improvements have been determined:

1. Estimate the increase in water rates for household customers.

2. Estimate the increase in the annual cost of water as a result of residuals management improvements for household customers by Census-based income class.

3. Based on the ratio of water cost increase as a result of additional residuals handling expenditures to household income by Census-based income class, estimate the number and percentage of households (total and within income classes) for which the estimated increase in household cost of water exceeds the chosen percent of median household income achievability threshold.

4. For water systems in which the number and/or percentage of adversely affected households exceed the relevant threshold, assess the potential for using rate-structure-based methods to shift the potential water rate increase away from households for which the increase is determined to be too great.

Embedded within these four steps are two important threshold criteria that are not prescribed here. The first criterion is the percent of median household income achievability threshold which represents the maximum acceptable portion of household income that could be expended on new residuals management treatment technologies without significantly affecting a household's financial condition. It is important to remember that, this threshold value represents that fraction of income which can be spent by the household on the incremental cost of the new NPDES permitting requirements. The second criterion to be set is the number of households whose cost share is greater than the threshold percent of income that would cause the technology costs to be considered not economically achievable. Ultimately, which percent of income achievability threshold used, as well as the number of households for which rates exceed the percent of income threshold, are important policy decisions for the Director to consider.

In order to provide a numerical example of this suggested NPDES residuals management economic achievability methodology, EPA selected a median annual household income threshold. This threshold is based on a review of the economic support documents from past Effluent Limitation Guideline (ELG) rulemakings. Particular attention was focused on the regulated entities that operate as a local monopoly much the same way as PWSs operate. Through this review, EPA found that the economic achievability analysis that most closely mirrored the proposed drinking water NPDES permit cost achievability methodology was conducted for the final "Effluent Limitations Guidelines, Pretreatment Standards, and New

Source Performance Standards for the Landfills Point Source Category" rulemaking. The Landfills ELG economic achievability analysis used a compliance cost share of household income test. This test was used to assess community level economic impacts when municipally-owned landfills would likely pass costs on to household customers. The ratio of the average per household share of compliance costs to median household income was calculated and if the ratio exceeded a 1.0 percent threshold EPA determined that the technology costs would likely have a "severe impact" to the community. Although the achievability methodology presented here is more refined, the 1.0 percent of median household income threshold value from the Landfills ELG will be utilized in the example analysis. Because the 1.0 percent threshold in the Landfills ELG signified a high probability of severe economic impacts to the community EPA recommends to the Director that the percent of median household income ultimately selected be lowered if moderate impacts are the measure of interest.

EPA did not select a value for the maximum number of households being served by the PWS that would be allowed to receive a treatment cost share greater than the threshold percent of income in the following example. The Agency does want to note that: (1) a decrease in the allowed percentage of households whose share of costs exceeds the household income threshold (or a decrease in the income threshold) will make the economic achievability more stringent; and (2) increasing the number of households that can exceed the income threshold (or raising the income threshold value) will have the effect of making the achievability test less stringent.

The remainder of this section demonstrates how to go about completing the four steps to determining the economic achievability of NPDES residuals management technology improvements at PWSs.

13.2.1 Estimate Increase in Water Rates to Household Customers

Regardless of the specific criteria used to determine economic achievability for PWSs, the analysis should begin with estimating the increase in total water costs to all households in the water system service territory due to the proposed improvements. This figure represents the total revenue to be raised by the increase in water rates to household customers, and the estimated quantity of water consumed by households. Estimating the change in water rates involves two main steps:

1. Estimate the aggregate rate effect due to technological improvements; and
2. Estimate the change in water rates per unit of consumption, by customer class.

13.2.1.1 Estimate Total Rate Effect of Compliance Costs

The estimated change in water rates, and resulting costs to households, should reflect how the cost to adopt technology improvements would actually be incorporated into a PWS's rate structure. The change in a PWS's revenue requirements is typically the basis for setting water rates. For annually recurring costs (e.g., operation and maintenance (O&M) costs), this analysis is straightforward: such costs are simply added to the system's total revenue requirements. However, for capital or other non-annually recurring costs, completing this analysis will require several assumptions.

The first assumption involves how these costs would be financed, including the cost and terms of the financing. Funds may be borrowed, taken from current operating revenue, or, if the company is privately owned, gained from issuing equity stakes in the company. The recommended assumption is to use the weighted average of the reported cost of capital and repayment periods for projects undertaken within the past five years to establish the cost and terms of the capital required.

The second assumption involves how costs would be incorporated into the PWS's near-term rate structure. This issue includes the cost recovery and rate-making practices at the affected PWS. The cost recovery for capital outlays may be:

- Fixed to a constant annual value over the cost recovery period, or
- Based on a framework of depreciating rate base with an allowed rate of return.

Under the constant annual payment framework, the cost analysis is relatively straightforward. The annual charge for capital outlays is calculated as a constant annual payment, based on an interest rate[32] and repayment term of the amount to be financed. This approach is appropriate if the average repayment period is approximately equal to the estimated useful life of the capital improvements. The annual charge would be calculated as follows:

$$\text{Capital Charge} = \text{Capital Outlay} \times \frac{r \times (1+r)^N}{(1+r)^N - 1} \tag{Eqn. 13-1}$$

where:

Capital charge = The constant annual rate increase to recover the new technology capital outlay over the N year capital recovery period at the interest rate *r*.

Capital outlay = The capital outlay for implementing the new technology (or other non-annually occurring outlays associated with the new technology).

N = The number of years over which the Capital outlay is recovered in water system rates presumed to be equal to the estimated useful life of the new capital equipment.

r = The allowed interest rate for recovering capital outlay over the capital recovery period, presumed to be equal to the average of interest rates reported for recent borrowings by the water system.

The situation of a depreciating rate base with allowed rate of return follows the conventional regulated utility ratemaking framework, but the cost analysis is somewhat more complicated. The annual charge is based on the amount of capital outlay placed into "rate-base,"[33] the depreciation period for the capital outlay, and the allowed rate of return on the rate-base. The capital charge in any year is typically calculated as the sum of the straight-line depreciation of the initial rate-base value and the product of the rate of return and the depreciated rate-base value. Under this approach, the annual capital charge would be calculated as follows:

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[32] The interest rate should correspond to the credit ratings of the PWS. The bond yield for the appropriate credit rating can be found in sources such as S&P or Moody's Investor Services.

[33] "Rate-base" refers to the aggregate value of capital the PWS is entitled to recover through customer water rates, with a rate of return.

$$\text{Capital Charge} = \frac{\text{Capital Outlay}/\,\text{N} + \text{r} \times \left[\sum_{\text{i}=0}^{\text{n}} \left(\text{Capital Outlay}\right) \times \left(\text{N} - \text{i}\right)/\,\text{N} \right]}{\left(\text{n}+1\right)} \qquad \text{(Eq. 13-2)}$$

where:

Capital Charge = The average amount of the technology capital outlay recovered annually in the total water rate over the first (n+1) years of capital recovery. For this analysis, EPA would propose to look at a relatively short period of initial rate effect – e.g., the first three years, in which case the value *n* would be 2.
Capital Outlay = The capital outlay for implementing the new technology (or other non-annually recurring outlay associated with the new technology).
N = The number of years over which the Capital Outlay is depreciated for ratemaking purposes – presumed to be equal to the estimated useful life of the new capital equipment.
i = The number of years since placing the Capital Outlay into rate base.
n+1 = The total number of years for which the annual charge is calculated. For this analysis, EPA would use something like n+1=3, or n=2.
r = The allowed rate of return on rate base – presumed to be equal to the average of interest rates reported for recent borrowings by the water system.

Finally, the sum of the annual recurring costs and the charges for capital outlays for compliance with the proposed abatement technology yields the total increase in annual water rates resulting from the new technology:

$$\text{Total Rate Increase} = \text{Recurring Costs} + \text{Capital Charge} \qquad \text{(Eq. 13-3)}$$

where:

Total Rate increase = The annual increase in total water system rates resulting from implementing new technology.
Recurring Costs = Technology costs that recur annually – e.g., recurring operating and maintenance expenses.
Capital Charge = Annual recovery of the capital outlay for new technology.

13.2.1.2 Estimate Rate Effect per Unit of Water Consumed

The total rate increase must be allocated to the different types of customers the PWS serves. As above, this analysis may require different treatments for the recurring cost and capital cost components.

The recurring cost component is assumed to be the same for all customer classes. (This would not be true if pretreatment contributed to technology costs, as pretreatment requirements are derived from certain customer classes). The recurring cost rate effect is calculated by dividing the annual recurring costs charge by the total volume of finished and partially treated[34] water sold annually by the PWS.

$$\Delta Rate_{RecurringCosts} = \text{Recurring Costs} \div \text{Treated Volume} \qquad \text{(Eq. 13-4)}$$

where:

$\Delta Rate_{RecurringCosts}$ = Increase in water system rates, *per-unit-consumed*, from the recurring cost component of new technology (assume rate structure is preserved and increase is across-the-board).

Recurring Costs = Total rate increase from costs the recur annually.

Treated Volume = Total volume of finished and partially treated water sold annually.

As in subsection 13.2.1.1, the capital charge component presents a potentially more challenging case as the capital charge is more likely to be allocated differentially by customer class than the recurring cost component of the water rate charge. For example, if the amount of capital equipment required for compliance with the effluent limitation is determined by the peak water demand during a several-hour period of the day, then it would be reasonable to allocate capital costs according to the contribution of individual customer classes to demand levels during different periods (e.g., user profile during *low*-demand, *medium*-demand, and *high*-demand periods). Because PWS-specific rate structure information may not be available, and in order to be conservative in this achievability analysis, the capital charge should be allocated to the household rate class based on the *greater of*:

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[34] The Agency suggests including water that is treated at any level – i.e., both *finished water* and *partially treated water* – in the denominator for calculating the unit rate increases. The logic for this definition of the denominator is that the treatment requirements, and thus cost, will apply to the residuals of water treatment, whether for finished water or partially treated water.

1. The percentage of total water consumed by residential customers, or
2. The percentage of total water sales revenue from residential customers.

Once a component of capital costs has been allocated to the residential class, the average rate impact can be calculated based on the total water volume sold to residential customers.

$$\Delta \text{ Rate}_{\text{Capital Charge}} = \frac{\left[\text{Max}\left(\text{Water Share}_{\text{res}}, \text{Rev Share}_{\text{res}}\right) \times \text{Capital Charge}\right]}{\text{Treated Volume}_{\text{res}}} \quad \text{(Eq. 13-5)}$$

where:

$\Delta\text{Rate}_{\textit{Capital Charge}}$ = Increase in water system rates to residential customers, *per-unit-consumed*, from the capital charge component of new technology costs

$\text{Water Share}_{\textit{res}}$ = Residential customers' share of total water consumption

$\text{Rev Share}_{\textit{res}}$ = Residential customers' share of total water sales revenue

Capital Charge = Total annual rate increase from the new technology capital outlay

$\text{Treated Volume}_{\textit{res}}$ = Total volume of finished water sold annually to residential customers, in same units as rate structure is expressed

Summing the Recurring Cost and Capital Charge rate components yields the total per-unit-consumed rate increase to residential customers:

$$\Delta\text{Rate}_{\text{Total}} = \Delta\text{Rate}_{\text{Recurring Costs}} + \Delta\text{Rate}_{\text{Capital Charge}} \quad \text{(Eq. 13-6)}$$

where:

$\Delta \text{ Rate}_{\textit{Total}}$ = Total increase in water system rates to residential customers, *per-unit-consumed*, resulting from new technology

$\Delta \text{ Rate}_{\textit{Recurring Costs}}$ = Increase in water system rates, *per-unit-consumed*, from the recurring cost component of new technology costs

$\Delta \text{ Rate}_{\textit{Capital Charge}}$ = Increase in water system rates to residential customers, *per-unit-consumed*, from the capital charge component of new technology costs

13.2.2 Estimate Increase in Annual Water Service Cost for Household Customers

The next step in the analysis is to calculate the increase in annual water service cost to households. This calculation involves multiplying the unit rate increase, from the preceding step, by the estimated average household water consumption. This general understanding can be more accurately described within the framework of the following two sub-steps:

1. Estimate the average quantity of water consumed per household; and,
2. Estimate the annual increase in household water service cost.

13.2.2.1 Estimate Average Household Water Consumption

Average household water consumption is calculated by dividing total water quantity supplied to residential customers by the estimated number of households served.[35] The number of households served by a PWS is estimated by dividing the reported number of people served by the system – available through EPA's Safe Drinking Water Information System (SDWIS) – by the average number of persons per household within the service area of the PWS. The average number of persons per household is calculated from Census data[36] for the ZIP codes reported as served by the PWS. Following is the calculation for the number of households served by a water system:[37]

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[35] The calculation of the number of households served is required because many PWSs do not know the number of households served, but rather, know the number of residential connections served. Since many multi-family dwellings (e.g., apartment buildings) do not have separate meters for each household, the number of residential connections will likely underestimate the number of households served. However, multi-family dwellings may not see 100% cost pass-through, due to some units being billed for water as part of rent, which is subject to market forces.

[36] Based on the most recently available Census data.

[37] In this equation, the average number of households is calculated by using the average household size by ZIP code (or county) and weighting by number of households reported in the ZIP code (or county), *both as reported by the Census*, instead of simply summing total population and households over the ZIP codes and dividing total population by total households. This calculation is necessary because the reported average household size for a ZIP code (or county) as reported in the Census frequently differs from the average household size that would be calculated for a ZIP code (or county) using the reported population and households for a ZIP code (or county).

$$\text{N Households}_{\text{est}} = \text{Persons} \Bigg/ \left[\frac{\sum_{z=1}^{Z} (\text{N HHS Census}_z \times \text{HHS Size Census}_z)}{\sum_{z=1}^{Z} \text{N HHS Census}_z} \right] \qquad \text{(Eq. 13-7)}$$

where:

$\text{N Households}_{\text{est}}$ = Estimated number of households served currently by the PWS.
Persons = Number of persons served by the PWS.
Z = The total number of zip codes (or counties) served by the PWS.
z = Zip Code or county index.
N HHS Census_z = Number of households reported in Census data for zip code (or county), *z*.
HHS Size Census_z = Average household size reported in Census data for zip code (or county), *z*.

To calculate annual water consumption per *average* household, divide the annual flow of water to residential customers (available from the PWSs) by the number of households served by the water system:

$$\text{HH Water Cons}_{\text{av}} = \frac{\text{Water Vol}_{\text{residential}}}{\text{N Households}_{\text{est}}} \qquad \text{(Eq. 13-8)}$$

where:

$\text{HH Water Cons}_{\text{av}}$ = Annual water consumption for the average household.
$\text{Water Vol}_{\text{residential}}$ = Total water volume delivered annually to residential customers.
$\text{N Households}_{\text{est}}$ = Estimated number of households served currently by the PWS.

13.2.2.2 Estimate Increase in Annual Water Service Cost for Household Customers, Based on Estimated Household Water Consumption

The water consumption quantity is then multiplied by the estimated change in per unit water rates to calculate the increase in annual water cost to household customers:

$$\Delta\text{Water Cost}_{\text{av hh}} = \text{HH Water Cons}_{\text{av}} + \Delta\text{Rate}_{\text{Total}} \qquad \text{(Eq. 13-9)}$$

where:

Δ Water Cost $_{\text{av hh}}$ = Increase in water service cost to the average household, resulting from new technology.

HH Water Cons $_{\text{av}}$ = Annual water consumption for the average household.

Δ Rate $_{\text{Total}}$ = Total increase in water system rates to residential customers, *per-unit-consumed*, resulting from new technology.

13.2.3 Estimate Number and Percentage of Households, by Water System, for which the Annual Household Water Service Cost Increase Exceeds a Percent of Income Achievability Threshold

As the initial test of economic achievability for residuals treatment under the NPDES program, calculate the number of households for which the estimated increase in water service cost will exceed the chosen income achievability threshold. As noted previously, the income achievability threshold used, as well as the maximum number of households being served by the PWS that would be allowed to receive a treatment cost share greater than the percent of income threshold before the proposed new NPDES treatment technology would be considered not economically achievable, are important decisions for the Director. The example threshold presented is 1.0% of median household income.

A household is counted as facing an achievability challenge at a given threshold if the ratio of the estimated water cost increase to household income exceeds the threshold. Implementing this achievability test concept requires several additional steps, as described below.

13.2.3.1 Adjust for the Difference in the Reporting Year of the Household Income Information for the Most Recent Census

The difference in the *reporting year* of the household income information should be adjusted for the most recent Census and the year for which new technology costs will be estimated. To compare the increase in water service cost with household income at current levels, the household counts by income range from the most recent Census need to be brought forward to the current year. Several issues arise in this adjustment:

- General change in household income over time;
- Shifts in household counts within the income distribution; and
- Change in the aggregate number of persons and households over time.

The decennial Census reports the number of households in specific income ranges. Below $50,000 household income, the household counts are reported in $5,000 ranges (with the exception of the first income range, which includes $0-$9,999). Above $50,000, the income ranges widen progressively, from $10,000 to $50,000, and finally ending at "greater than $200,000." Although the Census publishes a variety of sample-based updates between the decennial census years, it does not publish an update of the data on household count by income range. Table 13-1 provides an example of the income distribution information provided from the 2000 Census.

Table 13-1. Example of Income Distribution from the 2000 U.S. Census

Income Range	Number of Households
0 to 9,999	1,056
10,000 to 14,999	1,311
15,000 to 19,999	1,523
20,000 to 24,999	1,708
25,000 to 29,999	2,014
30,000 to 34,999	3,003
35,000 to 39,999	2,322
40,000 to 44,999	1,307
45,000 to 49,999	2,636
50,000 to 59,999	4,659
60,000 to 74,999	2,839
75,000 to 99,999	4,682
100,000 to 124,999	3,396
125,000 to 149,999	1,908
150,000 to 199,999	1,452
200,000 and Above	1,299

A two-step process is used to adjust the households-by-income-range data from the census year to the present (or as close to the present as is possible based on U.S. Census reporting). First, the income-range values from the census year are adjusted to the present year based on the change in median household income by state (or possibly county) as reported in the non-decennial series published in the American Community Survey and the Annual Social and

Economic Supplement (U.S. Census). This adjustment holds as constant the household counts by income range from the census year data, but shifts upward (or downward) the definition of the ranges to which the household counts apply based on the change in income at the 50th percentile of the household income distribution (see calculation in the equation below). As an example, Table 13-2 shows the income range limits from Table 13-1 adjusted for a 10 percent increase in household income. All that is done is the low-end and high-end of each income range is multiplied by 1.10. The number of households in each range remains constant for now.

$$\text{Income Range}_{t,l} = (1+\Delta\text{MHI}_l) \times \text{Income Range}_{\text{Census}} \qquad \text{(Eq. 13-10)}$$

where:

$\text{Income Range}_{t,l}$ = Income range value after adjustment to the present (time *t*) for location l (state or county)

$\Delta\text{ MHI}_l$ = Percent change in median household income from decennial census (e.g. 2000) to time *t* for location l (state or county)

$\text{Income Range}_{\text{Census}}$ = Income range value used in Census household-by-income level reports – e.g., $10,000.

Table 13-2. Example of Income Distribution Provided by the U.S. Census With Ranges Updated to Current Year (10% increase in income)

Income Range			Number of Households
0	to	10,999	1,056
11,000	to	16,499	1,311
16,500	to	21,999	1,523
22,000	to	27,499	1,708
27,500	to	32,999	2,014
33,000	to	38,499	3,003
38,500	to	43,999	2,322
44,000	to	49,499	1,307
49,500	to	54,999	2,636
55,000	to	65,999	4,659
66,000	to	82,499	2,839
82,500	to	109,999	4,682
110,000	to	137,499	3,396
137,500	to	164,999	1,908
165,000	to	219,999	1,452
220,000	and	Above	1,299

The second step is to adjust the number of households in the Census distribution – both in total and within the income ranges – according to the ratio of the total population currently served (again, as reported in SDWIS), to total population for the identified ZIP codes (or counties) as reported in the Census. This adjustment accounts for both the change in total population since the census year and for the population coverage differential resulting from only a part of the ZIP codes (or counties) reported by the drinking water system actually being served by the system (see calculation in equation below). As an example, Table 13-3 shows the number of households from Table 13-2 adjusted for a 3 percent increase in population. So, the number of households from Table 13-2 is multiplied by 1.03 for each income range.

$$\text{N Households}_{ir,t} = (\text{Persons Served}_{t} \div \text{Population}_{Census}) \times \text{N Households}_{ir,Census} \quad \text{(Eq. 13-11)}$$

where:

$\text{N Households}_{ir,t}$ = Number of households in Income Range *ir* at time *t.*
$\text{Persons Served}_{t}$ = Number of persons reported served by the PWS at time t.
$\text{Population}_{Census}$ = Total population reported at time of Census data for zip codes or counties served by the PWS.
$\text{N Households}_{ir,Census}$ = Number of households in Income Range *ir* as reported at time of Census data.

Table 13-3. Example of Income Distribution Provided by the U.S. Census With Ranges and Number of Households Updated to Current Year (10% increase in income and 3% increase in population)

Income Range			Number of Households
0	to	10,999	1,088
11,000	to	16,499	1,350
16,500	to	21,999	1,569
22,000	to	27,499	1,759
27,500	to	32,999	2,074
33,000	to	38,499	3,093
38,500	to	43,999	2,392
44,000	to	49,499	1,346
49,500	to	54,999	2,715
55,000	to	65,999	4,799
66,000	to	82,499	2,924
82,500	to	109,999	4,822
110,000	to	137,499	3,498
137,500	to	164,999	1,965
165,000	to	219,999	1,496
220,000	and	Above	1,338

13.2.3.2 Accounting for the Lack of Information on How Household Income is Distributed within the Census-Reported Income Ranges

The Census provides the number of households by the income ranges described above. In this analysis, the objective is to calculate the number of households for which the estimated increase in water service cost exceeds a threshold percentage of household income. For each PWS, the *household income level* at which the estimated increase in water service cost equals a threshold percentage is determined using on the equation below.

$$\text{Inc}_{\text{threshold level,i}} = \Delta\text{Water Cost}_{\text{av hh}} \div \text{Income Threshold}_{\text{i}} \qquad \text{(Eq. 13-12)}$$

where:

$\text{Inc}_{\text{threshold level, i}}$ = Threshold income level, based on income threshold i.

Δ $\text{Water Cost}_{\text{av hh}}$ = Increase in water service cost to the average household, resulting from compliance.

Income Threshold = Threshold percentage of income the compliance costs cannot exceed i.

This step is followed by the estimation of the number of households served by the PWS with household income less than that threshold income level. In all likelihood, a threshold income level will fall within, and not at the edge of, a Census income range. Accordingly, the fraction of households *within* a Census income range that fall below a threshold income level must be estimated. For simplicity's sake, assume that households are uniformly distributed *over the income values* within an income range. As a result, the fractional point at which the threshold income level lies within an income range will also be the fraction of households within that income range that fall below the threshold level. Of course, all households in an income range that is below the range in which the threshold income level falls will be below the threshold income level.[38]

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[38] The assumption of a uniform distribution of income within each income range inevitably involves error and could overstate or understate the fraction of households within an income range that fall below an impact threshold. Nevertheless, the assumption of a uniform distribution within an income range is a reasonable approach. In applying the uniform-distribution assumption, the Agency warns about the potential for overestimation of adverse impact in the lowest income range segment – less than $10,000 (before adjusting for income change over time) – if that range includes a threshold impact income value.

The occurrence of households for which the water service cost increase exceeds a threshold income level is calculated as follows:

$$\text{N Households}_{\text{ir*,inc}} = \frac{\left(\text{Inc}_{\text{threshold level}} - \text{Inc}_{\text{ir*,mn}}\right)}{\left(\text{Inc}_{\text{ir*,mx}} - \text{Inc}_{\text{ir*,mn}}\right)} \times \text{N Households}_{\text{ir*}} \qquad \text{(Eq. 13-13)}$$

where:

$\text{N Households}_{\text{ir*, inc}}$ = Number of households in Income Range *ir* *with income below threshold income level (*inc*), where Income Range *ir** contains the threshold income level *inc.*

$\text{Inc}_{\text{threshold level}}$ = Threshold income level, calculated above.

$\text{Inc}_{\text{ir*, mn}}$ = Minimum value of Income Range *ir*.*

$\text{Inc}_{\text{ir*, mx}}$ = Maximum value of Income Range *ir*.*

$\text{N Households}_{\text{ir}}$ = Total number of households in Income Range *ir** estimated served by the PWS.

Lastly, the total number of households with income below the threshold income level is aggregated over all income ranges.

$$\text{N Households}_{\text{inc}} = \text{N Households}_{\text{ir*, inc}} + \sum_{\text{ir}=1}^{\text{ir*}-1} \text{N Households}_{\text{ir}} \qquad \text{(Eq. 13-14)}$$

where:

$\text{N Households}_{\text{inc}}$ = Number of households over all income ranges with income below threshold income level (*inc*).

$\text{N Households}_{\text{ir*, inc}}$ = Number of households in Income Range *ir** with income below threshold income level (*inc*), where Income Range *ir** contains the threshold income level *inc.*

$\text{N Households}_{\text{ir}}$ = Number of households in Income Ranges *ir* below Income Range *ir*.*

Table 13-4 follows from the examples above. This table shows the number of households (and the percentage of households) that are expected to realize an increase in water costs higher than the achievability income threshold (1.0 percent of household income). In this example, assume the cost of compliance is $6.69 million, or $175.00 per household. The threshold income level is then $17,500 which falls in the adjusted Census income range of $16,500 - $21,999 (the shaded row in Table 13-4). The number of households in the Census income range where the increase in water cost has an impact greater than the achievability income threshold is calculated to be 285. The number of households above the achievability threshold in lower income ranges is always equal to the number of households in the range, while the number of households above the achievability threshold in higher income ranges is always equal to zero. The total number of households above the achievability income threshold is 2723, which equals 7 percent of the total households served by the PWS.

Table 13-4. Example of the Calculation of Number and Percent of Households above an Achievability Threshold (1.0% of Median Household Income)

Income Range			Number of Households	Compliance Costs Per Household	Achievability Threshold	Threshold Income Level	Number of Households above Achievability Threshold	Percent of Households above Achievability Threshold
0	to	10,999	1,088	$175.00	1.0%	$17,500	1,088	100%
11,000	to	16,499	1,350	$175.00	1.0%	$17,500	1,350	100%
16,500	to	21,999	1,569	$175.00	1.0%	$17,500	285	18%
22,000	to	27,499	1,759	$175.00	1.0%	$17,500	0	0%
27,500	to	32,999	2,074	$175.00	1.0%	$17,500	0	0%
33,000	to	38,499	3,093	$175.00	1.0%	$17,500	0	0%
38,500	to	43,999	2,392	$175.00	1.0%	$17,500	0	0%
44,000	to	49,499	1,346	$175.00	1.0%	$17,500	0	0%
49,500	to	54,999	2,715	$175.00	1.0%	$17,500	0	0%
55,000	to	65,999	4,799	$175.00	1.0%	$17,500	0	0%
66,000	to	82,499	2,924	$175.00	1.0%	$17,500	0	0%
82,500	to	109,999	4,822	$175.00	1.0%	$17,500	0	0%
110,000	to	137,499	3,498	$175.00	1.0%	$17,500	0	0%
137,500	to	164,999	1,965	$175.00	1.0%	$17,500	0	0%
165,000	to	219,999	1,496	$175.00	1.0%	$17,500	0	0%
220,000	and	above	1,338	$175.00	1.0%	$17,500	0	0%
Total			**38,228**				**2,723**	**7%**

13.2.3.3 Determining Public Water System-Level Achievability Income Thresholds

Once the number (and percentage) of households in a service territory for which the estimated increase in water service cost would exceed an achievability income threshold is calculated, the Director still has to determine if these numbers constitute an economically achievable solution for the *PWS as a whole*. As mentioned above, this important question is subjective and a policy decision that must be made by the permitting authority.

For example, if the permitting authority believes that 1.0 percent of household income is the correct achievability threshold, 2,723 or seven percent of the households served by the PWS would have difficulty paying for the higher cost of water associated with the compliance cost of the permit limitations.

13.2.4 Assessing the Impact of Rate Structure on the Achievability Determination

The example above assumes that all households served by the PWS share equally in the additional costs associated with compliance, which is not necessarily the case. A community and its PWS may be able to shift costs away from more economically vulnerable population segments via increasing block rates, *lifeline* rates or other income support mechanisms. These rate structures and programs should be considered when conducting an achievability analysis. Table 13-5 provides an example of how the achievability analysis can be modified to take into account a simplistic lifeline-type rate structure. In this case, the cost of compliance is the same as in the example above ($6.69 million). However, in this example, because of a lifeline rate structure, no household with annual income below $16,500 will incur any additional rate increase. Therefore, the cost of compliance is shared among the remaining households at a greater rate ($186.92 per household versus $175.00 in the earlier example). In this case, the threshold income level rises to $18,692, but at the same time, fewer households exceed the achievability threshold (two percent versus seven percent in the example above). The lifeline rate structure partially mitigates the achievability concerns of this effluent limitation. Of course, the permit authority still has to decide if the lifeline rate structure mitigates the achievability issue enough to determine that the effluent limitations are economically achievable.

If a PWS has an increasing block rate structure, they could choose to only increase the highest end of the block rates. This would pass the entire increase in cost to households that are consuming the largest quantities of water and are most likely those households that can best afford a rate increase.

Table 13-5. Example of the Calculation of Number and Percent of Households above an Achievability Threshold (1.0% of Median Household Income) assuming a Lifeline Rate Structure for Income Below $16,500

Income Range			Number of Households	Compliance Costs Per Household	Achievability Threshold	Threshold Income Level	Number of Households above Achievability Threshold	Percent of Households above Achievability Threshold
0	to	10,999	1,088	$0	1.0%	$0	0	0%
11,000	to	16,499	1,350	$0	1.0%	$0	0	0%
16,500	to	21,999	1,569	$186.92	1.0%	$18,692	628	40%
22,000	to	27,499	1,759	$186.92	1.0%	$18,692	0	0%
27,500	to	32,999	2,074	$186.92	1.0%	$18,692	0	0%
33,000	to	38,499	3,093	$186.92	1.0%	$18,692	0	0%
38,500	to	43,999	2,392	$186.92	1.0%	$18,692	0	0%
44,000	to	49,499	1,346	$186.92	1.0%	$18,692	0	0%
49,500	to	54,999	2,715	$186.92	1.0%	$18,692	0	0%
55,000	to	65,999	4,799	$186.92	1.0%	$18,692	0	0%
66,000	to	82,499	2,924	$186.92	1.0%	$18,692	0	0%
82,500	to	109,999	4,822	$186.92	1.0%	$18,692	0	0%
110,000	to	137,499	3,498	$186.92	1.0%	$18,692	0	0%
137,500	to	164,999	1,965	$186.92	1.0%	$18,692	0	0%
165,000	to	219,999	1,496	$186.92	1.0%	$18,692	0	0%
220,000	and	Above	1,338	$186.92	1.0%	$18,692	0	0%
Total			**38,228**				**628**	**2%**

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SECTION 14

GLOSSARY, ACRONYMS, AND ABBREVIATIONS

A

Activated carbon – Carbon particles usually obtained by carbonization of cellulosic material in the absence of air and possessing a high adsorptive capacity. Process is to typically heat carbon to increase porosity surface area.

Administrator – The Administrator of the U.S. Environmental Protection Agency.

Adsorption – The adherence of a gas, liquid, or dissolved material to the surface of a solid.

Aeration – Process that mixes air and water, normally by injecting air into water, spraying water into the air, or allowing water to pass over an irregular surface, to release compounds from the water through oxidation, precipitation, or evaporation.

Agency – The U.S. Environmental Protection Agency.

Alkalinity – The capacity of water to neutralize acids, a property imparted by the water’s content of carbonates, bicarbonates, hydroxides, and occasionally borates, silicates, and phosphates. It is expressed in milligrams per liter of equivalent calcium carbonate.

Alum – A common name in water and wastewater treatment field for commercial-grade aluminum sulfate ($Al_2(SO_4)_3 \cdot 14H_2O$).

Anion – The ion in an electrolyte solution that carries the negative charge and that migrates toward the anode under the influence of a potential difference.

Anode – Positive pole of an electrolytic system, towards which anions (negatively charge ions) migrate.

Aquifer – A natural underground layer, often composed of sand or gravel, that contains water.

B

Backwash – The process of reversing the flow of water back through the filter media to remove the entrapped solids.

Basin – 1) A natural or artificially created space or structure, surface or underground, which has a shape and character of confining material that enable it to hold water. The term is sometimes used for a receptacle midway in size between a reservoir and a tank. 2) The surface area within a given drainage system. 3) A shallow tank or depression through which liquids may be passed or in which they are detained for treatment or storage.

Batch (intermittent) discharge – A discrete volume or mass of liquid or solid residuals that are collected and discharged periodically. Equalization or slower discharge rate of batch discharges may decrease negative impacts on the receiving stream.

Biochemical Oxygen Demand (BOD) – The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions.

BOD_5 – Biochemical oxygen demand measured over a 5-day period.

Best professional judgment (BPJ) – The method used by permit writers to develop technology-based NPDES permit conditions on a case-by-case basis using all reasonably available and relevant data.

C

Cathode – Negative pole of an electrolytic system, towards which cations (positively charge ions) migrate.

Cation – The ion in an electrolyte solution that carries the positive charge and that migrates toward the cathode under the influence of a potential difference.

Centrate – Water separated from the solids by a centrifuge.

Centrifuge – A mechanical device in which centrifugal force is used to separate solids from liquids and/or to separate liquids of different densities.

CFR – Code of Federal Regulations.

Clarification – Separation and concentration of solids from liquid/solid mixtures that are mostly liquid (contrast with dewatering and thickening).

Clarifier – A large circular or rectangular tank or basin in which water is held for a period of time, during which the heavier suspended solids settle to the bottom by gravity.

Clay – 1) Soil consisting of inorganic material, the grains of which have diameters smaller than 0.002 millimeters. 2) A mixture of earthy matter formed by the decay of certain minerals. The composition of clays varies widely and dictates its use. It is sometimes used in water treatment to aid coagulation and to remove tastes and odors.

Clean Water Act (CWA) – Federal legislation enacted by Congress to “restore and maintain the chemical, physical, and biological integrity of the nation’s waters” (Federal Water Pollution Control Act of 1972, as amended, 33 U.S.C. 1251 et seq).

Clear well – A reservoir for storage of finished water prior to distribution.

Coagulant – A chemical added to water that has suspended and colloidal solids to destabilize particles, allowing subsequent floc formation and removal by sedimentation, filtration, or both.

Coagulation – As defined in 40 CFR 141.2, a process in which colloidal and suspended materials are destabilized and agglomerated into flocs by using coagulant chemicals and mixing.

Colloids – Finely divided solids that will not settle but may be removed by coagulation of biochemical action or membrane filtration; they are intermediate between true solutions and suspensions.

Community Water System (CWS) – A water system that supplies drinking water to 25 or more of the same people year-round.

Contaminant – Anything found in water (including microorganisms, minerals, chemicals, radionuclides, etc.) that may be harmful to human health or the environment.

Continuous discharge – A volume or mass of liquid or solid residuals that are discharged at constant flow without significant interruption.

Conventional filtration – As defined in 40 CFR 141.2, a series of processes including coagulation, flocculation, sedimentation, and filtration resulting in substantial particulate removal.

Conventional pollutants – Constituents of wastewater as determined by Section 304(a)(4) of the CWA and EPA regulations. Conventional pollutants are classified as biochemical oxygen demand, total suspended solids, oil and grease, fecal coliform, and pH.

D

Decant – To draw off the liquid from a basin or tank without stirring up the sediment in the bottom.

Deep-well injection – Long-term or permanent disposal of untreated, partially treated, or treated wastewaters by pumping the wastewater into underground formations of suitable character through a bored, drilled, or driven well. Most commonly used for desalination plant concentrates.

Dewatering – Separation of liquid from liquid/solid mixtures that are predominantly solids, often containing very low moisture content to start with (contrast with clarification and thickening).

Dewatering processes – Mechanical and non-mechanical methods used to remove excess liquids from residual solids in order to concentrate the solids. These methods include belt presses, centrifuges, filter presses, vacuum presses, and lagoons.

Diatomaceous earth filtration –filtration method in which the filter media, diatomaceous earth, is deposited on a support membrane or screen (called a septum) prior to each filter run (pre-coat). The filter media is washed and wasted at the end of each filter run.

Direct discharge – The discernible, confined, and discrete conveyance of pollutants to United States surface waters such as rivers, lakes, and oceans. See 40 CFR 122.2.

Direct discharger – A facility that discharges or may discharge treated or untreated wastewaters into waters of the United States.

Direct filtration – As defined in 40 CFR 141.2, a series of processes including coagulation and filtration, but excluding sedimentation, resulting in substantial particulate removal.

Direct recycle – The return of recycle flow within the treatment process without first passing through treatment or equalization.

Discharge – The discernible, confined, and discrete conveyance of pollutants to: 1) United States surface waters such as rivers, lakes, and oceans (“direct discharge”), or 2) a publicly owned, privately owned, federally owned, combined, or other treatment works (“indirect discharge”). Note that the definition at 40 CFR 122.2 excludes indirect discharges to publicly owned treatment works; however, in this report, “discharge: refers to any direct or indirect discharge.

Disinfectant – As defined in 40 CFR 141.2, any oxidant, including but not limited to chlorine, chlorine dioxide, chloramines, and ozone added to water in any part of the treatment or distribution process, that is intended to kill or inactivate pathogenic microorganisms.

Disinfection – As defined in 40 CFR 141.2, a process that inactivates pathogenic microorganisms (such as bacteria, viruses, and protozoa) in water by chemical oxidants or equivalent agents. Disinfection may be a chemical (commonly chlorine, chloramine, or ozone) or physical process (e.g., ultraviolet light).

Disinfection by-products (DBPs) – Organic compounds formed by the reaction of the disinfectant, natural organic matter, and the bromide ion. Regulated DBPs include trihalomethanes, haloacetic acids, bromate, and chlorite.

Disposal – Intentional placement of residuals into or on any land, in either a permitted waste disposal facility (e.g., landfill) or land application for agricultural or other purposes. Does not include direct or indirect discharge of residuals.

Dissolved-air flotation – A method of solids separation, whereby a side stream is saturated with air at high pressure and then injected into the flotation tank to mix with the incoming water stream. As the air bubbles rise to the surface they attach to floc particles and create a sludge layer at the surface of the tank, which is then removed for disposal.

Distribution system – A network of pipes leading from a treatment plant to customers' plumbing systems.

E

Electrodialysis – A method of water treatment that utilizes electric current applied to permeable membranes to remove minerals and salts from water.

Emergency discharge – A volume or mass of liquid or solid residuals that are discharged only during extenuating circumstances (i.e., a treatment process malfunction). Also referred to as upset or bypass discharge.

Equalization – A method used to control the flow of water or residuals stream by providing storage and detention time between the point of origin and the return (or next) location of the water or residuals stream. The water or residuals stream is then removed from the storage unit at a controlled, uniform rate.

Evaporation – The process by which water or other liquid becomes a gas. Water from land areas, bodies of water, and all other moist surfaces is absorbed into the atmosphere as a vapor.

Evaporation ponds – Dewatering and concentration of concentrates using evaporation.

F

Facility – All contiguous property and equipment owned, operated, leased, or under the control of the same person or entity.

Filter press – A press operated mechanically for partially separating water from solid materials.

Filter-to-waste – Provision in a filtration process to allow the first filtered water, after backwashing a filter, to be washed or reclaimed. Cleans filter prior to being put back into service after backwashing.

Filtrate – The water separated from the solids by a filter press or the liquid that has passed through a filter.

Filtration – As defined in 40 CFR 141.2, a process for removing particulate matter from water by passage through porous media.

Finished water – As defined in 40 CFR 141.2, water that is introduced into the distribution system of a public water system and is intended for distribution and consumption without further treatment, except as treatment necessary to maintain water quality in the distribution system (e.g., booster disinfection, addition of corrosion control chemicals).

Floc – Collections of smaller particles that have come together (agglomerated) into larger, more settleable particles as a result of the coagulation-flocculation process.

Flocculation – As defined in 40 CFR 141.2, a process to enhance agglomeration or collection of smaller floc particles into larger, more easily settleable particles through gentle stirring by hydraulic or mechanical means.

Flow – 1) The movement of a stream of water or other mobile substance from place to place; a stream of water; movement of silt, water, sand, or other material. 2) The fluid that is in motion. 3) The quantity or rate of movement of a fluid; discharge; total quantity carried by a stream. 4) To issue forth or discharge.

Freeze-assisted sand beds – A structure used to freeze and thaw residuals to change the characteristics to a more granular consistency that is easier to dewater. Most commonly used with alum residuals.

G

Gravity filter – A rapid sand filter of the open type, the operating level of which is placed near the hydraulic grade line of the influent and through which the water flows by gravity.

Ground water – Water in a saturated zone or stratum beneath the surface of land or water.

H

Haloacetic acids (HAA5) – The five haloacetic acid compounds include monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid. All are disinfection by-products.

Hardness – A characteristic of water, imparted by salts of calcium, magnesium, and iron such as bicarbonates, carbonates, sulfates, chlorides and nitrates, that cause curdling and increased consumption of soap, deposition of scale in boilers, damage in some industrial processes, and sometimes objectionable taste.

I

Impoundment – A pond, lake, tank, basin, or other space, either natural or man-made that is used for storage, regulation, and control of water.

Indirect discharge – The discernible, confined, and discrete conveyance of pollutants to a publicly owned treatment works. See 40 CFR 122.2.

Indirect discharger – A facility that discharges or may discharge wastewaters to a publicly owned treatment works.

Influent water – Raw water plus any recycle streams.

Inorganic contaminants – Mineral-based compounds such as metals, nitrates, and asbestos. These contaminants are naturally-occurring in some water, but can also arise through farming, chemical manufacturing, and other human activities.

Ion – A charged atom, molecule, or radical, the migration of which affects the transport of electricity through an electrolyte solution or, to a certain extent, through a gas. An atom or molecule that has lost or gained one or more electrons. By such ionization it becomes electrically charged. An example is the alpha particle.

Ion exchange (IX) – Process using a resin formulated to have capability to adsorb cationic or anionic species, such as arsenate.

Ion-exchange regenerant – A chemical solution used to restore an exhausted bed of ion exchange resins to the fully ionic (regenerated) form necessary for the desired ion exchange to again take place effectively.

L

Lagoon – Basin or artificial impoundment containing solid or liquid material for purposes of storage, treatment, or disposal.

Lime – Any of a family of chemicals consisting essentially of calcium hydroxide made from limestone (calcite) that is composed almost wholly of calcium carbonate or a mixture of calcium and magnesium carbonate.

Long-term average (LTA) – Average pollutant levels achieved over a period of time (EPA recommends five years) by a plant or technology option.

M

Maximum Contaminant Level (MCL) – The highest level of a contaminant that EPA allows in drinking water. MCLs ensure that drinking water does not pose either a short-term or long-term health risk. EPA sets MCLs at levels that are economically and technologically feasible. States can set MCLs that are more stringent than EPA MCLs.

Mechanical dewatering device – A device that operates mechanically to remove water from residuals and produce a non-flowing residual. Examples include centrifuges, filter presses, belt presses, plate press, and vacuum filters. Contrast with non-mechanical dewatering.

Median – In a statistical array, the value having as many cases larger in value as cases smaller in value, or 50th percentile.

Membrane concentrate – The reject stream generated when the source water is passed through a membrane for treatment.

MGD – Million gallons per day.

mg/L – Milligrams per liter.

Microfiltration – A method of water treatment that utilizes a membrane to separate micrometer or submicrometer particles from a solution. The method clarifies water by trapping particles and microorganisms in the membrane, while allowing dissolved substances to pass through with the permeate (i.e., clean water).

Micron – A unit of length equal to one micrometer (µm). One millionth of a meter or one thousandth of a millimeter. One micron equals 0.00004 of an inch.

Microorganisms – Tiny living organisms that can be seen only with the aid of a microscope. Some microorganisms can cause acute health problems when consumed in drinking water. Also known as microbes.

Monofill – An ultimate disposal technique for water treatment plant sludge in which the sludge is applied to a landfill designed for sludge only.

N

North American Industry Classification System (NAICS) – NAICS was developed jointly by the United States, Canada, and Mexico to provide comparability in statistics about business activity across North America.

Nanofiltration – A method of water treatment that utilizes membranes and has the primary goal of removing hardness, bacteria, viruses, and organic-related color.

Nonconventional pollutants – Pollutants that are neither conventional pollutants (40 CFR 401.16) nor priority pollutants (40 CFR 423 Appendix A).

Non-mechanical dewatering process – Process to separate solids from liquids in liquid/solid mixtures without the use of mechanical devices, examples include sand or similar drying beds, dewatering lagoons (lagoons designed for routine solids clearing), and freeze-assisted sand beds. Contrast with mechanical dewatering and disposal, which includes long-term lagoons (i.e., lagoons that are cleaned of solids every 10 to 20 years or more).

Non-Transient, Non-Community Water System (NTNCWS) – A water system that supplies water to 25 or more of the same people at least six months per year in places other than their residences. Some examples are schools, factories, office buildings, and hospitals that have their own water systems.

Nonwater quality environmental impact – Deleterious aspects of control and treatment technologies applicable to point source category wastes, including, but not limited to air pollution, noise, radiation, sludge and solid waste generation, and energy use.

National Pollutant Discharge Elimination System (NPDES) – As authorized by the Clean Water Act, the NPDES permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Point sources are discrete conveyances such as pipes or man-made ditches. Individual homes that are connected to a municipal system, use a septic system, or do not have a surface discharge do not need an NPDES permit; however, industrial, municipal, and other facilities must obtain permits if their discharges go directly to surface waters. In most cases, the NPDES permit program is administered by authorized states.

O

Off site – Outside the boundaries of a facility.

On site – The same or geographically contiguous property, which may be divided by a public or private right-of-way, provided the entrance and exit between the properties is at a crossroads intersection, and access is by crossing as opposed to going along the right-of-way. Noncontiguous properties owned by the same company or locality but connected by a right-of-way, which it controls, and to which the public does not have access, is also considered on-site property.

Operating capacity – The maximum finished water production rate at a water treatment plant approved by the state drinking water program authority.

Organic contaminants – Carbon-based chemicals such as solvents and pesticides that can get into water through runoff from cropland or discharge from factories.

Outfall – The mouth of conduit drains and other conduits from which a facility discharges effluent into receiving waters.

P

Pathogen – A disease-causing organism.

Permeability – The property of a material that permits appreciable movement of water through it when it is saturated and the movement is actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water.

pH – An expression of the intensity of the basic or acid condition of a solution. Mathematically, pH is the negative logarithm (base 10) of the hydrogen ion concentration, [H+]. [pH = log (1/H+)]. The pH may range from 0 to 14, where 0 is most acidic, 14 most basic, and 7 neutral. Natural waters usually have a pH between 6.5 and 8.5.

Pollutant – Under the Clean Water Act, a dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical waste, biological materials, certain radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. This definition includes residuals (including miscellaneous residuals) generated by water treatment plants. See 40 CFR 122.2.

Pollution prevention – The use of materials, processes, or practices that reduce or eliminate the creation of pollutants or residuals.

Polymer – A synthetic organic compound with high molecular weight and composed of repeating chemical units (monomers). Polymers may be polyelectrolytes (such as water soluble flocculants), water-insoluble ion exchange resins, or insoluble uncharged materials (such as those used for plastic or plastic-lined pipe).

Potable water – Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for domestic consumption.

Precipitative softening – A method of water treatment with the primary goal of reducing water hardness. The method may include lime softening, sedimentation/precipitation, filtration, and disinfection.

Presedimentation – Water treatment operation that is at the head of the plant. Its primary purpose is to remove a significant percentage of suspended solids and other contaminants in the water prior to other water treatment operations (e.g., conventional filtration, precipitative softening). This water treatment operation may require a small addition of water treatment chemicals, such as polymer coagulants (e.g., 0.5 to 1 mg/L), to aid sedimentation.

Priority pollutant – 126 compounds listed in 40 CFR Part 423 Appendix A that are a subset of the toxic pollutants and classes of pollutants outlined pursuant to Section 307 of the CWA.

Process wastewater – Any water that, during source water treatment operations, comes into direct contact with or results from the storage, production, or use of any raw material, by-product, or waste product. Wastewater from equipment cleaning, direct-contact air pollution control devices, rinse water, stormwater associated with industrial activity, and contaminated cooling water are considered to be process wastewater. Process wastewater may also include wastewater that is contract hauled for off-site disposal. Sanitary wastewater, uncontaminated noncontact cooling water, stormwater not associated with industrial activity, and finished drinking water are not considered to be process wastewater.

Public Water System (PWS) – Any water system that provides drinking water to at least 25 people for at least 60 days annually.

Publicly owned treatment works (POTW) – A treatment works as defined by Section 212 of the CWA, which is owned by a state or municipality (as defined by Section 502(4) of the CWA). This definition includes any devices and systems used in the storage, treatment, recycling and reclamation of municipal sewage or industrial wastes of a liquid nature. It also includes sewers, pipes and other conveyances, only if they convey wastewater to a POTW treatment plant. The term also means the municipality, as defined in Section 502(4) of the CWA, that has jurisdiction over the indirect discharges to and the discharges from such a treatment works.

Purchased water – Water obtained from a third-party vendor.

R

Radionuclides – Any man-made or natural element that emits radiation; may cause cancer after many years of exposure through drinking water.

Raw water – Water in its natural state, prior to any treatment for drinking.

Recovery – The process of extracting some other useable constituent from one or more residuals streams, for example, recovery of alum from coagulation sludge, lime from precipitative softening sludge, and salt from concentrates.

Recycle – Process of returning liquid or combined liquid/solid residuals streams back to the water treatment process (e.g., filter backwash recycling).

Regeneration – 1) In ion exchange, the process of restoring an ion exchange material to the state employed for adsorption. 2) The periodic restoration of exchange capacity of ion exchange media used in water treatment.

Reservoir – See “impoundment.”

Residuals – The solid, liquid, or mixed solid/liquid materials generated during source water treatment. Examples of residuals include: sludges and wastewaters generated from presedimentation, coagulation, flocculation, sedimentation, clarification, precipitative softening, filter backwash operations, and filter-to waste; membrane reject wastewaters; ion exchange resins and concentrate wastewaters; activated carbon wastes; and other miscellaneous residuals. Residuals include those accumulated for batch discharge.

Residuals treatment – Any activity designed to change the character or composition of liquid and solid residuals streams from water treatment processes as needed to render it amenable to recycle, recovery, reduce its volume, or prepare it for transportation, storage, disposal, or discharge. For example, this would include equalization, thickening, mechanical dewatering, non-mechanical dewatering, and other processes defined separately.

Reverse osmosis – A method of water treatment that involves the application of pressure to a concentrated solution that causes the passage of a liquid from the concentrated solution to a weaker solution across a semipermeable membrane. The membrane allows the passage of the solvent (water) but not the dissolved solids (solutes). This method is typically used, in combination with pretreatment, for desalination and the removal of ions, radionuclides, bacteria, and viruses.

S

Sand drying beds – Similar to evaporation ponds; evaporation is used to dewater and concentrate liquid/solid residuals mixtures. One difference is that these structures are also engineered to filter out solids so that a portion of the liquid is removed via subsurface infiltration into ground water or the vadose zone.

Screen – A device with openings, generally of uniform size, used to retain or remove suspended or floating solids in flowing water or wastewater and to prevent them from entering an intake or passing a given point in a conduit. The screening element may consist of parallel bars, rods, wires, grating wire mesh, or perforated plate. The openings may be of any shape, although they are usually circular or rectangular.

Safe Drinking Water Information System (SDWIS) – Database containing information about drinking water treatment systems and plants. There is a federal SDWIS and state SDWIS. SDWIS identification numbers (or PWS IDs) are nine characters in length, with the first two digits usually composed of the state abbreviation.

Sedimentation – Separation of solids and liquids from mixtures. Discrete and hindered settling principally involves separation of solids from mixtures that are predominantly liquids, and these processes are referred to as "clarification." Sedimentation refers to the physical separation process, in contrast to non-mechanical dewatering, which is a residuals treatment process, and disposal, which is a residuals destination.

Sedimentation basin – A basin or tank in which water or wastewater containing settleable solids is retained in order to remove by gravity a part of the suspended matter. Also called sedimentation tank, settling basin, and settling tank.

Sequestering – To render inactive, such as chelation (binding of metal ion to form an inactive metal compound).

Settleable solids – That matter in wastewater that will not stay in suspension during a preselected settling period, such as one hour, but either settles to the bottom or floats to the top.

Settling – See "sedimentation."

Settling basin – See "sedimentation basin."

Site – See "facility."

Slow sand filtration – As defined in 40 CFR 141.2, a process involving passage of raw water through a bed of sand at low velocity (generally less than 0.4 meters/hour) resulting in substantial particulate removal by physical and biological mechanisms.

Sludge – The accumulated solids separated from liquids during processing.

Sludge thickener – A tank or other piece of equipment designed to concentrate water treatment sludges.

Source reduction – Any practice prior to recycling, treatment, or disposal that reduces the amount of any hazardous substance, pollutant, or contaminant entering any residuals stream or otherwise released into the environment. Source reduction can include equipment or technology modifications, process or procedure modifications, substitution of raw materials, and improvements in housekeeping, maintenance, training, or inventory control.

Source water – Intake (raw) water treated and/or distributed by utilities.

Spent filter backwash water – A stream containing particles that are dislodged from filter media when water is forced back through a filter (backwashed) to clean the filter.

Standard Industrial Classification (SIC) – A numerical categorization system used by the U.S. Department of Commerce to catalogue economic activity. SIC codes refer to the products, or group of products, produced or distributed, or to services rendered by an operating establishment. SIC codes are used to group establishments by the economic activities in which they are engaged. SIC codes often denote a facility's primary, secondary, tertiary, etc. economic activities. This system predated NAICS.

Supernatant – The water standing above a sediment or precipitate.

Surface waters – Waters of the United States, as defined at 40 CFR 122.2, including, but not limited to, oceans and all interstate and intrastate lakes, rivers, streams, creeks, mudflats, sand flats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, and natural ponds.

Suspended solids – Solid organic and inorganic particles that are held in suspension by the action of flowing water and are not dissolved.

System – One or more water treatment facilities that produce and deliver finished water to customers over the same distribution network.

T

Thickener supernatant – Thickener supernatant is the clarified water that exits the units after particles have been allowed to settle out.

Thickening – Gravity separation and concentration of solids from liquid/solid mixtures that are mostly solids.

Total suspended solids (TSS) – Solids in water that can be trapped by a filter. TSS can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage.

Total trihalomethanes (TTHM) – The trihalomethane compounds include trichloromethane (chloroform), dibromochloromethane, bromodichloromethane and tribromomethane (bromoform).

Toxic pollutants – those pollutants listed by the Administrator under CWA Section 307(a) and listed at 40 CFR 401.15

Transient, Non-Community Water System (TNCWS) – A water system that provides water in a places such as a gas station or campground where people do not remain for long periods of time.

Treatment – Any method, technique, or process designed to change the physical, chemical, or biological character or composition of any metal-bearing, oily, or organic waste in order to neutralize such wastes, to render such wastes amenable to discharge, or to recover metal, oil, or organic content from the wastes.

Trihalomethane (THM) – As defined in 40 CFR 141.2, one of the family of organic compounds, named as derivatives of methane, wherein three of the four hydrogen atoms in methane are each substituted by a halogen atom in the molecular structure.

Turbidity – The cloudy appearance of water caused by the presence of suspended and colloidal matter that cause the scattering and adsorption of light. In the drinking water industry, a turbidity measurement is used to indicate the clarity of water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. WTPs may be able to correlate turbidity to suspended solids. Because source water quality varies seasonally, weekly or monthly correlations may be necessary.

U

Ultrafiltration – A method of water treatment that uses membranes in a pressure-driven process for concentrating solutions containing colloids and higher molecular weight materials. The method typically removes viruses, colloids, clays, bacteria, humic acids, and fulvic acids.

Underground injection – The technology of placing fluids underground, in porous formations of rocks, through wells or other similar conveyance systems.

Utility – The public or private entity managing the business aspects of the production and distribution of finished water from one or more water treatment systems (e.g., billing customers for water service, paying utility employees and third-party vendors for services and products provided to the utility, paying servicing fees for any outstanding debts). Customers are usually more familiar with utility as a water supplier than a system, in those utilities that operate multiple systems.

V

Vacuum-assisted drying beds – Dewatering technology in which a vacuum is applied to the underside of porous media plates to remove the water from residuals.

Vadose zone – Area between the land surface and the water table.

W

Wastewater – See "process wastewater."

Wastewater treatment – The processing of wastewater by physical, chemical, biological, or other means to remove specific pollutants from the wastewater stream, or to alter the physical or chemical state of specific pollutants in the wastewater stream. Treatment is performed for direct or indirect discharge of treated wastewater, recycle of treated wastewater to the same process that generated the wastewater, or for reuse of the treated wastewater in another process.

Water treatment – Any activity associated with altering the character or composition of source water prior to storage, transmission, distribution, and consumption by public water utility consumers. This treatment takes place at a water treatment plant (see definition).

Water treatment plant (WTP) – A water treatment facility in which ground water, surface water, or other source water is processed to produce potable water for storage, transmission, distribution, or consumption by public water utility consumers. For the purposes of the industry review, this term does not encompass off-facility treatment stations (e.g., booster chlorination stations, fluoridation stations, corrosion control treatment stations) or off-site water transfer infrastructure (e.g., tunnel transferring turbid water from one watershed body to another waterbody upstream of the facility, water towers that are downstream of the facility).

Water treatment system – One or more water treatment plants that produce and deliver finished water to customers over the same distribution network.

Water treatment utility – See "utility".

Watershed – The land area from which water drains into a stream, river, or reservoir.

Well – A bored, drilled or driven shaft whose depth is greater than the largest surface dimension; a dug hole whose depth is greater than the largest surface dimension; an improved sinkhole; or a subsurface fluid distribution system.

Z

Zero discharge – Disposal of process residuals other than by direct discharge to a surface water or by indirect discharge to a publicly owned, privately owned, federally owned, combined, or other treatment works.

APPENDIX A

SURVEY DESIGN AND CALCULATION OF NATIONAL ESTIMATES

APPENDIX A

SURVEY DESIGN AND CALCULATION OF NATIONAL ESTIMATES

One of the data collection activities undertaken by EPA was a survey of drinking water treatment facilities, known as the Water Treatment Plant Questionnaire. This appendix provides detailed information about the statistical methods used in conducting the survey. Section A.1 provides a discussion of the sample frame created for the survey. Section A.2 presents the statistical sample design used to select treatment systems for inclusion in the survey. Section A.3 describes the response rates for Part A of the questionnaire (technical questions). Section A.4 presents the statistical methods used to calculate national estimates of various operating characteristics based upon the responses to Part A. The national estimates are provided in Section 3 of this report. Section A.5 provides references.

A.1 SAMPLE FRAME

This section provides an overview of the sample frame used to select systems for the survey. Further information about the sample frame and survey design can be found in EPA’s Information Collection Request Supporting Documentation (U.S. EPA, 2006).

For the survey, EPA originally considered approximately 160,000 public water systems that collectively provide 90 percent of the nation’s drinking water. After examining existing data sources, EPA reduced the target population for the survey to a relatively small subset to reduce industry’s burden and to obtain information from systems most likely to produce residuals. Specifically, the target population included all public water systems except those in the following groups:

- Systems serving fewer than 10,000 people were excluded because, while they account for 93 percent of community water systems (CWSs), EPA estimates they contribute less than nine percent of the residuals from the industry (U.S. EPA, 2006).

- CWSs that do not produce residuals were excluded either because they do not treat the source water, or they treat it in a manner that is unlikely to produce residuals.
- About 10 non-community water systems (NCWS) serving populations greater than 10,000 were excluded because they do not serve permanent resident populations and, thus, may have different discharge practices and financial characteristics.

The sample frame from which the sample was drawn was derived from EPA's Safe Drinking Water Information System (SDWIS), a database that stores routine data about the nation's drinking water. The data in SDWIS were combined with additional data from other sources, such as the 2000 CWSS (Community Water System Survey) – which has operational and financial data not available in SDWIS – and the May 14, 1996 Information Collection Rule to support future regulation of microbial contaminants, disinfectants, and disinfection byproducts – which has engineering and operations information not available in SDWIS. The database created from these sources provided a complete listing of all systems in the United States. The sample frame database also contained information about each treatment plant within a system. Information maintained in the sample frame database at the system level included:

- Public Water System identification number PWSID, name, owner, and contact information;
- Primary water source;
- Population served; and
- Community served.

Information contained in the sample frame database at the treatment facility (plant) level included:

- Facility Registration System identification number FRSID, name, and location;
- Associated PWSID;
- Primary water source;

- Estimated population served;
- Treatment method information; and
- Discharge information.

The data associated with systems was considered to be of high quality. The quality of the information about individual plants, however, varied, with high-quality information about primary water source and treatment method but poor quality information about discharge and population served.

The plants that met the criteria presented above formed the target population. However, data collected by the CWSS, as well as other data available in SDWIS, focused on information at the system level rather than information for each individual plant. Thus, EPA decided to create a sample frame of water treatment systems and to request information from each system about its member plants. Specifically, the questionnaire that was sent to each sampled system asked a series of qualifying questions to determine if the system had any plants within the target population. Systems were only required to complete the remaining questions if they had plants within the target population.

EPA determined that the sample frame of treatment systems has a nearly 100 percent coverage rate for the target population. The sample frame database provided a complete listing of all community water systems in the United States serving at least 10,000 people at the time it was finalized. Because no treatment plant in a system serving fewer than 10,000 people could serve more than 10,000 people, the sample frame should contain all systems that have members of the target population. There is, however, a small probability that between the times that the sample frame database was finalized and the sample was selected, the size of the population served by a single-facility system could have moved from fewer than 10,000 to over 10,000. In such a case, the facility would be in the target population but its system would not be in the sample frame. EPA has judged the likelihood of such a case occurring as being very small.

A.2 SAMPLE DESIGN

This section describes the sample design for the survey. A sample design identifies the way in which the survey data are to be collected. EPA chose to use a stratified sample design that required only some systems to respond. The systems and plants identified from the stratified sample are statistically representative of all systems and plants in the target population.

A.2.1 Statistical Design and Strata

EPA used a stratified sample design to select treatment systems to receive a questionnaire. Stratification is performed by selecting one or more characteristics of interest and dividing the members of the population into “strata” that are defined by those characteristics. Generally, the sample frame identifies these characteristics or provides a basis to reasonably assign characteristics to each population member. Stratified sampling consists of selecting a probability-based sample from within each stratum, then combining them to constitute the total sample. There are several benefits that can result from a stratified sampling approach, including:

- Ensuring that the sample contains representatives from every stratum;
- Improving the precision of parameter estimates (if the strata are defined appropriately);
- Allowing important parameters to be estimated at the stratum level; and
- Allowing certain subpopulations of particular interest to be sampled at a greater rate than others.

To select systems to receive questionnaires, EPA used the following stratification variables, which were available from the sample frame:

- Size of population served;
- Primary water source (surface water or ground water); and
- Treatment type.

Size of population served was selected for use in stratification because it served as a surrogate for the volume of water treated and the volume of residuals that are produced. EPA considered two population size groups. The chosen cut-point was 50,000, because a review of existing literature showed that this cut-point is commonly used in evaluating drinking water systems. Primary water source was selected as a stratification variable because substantial differences can exist in the amount and type of residuals that a plant produces between treating surface water and treating ground water. Surface water, which is taken from above-ground sources such as rivers, lakes, wetlands, or estuaries, is more vulnerable to contamination and usually needs treatment before it is safe to drink. Ground water, which is pumped from underground aquifers through drilled wells or from springs, is protected by layers of soils and other subsurface materials and often needs only minimal treatment.

EPA considered larger systems (i.e., those serving populations greater than 50,000) to be more likely to have residual management (or treatment) than small systems. Thus, for larger systems, EPA considered treatment type as an additional stratification variable, because it can affect the volume and characteristics of the residuals generated. Treatment type often depends on the plant’s size, its source water quality, and other environmental factors, such as climate. It may also depend on the experience of the plant operator or engineer with the treatment technologies. In addition, state or federal regulatory requirements may affect technology choices. EPA considered the following four treatment types:

- Softening or ion exchange (SOFT/IX);
- Conventional and direct filtration, including coagulation/flocculation (CONV);
- Membrane technology, including reverse osmosis, ultrafiltration, and electrodialysis (MEM); and
- Other, including filtration without coagulation/flocculation, activated carbon, activated alumina, and aeration (OTHER).

In addition to these stratification variables, EPA also considered whether a system’s water quality region would be an appropriate stratification variable, because geographic differences in source water characteristics could affect treatment and residuals generation.

However, EPA determined that use of water quality region in conjunction with the other stratification variables would have resulted in an extremely inefficient statistical sample design with large variance estimates. Instead, EPA incorporated water quality region into the sample selection mechanism in a manner that would not disproportionally affect variance. First, EPA sorted the plants by water quality region within each stratum defined by the four stratification variables. EPA then drew a systematic sample from each cell, which involves selecting every k^{th} plant, where *k* is determined randomly according to the selection rate. In this manner, EPA ensured that the sample was reasonably diverse from a geographical perspective while achieving an efficient sample design.

A.2.2 Target Precision Expected from the Sample Design

For the final sample design, EPA selected a total of 616 systems to receive the questionnaire. The number of systems selected was based on requirements concerning the precision of the survey estimates. The precision depends on both the sample design and the sample size. For the drinking water treatment (DWT) industry survey, the precision requirement was defined in terms of the width of a 95 percent confidence interval for an estimated proportion. Because a proportion of 0.5 (or 50 percent) results in the largest possible variance for the binomial distribution, EPA used that case in defining the target precision. Based upon EPA’s simulation, the sample would be expected, with 95 percent confidence, to yield sufficient data to estimate the value of an unknown proportion to within ±0.05 of its true value for the target population. This precision target will hold when the proportion’s true (unknown) value is equal to 0.5, and even greater precision is expected when the true value of the proportion is not equal to 0.5. Furthermore, the simulation estimated that a statistical sample of 593 systems distributed among the sampling strata would result in a sample of 673 plants from the target population, which would then represent an estimated 2,402 plants in the total population. (After including additional systems into its sample frame, EPA slightly increased the sample size to 616 systems.)

A.2.3 Sample Selection Procedure

The statistical selection of systems to receive questionnaires, as noted above, was done systematically within each stratum after sorting by water quality region to ensure geographic diversity within the sample. In addition, EPA sampled at a higher rate among strata that were mostly likely to produce residuals. EPA sampled more large systems than small ones and more surface water systems than ground water systems. In summary, the sample design had the following characteristics:

- Systems for large populations (greater than 50,000) were four times more likely to be selected than systems serving small populations (between 10,000 and 50,000);
- Systems with surface water as the primary water source were three times more likely to be selected than systems with ground water;
- Larger populations were selected on the basis of (i.e., stratified by) primary water source and treatment method, while smaller populations were stratified by primary water source only; and
- A minimum of five systems were selected from each cell.

The specific strata, the number of systems within each stratum, the sampling fraction, and number of systems that were selected in each stratum for the DWT industry survey as part of the statistical sample are shown in Table A-1. In the original sample design, EPA included an allotment for a judgment sample of 25 systems that would not have been part of the statistical estimates. However, EPA later chose to increase the statistical sample size and used the allotment from the judgment sample for this purpose.

Table A-1. DWT Survey Strata, Population Size, and Sample Size

Stratum			Sample Information		
Size of Population Served	**Primary Water Source**	**Treatment Method**	**Sampling Fraction (Percent) [a]**	**Number of Systems in Frame**	**Number of Systems in Statistical Sample**
10,001-50,000	Ground	Any	6	625	37
	Surface	Any	18	1,044	187
	Total	Sub-total		1,669	224
More than 50,000	Ground	Conventional Filtration	100	8	8
		Membrane	100	5	5
		Other	24	82	20
		Softening	24	50	12
		Ion Exchange	100	5	5
		Sub-total		150	50
	Surface	Conventional Filtration	72	288	208
		Membrane	72	26	19
		Other	72	86	62
		Softening	72	67	49
		Ion Exchange	100	4	4
		Sub-total		471	342
	Sub-total			621	392
Total				**2,290**	**616**

a – A minimum of five systems were sampled from each stratum.

A.3 RESPONSE STATUS

This section describes the response rates, non-response evaluations, bias considerations, and unusual situations requiring adjustments to the Part A responses.

A.3.1 Response Rates

Table A-2 shows the final disposition of Part A responses to the survey by stratum. In the rest of the document, references to the "survey" and "responses" pertain only to the Part A (technical) responses. Table A-2 addresses the number of non-responding systems but does not address non-responses to individual questions. Data were analyzed without any adjustments made for missing responses to individual questions.

Despite EPA efforts to obtain the missing information through repeated phone calls and email communications with the survey respondents, 46 surveys had one or more missing responses and/or responses needing clarification at the completion of the survey. An additional 28 surveys had missing information; however, these surveys included 27 surveys from Puerto Rico and one survey from New York. The next section describes EPA's evaluation of potential patterns in the non-responses.

Table A-2. DWT Survey Part A: Strata, Population Size, and Sample Size, and Response Information for Systems

Stratum			Sample Information			Response/In-Scope Information For SYSTEMS			
Size of Population Served	**Primary Water Source**	**Treatment Method**	**Sampling Fraction (Percent) [a]**	**Number of Systems in Frame**	**Number of Systems in Sample**	**Number of Responses Received**	**Number of Non-Respondents**	**Number In-Scope Respondents**	**Estimated Population In-Scope**
10,001-50,000	Ground	Any	6	625	37	17	20	17	283
	Surface	Any	18	1,044	187	125	62	125	694
	Sub-total			1,669	244	142	82	142	978
More than 50,000	Ground	Conventional Filtration	100	8	8	5	3	5	5
		Membrane	100	5	5	3	2	3	3
		Other	24	82	20	8	12	8	33
		Softening	24	50	12	11	1	11	46
		Ion Exchange	100	5	5	3	2	3	3
		Sub-total		150	50	30	20	30	90
	Surface	Conventional Filtration	72	288	208	175	33	174	242
		Membrane	72	26	19	14	5	14	19
		Other	72	86	62	43	19	42	58
		Softening	72	67	49	37	12	37	51
		Ion Exchange	100	4	4	2	2	2	2
		Sub-total		471	342	271	71	269	373
	Sub-total			621	392	301	91	299	463
Total				**2,290**	**616**	**443**	**173**	**441**	**1,441**

a – A minimum of five systems were sampled from each stratum.

A.3.2 Non-Response Evaluation

This section describes EPA's evaluation of potential non-response patterns to the survey. Such patterns are evaluated as a function of known information about *all* systems that were included in the sample. Some information about the sampled systems is available in the sampling frame. Specifically, the sample frame includes (1) information that was used to define sampling strata, and (2) other system characteristics that were not used to create sampling strata. For the DWT survey, EPA used the size of the population served, the primary water source, and the treatment method to create the sampling strata. Other information available in the DWT survey sampling frame used to examine potential non-response patterns includes:

- EPA Region,
- Water Quality Region,
- State, and
- Type of owner.

EPA combined the information from the sampling frame with the results of the DWT survey to prepare summaries of non-response rates compared with system characteristics. Tables A-3 through A-7 provide summaries of non-response rate of the sampled systems in relation to several of the variables. In particular:

- Table A-3 shows the non-response information by stratum,
- Table A-4 shows the non-response information by EPA Region,
- Table A-5 shows the non-response information by Water Quality Region,
- Table A-6 shows the non-response information by state, and
- Table A-7 shows the non-response information by type of owner.

Each of the five tables contains the following information:

- Variable level,
- Total number of systems in the DWT survey sample,
- Number and percent of sampled systems whose responses indicated that they were unqualified for participation in the survey,
- Number of qualified systems responding to the survey (and percent of all sampled systems not known to be unqualified),

- Number of non-responding systems (which includes those systems that did not return the questionnaire and those systems that returned the questionnaire but only provided partial responses (response to Question 1, indicated they were qualified to participate in the survey), and
- Number of known in-scope non-respondents (i.e., only responded to Question 1 and indicated they were in-scope).

As noted in the bullets above, there were two types of non-responding systems defined for the summaries: those for which no responses were received, and those that sent partial responses. The latter group comprises the "known in-scope non-respondents" systems. The percentages shown in Tables A-3 through A-7 are calculated differently for various columns. For the number of unqualified systems, the denominator of the percentage is the number of systems sampled. For the number of responding and non-responding systems that were not known to be unqualified, the denominator of the percentage subtracted the number of unqualified systems from the total number sampled, or equivalently, the sum of the numbers of systems that were known to be qualified and the systems for which there was no response at all. For example, in the first row of Table A-3, the percentage of unqualified systems is equal to 19 divided by 37, and the percentage of non-responding systems is equal to 3 divided by 18 (37 – 19).

Upon examining Tables A-3 through A-7, EPA noted the following situations with increased rates of non-response:

- In Table A-3, most strata have between 20 and 40 percent non-response rates. The two exceptions, at 50 and 75 percent, are the two ion exchange strata for populations greater than 50,000. Both of these strata have no more than five members.
- In Table A-4, EPA Region 2 has a significantly higher non-response rate (62%) than the other regions, due in part to non-response by systems in Puerto Rico.
- In Table A-5, systems with a Water Quality Region specification of "e" have a 95% non-response rate, while all other regions have non-response rates of less than 40%. The "None" category includes Puerto Rico and Guam.
- In Table A-6, the states that have a greater than 50% non-response rate include Maryland and Puerto Rico. Mississippi, Nebraska, and Utah have 50% response rates, but there were only 2 qualified systems sampled in each.
- In Table A-7, non-response rates were similar for all types of owner.

In examining all five tables together, it is clear that the primary place where there is a significant non-response pattern is caused by the partial responses from the systems in Puerto Rico.

A.3.3 Bias Considerations

Non-response bias occurs when the survey responses that would have been received from a group of sampled subjects who do not respond to the survey are systematically different than the actual responses received from the subjects who did complete the survey. Thus, non-response bias can be present any time there are non-respondents, regardless of whether there are any obvious patterns in respondents and non-respondents. However, in the case of the DWT survey, there is a clear pattern of non-response from the Puerto Rico systems that could have an associated non-response bias due to potential differences in characteristics between Puerto Rico systems and the responding systems. The presence of non-response bias related to partial responses from Puerto Rico systems may lead to inaccurate national estimates of variables measured by the survey. This is due to the fact that the different values of survey responses from Puerto Rico are not incorporated into the national estimate, causing under- or over-estimates of the variables of interest. As explained below, EPA considers that inaccurate national estimates are unlikely, even considering the non-responses from Puerto Rico.

There are three available options for addressing the issue of potential response bias due to the partial responses from the Puerto Rico systems that were included in the sample. Each of the options, with information about assumptions and consequences are presented below.

(1) Assume that Puerto Rico systems are similar to others within strata.

The purpose of placing systems into strata for the sample selection (and into domains for the analysis) is to create sets of systems that should have similar survey responses based on the fact that they have similar characteristics with regard to population size, primary water source, and treatment method. Because EPA placed the Puerto Rico systems into strata based on these characteristics, EPA would assume that all other systems in the strata would produce similar results to those that would be expected from the Puerto Rico systems. If it can be assumed that the strata are homogenous, EPA would expect no non-response bias because other similar systems are present. As a result, the methods that EPA have used to adjust for unit non-response will be adequate to account for the Puerto Rico systems, and no additional adjustments to the survey analysis will be required.

(2) Make additional efforts to obtain data from some of the Puerto Rico systems.

The electronic/mailed survey used with the DWT survey failed to obtain all the necessary data from the Puerto Rico systems to include in the survey response database. This may be due to one of two likely reasons: (a) the systems were unwilling to respond to a particular question in the questionnaire, or (2) the systems could not reliably respond to a questionnaire in English. To counter these reasons, EPA could choose one of two alternatives to collect data from the Puerto Rico systems. The first alternative is for EPA to follow up with several of the systems and attempt to collect some data. EPA did contact the system, but did not receive a response.. A second alternative is for EPA to translate the questionnaire into Spanish and resubmit it to the sampled Puerto Rico systems. If the Puerto Rico systems did not respond, EPA would then need to address non-response associated with these systems. If some responses were received from follow-up efforts, EPA can adjust the analyses to incorporate the new data, including a revision of the non-response adjustments to the survey weights.

(3) Re-define the target population to represent the 50 states and DC.

Because the most significant non-response issue is that of partial responses from Puerto Rico, which is a territory rather than a state, EPA could choose to change the scope of the survey results to apply to only the 50 United States and the District of Columbia. This would also result in the elimination of any data from systems from other territories, such as Guam and Saipan, as well as Puerto Rico. If this approach was taken, EPA would need to revise the survey weights to account for changes in the probability of selection and redo the analysis incorporating the new survey weights.

EPA considers Option 1 to be the most reasonable alternative for three reasons. First, the sample design was developed to place Puerto Rico systems within strata based on characteristics they shared with other systems. Thus, EPA expected Puerto Rico responses to be similar to those for other systems within the associated strata, and thus, it would not be appropriate to redefine the target population (i.e., Option 3). Second, a logistic regression analysis of the non-response rates in Table 1 shows that there are no statistically significant differences in the non-response rates among the various strata. Thus, the strata that contain the Puerto Rico systems (small surface-water systems, large surface-water systems with conventional treatment, and large surface-water systems with "other" treatment) are similar to the other strata with regard to non-response rates. Third, during permit support activities, EPA visited and evaluated several Puerto Rico systems. The engineering team noted many similarities to systems operated elsewhere. While these observations are subjective, they support a finding that Option 1 is a reasonable assumption.

Table A-3. Survey Part A: Non-Response by Stratum

Stratum			**Number in Sample**	**Number Unqualified (%)**	**Number Respondents (%)**	**Number Non-Respondents (%)**	**Number Non-Respondents in Scope**
Size of Population Served	**Primary Water Source**	**Treatment Method**					
10,001-50,000	Ground	Any	37	19 (51)	15 (83)	3 (17)	1
	Surface	Any	187	21 (11)	118 (71)	48 (29)	26
	Sub-total		224	40 (18)	133 (72)	51 (28)	27
More than 50,000	Ground	Conventional Filtration	8	1 (13)	6 (86)	1 (14)	1
		Membrane	5	0 (0)	3 (60)	2 (40)	0
		Other	20	10 (50)	8 (80)	2 (20)	1
		Softening	12	0 (0)	8 (67)	4 (33)	3
		Ion Exchange	5	1 (20)	1 (25)	3 (75)	3
		Sub-total	50	12 (24)	26 (68)	12 (32)	8
	Surface	Conventional Filtration	208	5 (2)	147 (72)	56 (28)	37
		Membrane	19	1 (5)	11 (61)	7 (39)	3
		Other	62	13 (21)	27 (55)	22 (45)	18
		Softening	49	1 (2)	32 (67)	16 (33)	9
		Ion Exchange	4	0 (0)	2 (50)	2 (50)	0
		Sub-total	342	20 (6)	219 (68)	103 (32)	67
	Sub-total		392	32 (8)	245 (68)	115 (32)	75
Total			616	72 (12)	378 (69)	166 (31)	102

Table A-4. Survey Part A: Non-Response by EPA Region

EPA Region	Number in Sample	Number Unqualified (%)	Number Respondents (%)	Number Non-Respondents (%)	Number Non-Respondents in Scope
01	38	5 (13)	28 (85)	5 (15)	2
02	62	10 (16)	20 (38)	32 (62)	24
03	65	4 (6)	37 (61)	24 (39)	14
04	147	16 (11)	93 (71)	38 (29)	25
05	82	3 (4)	68 (86)	11 (14)	7
06	68	10 (15)	38 (66)	20 (34)	12
07	27	1 (4)	19 (73)	7 (27)	2
08	26	3 (12)	17 (74)	6 (26)	2
09	82	16 (20)	45 (68)	21 (32)	13
10	19	4 (21)	13 (87)	2 (13)	1

Table A-5. Survey Part A: Non-Response by Water Quality Region

Water Quality Region	Number in Sample	Number Unqualified (%)	Number Respondents (%)	Number Non-Respondents (%)	Number Non-Respondents in Scope
Appalachia	33	5 (15)	24 (86)	4 (14)	2
Central North	24	2 (8)	18 (82)	4 (18)	2
Central South	31	2 (6)	21 (72)	8 (28)	2
Florida	31	9 (29)	13 (59)	9 (41)	3
Great Lakes	74	3 (4)	60 (85)	11 (15)	7
Mid Atlantic	72	3 (4)	47 (68)	22 (32)	17
North East	116	18 (16)	67 (68)	31 (32)	15
North Mountain	4	0 (0)	4 (100)	0 (0)	0
North West	18	4 (22)	12 (86)	2 (14)	1
South East	50	3 (6)	32 (68)	15 (32)	10
South Mountain	26	2 (8)	18 (75)	6 (25)	2
South West	74	15 (20)	38 (64)	21 (36)	13
Texas	41	4 (10)	23 (62)	14 (38)	9
None	22	2 (9)	1 (5)	19 (95)	19

Table A-6. Survey Part A: Non-Response by State/Territory

State	Number in Sample	Number Unqualified (%)	Number Respondents (%)	Number Non-Respondents (%)	Number Non-Respondents in Scope
AL	15	1 (7)	12 (86)	2 (14)	2
AR	9	3 (33)	5 (83)	1 (17)	1
AZ	8	0 (0)	7 (88)	1 (13)	0
CA	68	14 (21)	36 (67)	18 (33)	11
CO	15	0 (0)	10 (67)	5 (33)	2
CT	8	0 (0)	7 (88)	1 (13)	1
FL	31	9 (29)	13 (59)	9 (41)	3
GA	21	0 (0)	13 (62)	8 (38)	4
GU	1	1 (100)	0	0 (NA)	0
HI	1	0 (0)	1 (100)	0 (0)	0
IA	9	0 (0)	6 (67)	3 (33)	1
ID	1	0 (0)	1 (100)	0 (0)	0
IL	20	1 (5)	16 (84)	3 (16)	2
IN	11	2 (18)	7 (78)	2 (22)	1
KS	7	1 (14)	4 (67)	2 (33)	0
KY	16	1 (6)	10 (67)	5 (33)	5
LA	4	0 (0)	3 (75)	1 (25)	0
MA	20	5 (25)	12 (80)	3 (20)	0
MD	7	0 (0)	3 (43)	4 (57)	1
ME	1	0 (0)	1 (100)	0 (0)	0
MI	8	0 (0)	8 (100)	0 (0)	0
MN	8	0 (0)	8 (100)	0 (0)	0
MO	9	0 (0)	8 (89)	1 (11)	0
MP	1	1 (100)	0	0 (NA)	0
MS	3	1 (33)	1 (50)	1 (50)	0
MT	1	0 (0)	1 (100)	0 (0)	0
NC	29	1 (3)	21 (75)	7 (25)	6
ND	2	0 (0)	2 (100)	0 (0)	0
NE	2	0 (0)	1 (50)	1 (50)	1
NH	4	0 (0)	4 (100)	0 (0)	0
NJ	19	6 (32)	7 (54)	6 (46)	2
NM	3	2 (67)	1 (100)	0 (0)	0
NV	3	0 (0)	1 (33)	2 (0)	2
NY	24	4 (17)	13 (65)	7 (35)	3
OH	25	0 (0)	20 (80)	5 (20)	3
OK	11	1 (9)	6 (60)	4 (40)	2
OR	11	3 (27)	6 (75)	2 (25)	1
PA	35	3 (9)	19 (59)	13 (41)	8
PR	19	0 (0)	0 (0)	19 (100)	19
RI	3	0 (0)	2 (67)	1 (33)	1
SC	11	1 (9)	6 (60)	4 (40)	4
SD	3	2 (67)	1 (100)	0 (0)	0
TN	21	2 (10)	17 (89)	2 (11)	1
TX	41	4 (10)	23 (62)	14 (38)	9
UT	3	1 (33)	1 (50)	1 (50)	0
VA	20	1 (5)	13 (68)	6 (32)	5
VT	2	0 (0)	2 (100)	0 (0)	0
WA	7	1 (14)	6 (100)	0 (0)	0
WI	10	0 (0)	9 (90)	1 (10)	1

State	Number in Sample	Number Unqualified (%)	Number Respondents (%)	Number Non-Respondents (%)	Number Non-Respondents in Scope
WV	3	0 (0)	2 (67)	1 (33)	0
WY	2	0 (0)	2 (100)	0 (0)	0

Table A-7. Survey Part A: Non-Response by Type of Owner

Owner Type	Number in Sample	Number Unqualified (%)	Number Respondents (%)	Number Non-Respondents (%)	Number Non-Respondents in Scope
Federal Government	8	2 (25)	4 (67)	2 (33)	2
Local Government	503	56 (11)	307 (69)	140 (31)	85
Private	92	10 (11)	61 (74)	21 (26)	13
Public/Private	4	1 (25)	2 (67)	1 (33)	0
State Government	5	2 (40)	2 (67)	1 (33)	1
Unknown	4	1 (25)	2 (67)	1 (33)	1

A.3.4 Assumptions Used to Modify Responses

While analyzing the survey responses, it was necessary for EPA to make assumptions about the responses under certain circumstances. These circumstances, and EPA's actions, were:

- If a system had multiple similar plants but a common residuals treatment system, EPA treated the multiple plants as a single plant having one residuals treatment system.
- If one plant discharged to another plant within the same system for residuals treatment but the finished water processes were significantly different (e.g., desalination and conventional), the process was recorded as multiple plant information. For the site without a residuals treatment system, the discharge was a zero or indirect discharge to the other site. For the site with the residuals treatment system, the discharges from both plants were influent to the residuals treatment system.

Additionally, some treatment facilities provided unusual responses. These systems, their issues, and EPA's resolution are noted below.

- The cities of Phoenix and Mesa, AZ, co-owned the Val Vista plant (AZ0407025). As a result, separate sets of economic responses were submitted for each system, while only one set of technical responses was submitted for the plant. In this situation, two "pseudo-plants" were created, one within each system, and the technical responses were apportioned to each of the pseudo-plants proportionally to the percentage of operating costs paid by each system.
- The Hillsboro and Joint Water Commission (JWC) plant is jointly owned by the cities of Hillsboro (PWS OR4100379), Tigard (OR4100878), Beaverton (OR4100081) Tualatin (OR4100665), and Forest Grove (OR4100305). Only Hillsboro was included in the sample, but they provided data for the jointly-owned plant. The plant information was scaled down to represent only the City of Hillsboro and not the other four cities that own and use water from the plant.
- The sample included both the City of Poughkeepsie (NY1330291) and Town of Poughkeepsie (NY1302774). The data for the Town of Poughkeepsie was received first, so it was included in the analysis. The City of Poughkeepsie data was a duplicate of the Town of Poughkeepsie

data. Thus, the City of Poughkeepsie was determined to be out-of-scope and was not included in the analysis.

- The Lancaster County (SC) Water system (SC292001) and the Union County (NC) Water System (NC0190413) share ownership of a single plant. Only the SC system was included in the sample. It uses 40 percent of the total water production from the plant, while the NC system uses the other 60 percent. The survey response includes complete technical information for the plant but economic data for only the SC system. The technical data was scaled down to represent only the SC system.

A.4 STATISTICAL METHODS FOR CALCULATING ESTIMATES

The following subsections discuss the methods that were used to calculate the national estimates of the technical and economic characteristics of DWT plants and systems. Section A.4.1 discusses the survey weights that were calculated for the DWT survey. Section A.4.2 discusses the methods used to organize the results for presentation in this report. Finally, Section A.4.3 presents the methods for calculating the national estimates. A complete discussion of the statistical methods can be found in Cochran (1977).

A.4.1 Survey Weights

Survey weights are applied during the analysis of survey data to obtain unbiased estimates of the population parameters of interest. Because a sample of DWT systems was selected, the results for any given respondent may represent more than one plant or system. The weight indicates the number of plants or systems that are represented by the respondent. These weights are used in calculating unbiased estimates of the national estimates. The survey weights have been obtained in the manner prescribed by Office of Management and Budget (2006).

The subsections that follow describe the calculation of the survey weights for the DWT survey. Section A.4.1.1 presents the method used for calculating the base survey weights. Section A.4.1.2 presents the methods used for adjusting the weights for ineligible and non-responding systems. Section A.4.1.3 provides a table showing the actual weights that were calculated for the DWT survey.

A.4.1.1 Base Survey Weight Calculation

The first step in obtaining the survey weights required to ensure unbiased estimates of population parameters was to calculate base survey weights. These base survey weights are defined to be the inverse of the probability of selection. That is, for stratum *h*,

$$w_h = \frac{N_h}{n_h}, \qquad \text{(Eq. A.1)}$$

where N_h is the number of systems in the stratum and n_h is the number of systems.

A.4.1.2 Eligibility and Non-Response Adjustments to Survey Weights

Because not all systems responded to the survey, and also because some of the systems included in the sample were not eligible to participate, the base survey weights may inaccurately represent the systems within each stratum. To ensure that the weights are representative, the base weights are adjusted to account for ineligible systems that are in the sample and population and to account for systems that did not respond to the survey. Potential respondents can be divided into four categories:

1. Eligible respondents (*r*);
2. Eligible non-respondents (*e*);
3. Ineligible respondents (*i*); and
4. Systems with unknown eligibility (*u*).

For the DWT survey, it was not possible to determine whether non-respondents were eligible or not eligible, so all non-respondents were placed into the category of unknown eligibility (i.e., $e = 0$).

The eligibility and non-response adjustments were made in two steps. In the first step, the base weight was adjusted for ineligibility. The specific equation for obtaining the eligibility-adjusted survey weights was

$$\dot{w}_h = w_h \cdot \frac{r_h + u_h + i_h}{r_h + u_h}, \qquad \text{(Eq. A.2)}$$

where r_h is the number of eligible respondents, u_h is the number of systems with unknown eligibility, and i_h is the number of ineligible respondents. In the second step, the eligibility-adjusted weight was adjusted for non-response using the following equation

$$\ddot{w}_h = \dot{w}_h \cdot \frac{r_h + u_h}{r_h}\ . \qquad \text{(Eq. A.3)}$$

In this case, the value of u_h *represents all non-respondents.*

A.4.1.3 Final Survey Weights

Table A-8 contains the base and adjusted survey weights that were used in the analysis of the DWT survey data. These weights were calculated using Equations (A.1), (A.2), and (A.3).

Table A-8. Survey Part A: Calculated Survey Weights

Size of Population Served	Primary Water Source	Treatment Method	Base Survey Weights	Eligibility Adjustment	Non-Response Adjustment	Final Survey Weights
10,001-50,000	Ground	Any	16.89	2.31	1.07	41.67
	Surface	Any	5.58	1.30	1.22	8.85
More than 50,000	Ground	Conventional Filtration	1.00	1.14	1.17	1.33
		Membrane	1.00	1.67	1.00	1.67
		Other	4.10	2.22	1.13	10.25
		Softening	4.17	1.09	1.38	6.25
		Ion Exchange	1.00	1.25	4.00	5.00
	Surface	Conventional Filtration	1.38	1.13	1.25	1.96
		Membrane	1.37	1.36	1.27	2.36
		Other	1.39	1.38	1.67	3.19
		Softening	1.37	1.20	1.28	2.09
		Ion Exchange	1.00	2.00	1.00	2.00

A.4.2 Organization of Results using Analysis Domains

The sample design for the DWT survey defined the way in which the survey participants were selected and data were to be collected. For this survey, DWT systems were selected using a stratified sampling design, with the size of the population served, primary water source, and primary treatment method used as stratifying variables. Technical data were collected for qualifying treatment plants that were part of the selected systems, and economic data were collected for the systems themselves.

There were many cases observed where the characteristics of a particular plant differed from that of the system as a whole. For example, there were some systems that served over 50,000 people that had individual plants serving fewer than 50,000 people. Similarly, a system that used primarily surface water could have had a plant that used primarily ground water. Because EPA's interest concerning the technical operational data is at the plant level, EPA chose to present the results of the technical data based on the characteristics of the plants rather than based on the survey strata (which was based on system-level characteristics). EPA defined a set of "domains" of a plant for presenting the national estimates of the technical data. These domains correspond to the sampling strata; that is, the domains are based on the number of people served, the primary water source, and the treatment method used at the plant.

For population served, the plant domain that was used in technical analyses presented in Section 3.2 was defined using the population served by the plant. Specifically, plants were divided into one of two groups: those that served between 10,000 and 50,000, and those that served more than 50,000. For the system-level economic analyses presented in Section 3.3, system domains for population served were defined by summing the population counts served by each individual plant within the system (for which data were available). Systems were placed into one of two categories: those that served between 10,000 and 50,000 and those that served more than 50,000.

For primary water source, the domain for each plant used in the technical analyses of Section 3.2 was defined as the water source with the largest percentage as reported in Question 2e of the survey. The system domain used for the economic analyses of Section 3.3 was defined to be the domain for the largest plant in the system, as defined by gallons of water produced from Question 2d of the questionnaire. There were several instances where this method for defining system domain may have produced inaccurate results. For example, consider a system that has three plants, one that produces 3 million gallons per day (MGD) using 100%

surface water, and two others that each produce 2 MGD using 100% ground water. The system as a whole uses more ground water, but it is classified into the surface-water domain based on the use of the primary source from the largest plant. There are other similar scenarios that could result in misclassification of the primary water source. Despite the potential misclassifications, EPA chose to define system domains for primary water source using the characteristics of the plant with the largest water production.

For treatment method, plant domains were defined using the treatment methods provided in their response to Question 2f of the survey. If there was a single treatment method listed (or there were several different methods that fell under the same grouping as shown in Section A.2.1) the plant was assigned to that treatment method grouping. There were several cases where a plant indicated that it used more than one treatment method (in different groupings). Table A-9 shows the types of multiple-treatment-methods plants that responded to the survey and the number of plants in each group. Based on an examination of the individual cases, each of these plants was assigned by an expert to one of the treatment methods. Table A-9 also shows the way the plants were assigned to treatment methods.

Table A-7. Survey Part A: Assignment of Multiple-Treatment Plants to Treatment Types

Treatment Types	Treatment Type for Analyses	Number of Cases
Conventional Filtration plus some other method of treatment	Conventional	451
Dechlorination, Primary Disinfection, and Ultrafiltration	Membrane	1
Other, Primary Disinfection, and Reverse osmosis	Membrane	1
Nanofiltration and Primary Disinfection	Membrane	3
Primary Disinfection and Reverse osmosis	Membrane	1
Precipitative and Primary Disinfection	Softening	4
Ion exchange and Primary Disinfection	Softening	2
Dechlorination, Microfiltration, Presedimentation, and Primary Disinfection	Other	1
Microfiltration, Presedimentation, and Primary Disinfection	Other	1
Dechlorination, Other, and Primary Disinfection	Other	2
Other, Presedimentation, and Disinfection	Other	1
Microfiltration and Primary Disinfection	Other	2
Other and Primary Disinfection	Other	11

A.4.3 National Estimates Based Upon Part A Responses

National estimates were calculated directly from Part A of the survey results for each of the questions, except Question 2j and the questions requesting contact information. EPA presents the methods used to calculate the national estimates in the report. Section A.4.3.3 contains a discussion of the methods used to obtain baseline estimates for pollutant loadings.

A.4.3.1 Estimates and Standard Errors

Several types of population estimates were calculated from the DWT survey data. For numeric data (e.g., flow volume, number of connections), these estimates included minima, maxima, medians, means, and totals. The category of numeric variables also included several cases where two or more numeric variables were combined. For example, cost per connection was a numeric variable that was calculated by dividing the total cost for a plant by the total number of connections for the plant. For “characteristic” data (i.e., categorical responses to questions asking whether plants or systems had certain characteristics), the types of estimates calculated included proportions/percentages and counts. Although the DWT survey was designed as a stratified sample, stratified sampling estimators were not directly relevant because the results are reported for domains rather than for the strata.

The formulas used to calculate the estimates are provided in the subsections below. Several terms are common to these formulas, including:

- H is the total number of strata;
- n_h is the number of sampled plants or systems in stratum h;
- f_h is the sampling rate for stratum h;
- y_{hi} = the measurement of interest collected from the i^th^ sampled member of stratum h;
- w_{hi} = the survey weight associated with the i^th^ sampled member of stratum h, which is equal to $\ddot{w}_h$ from Equation (A.3);

- $z_{hi} = \begin{cases} y_{hi} & if\ (h,i)\ belongs\ to\ Domain\ D \\ 0 & otherwise \end{cases}$; and
- $v_{hi} = \begin{cases} w_{hi} & if\ (h,i)\ belongs\ to\ Domain\ D \\ 0 & otherwise \end{cases}$.

All of the formulas discussed below are implemented in SAS® using the procedures UNIVARIATE for minima, maxima, and median, and SURVEYMEANS for means, totals, counts, and proportions (SAS Institute Inc., 2008).

Minima and Maxima

The population minimum value of a continuous variable was estimated using the smallest observed value of the variable among all strata. Similarly, the population maximum was estimated using the largest observed value of the variable among all strata. Minimum and maximum values within strata were estimated using the smallest and largest observed value within the stratum.

Medians

The population median, or 50th percentile, was estimated using the following formula:

$$\hat{y}_{0.5} = \begin{cases} 0.5 \cdot (y_{(i)} + y_{(i+1)}) & if\ \sum_{j=1}^{i} w_j = 0.5 \cdot \sum_{j=1}^{n} w_j \\ \\ y_{(i+1)} & if\ \sum_{j=1}^{i} w_j < 0.5 \cdot \sum_{j=1}^{n} w_j < \sum_{j=1}^{i+1} w_j \end{cases}, \qquad \text{(Eq. A.4)}$$

where $y_{(i)}$ indicates the ith smallest value within the domain or stratum and w_i is the weight associated with that value.

Means

The formula that was used to calculate estimates of population means for domains can be written as

$$\bar{y}_D = \frac{\sum_{h=1}^{H}\sum_{i=1}^{n_h} v_{hi} \cdot z_{hi}}{\sum_{h=1}^{H}\sum_{i=1}^{n_h} v_{hi}}. \qquad \text{(Eq. A.5)}$$

The variance of this estimated mean is calculated as

$$V(\bar{y}_D) = \sum_{h=1}^{H}\left[\frac{n_h \cdot (1 - f_h)}{n_h - 1} \cdot \sum_{i=1}^{n_h}\left(r_{hi} - r_h\right)^2\right], \qquad \text{(Eq. A.6)}$$

where

$$r_{ij} = \frac{v_{hi} \cdot \left(z_{hi} - \bar{y}_D\right)}{\sum_{h=1}^{H}\sum_{i=1}^{n_h} v_{hi}} \qquad \text{(Eq. A.7)}$$

and

$$r_h = \frac{\sum_{i=1}^{n_h} r_{hi}}{n_h}. \qquad \text{(Eq. A.8)}$$

The standard error of the estimated mean is the square root of the variance shown in Equation (A.6).

Totals

The formula for estimates of population totals, **Y_D**, *for domains can be written as*

$$Y_D = \sum_{h=1}^{H}\sum_{i=1}^{n_h} v_{hi} \cdot z_{hi}. \qquad \text{(Eq. A.9)}$$

The variance of this estimated total is

$$V(Y_D) = \sum_{h=1}^{H}\left[\frac{n_h \cdot (1 - f_h)}{n_h - 1} \cdot \sum_{i=1}^{n_h}\left(v_{hi} \cdot z_{hi} - a_h\right)^2\right], \qquad \text{(Eq. A.10)}$$

where

$$a_h = \frac{\sum_{i=1}^{n_h} v_{hi} \cdot z_{hi}}{n_h}. \qquad \text{(Eq. A.11)}$$

The standard error of the estimated total is the square root of the variance.

Ratios

There were several cases where new variables were defined as ratios of two measured variables. For example, in Table 3-35, the estimated sales revenue per volume was defined using the total sales and the total water volume. For these types of estimates, EPA defined a new variable as the ratio of the two component variables, calculated this ratio for each responding plant or system, and used Equations (A.5) through (A.8) to calculate the estimates of the mean ratio and its standard error.

Plant Counts

Estimates for the number of plants or systems within domains are obtained using the equations presented for domain totals. In this case, the values of the continuous variable for which totals are calculated are replaced with indicator variables corresponding to whether the plant or system possesses the characteristic of interest. For example, if we define $y_{hi} = 1$ if the i^{th} plant in stratum h uses conventional filtration and 0 if it does not for all sampled plants, equation (A.9) can be used to estimate the total number of plants within each domain that use conventional filtration. Equation (A.10) can also be used to calculate the variability of the plant counts as well as its standard error.

Proportions/Percentages

Estimates of population proportions for domains are calculated in a similar manner to plant counts using Equations (A.5) through (A.8) applied to the indicator variables defined for plant counts. The overall national estimates of proportions (using the strata rather than domains) are calculated as

$$\hat{p}_{st} = \sum_{h=1}^{12} w_h \hat{p}_h \, , \qquad \text{(Eq. A.12)}$$

where

$$\hat{p}_h = \frac{a_h}{n_h} \, . \qquad \text{(Eq. A.13)}$$

The variance of the estimated population proportion is

$$V(\hat{p}_{st}) = \sum_{h=1}^{12} w_h^2 \frac{\hat{p}_h(1-\hat{p}_h)}{n_h - 1}(1 - f_h) \qquad \text{(Eq. A.14)}$$

and its standard error is the square root of the variance.

A.4.3.2 Confidence Intervals

In many cases, there will be interest in obtaining confidence intervals for the national parameters rather than "point" estimates of the parameters. Confidence intervals provide a range of probable values that the population parameter could be. The following formula is used to calculate a confidence interval for a domain mean:

$$CI = \bar{y}_D + z_{\alpha/2} \cdot SE(\bar{y}_D), \qquad \text{(Eq. A.15)}$$

where $z_{\alpha/2}$ is the upper 100(α/2) percentile of a standard normal distribution and $SE(\bar{y}_D)$ is the standard error for $\bar{y}_D$. For other population parameters, confidence intervals are obtained using the associated estimates and their standard errors in Equation (A.15).

A.4.3.3 Baseline Pollutant Loading Estimates

In addition to providing basic estimates using the specific questions on the DWT survey, EPA examined the source of pollutant loadings. For this analysis, plants were divided into domains based on five parameters: treatment plant type, separation of residuals employed, discharge status, population served (as a surrogate for flow volume), and use of chlorination. Treatment method was defined as in Section A.2.1. For the other parameters, EPA classified plants in the following manner:

- Separation of residuals was "Yes" if the plant used thickening, drying, mechanical dewatering, non-mechanical dewatering, evaporation ponds, equalization, or sediment tank ponds to treat residuals.

- Discharge status was direct, indirect, or both, based on the plant's response to Question 2k of the questionnaire.

- Four size categories were defined based on the population they served: 10,000 to 50,000, 50,001 to 100,000, 100,001 to 500,000, and more than 500,000.
- Chlorination plants included those that used some form of calcium hypochlorite, chloramination, free chlorine, gaseous chlorine, or sodium hypochlorite as their primary disinfection.

EPA prepared separate tables for chlorination and non-chlorination plants.

A.5 REFERENCES

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APPENDIX B

COMPOSITION OF COMMON DRINKING WATER TREATMENT CHEMICALS ILLUSTRATING PRODUCTION IMPURITIES

(Source: American Water Works Association (AWWA), David A. Cornwell, Michael J. Macphee and Richard Brown, 2002. *Trace Contaminants in Drinking Water Chemicals*, AWWA Research Foundation)

Table B-1. Composition of Aluminum-Based Coagulants Illustrating Production Impurities

Pollutant	Median Concentration (mg/kg dry weight) [a]		
	Standard Alum	**Low-iron Alum**	**Polyaluminum Chloride (PACl)**
Aluminum	90,000	89,400	153,911
Antimony	<0.8	<0.8	<1.2
Arsenic	<2.06	<2.00	<2.6
Barium	<0.10	<0.10	0.21
Cadmium	<0.1	<0.1	<0.2
Calcium	62	62	149
Chromium	66	0.6	0.6
Cobalt	<0.20	<0.15	<0.41
Copper	1.86	0.21	1.34
Iron	1,300	39	91
Lead	<4.1	<4.1	<4.1
Magnesium	33	14	41
Manganese	2.5	0.8	3.2
Mercury	<0.82	1.03	1.44
Molybdenum	<1.7	<1.7	<1.4
Nickel	0.90	0.41	1.65
Phosphorus	89	<4	<9
Potassium	7.5	7.7	10.7
Selenium	<4.1	<5.1	<2.1
Silicon	52	14	56
Silver	<0.82	<0.82	<1.65
Sodium	247	577	546
Strontium	1.03	0.41	0.41
Sulfur	Not analyzed	Not analyzed	Not analyzed
Tin	<2.1	<2.1	<2.7
Titanium	27	1.2	3.0
Vanadium	39	0.20	6
Yttrium	<0.41	<0.30	<0.52
Zinc	3	16	14
Zirconium	12	0.4	0.9

Source: American Water Works Association (AWWA), David A. Cornwell, Michael J. Macphee and Richard Brown, 2002. *Trace Contaminants in Drinking Water Chemicals*, AWWA Research Foundation.
a – The less than sign denotes that the value was below sample-specific method detection limits (MDL); the value listed is the MDL.

Table B-2. Composition of Iron-Based Coagulants Illustrating Production Impurities

Pollutant	Single Sample Concentration (mg/kg dry weight) [a]			
	Ferric Chloride			Ferric Sulfate
	SPL#1	SPL#2	TiO2#1	
Aluminum	1,289	19,737	3,158	82
Antimony	9	6	7	<4
Arsenic	<5	<3	<3	<4
Barium	0.3	1	18	1
Cadmium	1.0	1.0	1.0	1.4
Calcium	158	974	153	371
Chromium	124	111	100	<1
Cobalt	17	8	22	8
Copper	95	82	6	<0.4
Iron	355,263	305,263	315,789	228,866
Lead	53	<5	<13	41
Magnesium	55	316	316	173
Manganese	1,868	1,079	2,553	169
Mercury	<5	<3	5	No data
Molybdenum	<1	3	18	<0.8
Nickel	58	39	11	23
Phosphorus	29	263	42	163
Potassium	26	23	50	56
Selenium	No data	<3	<3	No data
Silicon	12	<1	15	8
Silver	<5	<2	<2	<4
Sodium	211	395	895	47
Specific Gravity	1.4	1.4	1.4	No data
Strontium	2	4	9	2
Sulfur	158	2,579	63	206,186
Tin	<5	<3	14	<4
Titanium	2	24	10,789	13
Vanadium	95	79	1,553	227
Yttrium	<1	<0.5	<0.5	<0.8
Zinc	45	53	258	37
Zirconium	10	8	4,474	6

Source: American Water Works Association (AWWA), David A. Cornwell, Michael J. Macphee and Richard Brown, 2002. *Trace Contaminants in Drinking Water Chemicals*, AWWA Research Foundation.

a – The less than sign denotes that the value was below sample-specific method detection limits (MDL); the value listed is the MDL.

SPL – Steel pickle liquor derived.

TiO2 – Derived during manufacture of titanium oxide.

Table B-3. Composition of Potassium Permanganate in Samples from One Study Illustrating Production Impurities

Pollutant	Single Sample Concentration (mg/kg dry weight) [a]	
	Product #1	**Product #2**
Aluminum	560	610
Antimony	<10	<10
Arsenic	<10	<10
Barium	11	100
Cadmium	<1	<1
Calcium	39	230
Chromium	44	72
Cobalt	<2	<2
Copper	<1	<1
Iron	320	520
Lead	<49	<400
Magnesium	<0.3	<0.3
Manganese	333,000	336,000
Mercury	79	<10
Molybdenum	24	12
Nickel	26	31
Potassium	238,000	234,000
Selenium	73	80
Silicon	750	1,000
Silver	82	79
Sodium	370	3,300
Strontium	1	7
Tin	<10	<10
Titanium	4	9
Vanadium	<2	<2
Yttrium	2	<2
Zinc	2	3
Zirconium	3	<2

Source: American Water Works Association (AWWA), David A. Cornwell, Michael J. Macphee and Richard Brown, 2002. *Trace Contaminants in Drinking Water Chemicals*, AWWA Research Foundation.

a – The less than sign denotes that the value was below sample-specific method detection limits (MDL); the value listed is the MDL.

Table B-4. Composition Data for Organic Polymers Illustrating Production Impurities

Pollutant	Concentrations for 12 Organic Polymers (mg/kg wet weight) [a]		
	Minimum	**Maximum**	**Median**
Aluminum	<0.50	2,200	<40
Antimony	<1	<240	<76
Arsenic	<1	<240	<76
Barium	<0.01	<3	<1
Cadmium	<0.10	<25	<8
Calcium	0.50	120	73
Chromium	<0.20	<49	<16
Cobalt	<0.20	<49	<16
Copper	<0.10	<25	<8
Iron	<0.20	<340	<17
Lead	<1	<460	<78
Magnesium	<0.30	54	7
Manganese	<0.02	8	3
Mercury	<1	<240	<76
Molybdenum	<0.20	<49	<16
Nickel	<0.04	<49	<16
pH (standard units)	4.2	6.8	5.7
Potassium	<4.00	<970	<324
Selenium	<1	<240	<160
Silicon	<1	130	<52
Silver	<0.80	<190	<61
Sodium	85	27,000	940
Specific Gravity (no units)	0.99	1.14	1.04
Strontium	<0.02	<3	<1
Sulfur	13	4,100	695
Tin	<1	<240	<76
Titanium	<0.10	490	<8
Total organic carbon (TOC)	4,178 (one sample)	No data	No data
Vanadium	<0.20	<49	<16
Yttrium	<0.20	<49	<16
Zinc	<0.10	230	<12
Zirconium	<0.20	140	<17

Source: American Water Works Association (AWWA), David A. Cornwell, Michael J. Macphee and Richard Brown, 2002. *Trace Contaminants in Drinking Water Chemicals*, AWWA Research Foundation.

a – The less than sign denotes that the value was below sample-specific method detection limits (MDL); the value listed is the MDL.

Table B-5. Composition Data for Lime Products Illustrating Production Impurities

Pollutant	Single Sample Concentration (mg/kg as Ca(OH)2 dry weight)a			
	Hydrated lime #1	Hydrated lime #2	Hydrated lime #3	Pebble lime
Aluminum	2,154	2,700	2,267	1,135
Antimony	<15	<2	<67	<2
Arsenic	<15	<2	<67	<2
Barium	77	13	27	5
Cadmium	<1.5	0.2	<6.7	<0.2
Calcium	507,692	495,000	493,733	495,676
Chromium	<3.1	2	<13.3	1
Cobalt	<3.1	0.4	<13.3	<0.3
Copper	1.5	2	<6.7	0.5
Iron	846	1,600	1,067	560
Lead	<15	<4	<333	<3
Magnesium	7,231	7,700	16,667	4,465
Manganese	35	23	73	16
Mercury	<15	<2	<6.7	<2
Molybdenum	4.6	<0.4	<13.3	<0.3
Nickel	<3.1	1	<13.3	0.5
Potassium	785	860	1,067	832
Selenium	<15	<2	<67	<2
Silicon	4,154	4,600	6,467	1,665
Silver	<12	<2	<53	<2
Sodium	1,277	49	3,000	22
Strontium	338	240	307	212
Tin	<15	<2	<67	<2
Titanium	74	66	87	26
Vanadium	3.1	3	<13.3	2
Yttrium	<3.1	1	<13.3	1
Zinc	9	4	6.7	2
Zirconium	3.1	3	<13.3	2

Source: American Water Works Association (AWWA), David A. Cornwell, Michael J. Macphee and Richard Brown, 2002. *Trace Contaminants in Drinking Water Chemicals*, AWWA Research Foundation.
a –The less than sign denotes that the value was below sample-specific method detection limits (MDL); the value listed is the MDL.

Table B-6. Composition Data for Caustic Soda Illustrating Production Impurities

Pollutant	Single Sample Concentration (mg/kg dry weight)[a]			
	50%	**50%**	**25%**	**50%**
Aluminum	8	5	<2	<1
Antimony	<2	<2.0	<4	<2
Arsenic	<2	<2.0	<4	<2
Barium	<0.02	<0.02	0.2	0.6
Cadmium	<0.2	<0.2	<0.4	<0.2
Calcium	<1	1	24	6
Chromium	<0.4	<0.4	<0.8	1
Cobalt	<0.4	<0.4	<0.8	<0.4
Copper	0.2	<0.2	<0.4	<0.2
Iron	1	2.0	6	36
Lead	<2	<2.0	<20	<20
Magnesium	0.2	0.4	4	2
Manganese	<0.04	<0.04	<0.08	0.6
Mercury	<2	<2.0	<4	<2
Molybdenum	<0.4	<0.4	<0.8	0.6
Nickel	<0.4	<0.4	<0.8	1
pH (standard units)	9.94	11.10	12.80	10.70
Phosphorus	112	<8	<4	7
Potassium	320	1,180	560	980
Selenium	<2.0	<2.0	<4	<2
Silicon	340	480	44	166
Silver	<2	<1.6	<3	<2
Sodium	508,000	510,000	444,000	508,000
Specific gravity (no units)	1.53	1.53	1.22	1.52
Strontium	0.4	0.2	4	2.4
Sulfur	18	36	60	168
Tin	<2	<2	<4	<2
Titanium	<0.2	<0.4	0.8	<0.2
Vanadium	<0.4	<0.4	<0.8	<0.4
Yttrium	<0.4	<0.4	<0.8	<0.4
Zinc	0.4	<0.2	1.2	0.4
Zirconium	<0.4	<0.4	<0.8	<0.4

Source: American Water Works Association (AWWA), David A. Cornwell, Michael J. Macphee and Richard Brown, 2002. *Trace Contaminants in Drinking Water Chemicals*, AWWA Research Foundation.

a – The less than sign denotes that the value was below sample-specific method detection limits (MDL); the value listed is the MDL.

APPENDIX C

POTW PERCENT REMOVALS

(Sources**:** U.S. Environmental Protection Agency (U.S. EPA), 1982. *Fate of Priority Pollutants in Publicly Owned Treatment Works* (EPA 440/1-82/303, September 1982 and U.S. EPA, 1994. National Risk Management Research Laboratory (NRMRL) Treatability Database Version 5.0, Cincinnati, OH)

Table C-1. POTW Removals

DWT Parameter Name	POTW Removal (fraction)
Aluminum, Dissolved	0.91
Aluminum, Total	0.91
Aluminum, Unknown	0.91
Ammonia, Total	0.39
Ammonia, Unionized	0.39
Ammonia, Unknown	0.39
Arsenic	0.6577
Barium, Unknown	0.5515
Benzene	0.95
Cadmium, Total	0.9005
Chlorine, Free	1
Chlorine, Total Residual	1
Chloroform	0.73
Chromium	0.8033
Copper, Dissolved	0.842
Copper, Total	0.842
Copper, Unknown	0.842
Dichloroboromomethane	0.6424
Lead, Total	0.7745
Lead, Unknown	0.7745
Manganese, Total	0.406
Manganese, Unknown	0.406
Manganese, Dissolved	0.406
Mercury, Unknown	0.9016
Nickel, Unknown	0.5144
Zinc, Total	0.7914
Selenium	0.3433
Zinc, Unknown	0.7914
Aluminum	0.91
Ammonia	0.39
Barium	0.5515
Cadmium	0.9005
Copper	0.842
Lead	0.7745
Manganese	0.406
Mercury	0.9016
Nickel	0.5144
Zinc	0.7914
Phosphorus, Total	0.69
Phosphorus as P	0.69

Table C-1. POTW Removals

DWT Parameter Name	POTW Removal (fraction)
Trihalomethane	0.73
Trihalomethane, Total	0.73
Trihalomethane, Unknown	0.73
Mercury, Total	0.9016
Boron	0.3042
Fluoride	0.6135
Iron	0.8199
Oil & Grease	0.8608
Chlorodibromomethane	0.0073
Magnesium	0.1414
Nitrogen, Total	0.5741
TKN	0.5741
Hydrogen Sulfide	0.5741
TSS	0.8955
Turbidity	0.8955
BOD	0.8912
Calcium	0.0854
Chlorides	0.5741
Nitrates	0.5741
Nitrites	0.5741
Phosphates	0.3252
Settleable Solids	0.8955
SS	0.8955
CBOD5	0.8912
Sulfate	0.8461
Total Organic Carbon	0.7028
TDS	0.08
Bromoform	0.73
Haloacetic Acids	0.73

DWT – Drinking Water Treatment.

APPENDIX D

TOXIC WEIGHTING FACTORS (TWFS)

(Source: U.S. EPA. 2006. Toxic Weighting Factor Development in Support of CWA 304(m) Planning Process. Washington, DC. (June). EPA-HQ-OW-2004-0032-1634)

Table D-1. Toxic Weighting Factors

DWT Parameter Name	TWF (toxic weighted pounds per pound of pollutant)
Aluminum, Dissolved	0.064691216
Aluminum, Total	0.064691216
Aluminum, Unknown	0.064691216
Ammonia, Total	0.00111
Ammonia, Unionized	0.00111
Ammonia, Unknown	0.00111
Arsenic	4.041333333
Barium, Unknown	0.001990757
Benzene	0.031678038
Boron, Total	0.17721519
Cadmium, Total	23.1168
Calcium, Unknown	0.000028
Chlorides	2.43478E-05
Chlorine, Free	0.509162182
Chlorine, Total Residual	0.509162182
Chlorine, Unknown	0.509162182
Chlorodibromomethane	0.044483378
Chloroform	0.002078389
Chromium	0.075696709
Copper, Dissolved	0.634822222
Copper, Total	0.634822222
Copper, Unknown	0.634822222
Dichloroboromomethane	0.032918058
Fluoride, Total	0.035
Fluoride, Unknown	0.035
Hydrogen Sulfide	2.801446667
Iron, Dissolved	0.0056
Iron, Total	0.0056
Iron, Unknown	0.0056
Lead, Total	2.24
Lead, Unknown	2.24
Magnesium	0.000865533
Manganese, Dissolved	0.07043299
Manganese, Total	0.07043299
Manganese, Unknown	0.07043299
Mercury, Total	117.1180233
Mercury, Unknown	117.1180233
Nickel, Unknown	0.108914308
Nitrogen, Total	
Phosphate, Total	

Table D-1. Toxic Weighting Factors

DWT Parameter Name	TWF (toxic weighted pounds per pound of pollutant)
Sulfate	0.0000056
Zinc, Total	0.046886
Nitrates	0.000746667
Nitrites	0.0032
BOD	
Oil and Grease	
Phosphorus, Total	
Radium, Combined	
Salinity	
Selenium	1.121344
Settleable Solids	
TDS	
Total Organic Carbon	
Trihalomethane, Total	
TSS	
Zinc, Unknown	0.046886
Aluminum	0.064691216
Ammonia	0.00111
Barium	0.001990757
Cadmium	23.1168
Calcium	0.000028
Copper	0.634822222
Fluoride	0.035
Iron	0.0056
Lead	2.24
Manganese	0.07043299
Mercury	117.1180233
Nickel	0.108914308
Zinc	0.046886

DWT – Drinking Water Treatment.

Blanks indicate that EPA has not derived TWFs for these chemicals. EPA does not assign toxicity values to conventional pollutants or bulk parameters; therefore, these chemicals do not have TWFs.

APPENDIX E

NATIONAL ESTIMATES: WATER TREATMENT PLANT COUNTS FOR POLLUTANT LOADINGS ESTIMATES

Table E-1. WTP Counts for Pollutant Loadings Excluding Chlorination Pollutants

Treatment Plant Type	Solid/Water Separation of Residuals	Population Served (Corresponds to Discharge Flow Rate)	National Estimates (Number of WTPs)		
			Direct	Indirect	Both
Lime Softening	Yes	10,000 to 50,000	46	41	23
		50,000 to 100,000	55	8	7
		100,000 to 500,000	33	19	4
		More than 500,000	6	2	0
	No	10,000 to 50,000	31	42	0
		50,000 to 100,000	2	10	0
		100,000 to 500,000	8	2	6
		More than 500,000	2	0	0
Coagulation & Filtration	Yes	10,000 to 50,000	257	181	40
		50,000 to 100,000	63	34	28
		100,000 to 500,000	48	46	14
		More than 500,000	4	4	4
	No	10,000 to 50,000	36	203	0
		50,000 to 100,000	4	22	4
		100,000 to 500,000	8	4	0
		More than 500,000	0	0	0
Filtration only	Yes	10,000 to 50,000	22	31	8
		50,000 to 100,000	0	0	0
		100,000 to 500,000	2	0	0
		More than 500,000	0	2	0
	No	10,000 to 50,000	0	28	0
		50,000 to 100,000	0	2	0
		100,000 to 500,000	0	0	0
		More than 500,000	0	0	0
Desalting Membrane	Yes	10,000 to 50,000	2	8	8
		50,000 to 100,000	0	0	0
		100,000 to 500,000	0	0	0
		More than 500,000	0	0	0
	No	10,000 to 50,000	4	4	8
		50,000 to 100,000	0	2	0
		100,000 to 500,000	0	2	2
		More than 500,000	0	0	0
Ion Exchange & Adsorption	Yes	10,000 to 50,000	19	0	0
		50,000 to 100,000	0	0	0
		100,000 to 500,000	0	6	0
		More than 500,000	0	0	0
	No	10,000 to 50,000	0	65	0
		50,000 to 100,000	0	2	0
		100,000 to 500,000	0	0	0
		More than 500,000	0	0	0

Table E-1. WTP Counts for Pollutant Loadings Excluding Chlorination Pollutants

Treatment Plant Type	**Solid/Water Separation of Residuals**	**Population Served (Corresponds to Discharge Flow Rate)**	**National Estimates (Number of WTPs)**		
			Direct	**Indirect**	**Both**
None	Yes	10,000 to 50,000	0	19	0
		50,000 to 100,000	0	0	0
		100,000 to 500,000	2	0	0
		More than 500,000	0	0	0
	No	10,000 to 50,000	19	0	0
		50,000 to 100,000	0	0	0
		100,000 to 500,000	0	0	0
		More than 500,000	0	0	0

Table E-2. WTP Counts for Pollutant Loadings Chlorination Pollutants

Treatment Plant Type	Chlorination	Dechlorination of Residuals (in 2f and/or 2h)	Population Served (Corresponds to Discharge Flow Rate)	National Estimates (Number of WTPs)		
				Direct	Indirect	Both
Lime Softening	Yes	Yes	10,000 to 50,000	12	0	8
			50,000 to 100,000	8	0	5
			100,000 to 500,000	2	2	2
			More than 500,000	2	0	0
		No	10,000 to 50,000	66	83	15
			50,000 to 100,000	42	17	2
			100,000 to 500,000	37	15	8
			More than 500,000	5	2	0
	No [a]	NA	NA	16		
Coagulation & Filtration	Yes	Yes	10,000 to 50,000	39	2	8
			50,000 to 100,000	14	0	12
			100,000 to 500,000	25	0	4
			More than 500,000	4	0	2
		No	10,000 to 50,000	221	356	28
			50,000 to 100,000	48	49	16
			100,000 to 500,000	27	48	6
			More than 500,000	0	2	0
	No [a]	NA	NA	94		
Filtration only	Yes	Yes	10,000 to 50,000	8	10	0
			50,000 to 100,000	0	0	0
			100,000 to 500,000	0	0	0
			More than 500,000	0	0	0
		No	10,000 to 50,000	15	47	8
			50,000 to 100,000	0	0	0
			100,000 to 500,000	0	0	0
			More than 500,000	0	2	0
	No [a]	NA	NA	7		
Desalting Membrane	Yes	Yes	10,000 to 50,000	0	0	0
			50,000 to 100,000	0	0	0
			100,000 to 500,000	0	0	0
			More than 500,000	0	0	0
		No	10,000 to 50,000	0	8	6
			50,000 to 100,000	0	0	0
			100,000 to 500,000	0	0	0
			More than 500,000	0	0	0
	No [a]	NA	NA	27		

Table E-2. WTP Counts for Pollutant Loadings Chlorination Pollutants

Treatment Plant Type	Chlorination	Dechlorination of Residuals (in 2f and/or 2h)	Population Served (Corresponds to Discharge Flow Rate)	National Estimates (Number of WTPs)		
				Direct	Indirect	Both
Ion Exchange & Adsorption	Yes	Yes	10,000 to 50,000	19	0	0
			500,00 to 100,000	0	0	0
			100,000 to 500,000	0	0	0
			More than 500,000	0	0	0
		No	10,000 to 50,000	0	57	0
			50,000 to 100,000	0	0	0
			100,000 to 500,000	0	0	0
			More than 500,000	0	0	0
	No [a]	NA	NA	16		
None	Yes	Yes	10,000 to 50,000	0	0	0
			50,000 to 100,000	0	0	0
			100,000 to 500,000	0	0	0
			More than 500,000	0	0	0
		No	10,000 to 50,000	19	19	0
			50,000 to 100,000	0	0	0
			100,000 to 500,000	2	0	0
			More than 500,000	0	0	0
	No [a]	NA	NA	0		

a – For plants that do not add chlorine, EP A assumes that pollutant loadings of chemicals from chlorination, such as disinfection by-products, are zero.