Management of Process Wastewater at Coal-Fired Power Plants

Reuse and Treatment for Process Wastewater After Ash Pond Closure or Conversion

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Technical Update, April 2012

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ACKNOWLEDGMENTS

The following organization, under contract to the Electric Power Research Institute (EPRI), prepared this report:

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This report describes research sponsored by EPRI.

EPRI would like to thank its members who contributed case study information and input for this Technical Update.

This publication is a corporate document that should be cited in the literature in the following manner:

Management of Process Wastewater at Coal-Fired Power Plants: Reuse and Treatment for Process Wastewater After Ash Pond Closure or Conversion. EPRI, Palo Alto, CA: 2012. 1023779.

ABSTRACT

A confluence of drivers is causing utilities to consider closing ash ponds and converting to dry ash handling. These drivers include wastewater discharge regulations on salinity, chlorides, nutrients, and metals, as well as solid waste regulations resulting from concerns with pond safety. Because ash ponds at many sites receive a variety of wastewaters, even if a plant converts to dry ash handling and thereby reduces or eliminates ash sluice water, other wastewater streams will still require treatment. Examples of these other streams include coal pile runoff, water treatment residuals, ash handling area washdown, cooling tower blowdown, plant drains, and equipment cleaning wastes. This Technical Update provides guidance on the management of these other process wastewater streams.

Keywords

Ash pond
Ash conversion
Blowdown
Process wastewater
Recycle
Reuse
Runoff
Wastewater treatment

ACRONYMS AND ABBREVIATIONS

μg/L	micrograms per liter
AACE	American Association of Cost Engineers
$CaCO_3$	calcium carbonate
cf	cubic feet
EDTA	ethylenediaminetetraacetate
ELG	Effluent Limitation Guidelines
EPRI	Electric Power Research Institute, Inc.
FGD	flue gas desulfurization
gpm	gallons per minute
gpm/sf	gallons per minute per square foot
ICR	information collection request
lbs/day	pounds per day
mg/L	milligrams per liter
NPDES	National Pollutant Discharge Elimination System
PISCES	Power Plant Integrated System- Chemical Emissions Study
ppm	parts per million
RCRA	Resource Conservation and Recovery Act
RO	reverse osmosis
rpm	revolutions per minute
QA/QC	quality assurance/quality control
TDS	total dissolved solids
TSS	total suspended solids
USEPA	United States Environmental Protection Agency

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INTRODUCTION

Purpose

The objective of this Technical Update is to provide insights and guidance on wastewater management changes resulting from ash pond closure or conversion from wet to dry ash handling.

Process wastewater stream management approaches include water reuse and recycling to minimize wastewater that needs treatment, construction of treatment facilities to replace the settling and equalization provided by ponds, continued use of regulatory-compliant ponds, or a combination of these approaches. Beyond addressing current concerns, utilities will also want to be sure today's management decisions provide flexibility to meet future water management needs such as water conservation and ever-tightening discharge limits that may necessitate advanced treatment.

Because at many sites ash ponds receive a variety of wastewaters, even if a plant converts to dry ash handling and thereby reduces or eliminates ash sluice water, other wastewater streams will still require treatment. Examples include coal pile runoff, water treatment residuals, ash handling area washdown, cooling tower blowdown, plant drains, and equipment cleaning wastes. Power plants will need to plan actively for the management of these remaining process wastewater streams.

Scope

This Technical Update provides guidance on the options and considerations in planning process wastewater management. Case studies of facilities in various stages of planning for management of process wastewater are presented within this Technical Update. Process wastewater management guidance presented in this document focuses on the following:

- Characterization of Process Wastewater – Understanding water flows and water quality are critical to reuse and recycle plans as well as treatment. Section 2 provides an overview of typical process wastewater streams based on available plant data and their flow and influent water quality characteristics. Flows and water quality vary greatly among streams and it is important to understand typical process wastewater streams to plan for management options.
- Process Wastewater Management Planning –Developing a plan of action for management of process wastewater requires a planning framework. Section 3 provides an overview of issues managers should consider when developing a process wastewater management strategy and provides guidance for development of an agenda to meet these goals.
- Flow and Mass Balance Development – Managing wastewater in ash ponds typically requires minimal insight on the streams entering the ponds because ponds are built for long-term storage or disposal of solids, as well as for wastewater treatment. The typically large size of ponds provides significant equalization and solids removal due to low overflow rates (flow/area) and dilution of more concentrated streams. If a tank-based treatment system is

used, influent flows must be well understood to size the system properly. Water flow balances and mass balance development are discussed in Section 4.

- Water Reuse – Management through reuse reduces the size and cost of wastewater treatment. Treatment may be required for some reuse schemes. Understanding the water quality requirements of potential reuse options and the water quality of wastewater streams is critical to planning water reuse options. Section 5 describes management of process wastewater through reuse.
- Wastewater Treatment – If wastewater is to be managed in a tank-based treatment system rather than ponds, it is important to understand water quality requirements for discharge or reuse; treatment required to meet these requirements; and how to design, size, and estimate costs of treatment system units. Sections 6 and 7 discuss wastewater treatment design considerations and cost estimates.

The Electric Power Research Institute, Inc. (EPRI) has provided guidance on treatment of flue gas desulfurization (FGD) wastewater in various previous reports [1, 2, 3, 4, 5, 6, 7, 8, 9]. Fly ash sluice water is typically a large source of solids and liquid-phase pollutants to ash ponds. EPRI has provided guidance on management of fly ash sluice water in past reports [10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20]. Therefore, management of process wastewaters other than FGD wastewater and fly ash sluice water is the subject of this Technical Update.

Solid wastes such as pyrites, cooling tower basin sludge, treatment sludges, and waste oil are also not addressed in this report. More information is available on these wastes in a previous EPRI document [21].

Study Limitations

The data presented in this study come from a variety of sources, including previous EPRI reports and interviews with power plant managers. As part of the U.S. Environmental Protection Agency's (USEPA's) review of Effluent Limitation Guidelines (ELGs) for the steam electric industry, a questionnaire was issued to power plants and responses sought relating to current power plant wastewater practices. Some of the data presented in this study were from power plant responses to the USEPA information collection request (ICR). Water quality data presented in this Technical Update come from samples collected by various sources. Therefore, the quality of much of the data could not be verified. Sample methods, sample filtration, sample preservation, and analytical methods differed among the data reviewed. Matrix spike/matrix spike duplicate samples were not available for most data sets used within this study.

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OVERVIEW OF PROCESS WASTEWATER CHARACTERISTICS

The purpose of this section is to provide an understanding of the composition of various process wastewater streams. Understanding water flows and water quality characteristics of process wastewater streams is important to the decision-making process to determine wastewater management options. The number and types of wastewater streams that flow to ash ponds vary greatly among plants. Each wastewater stream has unique characteristics and may have varying management issues (solids, trace metals, low or high pH, etc). This section provides discussion on the types of process wastewater streams that are typically managed in ash ponds. Typical flows and available data on key water quality parameters for common process wastewater sources are also presented. The available data set of water quality parameters presented within this section is limited to a small number of plants and should not be considered comprehensive for the industry. Data provided are a "snapshot in time" and do not represent trends over extended periods.

Types of Process Wastewater Streams

Ash sluice water is a major wastewater stream at a power plant, and typically the largest contributor of flow and pollutants to an ash pond. However, there are typically various other wastewater streams co-managed with ash sluice water in ash ponds. If a plant converts to dry ash handling, these other streams will still need to be managed. Table 2-1 provides a summary of common process wastewater sources, including key water chemistry characteristics of each wastewater stream that may affect treatment of this wastewater source. Process wastewater streams differ widely in composition. Certain streams are corrosive or acidic, some streams may have high concentrations of suspended solids or metals, and some wastewater streams may be high-quality water and could be used for other purposes within the plant instead of being discharged.

Table 2-2 summarizes the information obtained from coal-fired power plants as part of the responses to the USEPA's ICR regarding process wastewater streams that are currently managed by plants. Power plants as part of their ICR responses identified over 80 types of process wastewater. This wide range of wastewater streams highlights the variety of different wastewater challenges that power plants face as they close their ash ponds and require other management of these streams. Most facilities currently manage the majority of these streams in ponds.

This report does not focus on FGD wastewater because this process wastewater stream will likely require separate management or pre-treatment before combining with other process wastewater streams. Wastewater generated from FGD scrubber blowdown is difficult to manage due to its elevated temperature, corrosive and scaling characteristics, and concentrated levels of trace metals such as mercury and selenium. EPRI has done extensive research on FGD wastewater characteristics and treatment [1, 2, 3, 4, 5, 6, 7, 8, 9].

Table 2-1
Summary of Characteristics of Select Process Wastewater

Wastewater	Source	Frequency of Generation	Wastewater Characteristics Affecting Management
FGD Wastewater	Coal	Varies (continuous or several times daily)	Suspended solids, trace metals, nutrients, total dissolved solids, chlorides, sulfate
Bottom ash sluice water	Coal	Intermittent (several times per day)	Suspended solids, abrasive
Cooling Tower Blowdown	Cooling water	Intermittent (several times per day)	Trace metals, chlorine, priority pollutants, chromium, zinc
Demineralizer regeneration waste	Raw water treatment	Intermittent (several times per day)	Varies from acidic to basic, high salinity
Boiler blowdown	Steam cycle contaminants	Intermittent (several times per day)	High quality (<15 mg/L TSS)
Floor and yard drains	Pump seals, sumps, cleaning, lab analyses	Continuous	Potentially contaminated with oil, suspended solids, and trace metals. Can have large variability due to sumps
Pyrites sluice water	Coal	Intermittent (several times per day)	Suspended solids, abrasive
Coal pile runoff and pyrite pile runoff	Precipitation	Varies (after rainfalls)	Can be neutral to acidic with high levels or iron and trace metals
Fireside cleaning	Furnace surfaces	1 to 6 times annually	High metals, suspended solids levels
Boiler chemical cleaning	Boiler tube internals	Once every 2 to 5 years	High metals, copper, solvent levels
Sanitary waste	Utility personnel	Continuous	Organic contaminants

Note:
mg/L = milligrams per liter
TSS = total suspended solids

As is shown in Table 2-2, with a potential for over 80 process wastewater sources at a power plant, this creates a challenging scenario for wastewater management if ponds are closed. To develop a water management plan, a utility should understand the flows and water chemistry of these various sources, as well as if these flows are intermittent or continuous.

Table 2-2
Process Wastewater Streams Identified in USEPA's Information Collection Request

Process Wastewater Streams

- Acid mine drainage
- Air heater cleaning water
- Ash haul road runoff
- Ash hopper seals & cooling
- Ash overflow tank
- Ash pile runoff
- Ash seal water
- Ash settling basin
- Boiler blowdown
- Boiler drain
- Boiler fireside cleaning water
- Boiler tube cleaning water
- Bottom ash hopper overflow
- Bottom ash sluice
- Car rinse
- Clarifier blowdown
- Clarifier de-sludge wastewater
- Clarifier strainer removal system
- Coal landing facility sump
- Coal pile runoff
- Coal prep plant discharge
- Coal truck unloader area
- Combined ash sluice
- Combustion turbine cleaning
- Cooling tower blowdown
- Cooling tower overboard
- Deep well rehabilitation wastes
- Demineralizer regeneration waste
- Economizer ash removal system
- Economizer ash sluice
- Equalization basin overflow
- Equipment washdown
- Filter backwash
- Fines thickener underflow
- Fire protection washwaters
- Floor drain wastewater
- Fly ash handling excess water
- Fly ash transfer building sump
- Furnace seats
- General runoff
- Groundwater collection water
- Groundwater from underdrains
- Gypsum pile runoff
- Raw water strainer backwash
- Hydrobin
- Hydroveyor transport water
- Ion exchange wastewater
- Landfill runoff
- Leachate
- Lift station
- Limestone pile runoff
- Lube water
- Mag thickener overflow
- Metal cleaning wastewater
- Mill pyrite removal system
- Mill reject sluice
- Natural gas system wastewater
- Neutralization basin
- Non-contact cooling water
- Oily wastewater separator
- Equipment once-through cooling water (not for boiler steam-cycle cooling)
- Parking lot drain
- Plant service water
- Plant sumps
- Pond underdrain/seepage
- Precipitator/overflow sumps
- Pyrites sluices
- Regeneration waste
- RO reject water or concentrate
- Roof drain
- Slag quench water
- Slag tank overflow
- Soot blowing wash water
- Steam turbine cleaning water
- Storm water
- Track hopper sump
- Transformer and miscellaneous cooling
- Treated sanitary wastewater
- Vacuum filter pump seal water
- Wastewater collection sumps
- Yard drain

Flow

To plan for wastewater management after pond closure, power plants will first need to have an understanding of all wastewater flows to be re-routed, what the average flows are of each wastewater stream, whether the flows are intermittent or continuous, variability of the flows over time, typical batch sizes for intermittent flows, and peak flows for design.

Figure 2-1 shows ranges of average daily flowrates for various wastewater sources. This information was obtained from data that power plants provided to the USEPA as part of the ELG ICR. Each line on Figure 2-1 represents the 5th and 95th percentile range of data values obtained from the ICR and the dash represents the median value of each flow range. This figure shows that ash sluicing flows (bottom ash sluice, combined ash sluice, fly ash sluice) are generally the larger wastewater flows from coal-fired power plants. In addition, cooling tower blowdown represents a significant flow.

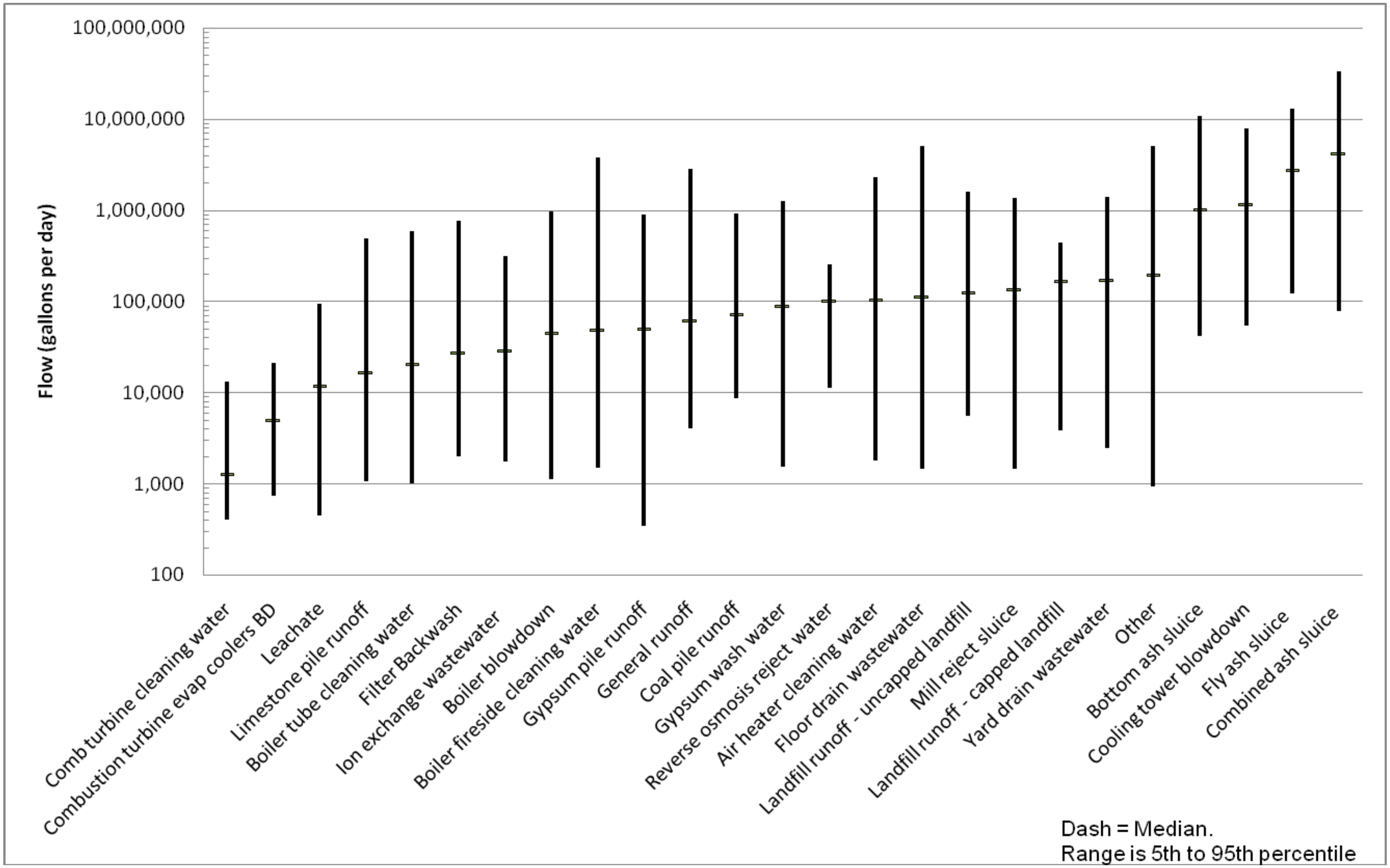

Figure 2-1
Process Wastewater Flow Data Obtained from ICR

Figure 2-2 shows the median values of each of the process wastewater streams in Figure 2-1. The median fly ash sluice flowrate from the ICR is 1,900 gallons per minute (gpm) and the median bottom ash sluice flow rate is roughly 700 gpm. Bottom ash sluicing can be a significant flow, so if conversion of only fly ash to dry handling is planned, it is important to understand whether bottom ash sluice water will continue to be managed in a pond or whether it will be managed as tank-based treatment.

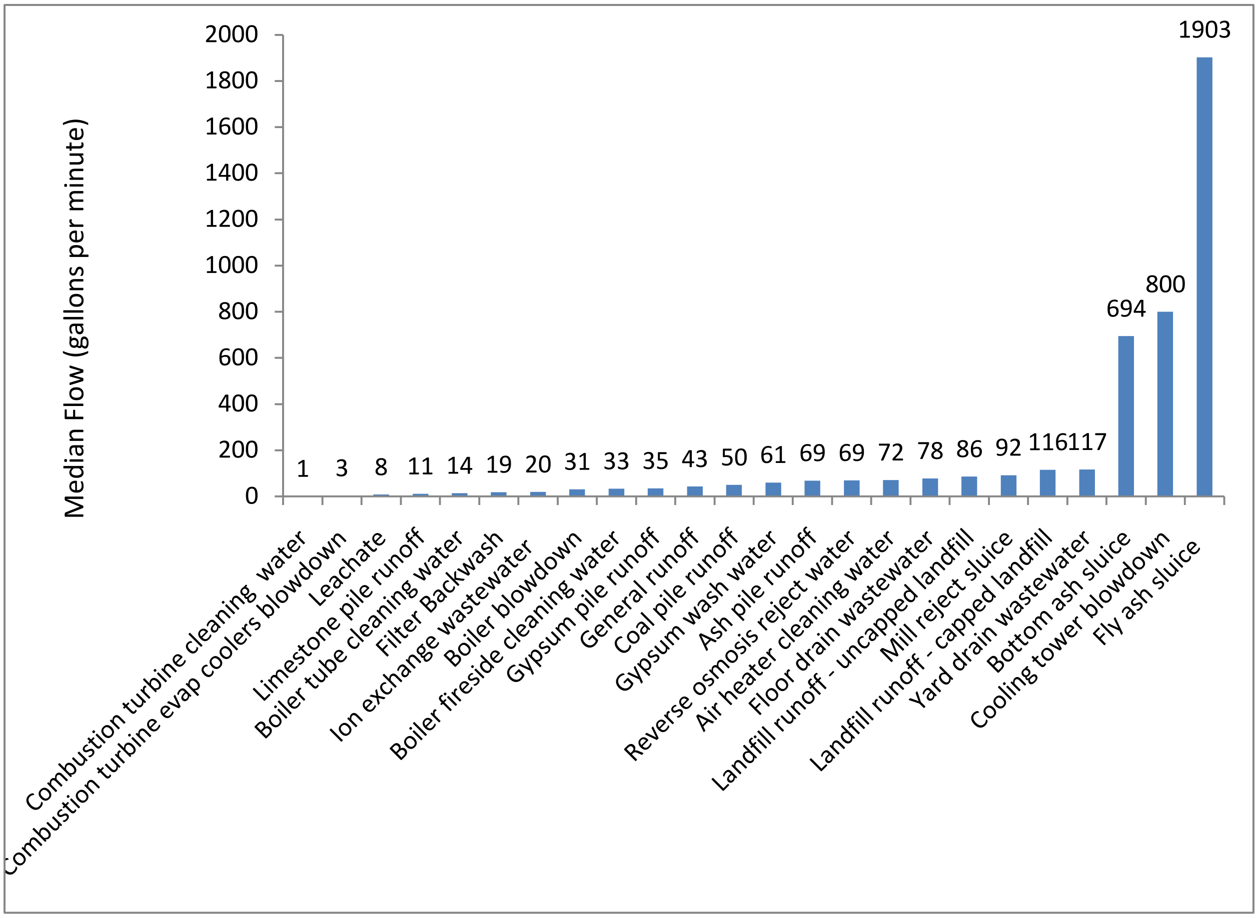

Figure 2-2
Process Wastewater Median Flow Data in Gallons per Minute

Another flow that would significantly affect treatment plant sizing if treatment is required prior to discharge is cooling tower blowdown. The median cooling tower blowdown flow is 800 gpm.

The other process wastewater flows shown in Figure 2-2 show median ranges from 1 to 117 gpm based on average daily flow. However, some of these wastewater streams are only generated intermittently. For example, air preheater washings typically occur approximately once per year and last approximately one to three days. Boiler fireside cleanings occur up to a few times per year and over a similar timeframe. Boiler chemical cleaning wastewater is generated approximately every three to five years and results in a discharge over one to three days. Storm water is also an intermittent flow. Management strategies for these intermittent streams should include flow equalization so that they do not overwhelm treatment systems.

Water Quality

Developing an understanding of water quality characteristics of various process wastewater streams is essential to planning water reuse and water treatment. Various factors affect the water matrix associated with process wastewater. The physical, chemical, and biological treatment technologies typically used for power plant wastewater are all affected by the water matrix. The wastewater pH and temperature will affect the solubility and activity of the chemistry of the water matrix. These variables affect the chemical, physical, and biological treatment technologies by influencing the reaction kinetics, and the mass transfer of the water and constituents through the water treatment process. Parameters described in this section that affect wastewater technologies available for treatment prior to reuse or discharge include:

- Total Suspended Solids
- Trace Elements
- Total Dissolved Solids and Scale-Forming Ions
- Alkalinity
- pH

Total Suspended Solids

In addition to flow, total suspended solids (TSS) is also an important parameter of concern due to the current ELG limit of 30 milligrams per liter (mg/L) TSS for certain power plant discharges. Suspended solids loading to a tank-based treatment plant is important, as it will drive the size of the equipment used to dewater the solids removed from the wastewater. In samples collected in the EPRI Power Plant Integrated System-Chemical Emissions Study (PISCES), ash pond influent TSS ranged from 41 to 20,000 mg/L [15].

By design, water conveying ash will have high suspended solids content. However, most of the ash will settle out very quickly in the ash pond. For example, in the dozens of samples collected in the PISCES program, the median fly ash sluice water TSS after one hour of settling was only 150 mg/L [22]. Runoff from coal piles, ash, or other material stockpile areas can carry high loadings of fines in initial flushes of water.

Various process wastewater streams such as plant sumps, air pre-heater washes, and coal pile runoff contain a wide range of TSS values. The range and variability of data are important to understand the sizing and operational cost of dewatering equipment in a treatment plant. Other process wastewaters are very low in suspended solids, such as cooling tower blowdown and demineralizer and softener regeneration wastes. It should be noted that the concentrations do not reflect the overall mass loading of suspended solids (which is determined by concentration, as well as by flow and frequency of flow).

Trace Elements

It is important to understand whether trace elements are in particulate or dissolved form, as particulates can be settled out while dissolved constituents require some form of chemical treatment. If selenate is present and requires treatment prior to discharge, biological treatment may be an option.

Figure 2-3 shows loadings of metals in liquid streams at six sites included within EPRI's PISCES program. Fly ash sluice water is shown as a significant contributor to metals based on these data. Bottom ash and pyrites sluice water contribute much less to the overall loading of metals to an ash pond.

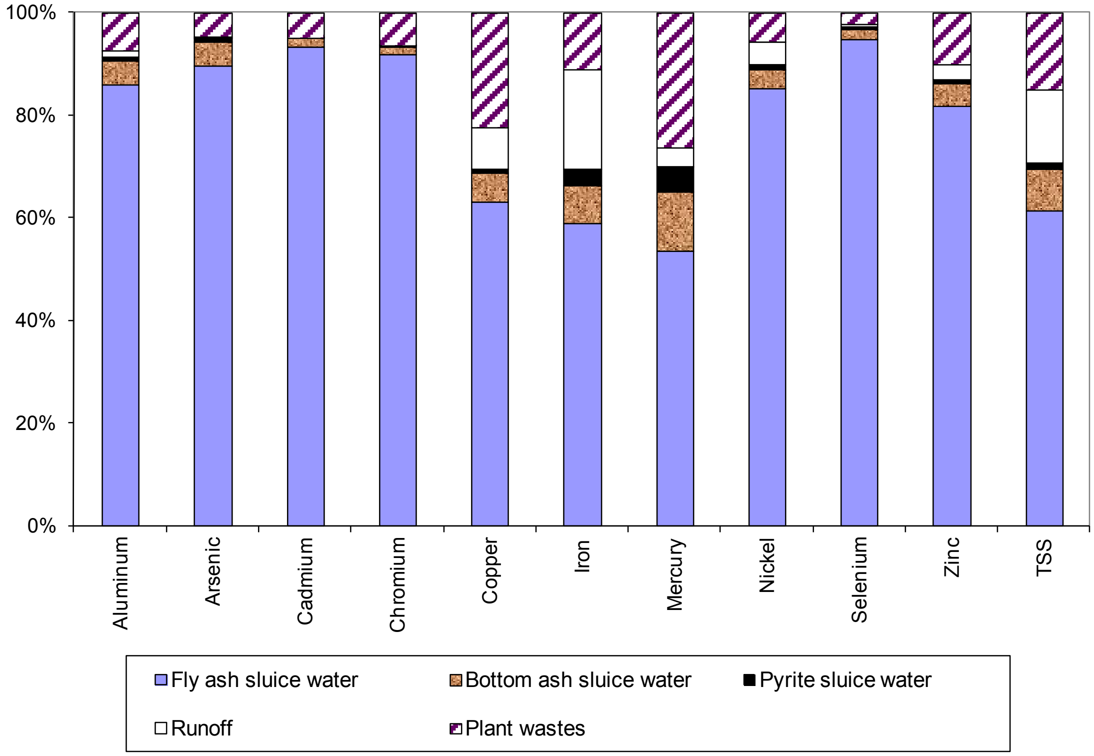

Figure 2-3
Loadings of Metal in Liquid Streams to Ash Ponds at Six PISCES Sites

Note: "Liquid" samples were collected from water decanted after at least one hour of settling to evaluate the contribution of streams to an ash pond after bulk solids settling.

Total Dissolved Solids and Scale-Forming Ions

Total dissolved solids (TDS) and electrical conductivity are good relative indicators of the ionic strength of water. Generally, the higher the TDS, the more competing matrix chemistry impacts there will be on a water treatment technology such as pre-treatment technologies for cooling tower makeup water. Streams that do not contact soluble materials tend to be low in TDS, such as bottom ash sluice water (a median of 90 mg/L TDS in nearly 30 samples collected in the PISCES program) and pyrite sluice water (120 mg/L TDS median). Fly ash is more soluble, reflected in higher TDS during the PISCES sampling (fly ash sluice water and economizer ash sluice water samples both had medians of 800 mg/L TDS). Various wastewater sources have high TDS levels. For example, one sample of demineralizer brine effluent was collected during the study and had a concentration of 35,000 mg/L. Air preheater washes and coal pile runoff also had a wide range of TDS values (90 to 3,000 mg/L) among the data collected. It should be noted that the concentrations do not reflect the overall mass loading of dissolved solids (which is determined by concentration, as well as by flow and frequency of flow).

Various cations and anions can combine to form insoluble precipitates or scale. Solubility is a function of the ion concentration, the solution ionic strength, ion activity, pH, and temperature. Sparingly soluble salts such as calcium carbonate ($CaCO_3$), sulfate salts of calcium, barium and strontium, reactive silica or silica dioxide, and metal oxides are typical scales that can be problematic with scale-sensitive treatment technologies. Calcium and magnesium salts are ubiquitous in most ground and surface waters. They are notable scale-forming ions that are quantified by hardness measurements. Additionally, strontium and barium can be found in power plant source water from groundwater and surface waters. They too will form scale with certain anions. Median values of calcium and magnesium levels at PISCES sites in process wastewaters are shown in Figure 2-4. The values shown in Figure 2-4 are concentrations and do not reflect the overall mass loading (which is determined by concentration, as well as by flow and frequency of flow). The ash sluice water samples analyzed reflect the liquid portion after one hour of settling; therefore, most of the calcium and magnesium in the solid ash is not included.

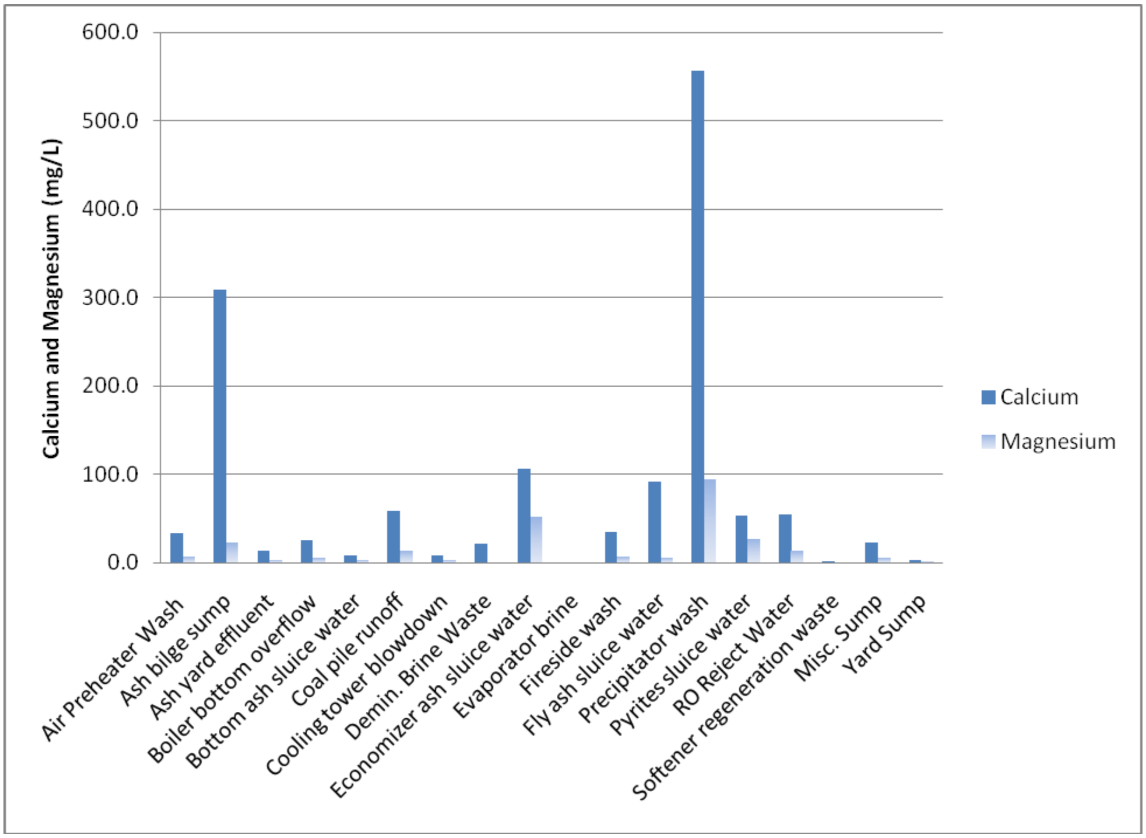

Figure 2-4
Calcium and Magnesium Levels in Liquid Streams to Ash Ponds at PISCES Sites

Sulfate is also a significant scale-forming ion that combines with calcium, strontium, and barium to form scale over a wide pH range. Reactive silica in water will create scale-fouling issues with membranes. Each process wastewater is subtly different and therefore will have a different scale potential. Scale typically can be controlled by softening, controlling the pH and temperature, and/or through the addition of antiscalants or complexing agents. Scale formation will affect treatment processes for water reuse and discharge.

Alkalinity and pH

Alkalinity is a measure of the carbonate chemistry in water. Understanding alkalinity concentrations and forms is important in understanding the potential for carbonate scale formation, which can affect water reuse and various treatment technologies. $CaCO_3$ is a common scale formed in waters with high alkalinities and moderate to high hardness. Above pH 10.3, carbonate is the principal species present. Carbonate and bicarbonate are equal at pH 10.3. At pH 8.3, the predominant species is bicarbonate and little carbonate or carbonic acid is present. Bicarbonate and carbonic acid are equal at pH 6.3. Below this pH, carbonic acid predominates. Calcium carbonate scale will develop when calcium and carbonate are present above solubility.

The pH of process wastewater is highly variable but many process wastewater streams are near neutral. It is important to understand the pH of various process wastewater streams, as certain streams may need to be segregated and treated separately prior to being bled into a new wastewater treatment system. The pH of water contacting fly ash and coal are typically affected. Wastewater streams affected by fly ash and coal include fly ash sluice water, coal pile runoff, economizer sluice, and equipment washes. Some coals and fly ash are acidic (eastern bituminous coals), while others produce alkaline waters (higher calcium sub-bituminous coals). Bottom ash solids are less soluble, and sluice water is typically near neutral. Cooling tower blowdown and most water treatment system residuals will be near neutral unless chemical conditioning is done as part of the process. Demineralizer regeneration waste pH changes as the chemical regeneration cycle changes, ranging from highly acidic to highly caustic.

3

PROCESS WASTEWATER MANAGEMENT PLANNING

Developing a Wastewater Management Planning Framework

Planning for water management after ash pond closure or dry ash conversion is a complex issue that will require input from many parts of a utility's organization. Bringing stakeholders together early in the planning process will help create a water management plan that meets the power plant's goals. Elements of developing a water management plan include:

- Understanding of drivers for closure and/or conversion to dry ash handling. Potential drivers for closure are discussed further in this section.
- Developing a balance of water and wastewater flows. Both average and peak flows should be known. If they are not, a plan to obtain this information should be developed, as this information is critical in evaluation of water reuse and wastewater treatment options. Section 4 discusses this further.
- Developing mass balances for key water quality parameters. Mass balances should be developed for at least the following parameters: suspended solids, dissolved solids, and chlorides. Section 4 discusses this further.
- Identifying and evaluating potential water reuse options. Reuse may require treatment of internal wastewater streams. Section 5 discusses reuse further.
- Evaluating the need for wastewater treatment prior to discharge. The wastewater treatment needed will be based on influent water chemistry and discharge limitations. Section 6 discusses this further.

Given the various disciplines and areas of the facility from which the various process wastewater streams are derived, the complex regulatory environment with multiple pending regulatory changes that are anticipated for air, water and solids media, and the strategic decisions that require input, a variety of stakeholders will need to be involved in this planning effort.

An initial meeting is recommended to bring potentially affected stakeholders together at the onset of the planning process. Possible potential stakeholders from within the utility involved with the elements of planning include power plant and corporate environmental compliance staff; corporate and plant engineering and operations staff responsible for pond management, wastewater treatment, water treatment, and cooling tower management; plant management; and staff responsible for water rights. Additional stakeholders that may be involved throughout the planning process include regulatory agencies and public interest groups.

It is important to review the overall water management strategy for the facility when reviewing the need to close an ash pond. For example, a facility that is interested in zero liquid discharge in the future because of stricter regulatory limitations should have their overall water management strategy reviewed in the context of the future need to eliminate wastewater discharges. This planning can be used to ensure that short-term choices support (or at least do not obstruct) future efforts at treatment or reuse. Another planning consideration is to understand future water availability and reuse options.

It is important to understand data gaps as well and identify these data gaps early in the planning stage to develop a schedule to achieve the process wastewater management goals for the plant.

Drivers for Pond Closure or Conversion to Dry Ash Handling

This section discusses potential drivers for power plants to consider closure of their ash ponds or conversion to dry ash handling. A variety of drivers are pushing utilities to close ash ponds and/or convert from wet to dry ash handling. These drivers may include:

- Coal Combustion Residuals Proposed Rule
- Effluent Limitation Guidelines (ELG) for steam electric generating industry
- Future National Pollutant Discharge Elimination System (NPDES) permit limitations
- Other regulatory limitations
- Future plant expansion or plant-wide water use limitations

Coal Combustion Residuals Proposed Rule

Coal combustion residue or coal ash is currently exempt from federal regulation under an amendment to the Resource Conservation and Recovery Act (RCRA). There are two potential management options currently being considered in regulation promulgation. In the first, the USEPA may list coal combustion residuals as special wastes subject to regulation under subtitle C of RCRA, where the residual will be disposed in landfills or surface impoundments. Under the second proposal, USEPA would regulate coal ash under subtitle D of RCRA for non-hazardous wastes [23]. These regulations may require facilities to evaluate their current ash management practices and facilities may choose to alter these practices based on the potential options USEPA is considering.

Each proposal creates strong incentives for facilities to close existing fly ash ponds. The USEPA could also mandate use of pond liners, have facilities implement groundwater monitoring, and conduct other improvements that may lead facilities to decide to close their fly and/or bottom ash ponds and replace pond treatment with tank-based treatment.

Effluent Limitation Guidelines for Steam Electric Power Generating Industry

The USEPA is issuing an update to the 1982 ELG for the steam electric industry. The current ELG banned wet handling of fly ash at facilities built after 1982 by stating that new sources were subject to New Source Performance Standards including “no discharge of wastewater pollutants from fly ash transport water.” It is possible that the revised ELG, scheduled to be issued as a draft in 2012 and as final in 2014, will further limit the wet handling of ash.

Future NPDES Limitations

Facilities renewing these NPDES permits may face limits that are more stringent and require evaluation of their process wastewater treatment. Facilities may face additional monitoring or water quality limits of certain process wastewaters upstream of a treatment pond as part of their new permits.

Other Potential Regulations

In addition to possible future limits from the updated ELG, state and regional water quality limits below typical ash pond effluent water quality concentrations are driving plants towards dry ash handling, and potentially to eliminating discharges. Examples include mercury limits in the part per trillion level in the Great Lakes region, and nutrient limits in the Gulf of Mexico and Chesapeake Bay regions. Salinity and chlorides have also been raised as potential issues for power plants. Over 1,700 water bodies in the United States have been identified as being potentially impacted by salinity. Power plants discharging to these water bodies are subject to discharge limits on salinity or chlorides, which can be difficult to remove by conventional wastewater treatment.

Future Plant Expansion or Plant-Wide Water Use Limitations

Ash handling is often one of the largest uses of water other than cooling. Therefore, water scarcity may drive sites to convert to dry ash handling. As facilities plan for expansion, they may need to close out ash ponds to make room for other needs such as future landfills. Once existing ponds reach capacity, challenges in permitting new ash ponds may drive plants to build landfills.

A number of developments, some regulatory, could force space-limited facilities to evaluate closing an ash pond to free up space. For example, on July 6, 2011 the USEPA finalized the Cross-State Air Pollution Rule, which reduces power plant emissions that contribute to ozone and fine particle pollution across 27 states. Facilities will require implementation of air pollution equipment that may require facilities to re-evaluate availability of space at their facility and trigger the need to close their ash ponds.

Planning Agenda

Table 3-1 provides an example agenda for an initial meeting to discuss ash pond closure. The example below will not be applicable to every power plant and the information covered in Table 3-1 will likely require multiple sessions with some topics revisited multiple times through the planning process. The purpose of Table 3-1 is to provide an understanding of the types of issues that facilities face, as well as issues to address at the planning stage.

Table 3-1
Example Process Wastewater Planning Agenda

Agenda Items
1. Review overall objectives of the planning session
a. Develop understanding of the key issues driving the need for process wastewater management strategy.
b. Review decisions that resulted in this change in management strategy.
c. Review closure and conversion in context of overall wastewater management strategy for the facility.
d. Discuss schedule for planning and implementation.
e. Discuss key data gaps that require identification and how these gaps will be resolved.
f. Identify available water reuse and recycling options.

Table 3-1 (continued)
Example Process Wastewater Planning Agenda

Agenda Items
2. Identify Stakeholders a. Determine input needed from various disciplines at plant and corporate level, regulators, public, others. b. Identify roles and responsibilities of the various stakeholders involved. c. Determine level of involvement throughout the planning process for each stakeholder. d. Identify project leads and points of contact throughout planning process. e. Discuss communications among stakeholders throughout planning process.
3. Review key drivers for closure of ash pond or conversion to dry ash handling a. What current or future regulatory limitations are affecting the decision to close ash pond or convert to dry ash handling? b. Are there corporate drivers for pond closure or conversion to dry ash handling? c. Are there other risk drivers that are affecting the decision? d. Is corporate environmental policy impacting the ash pond management decision? e. Has the pond reached capacity or are there space limitations for future expansion? f. Are there other key decision criteria that have driven closure or conversion?
4. Review how drivers are affecting process wastewater management a. What current regulatory limitations will affect future process wastewater management? b. Are there current discharge limitations that will require pre-treatment of wastewater if pond is not used in the future? c. Will NPDES permit be renewed during the planning process? How will this affect wastewater management? d. Are there expected federal, state or local regulations that may affect future permitted discharges? e. Will changes need to be made to water management strategy for the facility due to impending regulations? f. Is water minimization a facility goal? If so, in what ways will this affect process wastewater management strategy? g. Are there other planned projects or future plant expansion that the facility will implement that may affect process wastewater management strategy? h. Are there space constraints within the facility that will limit options for wastewater management? i. Are there other facility or corporate goals that may affect process wastewater management strategy?

Table 3-1 (continued)
Example Process Wastewater Planning Agenda

Agenda Items
5. Review budget and schedule for planned projects a. What is the available budget for this work and how will this be funded? b. What is the timeline for ash pond closure or conversion to dry ash handling? c. Are there time constraints to implement new process wastewater management based on other planned facility projects? d. Are there regulatory deadlines that require compliance for projects that would affect schedule for management of process wastewater? e. How does process wastewater management fit into schedule for future planned projects? f. What is the timeline for implementation of process wastewater management?
6. Identify Information Needed to Develop Water Flow Balance a. Does the facility have a current water balance that shows inputs to current ash pond? b. What is the flowrate, frequency and duration of each wastewater source to the ash pond that will require future management? c. Are there process wastewater flows currently not entering the ash pond that will be managed by the future treatment system? d. Are there planned water management activities that will change future flows? If so, what are the estimated flows? e. Are there water use limitations that will be implemented that will affect future process wastewater flows? If so, what are future estimated flows? f. Does facility have long-term flow data over multiple seasons (2 to 3 years)? If not, what long-term data are available and what data gaps exist? g. Does facility have data on average flows? Identify data gaps. h. Does facility have information on peak expected flows for use in sizing treatment equipment? If not, identify data gaps. i. Has the facility created a water balance based on anticipated future flows from planned activities? j. For areas where there are data gaps, what type of flow monitoring equipment is available? k. Are resources (financial, labor, etc) allocated to address additional flow monitoring needed to fill data gaps? l. Will water balance be prepared using spreadsheet tool or is there a need for more complex or dynamic model? m. What modeling software will be used to prepare dynamic water balance if needed? Have resources been allocated to support this? n. How will data gaps affect overall schedule and budget?

Table 3-1 (continued)
Example Process Wastewater Planning Agenda

Agenda Items
7. Identify Information Needed to Develop Mass Balances a. Identify parameters of concern based on discharge limitations, potential water reuse and treatment options. b. Determine existing data available for the various wastewater sources that will be managed in the future. c. Do available data cover sufficient number of sampling rounds for characterization? d. Are sufficient data available on key wastewater treatment parameters such as TSS, TDS, chlorides, scale-forming ions, pH, metals? e. Are resources allocated to fill in data gaps as needed? f. Does facility have plans to use treatment processes such as softening that may require advanced water chemistry modeling? If so, are resources allocated to support this modeling effort? g. How will data gaps affect overall schedule and budget?
8. Identifying Potential Water Reuse/Recycling Options a. Will the ash pond continue to be used to manage process wastewater in the future? b. Are there wastewater streams that can be reused in other areas of the plant? c. Are there areas where water reduction may be incorporated? d. Identify plant processes where water may be reused (e.g. scrubber, cooling towers). Identify opportunities for water reuse to save on the overall footprint and operating cost of treatment. e. Incorporate revisions to proposed water balance based on water reuse options available and re-routing of wastewater streams where possible.
9. Identifying Water Treatment Options a. Will the ash pond continue to be used to manage process wastewater in the future? b. Based on water reuse options available, review revised water balance for flows that will require tank-based wastewater treatment. c. Will wastewater treatment be required as pre-treatment for water reuse applications? If so, review alternatives for wastewater treatment. d. Review alternatives for wastewater treatment for discharge.

Case Study: Planning

EPRI has interviewed a facility currently in the process of planning for future process wastewater management after the planned closure of its existing ash pond. There are space constraints at this facility such that the ash pond will need to be closed to allow for future expansion. The main driver for this facility to close its ash pond is that the facility is planning to install an FGD scrubber and will use the existing area of the ash pond for an FGD landfill. The facility currently handles dry fly ash but it can also be wet sluiced to the ash pond. They are also considering dry or partially dry bottom ash handling for future operations. All of the plant's process wastewater sources currently flow to its ash pond except unit condensers and boiler chemical cleaning waste. There is also a separate coal pile runoff pond.

The operational unit at the facility is designed for 270 MW and burns sub-bituminous coal. A selective catalytic oxidizer has been installed and is currently operational. The planned FGD scrubber may require 200 gpm of makeup water, which could be a water reuse opportunity for process wastewater streams.

The facility is currently planning for scrubber operations while also planning to remove equipment that has been permanently offline, potentially allowing for room to construct a tank-based wastewater treatment system to treat the remaining process wastewater streams. The facility has identified that they have data gaps in water quality data for certain streams such as RO reject and demineralizer regeneration waste. They have also identified data gaps in peak flows that will be used for sizing of treatment system equipment.

4

DEVELOPING WATER FLOW BALANCES AND MASS BALANCES

To plan water reuse, recycling, and treatment system design successfully, the water flow and characteristics throughout a plant must be understood. This section presents guidance on developing flow and water quality balances. Table 4-1 summarizes typical requirements and possible tools that can be used to determine these requirements.

Table 4-1
Overview of Typical Requirements for Various Water-Related Issues

Driver for Understanding Water	Typical Information Required	Possible Tool
High-level water use metric reporting ("water footprinting")	Annual water use	Water use data (such as from flow meters or pump run-time)
NPDES permit applications	Water flow diagram with average and peak flows	Single, static flow diagram
Treatment system design	• Water flow diagram with minimum, average and peak flows, to provide sufficient insight to size equalization storage and treatment units • To evaluate if treatment technologies have adequate turn down range, need to know minimum and peak flows • Solids loading • Loading of target trace pollutants (such as selenium) and parameters that affect treatment of these pollutants (such as nitrates, which affect biological wastewater treatment of selenium); iron co-precipitation increases solids handling requirements	Static flow diagram for each of several operating conditions
Water reuse, recycling	• Water flow diagram with average and peak flows, sufficient insight to ensure adequate water supply to each reuse point • Water chemistry of parameters that could cause operational problems such as corrosion (chlorides) and scaling (calcium) for recycled water sources	Dynamic flow diagram to evaluate effects of recycle throughout plant's water system

Table 4-1 (continued)
Overview of Typical Requirements for Various Water-Related Issues

Driver for Understanding Water	Typical Information Required	Possible Tool
Operational control monitoring, such as to help minimize water loss	Will need to monitor water chemistry changes to prevent operational problems	Dynamic flow diagram tied to real-time process monitoring equipment
Design and operation for high TDS waters, such as evaporators or lime softening	Water chemistry of parameters that could cause operational problems	Advanced chemistry modeling if ion strength is high enough that chemicals start to react with one another

Water Balance Development

Developing an understanding of the various process wastewater flows is key to an overall management strategy because flow quantity and variability change the concentration and mass loading of parameters that require removal for both wastewater treatment and for water reuse opportunities that require pre-treatment. Depending on the variability and number of flows water balances may be simple or complex, but they are useful tools in planning process wastewater management options.

There are various challenges associated with understanding flows. It is important to understand both average and peak flows. Average flow is important for some applications such as water footprint reporting and understanding annual operating costs of treatment. It is also important to understand peak flows for sizing of major equipment and pumps and to evaluate equalization. It is important to understand the ratio of peak to average flows in sizing equalization and in understanding estimated costs of treatment. While peak flows are used to size equipment, average flows are typically used to estimate operational costs such as chemical usage and solids handling and dewatering. Daily maximum flows will likely be known for major streams that are permitted, but these data may not be available for most process wastewater streams. Even if these data are recorded, they may not be tracked in the power plant's database, so additional effort may be required to locate and enter this information.

The typical means to understand flow at a discharge point is by developing a water balance. However, often times data gaps exist for process wastewater streams that prevent building an accurate balance.

A general methodology for developing water balances for average and peak flow is as follows:

1. Set up one balance for average conditions and another for peak flow conditions of each wastewater stream.
2. Identify all wastewater flows currently managed.
3. Determine if any other wastewater streams will be treated using tank-based treatment after the ash pond is closed and include these flows in the water balance.
4. Record all measured flow data. Data should be evaluated across a range of conditions, such as across an entire day, between peak and non-peak production, and between seasons.
5. Identify all streams for which there are no flow data.

6. Total flows to common tanks and units to find some of the missing values by difference. This approach introduces risk of error; evaporation, leakage, precipitation, and other factors will need to be accounted for in the calculation.
7. Where available, add pumped stream flows based on pump curves, timers, or other operating information for average and peak flows.
8. For remaining flows, collect flow data by field measurements. Field measurements can be collected by inline or clamp on flow meters for closed pipes and by in-line flow meters, pressure transducers, stilling well, or rectangular weirs for open channel flow.
9. Estimate storm water flows if those will be managed by future tank-based treatment. Estimate storm water using the product of area drained to a point times the amount of rainfall times a coefficient representing the percent of rainfall that will runoff the area (this will be 1.0 for impervious surfaces, and less than 1 for areas with pervious soils).
10. Include checks comparing calculated data with known criteria or measured values.
11. Discuss and re-discuss among stakeholders to ensure the data make sense, are complete, and are based on most current and best available information.

Spreadsheets may be used for simple flow balances. However, for more complex facilities managing various process wastewater streams, there are benefits from using a model or simulation software to develop accurate flow balances. Various software packages are available that facilities can use to develop water flow balances.

Case Study: Water Balance Development

A facility that was interviewed as part of this study attempted to create a water balance as a first step in assessing management of process wastewater streams. As they began to identify streams and tabulate flow data, they realized that for many of the streams identified, such as floor drains, they do not have good flow estimates. Only coal pile runoff, bottom ash sluice water, fly ash sluice water, and FGD water flows were known. From the outfall flow data available, it was clear that other streams represented a significant portion of the wastewater flow. The other remaining flows will require measurement or estimation. The facility is planning on using flow estimation software to complete a dynamic flow balance.

Case Study: Water Balance Development

A power company that was interviewed as part of this project is using a dynamic flow balance modeling software package to develop water balances for several of their facilities. The facilities have considered whether to continue pond-based treatment of process wastewater, or to convert to tank-based treatment. However, they have not determined at this time whether tank-based treatment will be used. The software package offers whole plant water modeling and can perform pH and equilibrium reactions as well. The intent is to have a dynamic water model to evaluate potential options and select the optimal path forward.

Mass Balance Development

Mass balances are developed using water quality criteria and flows for the various inputs to the treatment system to determine mass loading for design of treatment systems. Table 4-2 shows water quality parameters of potential interest based on common requirements for water reuse applications, common analytes of concern for wastewater streams in water reuse applications, and common analytes of concern in wastewater treatment for discharge based on common discharge limitations. The analytes in Table 4-2 can be grouped into the following:

- Trace elements: As described in Section 3, it is important to understand the loading associated with trace elements to determine the level of treatment required.
- Scale-forming or corrosive cations and anions: Scale-forming and membrane-fouling constituents such as $CaCO_3$, sulfate salts of calcium, barium and strontium, reactive silica or silica dioxide, and metal oxides can create issues for treatment systems for water re-use or discharge. Chlorides and fluorides are both corrosive anions that affect metallurgies. For instance, fluorides can affect the titanium metallurgy in evaporator/crystallizers. Treatment systems for waste streams that contain high chlorides levels like FGD wastewater may need to be built with corrosive-resistant materials. At bromide-application power plants, such as those using $CaBr_2$ to control mercury emission or using bromine for cooling tower biofouling control, bromide will be of interest.
- Nutrients: Nutrients may need to be sampled if there are discharge limitations that plants will need to comply with or limitations such as ammonia toxicity that will require detailed characterization of their wastestreams to determine sources and treatment. In addition, if a plant is required to remove selenate, it is important to understand feed water nutrient levels to determine required supplements for biological treatment.
- Field-collected water quality parameters: Field collected water quality parameters such as temperature and pH are important to understand if streams can be co-managed or will require separate management.
- Other miscellaneous parameters of concern: Hardness and alkalinity are indicators of the scaling potential of a wastewater. Total suspended solids and total dissolved solids are key parameters of concern.

In most instances the most important parameter of concern for process wastewater treatment is TSS, as suspended solids will require removal prior to discharge. A mass balance for TSS will likely need to be developed for facilities interested in process wastewater management planning. Of the list provided in Table 4-2, other key parameters of concern for most process wastewaters include TDS, scale-forming ions, chlorides, hardness, alkalinity, sulfate, calcium, and carbonate because these parameters will affect the ability for wastewaters to be reused throughout the plant and will affect the operations of treatment equipment. In addition to TSS, a categorical effluent limitation exists for oil and grease; however this analyte is only present in certain wastewaters. Depending on regulatory limits, mass balances of trace elements may also need to be performed.

Table 4-2
Constituents that Potentially Impact Wastewater Treatment for Reuse or Discharge

Trace Elements	Cations	Water Quality Parameters (Field Monitoring)
Aluminum	Calcium	pH
Antimony	Magnesium	Conductivity
Arsenic	Manganese	Dissolved Oxygen
Barium	Potassium	ORP
Beryllium	Silicon	Temperature
Boron	Sodium	
Cadmium	**Anions**	
Chromium	Carbonate	
Copper	Bromide	**Other**
Iron	Chloride	Alkalinity
Lead	Fluoride	Hardness
Mercury	Sulfate	Oil and Grease
Nickel	**Nutrients**	Total Dissolved Solids
Selenium	Ammonia-N	Total Suspended Solids
Silver	Nitrate-N	Chemical Oxygen Demand
Strontium	Nitrite-N	BOD, 5 Day
Thallium	Phosphorus-P, Total	Total Organic Carbon
Vanadium	Orthophosphate-P, Total	
Zinc	Total Kjeldahl Nitrogen	

Water Quality Modeling Tools

In most cases, when an understanding of water chemistry is needed in overall power plant modeling, water quality parameters can be considered as conservative. That is, salts will pass from one stream to another. Examples include tracking chloride to evaluate corrosiveness. Chlorides can be tracked the same way as water flow. However, more advanced modeling tools are needed for situations where parameters influence each other, such as in softening, or at the high salt concentrations in an evaporator or crystallizer. In these cases, water chemistry stoichiometry and chemical reactions must be tracked. This is facilitated by commercially available water chemistry models. These tools compute properties of wastewaters when mixed with additives, when wastewater is evaporated, and when newly formed solid phases react with dissolved materials in the wastewater. This information is used to determine treatment technologies that will be effective and identify specialized materials of construction as needed. These are important considerations in developing costs of the treatment system.

These tools require input of water chemistry parameters for the water streams considered. If these data are not available, they will need to be supplemented with sample collection and analysis.

Sampling and Analytical Methods

Some sampling of process wastewater streams will likely be needed to fill in data gaps to complete mass balances and gather required water quality data to determine treatment options for reuse and discharge. As part of this characterization effort, power plants may elect to perform their own sampling or obtain outside resources to conduct sampling. Sample frequencies should be determined based on the significance of the wastewater source(s) being sampled, variability of the wastewater over time, and frequency of generation.

Information should be collected at the time of sampling on whether the stream is intermittent or continuous and its flow, frequency, and duration. The sampling point of each stream should be selected from the location that will most accurately represent the expected feed to the proposed new wastewater treatment system or feed for water reuse application for each stream.

To get a representative sample of heterogeneous streams such as ash sluice wastes, composite samples may need to be collected. The decision to collect a grab or composite sample will be based on what type of stream is being sampled and how the wastewater characteristics change throughout the course of the day. Several types of waste streams are generated during periodic equipment washes, such as boiler chemical cleaning, air preheater washes, precipitator washes, and boiler fireside washes. In general, the wash water consists of an initial slug of concentrated wastewater followed by diluted rinse water. Multiple samples may be collected to characterize the composition of the wash water at different stages in the process. Automatic composite samplers may be used to characterize streams that are known to change over the course of a day, such as ash pond influent, yard sumps, and coal pile runoff.

Once samples are collected, they will likely require some form of preservation, which may be keeping samples on ice or refrigerated, or adding preservatives such as acids. A Sampling and Analysis Plan should be developed that outlines sample locations and sample-collection procedures, including which analytes are to be sampled and what analytical methods will be used to analyze these samples. The Plan should also provide information on sample preservation; sample labels and chain of custody forms; and quality assurance/quality control (QA/QC) samples. The health and safety of the sampling effort should also be planned. Field QA/QC samples may include equipment rinse blanks, field blanks, field duplicate, and matrix spike/matrix spike duplicates. QA/QC samples will also be done in the laboratory as part of their internal assessment of analysis accuracy and precision.

The USEPA Method 1669 “clean” sampling protocols and 1600-series analytical techniques are used at locations where concentrations of metals are expected to be near or below detection limits of conventional methods. Some of these test methods have not been approved for regulatory use by USEPA or fully validated. Clean sample collection is performed to minimize contamination during sample collection and handling. Clean sample collection should be performed at process wastewater sampling locations with low levels of metals for adequate characterization, such as cooling tower blowdown.

It is important to understand the form in which trace elements are present. This is done by collecting data for both total and soluble concentrations. Field filtration of samples is required for soluble trace elements. Field filtration involves employing a 0.45-micron filter during sample collection.

The USEPA has identified that analysis of trace elements such as arsenic and selenium can be affected by the FGD water matrix, with a complex matrix influencing the reporting limit by increasing the dilution required to analyze the sample. USEPA has developed guidance for the analysis by USEPA Method 200.8 to conduct inductively coupled plasma mass spectroscopy analysis of trace elements to minimize matrix interferences associated with this wastewater [24].

In-line measurements of water quality parameters should also be collected during sample collection, with handheld instruments. Water quality parameters for collection include temperature, pH, conductivity, dissolved oxygen, and oxidation/reduction potential.

Table 4-3 contains example analytical methods for the parameters outlined within Table 4-2. The methods listed below have been used in the past for sampling of process wastewater. As described above, a subset of these parameters may be selected for analysis depending on the wastewater source and the analytes of concern for water reuse applications or discharge. It is recommended that both total and dissolved trace elements be collected to determine whether chemical precipitation will be needed to remove trace elements from the wastewater or whether particulate can be settled and/or filtered. In certain instances, if arsenic or selenium are parameters of concern, speciation may be required to determine the predominant form to select the correct treatment application, such as anoxic biological treatment for selenium removal.

Table 4-3
Example Analytical Methods that Can be Used for Process Wastewater Analysis

Parameter	Analytical Method
Trace Elements (Total and Dissolved)	
Aluminum	USEPA 200.8
Antimony	USEPA 200.8
Arsenic	USEPA 200.8
Barium	USEPA 200.8
Beryllium	USEPA 200.8
Boron	USEPA 200.8
Cadmium	USEPA 200.8
Chromium	USEPA 200.8
Copper	USEPA 200.8
Iron	USEPA 200.8
Lead	USEPA 200.8
Mercury	USEPA M1631
Nickel	USEPA 200.8
Selenium	USEPA 200.8
Silver	USEPA 200.8
Strontium	USEPA 200.8

Parameter	Analytical Method
Anions	
Carbonate	USEPA 310.2
Chloride	USEPA 300.1
Fluoride	USEPA 300.1
Sulfate	USEPA 300.1
Nutrients	
Ammonia	USEPA 350.1
Nitrite	USEPA 353.2
Nitrate	USEPA 353.2
Total Kjeldahl Nitrogen	USEPA 351.2
Orthophosphate	USEPA 365.3
Phosphorus, Total, P	USEPA 365.4
Other Parameters	
Alkalinity	USEPA 310.2
Hardness	USEPA 130.1
Oil and Grease	USEPA 1664A
Total Suspended Solids	USEPA 160.2

Table 4-3 (continued)
Example Analytical Methods that Can be Used for Process Wastewater Analysis

Parameter	Analytical Method
Thallium	USEPA 200.8
Vanadium	USEPA 200.8
Zinc	USEPA 200.8
Other Cations	
Calcium	USEPA 200.8
Magnesium	USEPA 200.8
Manganese	USEPA 200.8
Potassium	USEPA 200.8
Silicon	USEPA 200.8
Sodium	USEPA 200.8

Parameter	Analytical Method
Total Dissolved Solids	USEPA 160.1
Chemical Oxygen Demand	USEPA 410.4
Biochemical Oxygen Demand, 5 Day	USEPA 5210B
Total Organic Carbon	USEPA 415.1

5

WATER REUSE AND RECYCLING ALTERNATIVES AND CONSIDERATIONS

Many power plants are adopting a goal of overall water use reduction. This may be driven by a variety of reasons – including water scarcity and the cost of advanced treatment to meet strict discharge limits. Reusing water is one means to use less water at plants that have limited water supply. Wastewater treatment costs directly correlate with the flow of wastewater treated. Practicable means of recycling and reusing water are presented in this section in the context of reducing treatment cost by significantly reducing the flow of wastewater needing treatment. Examples include water reuse in cooling towers or scrubbers to benefit from the water reduction (evaporation) inherent in these processes.

Overview of Water Reuse Opportunities in Power Plants

Water reuse planning must take into consideration the quantity and quality of each water use, and quantity and quality of the wastewater streams. The myriad of water quality characteristics can be focused on suspended solids and salts content. Typically, salts are more problematic to treat; however, some reuse alternatives may be salt-tolerant. The primary candidates for reusing water are configurations where cleaner wastewater streams are used for water uses that can use low-quality water. The focus should be on the larger wastewater streams and water uses.

EPRI has previously developed a methodology to evaluate reuse of water for cooling towers; this method works well in considering reuse across a plant [25]. This methodology includes the following steps:

- Identify and characterize wastewater sources and constituents of concern
- Identify design and operating impacts on the system where water will be reused, and determine treatment needs
- Evaluate treatment requirements for water reuse
- Evaluate disposal issues

Identify and Characterize Wastewater Sources and Constituents of Concern

The biggest advantages in terms of water use and wastewater treatment cost reductions will come from reusing streams with the largest flows. However, these may not be the best candidates for reuse if they are of poor water quality. Table 5-1 describes typical wastewater streams in a power plant. The water quality of the significant streams in Table 5-1 is described in Section 2.

Table 5-1
Reuse Considerations for Typical Wastewater Streams in a Power Plant

Wastewater Stream	Flow* (MGD)	Relative Solids Load (Before Settling)	Relative Salt Load
Fly ash transport	>10	High	Medium
Cooling tower blowdown	1 to 10	Low	Low to Medium (depends on cycles)
Bottom ash quench and transport, if water used once	1 to 10	High	Low
Bottom ash quench and blowdown, if solids removed and water recirculated	<1	Medium	Low
Plant drains and sumps	1 to 10	Low to Medium	Low to Medium
Pump seals	<1	Low	Low
Boiler blowdown	<1	Low	Low
Miscellaneous washdown	<1	Low to High	Low to Medium
Demineralizer regeneration waste	<1	Low	Very High
Filter backwash	<1	Medium	Low
FGD blowdown	<1	High	High
Coal pile runoff	<1	M-H	Medium

Note:
* Flow is described for an 800 megawatt power plant. Larger plants could have higher flows than the ranges shown; smaller plants could have smaller flows.
MGD = million gallons per day

Identify Design and Operating Impacts on the System Where Water Will Be Reused and Determine Treatment Requirements

There are varying water quality requirements between water uses at a plant. Table 5-2 describes typical water uses in a power plant and the relative quality of water required. These are discussed in the sub-sections below. If wastewater being reused does not meet the water quality requirements of the water use, treatment will be needed. Options for treatment for reuse are discussed later in this section.

Table 5-2
Reuse Considerations for Typical Water Uses in a Power Plant

Water Use	Flow Requirements* (MGD)	Relative Water Quality Requirements
Fly ash transport	>10	Can accept-low quality water
FGD water make-up	1 to 10	Can accept-low quality water
Bottom ash quench and transport	1 to 10	Can accept-low quality water
Fly ash wetting	<1	Can accept-low quality water
Dust control – such as haul roads	<1	Can accept-medium quality water
Cooling tower make-up	>10	Can accept-medium quality water
Miscellaneous washdown	<1	Can accept-medium quality water
Boiler feedwater	<1	Requires high-quality water
Pump seals	<1	Requires high-quality water
Water and wastewater treatment operations, demineralizer water treatment plant feedwater, water to backwash filter, ion exchange regeneration, chemical mixing and dilution, clean in place	<1	Requires high-quality water

Note:
* Flow is described for an 800 megawatt power plant. Larger plants could have higher flows than the ranges shown; smaller plants could have smaller flows.
MGD = million gallons per day

Impacts of Reusing Water for Fly Ash Sluice

If a plant uses water to sluice fly ash, or a hydroveyor (a system in which water is used to generate a vacuum to move ash pneumatically), relatively low-quality water can be used, as long as fines are removed well enough to avoid abrading system components.

Impacts of Reusing Water for Cooling Tower Makeup

Cooling tower makeup is one of the most frequent areas for reuse of water. At some sites, all or nearly all wastewater streams are routed to the cooling tower. Evaporation from the cooling tower reduces wastewater. Because of the focus on cooling tower water chemistry for successful operation, much is known about water quality requirements. The quality of wastewater streams that are candidates for reuse as cooling tower makeup should conform to the following generic water quality requirements: 1) must not cause a wastewater effluent permit violation; and 2) must not cause an exceedance in air emissions permitted limits.

The cooling tower typically includes a basin with inherent surge capacity and heat sink advantages. Pretreatment may or may not be required, depending on the wastewater source and site's discharge limits. An evaluation of the cooling tower and basin materials of construction must be made to determine whether there are concerns for corrosion or impairment of performance. Cooling tower circulation water quality limitations must be compared with the anticipated quality following wastewater recovery.

Limiting concentrations of parameters of concern for cooling tower reuse have been provided in previous EPRI reports [25]. The water quality criteria for cooling towers are based upon practical experience. The major operational concerns include:

- Minimizing mineral scaling and biological fouling of heat transfer surfaces
- Minimizing corrosion of heat transfer and structural metal
- Minimizing fouling loads on cooling tower fill

Operational concerns for water reuse include inorganic scale formation, biofouling of media, clogging of media with high suspended solids, foaming, and odor release.

When reused water is supplied for cooling tower make-up, trace metals and volatile compounds in the reused water can present an environmental risk. Power plant workers may be exposed to cooling tower water when working around the tower and exposed to tower drift. Therefore, worker exposure should be considered when evaluating reuse options.

Impacts of Reusing Water for Flue Gas Desulfurization Source Water

FGD scrubber systems are good candidates for wastewater reuse, subject to the type of scrubbing system and the scrubber manufacturer's specific requirements. Evaporation from FGD systems reduces wastewater. Water for reuse should be evaluated against operational concerns including corrosion and inorganic scale formation, plugging of spray nozzles, and interference with scrubbing efficiency.

Although in most cases process wastewaters may be added as FGD scrubber makeup water, one facility that was interviewed as part of this study indicated that they had attempted a water reuse project where cooling tower blowdown was used for FGD scrubber makeup water. The results of their study concluded that it was very difficult for gypsum to be dewatered because the crystal structure changed after cooling tower blowdown was used as FGD scrubber makeup water. It was unclear why this occurred but the interviewee noted that gypsum dewatering improved once cooling tower blowdown use was stopped.

Impacts of Reusing Water for Fly Ash Conditioning

At plants with dry fly ash handling, a relatively small amount of water is needed to wet the ash before landfilling to stabilize the ash. This water can be very low quality, such as wet FGD blowdown, and the stabilized ash can lock up pollutants in the water. Water requirements for stabilizing ash range from 250 to 400 liters per cubic meter of fly ash [26].

Cementitious ash is pozzolanic and hardens when mixed with water. This can provide a means for disposing of chlorides and fines from FGD wastewater. This can reduce, or even eliminate, a liquid FGD blowdown. This practice is in use currently at some power plants.

Impacts of Reusing Water for Dust Control

Wastewater can be used to control dust in various areas of a power plant.

Coal Pile Dust Control

A typical usage rate is 300 gallons per acre per day; however, this rate may vary considerably depending on climatic conditions such as rainfall and evaporation rate [26].

Ash Handling Dust Control

High TDS and TSS wastewaters can generally be used for ash dust control during the handling and trucking process. This application requires relatively low quantities of water.

Dirt Roads Dust Control

Wastewater with moderate concentrations of TSS wastewaters can generally be utilized for dirt road dust control. Application of excessive wastewater volume can result in surface runoff issues that can lead to non-compliance with storm water management permit requirements. For example, the State of Michigan limits wastewater brine application for road dust control to 1,250 gallons per acre, at application intervals that ensure no surface runoff.

Impacts of Reusing Water for Bottom Ash Quench and Sluice

Bottom ash quench systems are often employed to remove and convey (by sluicing) the hot ash from bottom ash hoppers. Bottom ash sluice water systems can use water once (sluice water is discharged after moving the bottom ash to a pond or recovery area), or a recirculating water system can be used where after the bottom ash is settled out the water is returned to convey bottom ash again. In recirculating systems, the sluicing water is typically recirculated through settling and dewatering tanks for removal of ash fines. Some blowdown and/or treatment is required to maintain water quality. Low-quality wastewater can be used for sluicing bottom ash, as long as fines are removed well enough to avoid abrading system components and it is not corrosive or scaling to the ash sluice system.

Impacts of Reusing Water for Miscellaneous Washdown Water

Washdown water should be of filtered and disinfected quality to protect personnel from exposure from splashing and misting.

Impacts of Reusing Water for Boiler Feedwater

Demineralized water quality is required for makeup to high-pressure steam generators typically used in coal-fired power plants. Wastewater candidates for this application need to be low in TDS and particulate matter to minimize any pretreatment that may be required.

Boiler feedwater is produced typically by using a RO process followed by either an electro-deionization process or a mixed bed ion exchange process to produce demineralized water. In the steam-generation system, the boiler feedwater is typically added to internally recycled condensate and converted to high purity and high-pressure steam. Thus, the water quality specifications for boiler feedwater allow only trace impurities. For example, total organic carbon is typically limited to 100 micrograms per liter (μg/L) and silica (as SiO2) to less than 10 μg/L. Therefore, the potential use of recycled wastewater as makeup to the demineralization process must be carefully scrutinized to ensure that the applicable water quality specifications can be consistently maintained and that demineralized water treatment equipment can perform.

Impacts of Reusing Water for Boiler Blowdown Quench Water

Boiler blowdown may be quenched with direct contact cooling. Water used for this purpose is referred to as quench water.

Corrosion of carbon steel pipe downstream of quench water injection can be an operational issue. Steps must be taken to ensure that wastewater’s corrosive and scaling tendencies are chemically neutralized prior to reuse as quench water.

Impacts of Reusing Water for Pump Seal Water

Reuse for pump seals should be limited to low TDS (<500 mg/l) and TSS (<5 mg/l) water to protect the pumps. Operational issues to be addressed include obstruction of flow due to buildup of suspended matter and iron particulate.

Evaluate Treatment Requirements for Water Reuse

If wastewater does not meet the water quality needs for reuse, treatment will be required. Some candidate treatment technologies are the same as those used for treating water prior to discharge (discussed in Section 6), such as removal of suspended solids by clarification. However, removal of salts that cause scaling and corrosion will require other treatment technologies. These technologies are similar to those used at power plants for treating source water such as ion exchange, softening, or RO. Reused water will typically have more contaminants than plant source water (rivers, lakes, and groundwater), so these technologies may need a more robust design when used on recycled water.

Ion Exchange

Two types of ion exchange techniques typically used to treat water are strong-anion ion exchange and chelating resin. Strong-anion ion exchange removes anions such as arsenic, selenium, chromium, and chlorides. Chelating resin ion exchange removes heavy metals such as copper, nickel, cadmium, and zinc.

Ion exchange columns are typically protected from fouling by an upstream filter. In the ion exchange process, water enters the top of the vessel and the flow is evenly distributed. As the water moves through the vessel it passes through the ion exchange resin where anions or cations of concern are exchanged for desired ions, e.g. sodium ions. Treated water is collected at the base of the bed and exits to service. When the ion exchange resin becomes fully loaded, the vessel is taken out of service. The resin is regenerated, and then it is ready for service. Wastes include solids from filter backwash and resin regenerate.

Softening

For large-scale cooling systems, lime or lime/soda softening is recommended for make-up treatment, as hardness removal will usually allow the cooling tower to operate at higher cycles of concentration. Lime/soda softening removes hardness (calcium and magnesium) and carbonate alkalinity (CO_2, HCO_{3+1} and CO_{3+2}). Phosphate, fluoride, and suspended solids are also removed in make-up water softening. Some incidental removal of silica is expected. Additional treatment beyond softening may also be needed to meet water quality requirements.

Reverse Osmosis

Reverse osmosis a membrane filtration method that removes dissolved solids such as salts and heavy metals from contaminated waters. Contaminants in recycled water that may foul RO membranes include calcium, magnesium, alkalinity, sulfate, silica, chloride, iron, total organic carbon, and TSS. Therefore, in cases in which the quality of the feed water is poor, an upstream solids-removal process (conventional treatment, gravity filtration, microfiltration, or ultrafiltration), or lime softening may be necessary.

Evaluate Disposal Issues

Wastewater Effluent

Some water reuse strategies lead to a concentrating or “cycling up” of soluble constituents and fine particulates in wastewater. Discharge limits on permitted outfalls (and internal monitoring points) need to be considered in planning water reuse to ensure these limits are not exceeded.

Impacts associated with wastewater reuse from facilities that discharge either directly (governed by NPDES regulations) or indirectly (to municipal wastewater treatment systems) are dependent on the site-specific permit conditions. Wastewater effluent constituents that are currently regulated in a power plants under the Categorical Effluent Guideline rule of 1982 include TSS, oil and grease, pH, and in some wastewaters copper, iron, and zinc.

Land Disposal

Solid waste byproducts associated with treating water for reuse may include ash, dewatered sludge from cooling towers or wastewater treatment systems, or solids from water and wastewater treatment systems. Changes in contaminant levels in the solid waste byproducts because of wastewater reuse are not likely to affect land disposal requirements. However, changes in solid waste characteristics because of wastewater reuse should be evaluated.

6

WATER TREATMENT TECHNOLOGIES FOR WASTEWATER DISCHARGE

This section discusses options for treating process wastewater before it is discharged. Treating water so that it can be reused is also discussed in Section 5. Constructed treatment systems are typically more expensive than co-management of wastewaters in ponds. Further, they are mechanical systems that are subject to downtime for maintenance and require operation staff support. Therefore, reliability and redundancy must be built into the treatment plant design and operation plans commensurate with the uptime requirements of the associated power plant. Many coal-fired power plants therefore currently rely on pond-based management of these wastewaters.

Evaluating Process Wastewater Treatment Options for Discharge

In assessing the need for treatment of process wastewater streams for discharge previously managed in ash ponds, the following management options are considered:

1. Treatment of liquid and disposal of solids in a dedicated pond
2. Tank-based treatment of liquid and disposal of dewatered solids in a landfill
3. Zero liquid discharge configuration

In deciding how to manage and route the untreated process wastewater, a plant must consider the projected discharge characteristics against current and projected limits.

Waste and ash transport discharges are subject to the current technology-based national effluent standards, shown in Table 6-1[2]. Some discharges will be subject to water quality-based limits. The USEPA is currently updating the national Effluent Limitations Guidelines (ELGs), and the future limits for the industry are currently uncertain. They may contain technology-based limits that go beyond the current limits to include trace metals and other constituents.

Table 6-1
Categorical Effluent Standards (Title 40 CFR 423)

Parameter	Units	Monthly Average Limit	Daily Maximum Limit
TSS	mg/L	30	100
pH	standard units	6.0 to 9.0	not applicable
Oil and Grease	mg/L	15	20

Source: EPRI *Technical Manual: Guidance for Assessing Wastewater Impacts of FGD Scrubbers* (EPRI, 2006) [2]

Gravity Settling in Ponds

Constructed ponds have proven very effective for the removal of suspended solid and metals through gravity settling. The solids removal efficiency is usually greater than 99 percent and reduces TSS to below 30 mg/L [15]. Metals present as particulates are well removed. Removal of soluble pollutants is typically limited to precipitation of cationic metals (if pond is neutral or slightly alkaline). Figure 6-1 shows percent reduction of metals through ash ponds at PISCES sites, indicating that there are high removal efficiencies for metals through ash ponds. The best removal percentages are seen for metals that typically partition into the particulate form in power plant wastewater, such as mercury. Less removal is seen for metals that enter the ash pond with significant dissolved fractions, such as selenium. Settling tests have shown that lower overflow rates enhance solids and metals removal when using gravity settling methods [2].

The solubility of cationic metals is predominately controlled by pH, with a range of minimum solubility and increasing solubility above and below this minimum. This solubility is predominately controlled by hydroxides. However, anions such as carbonate, phosphate and sulfide can reduce the solubility, and other anions such as chloride can increase the solubility.

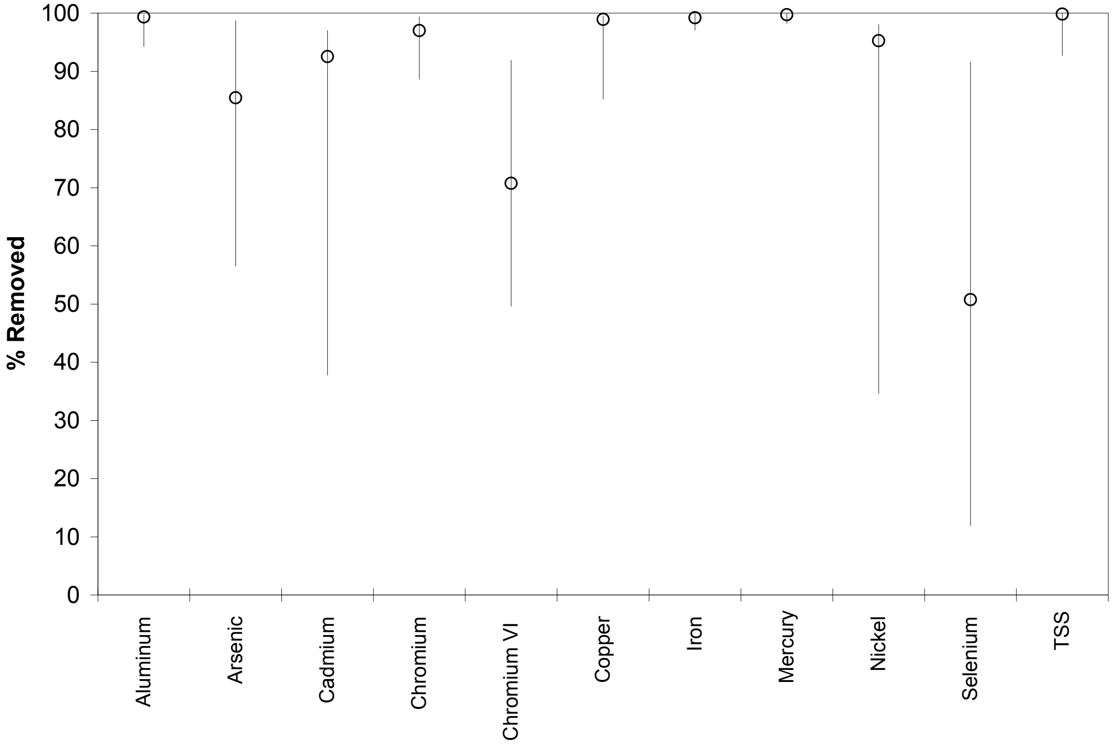

Figure 6-1
Metals Removal in Ash Ponds at PISCES Sites

Note: Range shows median, 5th and 95th percentile of Percent Removed at each of the PISCES program sites. Removal defined as [1 – (Median of Effluent samples) / (Median of Influent samples)].

Regulatory changes regarding ponds used at power plants are anticipated. The proposed Draft Coal Combustion Residuals Rule will consider the requirement of pond liners, leachate collection systems, and monitoring programs. The current regulatory uncertainty surrounding this Rule makes planning for pond design and operation problematic.

pH Control in Ponds

The pH of ash ponds can be controlled by adding an acid or caustic. Treatment of wastes for removal of trace metals using settling ponds requires effective pH control. pH control with acid or caustic feed at the head of the pond (not at the discharge point) enhances metals precipitation within the pond [15]. pH swings should be avoided to minimize spikes of metals concentrations in the pond effluent.

Table 6-2 shows the various mechanisms for particulate and soluble metals removal within ash ponds. Regardless of other factors, ash ponds provide very efficient metals removal. Metal-rich ash solids are removed through settling. To a lesser extent, metals are removed by precipitation and subsequent settling of the precipitated metals. Overall treatment of metals can be grouped into three categories, as shown in Table 6-2.

Arsenic and selenium precipitation is not controlled by hydroxide compounds. Therefore, pH does not have a direct influence on the solubility of these compounds. Removal is dependent on other reactions, such as precipitation by metals such as iron, adsorption, coprecipitation, biological uptake, and subsequent settling.

Table 6-2
Categories of Treatment Performance in Ponds

Category and Constituents	Treatment Mechanisms
Metals with solubilities influenced by pH: Copper, nickel, zinc, antimony, beryllium, aluminum	Particulate form removed by settling of bulk solids. Additional removal via precipitation that is controlled by pH-based solubility, which has a minimum point above and below which concentrations increase. For most cationic metals this minimum solubility is at pH above 8.0. Within the range of pH conditions seen in ash ponds (up to 9.5), solubility did not increase. Therefore, within typical ash pond pH conditions, the higher the pH the lower the concentration of these metals. Hexavalent chromium solubility is not affected by pH but the conversion to less toxic trivalent is increased at lower pH.
Metals with solubility unaffected by pH: Arsenic and selenium	Particulate form removed by settling of bulk solids. Additional treatment may occur through coprecipitation and biological removal.
Metals present primarily as solids: Iron, mercury, lead	Particulate form removed by settling of bulk solids. Low solubility so effluent concentration will be based on effectiveness of settling.

Source: *PISCES Water Characterization Water Toxics Summary Report* (EPRI, 2002) [15].

Passive Treatment

Engineered wetlands are designed and constructed to use vegetation, soils, and associated microbial activity to provide treatment of wastewater. Constructed wetlands take the form of surface flow wetlands (shallow constructed marshes), subsurface flow wetlands (planted beds of gravel or soil media with water flowing through the root zone), or variations on subsurface flow systems such as vertical down flow wetlands. Another form of passive treatment is passive biochemical reactors, which operate as subsurface wetlands without the vegetation. Passive biological treatment systems such as biochemical reactors and constructed wetlands have been shown to effectively remove anionic toxic metals, such as selenium, arsenic, boron and vanadium, from irrigation drainage water. Portions of some ash ponds have wetland conditions that, although not designed for metals removal, may provide treatment in that portion of the ash pond water flow that passes through them. Emergent macrophytes, shallow systems of attached algae (i.e., periphyton), submerged aquatic vegetation, and floating mats of plants such as water hyacinths have been shown to assimilate and then deposit arsenic and selenium in accumulated biomass.

Tank-Based Wastewater Treatment Processes for Treatment of Process Wastewaters

Constructed treatment systems are typically more expensive than co-management of wastewaters in ponds. Further, as noted above, they are mechanical systems that are subject to downtime for maintenance and require operation staff support. Therefore, reliability and redundancy must be built into the treatment plant design commensurate with the uptime requirements of the associated power plant.

The wastewater treatment processes selected for process wastewater treatment are determined by the parameters that require removal prior to discharge or co-mingling with non-similar wastestreams, consistent with the facility's NPDES permit. The main parameter of concern for process wastewater management is the removal of suspended solids from the waste stream, which is accomplished by settling. Additional parameters of concern may include metals removal. Chemical precipitation is used for the removal of many dissolved contaminants from liquid streams. Figure 6-2 shows a treatment train that would be appropriate for process wastewater treatment. The processes include equalization, chemical precipitation, clarification, pH adjustment, and solids dewatering. Filtration and organosulfide addition treatment processes (presented as dashed lines in the figure) are also possible treatment processes, although they would typically only be used if stringent metals limits exist that require enhanced metals removal.

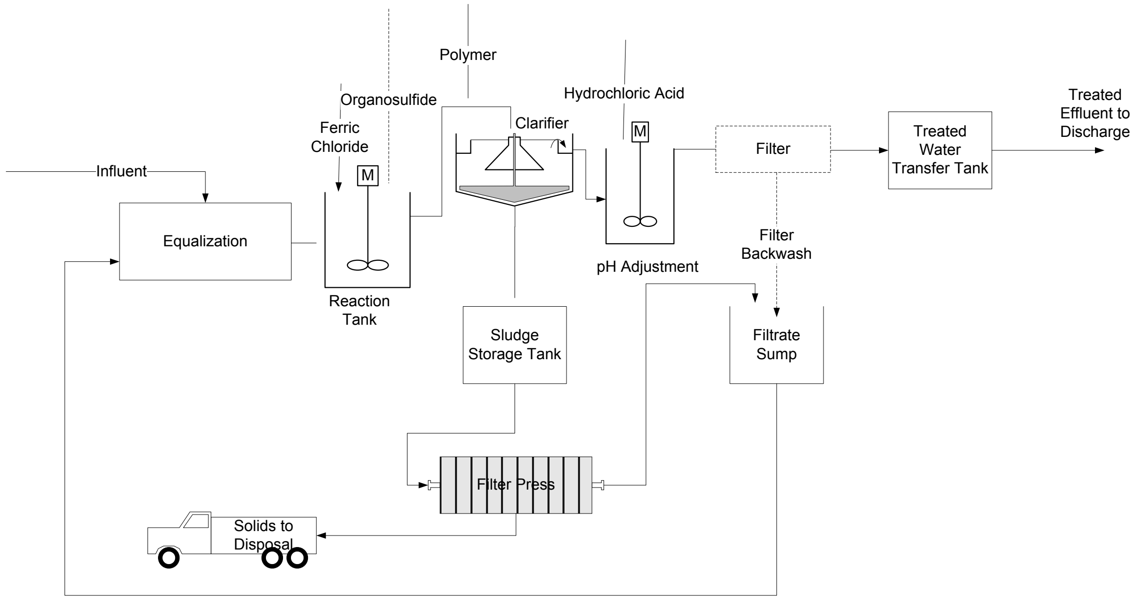

Figure 6-2
Process Flow Diagram for an Example Process Wastewater Treatment System

The function and basic design elements of each of the unit processes is described in further detail in this section. Design and operational considerations are discussed for the unit processes.

Table 6-3 provides typical design criteria for each of the treatment units. These design criteria are also used in determining the costs of treatment. The cost of treatment for wastewater discharge is discussed further in Section 7. Ferric chloride and organosulfide dosages are largely dependent on influent concentrations of constituents for removal.

Table 6-3
Typical Design Criteria for Process Wastewater Treatment

Equipment	Design Criteria	Criteria
Equalization	Hydraulic Detention Time, Hours	12 to 24 hours
Clarifier	Overflow Rate at Peak Flow, gpm/sf	0.33
Organosulfide Mix Tank	Organosulfide Dose, ppm	10*
Ferric Chloride Mix Tank	Ferric Chloride Dose, ppm	50*
	Hydraulic Detention Time, Minutes	15
Gravity Filters	Media	Anthracite and Sand
	Hydraulic Loading Rate, gpm/sf	3
	Backwash Rate, gpm/sf	20
	Backwash Duration, Minutes	15
Plate and Frame Filter Press	Feed Solids Concentration	Up to 10% - 20%
	Minimum Dewatered Solids Concentration	40%
	Preferred Dewatered Solids Concentration	Up to 60%
	Cycle Duration, hour	2

Notes:

ppm = parts per million
gpm/sf = gallons per minute per square foot
* Dosing can vary widely with wastewater characteristics. Value presented is an example.

Equalization

Flow equalization is a technology used to reduce flowrate and wastewater composition variations to improve the performance of the downstream processes, and to serve as storage of intermittent internal wastewater flows. Equalization is provided for in situations in which the flow is delivered to the treatment plant intermittently.

Equalization should be designed to provide continuous flow to the treatment plant. It is advantageous to maintain a constant flow to the treatment system to minimize fluctuations in chemical addition that might affect the ability of the clarifiers to remove suspended solids from the wastewater. Ideally, the wastewater flow will be kept at the lowest flow possible yet high enough to eliminate flow surges to the clarifier. Rapid changes in flow can result in clarifier instability.

Equalization serves the following functions for process wastewater treatment:

- Dampens the variability of flow, which reduces the loads on treatment processes and enables the use of smaller treatment systems than would otherwise be required to handle peak loads.
- Reduces the variability of wastewater composition, further improving the stability of treatment processes, particularly when chemical additions are needed to respond to changing requirements. The equalization of flow prevents short-term high volumes of incoming flow from forcing solids through clarification without removal.
- Allows for the storage of intermittent wastewater flows, including recycled flows within the treatment system such as filter backwash water.
- Controls the flow through each stage of the treatment system, allowing adequate time for the physical and chemical treatment processes to take place.

Equalization is generally placed at the beginning of a treatment train to accomplish the above functions. This allows the downstream clarifier and associated equipment to be sized smaller than if there were no upstream equalization to handle the peak daily flow rather than instantaneous peaks, which is needed if equalization is not provided. However, especially in cases where the wastewater treated contains high solids (greater than 2 percent), equalization can be placed after primary clarification, and a subsequent secondary clarifier is used further downstream.

For equalization design, the following factors must be considered:

- Site location constraints - sites may be limited by availability of space for construction of new large equalization systems
- Geometry - tanks or equalization basins may be constructed as rectangular or circular
- Construction - including clearing, access, and safety
- Mixing requirements - mixing may be required to keep solids from settling out within the equalization basin/tanks, requiring more maintenance
- Pump/pump control systems and other operational appurtenances- providing redundancy in the system and capacity for handling flow peaks.

In order to evaluate sizing for equalization, peak flows for all the various influent process wastewater streams that will flow to the treatment plant will need to be evaluated and peak daily flow determined. It is important to have a water balance with adequately characterized peak flows to assist in determining sizing for equalization. The volume of equalization must also account for recycle streams that are expected, if flows are returned to equalization. Storm water can be a significant contributing flow for equalization and depending on the site may be the major stream contributor to equalization. In addition, contingency should be provided for unforeseen issues such as future wastewater re-routing or increase in wastewater flow.

Typical hydraulic detention times for equalization vary based on site-specific requirements and constraints. Typical hydraulic detention times for process wastewater systems should be between 12 to 24 hours. The various factors that contribute to equalization sizing should also be weighed against economic constraints to determine optimal overall treatment plant sizing.

Chemical Precipitation

Chemical precipitation can be used to help remove dissolved trace metals. Metals are present in wastewater in either particulate or soluble form. Although some process wastewater treatment facilities may only require removal of suspended solids, adding the capacity for chemical precipitation may be needed to meet present or future discharge permit limits. A chemical precipitation system generally consists of a chemical feed system, mix tank, and mixer. Common processes in power plants to remove trace metals from wastewater include pH adjustment to cause precipitation of metal hydroxides, iron co-precipitation, and organosulfide addition.

As the chemistry of process wastewater entering a treatment plant may vary significantly, it is important to factor in flexibility to adjust dosing for a chemical precipitation system. Examples of design considerations include automatic pH control using caustic and acid addition, or flexibility in the programming of the programmable logic controller to account for easy user control of chemical dosing.

Metal Hydroxide Precipitation

Various metallic ions (Cu^{+2}, Ni^{+2}, Cd^{+2}, Cr^{+3}) can be precipitated from solution with the addition of sodium hydroxide. Metal precipitation techniques require good chemical feed control because some metals precipitate in a narrow pH range. For instance, to simultaneously remove Cu+2 and Ni+2, two separate precipitation stages will be required. Table 6-4 shows the optimal pH range for the precipitation of several metals [25].

Table 6-4
Optimal pH Range for Chemical Precipitation of Trace Metals

Metal	pH_{min}	pH_{max}
Cu^{+2}	7	7.5
Ni^{+2}	9	11
Cd^{+2}	9	11
Cr^{+3}	6.5	7

Source: *Use of Degraded Water Sources as Cooling Water in Power Plants* (EPRI, 2003) [25]

Iron Co-Precipitation

Metals removal can also be enhanced over that achieved by metal hydroxide precipitation through iron co-precipitation. Iron is added for precipitation of metals and for coagulation of suspended solids. The following is the simplified chemical equation to represent this reaction.

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_{3(solid)} + 3H^+$$

Equation 6-1

Dissolved metals concurrently adsorb and precipitate with the ferric hydroxide solid that is developed during this reaction. Heavy metals form their insoluble hydroxide products and attach to the highly charged, relatively dense ferric hydroxide precipitate. Ferric chloride is a common coagulant used to remove suspended particulate material in wastewater. An advantage of using ferric chloride over other coagulants for suspended solids removal is that the ferric hydroxide solid that is formed also binds and precipitates dissolved metals. Dosages for iron co-precipitation vary greatly. Dosages should be optimized based on the case-specific combined process wastewater streams being treated.

Mixing is critical within the process. Mixers should be designed to keep solids from settling on the bottom of the tank. Mixers for chemical mix tanks should be designed to minimize shear on iron precipitates (floc) and other metal hydroxide solids. Avoiding shearing of metal hydroxide floc improves solids settling and dewatering. A variable speed mixer is recommended to balance the requirement of adequate mixing for solids suspension and limiting of shear. Mixer speed adjustment should be used during system startup to identify the speed resulting in optimum solids mixing and particle size. Most reaction tanks in power plant wastewater treatment systems should have hydraulic detention times of up to 15 minutes. Radial flow impellers or axial flow impellers designed specifically for low-shear flocculation applications should be used. Influent mix tanks equipped with flocculating variable speed mixers should be designed with the variable frequency drive control between 1 and 5 feet per second and a maximum turbine tip speed of 2 feet per second.

Recirculation of sludge to the influent mix tank improves metals removal and the formation of a denser granular sludge that improves settling, reduces the need for polymer addition, and improves the subsequent dewaterability of the sludge. Recycle sludge should be added from the clarifier bottoms near the influent line to the mixing tanks to take advantage of mixing provided by entry flow turbulence.

Sludge recycle can produce large solids particles that tend to build up if water is removed from the surface. One way to overcome this is high energy mixing, with its adverse impact on iron floc. Another is with bottom exit tanks; however, bottom exit lines have a tendency to plug.

Another method to prevent flow short-circuiting and remove dense solids from the bottom of the tank is to include dip tubes at the discharge lines from the influent mix tank. The dip tubes normally take flow from the bottom of the mix tank, but are equipped with overflow openings. If the bottom of the tubes were to plug, the tanks will flow over the top of an open tee at the top of the dip tube and into the clarifier influent line. The mix tank exit connects to a gravity line that flows to the clarifier at a slope sufficient to prevent solids deposition even at low flow.

Organosulfide Addition

When metals removal is required to levels below those that can be met using iron co-precipitation and filtration, organosulfide metals precipitation can be used to help remove many trace metals. Organosulfide addition is typically used to enhance mercury removal in power plant wastewater. Organosulfide compounds are cationic metal-binding polymers that are used to counter the solubility of mercury and other cationic metal chloride complexes, and form precipitates of mercury that can be removed. Polymer addition may be needed after organosulfide precipitation to enhance flocculation.

Various organosulfides are available from numerous vendors (e.g. Nalco’s Nalmet-1689, Evonik’s TMT-15, etc). Organosulfides are used at numerous power plants for mercury removal from FGD wastewater. Some power plants have conducted treatability tests on different types of organosulfides and noted improved performance with one over another. At one site, organosulfide addition improved removal of dissolved mercury from FGD wastewater by up to one order of magnitude. The effect of sulfide precipitation on mercury treatment is also evidenced by the fact that several plants have improved mercury treatment by changing the concentration or type of organosulfide added (EPRI, 2010). One power plant has conducted treatability testing that showed that organosulfide addition alone was sufficient to meet mercury limits and the iron co-precipitation process is no longer used at that facility, reducing chemical operating costs. If power plants need to meet stringent mercury limits on their process wastewater, it is recommended that treatability testing be conducted to determine the optimal organosulfide type and dosage for the site-specific application.

Clarification

Polymer Addition

Clarifier performance can be enhanced by adding polymers. Polymer is often used to help coagulate solids prior to clarification. It is therefore prudent to include a flocculation well in the primary clarifier and to provide the ability to add polymer at this point. Polymer doses vary widely based on the type of polymer and the water chemistry. Polymer may be added to the mix tank effluent pipe to provide initial mixing in the gravity line to the clarifier. If a treatment plant employs sludge recycling this may eliminate the need for polymer. The need for polymer addition may increase during intermittent periods, such as when air heater and precipitator washes are treated causing elevated solids and metals loadings.

Care must be taken not to overdose polymers (particularly anionic polymers) to the clarifier. Such overdosing can cause binding of filter press filter cloths used to dewater solids removed by the clarifier. Overdosing polymers can also create solids that do not settle well, increasing solids passing through the clarifier. Polymer addition should be considered supplemental to achieving a dense, fast-settling particle through sludge recycling and use of low-shear sludge pumping and reactor mixing. Polymers capture solids but tend to trap water in the resulting matrix, thereby reducing the density of the resulting sludge.

Clarifier Overview

Clarifiers are used to settle out solids. Various types of clarifiers exist, including rectangular, circular, stacked, and plate-and-tube settlers. Rectangular and circular clarifiers are the most commonly used. For high solids- and metals-removal efficiencies by gravity settling methods, a surface overflow rate of 0.33 gallon per minute per square foot (gpm/sf) is recommended when treating process wastewaters. If a system is designed with parallel clarifiers, when one clarifier is out of service, a surface overflow rate of 0.5 gpm/sf is recommended.

Wastewater should flow by gravity to a clarifier. Clarifiers are equipped with a clarifier mechanism with rake arms used to remove settled solids. The flocculator provides gentle mixing of the solids and polymer to promote particle growth to enhance settling of the solids. The flocculated mixture passes below the skirt of the flocculation zone and enters the clarification zone. Solids settle to the conical, sloped bottom of the clarifier and clarified liquid rises to the top and exits as overflow from the clarifier. Table 6-3 shows a typical design criterion for clarifiers.

Lamella clarifiers have smaller footprints than traditional clarifiers so can be used if space is limited. However, lamella clarifiers cannot handle as high a solids loading as a traditional clarifier so would need an upstream primary clarifier if significant solids were present in the wastewater. Lamella clarifiers are most appropriate when they can be shop-fabricated and delivered. They tend to present less cost savings when larger than the size that can be shop-fabricated. Lamella clarifiers need to be indoors in cold climates while conventional clarifiers do not. Use of lamella clarifiers also necessitates building the upstream mix tanks on stilts to eliminate the need for pumping water after a floc is formed. This would also be true with circular clarifiers unless the clarifier is built in-ground.

Process wastewater varies widely in suspended solids, depending on the source. Process wastewater generally has lower suspended solids concentration than FGD wastewater. Generally, wastewater that contains greater than 2 percent solids (20,000 mg/L) may require two clarifiers (referred to as a primary and a secondary clarifier) instead of just a single clarifier. In the event that both primary and secondary treatment is required, the goal of primary clarification is to reduce solids to below 1,000 mg/L, not to completely remove solids. Secondary clarification is used to remove the remaining solids and other elements (e.g. metals) requiring removal.

Clarifiers are designed to provide for sludge thickening, with a steeply sloped floor and high-torque mechanisms. Primary clarifiers must be sized for solids-holding capacity as well as for hydraulic overflow. Sludge volume is limited in a sludge hopper so a larger thickener bottom is recommended to provide sludge volume adequate for effective sludge recirculation to the mix tank.

When using a lamella clarifier, sludge recirculation must be optimized and polymer addition minimized to produce a solid that will slide easily down the lamella plates. Otherwise, the sludge may tend to stick to the plates, causing sudden breakthrough of solids and frequent maintenance of draining the water level below the plates and cleaning them. A peak overflow rate of 0.5 gpm/sf is sufficient for solids settling in a lamella clarifier. However, sludge storage may not be sufficient.

Optimally, solids should thicken to 10 to 20 percent solids in the underflow from the primary clarifier/thickener. Sludge wasting flow is controlled based on the density of the sludge. Less than 10 percent solids results in poor dewatering, high moisture sludge cake, sludge sticking to filter cloths, increased operator attention, and long filter press cycle times. If sludge is greater than 20 percent solids, dewatering will be hampered by poor distribution of sludge to a filter cloth and plugging of sludge distribution piping. Over-thickening can be prevented by controlling the sludge-recycling rate or sludge wasting.

Measuring sludge density at a fixed depth in the clarifier is useful in controlling sludge wasting. It is recommended that positive displacement pumps be used for sludge recirculation and wasting to minimize shear.

It is desirable to flush the sludge lines from clarifiers when the sludge pumps are shut down to reduce the tendency of these lines to plug. It is best if sludge recirculation and wasting are combined in a single system so that sludge pumps and lines do not need to be turned off during normal operation.

Filtration

Filtration is used to remove TSS and heavy metals in particulate form. Filtration will typically not be used in process wastewater applications unless metals limits cannot be met with chemical precipitation and clarification. Sand filters can reduce TSS to below 10 parts per million and generally remove solids that are 5 micron or larger.

The selection of filter media is an important consideration in filtration design. The selection will affect the entire design and operational factors including removal efficiency, hydraulics, footprint requirements, and capital and operation costs. The primary media properties that should be considered include:

- Grain effective size, uniformity coefficient, shape, and density;
- Effective pore and collector size;
- Porosity;
- Bed depth

Use of two or more layers of media, each with a different specific gravity, promotes longer filtration cycles. Typical combinations of media used in dual-media filter beds include:

- Anthracite and sand;
- Granular activated carbon and sand;
- Resin beds and sand;
- Resin beds and anthracite; and
- Garnet and ilmenite (a titanium-iron oxide mineral).

Filters are prone to scaling in waters with high ionic strength. Pre-treatment, such as acidification, may be needed to help reduce scaling. Increased backwashing may also be necessary to help control scaling.

To maintain a desired effluent quality, filters are backwashed to reestablish their hydraulic and treatment capacity. The backwash reject water can be sent either back to the clarifier or to the head of the plant, depending on site-specific conditions. This return of backwash water increases the overall treatment plant sizing due to the extra waste stream that requires treatment. Filtration equipment includes the filter feed tank and filter pump (assuming pressure filter), filter, backwash tank, and backwash pumps. Design criteria for gravity filters are provided in Table 6-3.

Membrane filtration is not used traditionally in power plant wastewater treatment but may be used to target particulate metals that would typically pass through sand filters. Metal sulfide solids, such as are formed when organosulfides are added to precipitate mercury, tend to be very small and may pass a sand filter. Membranes called microfilters are typically sized at 0.1 to 10 micron pore size. As the pore size decreases, the head loss increases and flux decreases, adding to the size and cost of the membrane filter system.

Residuals Management

The solids removed in the treatment processes must be dewatered. The purpose of solids dewatering is to reduce the volume of material and prepare the solids for further processing, beneficial use, or disposal. All dewatering processes generate two products: a solids cake and a stream of liquid removed from the solids. Generally, the liquid stream is sent to the head of the wastewater treatment process.

If solids are to be landfilled, a regulatory limit of “no free liquid” in the dewatered sludge is often imposed. The most common wastewater treatment sludge dewatering technologies are centrifugal dewatering, pressure filtration using a belt press, and pressure filtration using a plate-and-frame filter press.

While there are three possible technologies, the choice typically falls between a belt press and plate-and-frame press. Centrifuges tend to have excessive wear when treating the typically abrasive power plant solids. In addition, centrifuges tend to have fines in the centrate, returning the fines to the process. This has a result of building fines in the treatment process, with adverse results on performance.

A summary comparison of sludge dewatering equipment is provided in Table 6-5.

Table 6-5
Comparison of Sludge Dewatering Equipment

Parameter	Centrifuge	Belt Press	Plate and Frame Press
Operation	Continuous	Continuous	Batch
Dewatering pressure (pounds per square inch)	Not applicable	<20	<220
Polymers	Yes	Yes	No
Dry cake (% solids)	< 50%	< 50%	60 – 80 %
Solids take the form of their container (thixotropic) potential	High	High	Low
Free water potential	High	High	Low
Capital cost	Mid	Lowest	Highest
Operation and maintenance cost	High	High	Lower

Plate and Frame Filter Press

Filter presses can be used in a wide range of solids characteristics, and produce a high-quality filtrate that lowers recycle stream treatment requirements. The process design conditions and criteria include cycle time, operating pressure, number of plates, feed method, type of feed system, layout and access, type of press, mechanical features, and safety. Filter presses dewater solids to 60 to 80 percent.

Belt Press

Belt filter presses dewater solids continuously using two or three moving belts and a series of rollers. The filter belt separates water from solids via gravity drainage and compression. The process design conditions and criteria include cake solids and solids capture, hydraulic loading rates, solids and polymer feed, belt washing, filtrate and dewatered-cake conveyance, equipment access and layout, and odor control.

Belt filter press energy requirements are low compared to some other dewatering method alternatives. Generally, a 2.5-meter wide belt press will require about 10 horsepower.

Hydraulic loading rate is the primary criterion for the design of belt presses. Typical hydraulic rates range from 15 to 22 gpm/ft of belt width [27].

Wastewater Stream-Specific Management Considerations

Process wastes vary significantly in terms of chemical characteristics, quantity, and frequency of generation. Therefore, proper management options for each waste should be considered in designing a treatment system.

Equipment Cleaning Waste

Periodic equipment cleaning at power plants includes cleanings with chemicals, and cleanings with only water. Water used for water-only cleaning or washing is typically managed along with other wastewater streams, although equalization or a dedicated settling area may be needed before mixing with other streams. Both chemical and non-chemical washing waste streams may have technology-based permit limits that must be met prior to co-mingling with other non-similar process wastewaters, consistent with the facility's NPDES permit.

Wastewater associated with boiler chemical cleaning may contain chelators such as ethylenediaminetetraacetate (EDTA), which solubilizes metals. It is not recommended to treat the boiler-cleaning wastewater in an onsite wastewater treatment system. Rinse water from boiler chemical cleaning is also not recommended for treatment, unless a separate batch treatment is provided to first treat the boiler chemical waste, and then the treated wastewater is fed to the plant. Bench-scale studies are recommended to examine the best treatment alternative for boiler chemical wastes. Bench-scale tests should be performed during the planning stage to determine how the wastes will be treated full-scale. Batch treatment may include an oxidizer such as Fenton's reagent (iron catalyst and hydrogen peroxide). This treatment process may take a week or more for the EDTA to be treated effectively with oxidation. The treated wastewater can then be bled into the influent of the wastewater treatment plant to remove suspended solids and if necessary metals that are no longer chelated.

Storm Water Runoff

The main management issue of storm water runoff is to divert and recycle/reuse as much of this water as possible. Engineering methods should be used to ensure that storm water/rainwater runoff is kept separate from process water, thus reducing the amount of water to be treated. Coal pile runoff, gypsum pile runoff, and pyrite pile runoff are examples of process-affected storm water. These carry suspended solids and trace metals, and may be acidic or caustic, and so require management.

Flow spikes associated with storm events are common management issues with storm water. The variability in flow associated with storm water needs to be accounted for in the sizing of both the treatment system and the equalization system. Equalization is required for storm water to handle peak flow. Flow equalization is needed, even if treatment units are sized for high flow, as it is not possible to go instantly from no flow to maximum flow in clarifiers. It is advisable to ramp up flow by about 20 percent of full capacity per hour. For example, for a 5,000 gpm clarifier flow should not be increased greater than 1,000 gpm per hour.

Bottom Ash Blowdown

Receiving bottom ash blowdown and treating it in a tank-based treatment plant can be challenging because of the characteristic temperature and flow variations with this wastewater stream. Although ponds have the capacity to handle these variations, treatment plants - especially biological treatment plants - cannot effectively treat wastewater with large swings in temperature or flow.

Demineralizer Regeneration Waste

Wastewater associated with demineralizer regeneration characteristically has large pH swings, high TDS, and toxicity issues. Figure 6-3 shows pH and conductivity swings in a plant's combined wastewater flow due to demineralizer regeneration cycles of caustic and acid washes. These highly acidic and alkaline spikes require neutralization. Demineralizer regeneration may require separate treatment if the wastewater stream cannot be combined and treated with other process wastewaters.

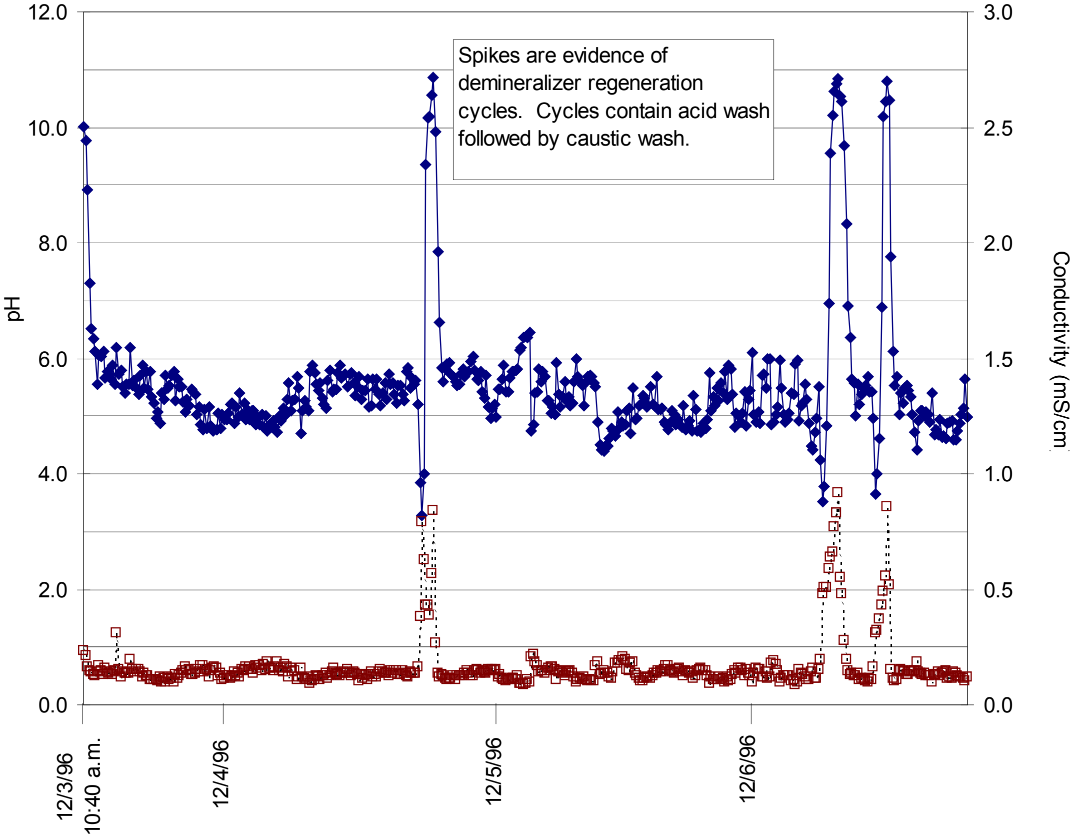

Figure 6-3
Effect of Demineralizer Regeneration Wastewater on pH of Overall Wastewater

Other High-Strength Intermittent Streams

Other high-strength intermittent streams must be accounted for to determine how these flows will be treated. High-strength streams could include streams with high metals content, high TSS, and/or acidic streams. Batch treatment processes may be utilized for wastewaters that contain low or intermittent flows and are of high strength. The batch-treated water can then be slowly bled into the influent of the larger process wastewater treatment plant. Separate treatment is generally required for streams that contain high flows and lower concentrations. Flexible chemical dosage should be considered for process wastewaters that will have only intermittent inputs to the system and could affect overall removals for the treatment system. In addition, dewatering equipment should be considered that are capable of handling electrostatic precipitator and air heater cleaning wastes.

7

WASTEWATER TREATMENT COST CONSIDERATIONS

This section presents fundamentals of estimating costs for treating process wastewater. Key choices that drive the cost of a process wastewater treatment system are presented.

As noted previously, constructed treatment systems are typically more expensive than co-management of wastewaters in ponds.

Factors Affecting Cost

System-Wide Considerations in Design

Some system-wide considerations in design that will affect the system size and cost include system redundancy, designing for future expansion, and materials of construction. These are discussed in Section 6.

The cost of treating process wastewater streams in tank-based systems will be influenced by several factors. Factors that affect capital and operating costs of wastewater treatment include the following:

- Influent flow
- Discharge water quality requirements
- Solids loading
- System redundancy
- Influent water quality
- Designing for expansion to meet future discharge limits
- Site-specific considerations, including space constraints, interferences and foundation requirements

Flow of Wastewater to the Treatment System

The flow of the treatment system is a key factor in the cost of many components of treatment. The flowrate of a treatment system directly influences capital, operations, and maintenance costs. Peak flow affects equipment sizing and therefore capital costs. Equipment is sized based on peak flows to handle maximum reasonable worst-case conditions. However, the plant generally operates at average flow conditions. Therefore, average flow affects operating costs such as chemicals and residuals handling and disposal.

The manner in which wastewater is sent to treatment can affect the ratio of peak to average flow. As discussed in the previous section, equalization can be employed to reduce the overall size of the downstream treatment plant. The more equalization capacity supplied up front, the smaller the capacity of the downstream treatment units needs to be. However, installing equalization is also a major cost component of a system and costs of equalization need to be weighed with treatment equipment costs to determine optimal cost scenario.

Discharge Water Quality Requirements

Discharge water quality requirements will drive the types of treatment processes needed. Solids separation in a clarifier, assisted by feed of chemicals such as coagulants and flocculants, is typically sufficient to meet suspended solids limits. If the facility has low trace metals limits, additional treatment may be required, which adds to the cost of the treatment system.

Solids Loading

Solids dewatering and residuals management (such as landfills) can represent a significant portion of a treatment system's capital and operating costs if the wastewater is high in solids. This is seen in FGD wastewater systems with solids of 1 to 5 percent, where solids dewatering at two facilities represented over 30 percent of the total capital cost of the treatment system. However, most process wastewater streams are typically much lower in solids so dewatering and residuals management become a smaller percentage. The influent solids load determines the number of clarifiers that will be used (generally only primary clarification for process wastewater). As discussed in the previous section, if solids are greater than 2 percent, primary and secondary clarifiers may be needed to adequately remove solids to below 30 mg/L to meet categorical effluent standards. The solids loading also determines solids handling and disposal operational costs, the greater the influent loading the greater the cost of handling and disposal.

Redundancy

It is important to determine how much redundancy to build into a treatment system. For instance, two treatment trains can be designed to allow individual units to be mixed and matched. If an individual treatment unit is out of service, the entire train would then be taken out of service, and the remaining train must handle the entire flow. Accommodations should be made to limit flow during periods when only one treatment train is online, such as during intermittent operation. Minimizing flow is particularly important if the process wastewater treatment system also treats storm water flows, such that other flows can be minimized when storm flows are present.

Redundancy helps to minimize system downtime, but increases cost. Some plants are built with full redundancy of separate treatment trains; other systems may have in-line redundancy for key mechanical equipment, while others may have no redundancy. When redundancy is provided, it can provide each system either with full capacity, or with some fraction of the system flow. Examples for a plant with 600 gpm design flow might include:

- Dual trains with no redundancy: each train sized for 300 gpm
- Dual trains with 100 percent redundancy: each train sized for 600 gpm
- Some redundancy at average flow: each train sized for a flow between 300 and 600 gpm. A typical approach is to provide two 80 percent units, or in this case, two units sized for 480 gpm. This allows operation over a short time with slight overloading of equipment, or no overloading at lower than peak flow conditions.

The number of treatment trains will significantly affect the final cost of the system. A two-train system will not cost twice that of a single train, but the costs will be significantly higher in a two-train system than a one-train system.

Water Chemistry of Influent

The water chemistry of the flow to the treatment system can influence cost of treatment. Water high in chlorides can necessitate use of corrosion-resistant alloys, or non-metallic equipment.

Water high in scaling potential may require chemical addition and precipitation to remove scale-forming compounds. Metal levels in influent may affect the chemical dosing.

Designing for Expansion to Meet Future Discharge Limits

Designing for expansion to meet future discharge limits is good practice as it will reduce future retrofit costs, but can affect the design and cost of the initial system. Designing for expansion can include providing additional yard or building space for future equipment, including treatment processes or processes like sludge recirculation for metals removal that are not yet required. Designing for expansion can also include providing pipe Ts for future connections, and providing sufficient power and other utilities, spare motor control center buckets, and spare room in instrumentation and control panels for future equipment.

Site-Specific Considerations

Space constraints, interferences and foundation requirements will contribute to capital costs of the treatment systems.

Estimating Capital Cost

Capital cost estimates for a process wastewater treatment plant can be developed by building up from the sub-systems. Process wastewater treatment will vary between plants, but typical sub-systems include:

- Equalization
- Clarification
- Effluent media filtration, if needed to reach limits
- Metals removal, if needed to reach limits
- Solids dewatering
- Building and other support equipment

The costs of wastewater treatment presented within this estimate are based on total installed costs. Total installed costs by definition include everything that will be required to install the system. This typically includes the following elements:

- Direct costs - equipment, delivery, taxes, and installation costs
- Indirect costs - engineering, construction, contingency for undefined, escalation permitting, startup and commissioning costs

Recommended Practice 18R-97 of the American Association of Cost Engineers (AACE) International [28] provides guidelines classifying cost estimates and their relative accuracy. The accuracy of the cost estimate is generally a function of the amount of engineering completed at the time of the estimate. Table 7-1 shows the class of total installed cost estimates, the relative accuracy, and the project definition percent complete for each class of estimate.

Table 7-1
Cost Estimating Guidelines

Estimate Class	Level of Accuracy	Project Definition
5	+100%/-50%	0-2%
4	+50%/-30%	1-15%
3	+30%/-20%	10-40%
2	+20%/-15%	30-70%
1	+20%/-10%	50-100%

Source: Recommended Practice 18R-97 (AACE International, 2005) [28]

The total installed cost, operation and maintenance cost estimates, and associated parametric cost graphs presented in this section are considered Class 5 cost estimates. Class 5 cost estimates are defined as an order of magnitude estimate and are generally prepared based on limited information containing a wide estimated accuracy range of +100 to -50 percent [28]. They are based on the information available at the time of the estimate. Actual final costs will depend on the actual labor and material costs, competitive market conditions, site conditions, final project scope, implementation schedule, and other variable factors.

Although ponds remain an option to manage process wastewater, this section focuses on cost estimating of wastewater treatment in tank-based treatment rather than constructed ponds. Costs of ponds are not covered in this update.

The overall cost of the entire system will also include system-wide cost factors outlined in Table 7-2. The cost factors will contribute to the overall cost of each subsystem.

Table 7-2
Factors that Affect the Additional Cost Items in a Wastewater Treatment System Cost Estimate

Additional Cost Items	Suggested Range		Factors
Site work	3%	5%	• Type of soil (inadequate soil bearing or the presence of rock) • Presence of groundwater • Site access limitations • Existing facilities/obstructions including utilities
Concrete	15%	20%	• Type of soil (inadequate soil bearing) • Presence of groundwater
Piping	6%	8%	• Mechanical layout can vary pipe configuration, lengths and special materials • Plant capacity can vary pipe sizes and cost
Miscellaneous metals and finishes	5%	15%	• Plant layout • Equipment layout • Special materials or coatings

Table 7-2 (continued)
Factors that Affect the Additional Cost Items in a Wastewater Treatment System Cost Estimate

Additional Cost Items	Suggested Range		Factors
Mechanical and heating ventilation and air conditioning	5%	10%	• Plant layout • Equipment layout • Desired degree of automation
Electrical	14%	30%	• Higher if field-fabricated, union shops and lower if factory-fabricated • Plant layout • Equipment layout • Desired degree of automation • Class of service
Instrumentation and control	10%	20%	• Desired degree of automation
Subcontractor overhead and profit	5%	15%	• Driven by market conditions at time (and location) of project • Proximity of the subcontractor • If contractor already working onsite
General contractor general conditions	11%	14%	• Driven by market conditions at time (and location) of project • Proximity of the subcontractor • If contractor already working onsite
Bonding and insurance	2.7%	3%	• Contractors performance and health and safety history
General contractor profit	14.1%	14.4%	• Market conditions in the area and how much work the contractors have
Miscellaneous unidentified cost	10%	30%	• Adequacy of project definition and degree of design completion • Quality of equipment vendor information
Engineering (design, services during construction, startup, and operator training)	15%	25%	• Complexity of the system • Degree of automation • Adequacy and completeness of design

Assumptions in Cost Calculations

All cost estimates require consideration of many assumptions. The following are typical cost factors that will need to be considered, and the assumptions made in the cost curves and worksheet in this manual. If these assumptions do not hold true, costs will need to be adjusted by the user.

- Does not include escalation. Costs are from 2010 and should be escalated based on actual construction date.
- Does not include piping from wastewater sources to the wastewater treatment plant, and from wastewater treatment plant to the outfall.

- Sales tax is not included. The project is assumed to be sales tax exempt.
- Dewatering for construction excavation is not included.
- The site is balanced cut/fill.
- Temporary fencing is not required.
- Curb and gutters are not required for roads or parking areas.
- Buried pipe depth is assumed to be 3 feet, 6 inches to the top of the pipe.
- Seeding of disturbed areas is required.
- No painting of galvanized steel, aluminum, stainless steel or PVC material is required.

Estimated Capital Cost

The total estimated +100%/-50% capital costs of an example physical/chemical treatment plant are shown in Figure 7-1. The costs are based on the following assumptions:

- Influent. Influent to the treatment system is assumed to contain less than 10,000 mg/L TSS, less than 2,000 mg/L TDS, and trace element concentration ranges that would be treated to below regulatory limits using iron co-precipitation and organosulfide addition.
- Equalization. The components of the equalization system included equalization tanks and equalization tank mixers. The costs of equalization are based on a 12-hour retention time. The equalization tank mixer is sized for 1 horsepower per 1,000 gallons. Equalization is assumed to be outdoors.
- Clarification. The clarification subsystem consists of clarifier, clarifier recycle sludge pumps, and polymer feed system. The clarification system is sized based on 0.33 gpm/sf. The sludge pumps are double diaphragm, positive displacement pumps sized based on 50 percent the flowrate of the system and two pumps per subsystem. The polymer system is assumed to be purchased as totes, so no tank is included.
- Metals removal. The metals removal subsystem consists of a reaction tank, reaction tank mixer, pH adjustment feed system, ferric chloride feed system, and organosulfide chemical feed pump.
- Dewatering equipment. The dewatering subsystem consists of a sludge holding tank, sludge holding tank mixer, filter press, filter press feed pumps, and filter cloth wash water tank. The sludge holding tank is sized for 24-hour hydraulic detention time. A plate-and-frame type filter press is assumed. The filter press sizing is based on 2 hours per cycle and the total dry solids generated per day, and operating the press one shift per day. Most process treatment systems will be sized to allow operation only one shift per day. However, in high-solids wastewater applications, or when a decision is made to reduce filter presses (such as to decrease capital but increase operating costs), there may be more than one shift of operation per day and therefore a smaller dewatering system.
- Supporting equipment. Supporting equipment for the process wastewater treatment system includes a pH adjustment tank, miscellaneous waste sump, pumps from the equalization tank(s), flushing pumps, seal water pumps, treatment effluent pumps, acid feed pump system for pH adjustment, caustic feed pump system for pH adjustment, caustic storage, acid storage, ferric chloride storage, and sump pumps.

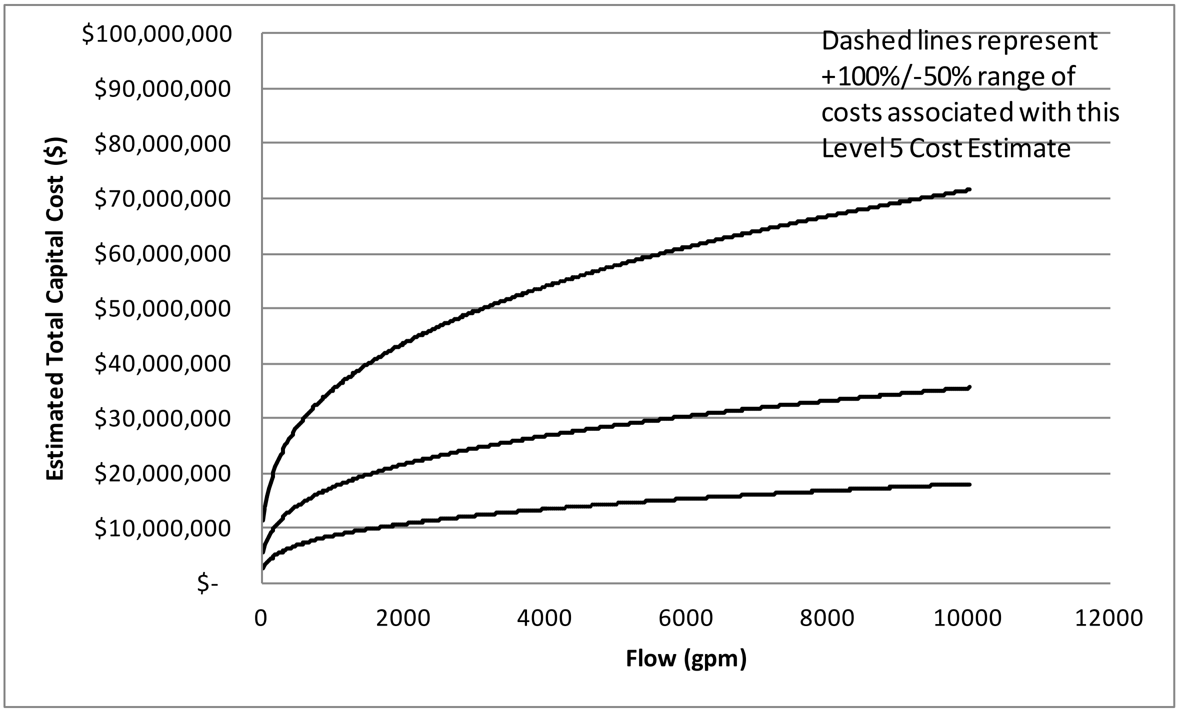

Figure 7-1
Parametric Cost Curve for Estimated Total Capital Costs Process Wastewater Treatment System

Operations and Maintenance Costs

Operating and maintenance (O&M) costs for process wastewater treatment will typically consist of the following elements: labor, chemicals, residuals disposal, utilities, and maintenance. This section presents a method for creating a rough estimate of the total O&M cost for physical/chemical wastewater treatment system. All estimates in this report should be considered for guidance only. Actual project costs will depend on the design of the treatment system, residual disposal costs, and staffing policy at a given facility. Operations and maintenance cost assumptions include the following:

- Maintenance costs are based on 5 percent of total installed costs for the facility.
- Labor assumes one full-time equivalent at 24 hrs/day operation and 7-day week work schedule.
- The primary utilities cost will be electricity. Typically, electrical demand is linearly proportional to the wastewater flow. Electricity cost is based on $0.02 per kilowatt-hour.
- Chemical costs are based on typical dosage rates and will vary based on site-specific conditions.
    - Ferric chloride (35%): $4.25/gallon
    - Hydrochloric acid (93%): $1.79/gallon
    - Caustic (25%): $1.68/gallon
    - Polymer: $25/pound
    - Organosulfide: $25/gallon

- Residuals are assumed non-hazardous and disposed in a non-hazardous waste landfill. Solids are dewatered to 40 percent. An additional eight labor hours per day are included for each shift of filter press operations. Electrical and maintenance costs based on the same assumptions above are also included specifically for filter press operations.

Table 7-3 presents means to estimate O&M costs. For those costs that are proportional to flow, the average daily flow should be used. The average flow is lower than the peak flow (used in sizing the equipment, which drives the system capital cost). Table 7-4 provides an example of the O&M cost calculation with an assumed capital cost of $29 million. The utility cost is assumed to be $0.02/kW-hr, with one shift of operations of the solids dewatering equipment.

Table 7-3
Operations and Maintenance Cost of Physical/Chemical Wastewater Treatment

Item	Annual O&M Cost ($/year)	Recommended Values if No Information is Available at Site
Labor	Cost = [Number of operators] * [Cost/operator]; where: Operators = 1 for dewatering per shift of dewatering + 4 for remainder of plant	Cost per operator: $100,000/year
Chemicals	Cost = [Average Flow as gpm] * 887	Will need site-specific chemical costs
Utilities	Cost for dewatering = 7* [Average Solids Load in lbs/day] Cost for remainder of plant = [60 * (Average Flow as gpm) + 3,600]	Will need site-specific electricity cost or accounting policy
Residuals Disposal	Cost = [(Average Solids Load in lbs/day) / 2000 / 0.4 * 0.85] * [$X/ton * 365 days/year]	Landfill disposal: $14/ton
Maintenance	Cost = 5% * Total Installed Equipment Cost	Will need site-specific policy on estimating maintenance

Table 7-4
Example Operations and Maintenance Cost of Physical/Chemical Wastewater Treatment

	Example Calculation of Annual O&M Cost ($/year)
Labor	Cost = [1+4]*[$100,000/operator/year] = $500,000
Chemicals	Cost= 500 gpm * 887 = $444,000
Utilities	Cost for dewatering = 7* (15,000 pounds per day) = $105,000 Cost for remainder of plant = 60 * [500 gpm] + 3600 = $33,600
Residuals Disposal	Cost = [(15,000 pounds per day) / 2000/ 0.4 * 0.85] * [$14/ton * 365 days/yr] = $81,000
Maintenance	Cost= 0.05 * $29,000,000 = $1,450,000
Total	**$2,600,000**

8

CONCLUSIONS

The purpose of this Technical Update is to provide guidance and insights on process wastewater management practices resulting from potential ash pond closure or conversion to dry ash handling. Plants will also be increasingly faced with evaluating water reuse alternatives for process wastewater streams as facilities comply with water use reduction goals and look to decrease the overall footprint and costs for installation of tank-based treatment systems.

Changes in water management will require extensive planning, including many stakeholders. It is critical to recognize that conversion to dry ash handling will not eliminate the need for wastewater management. The remaining wastewater streams, which can be managed relatively easily in a large ash-sluice-dominated ash pond, must be well understood in order to design an effective and efficient tank-based treatment system.

Tank-based treatment system costs rely largely on the flow rate of the influent stream. Given the wide variability in flows for various process wastewater streams, plants must evaluate installation of equalization as part of their treatment train to reduce the size of the treatment system.

Key parameters of concern in water management are TSS, TDS, scale-forming ions, chlorides, hardness, alkalinity, sulfate, calcium, carbonate, trace elements, and pH. These parameters will affect the ability for wastewaters to be reused throughout the plant and will affect the operations of treatment equipment. There is large variability in concentrations of parameters in process wastewaters. Certain high-strength wastewaters such as rinses from boiler cleaning may need to be treated separately in batch treatment prior to co-mingling with other wastewaters. Process wastewater contains varying amounts of particulate matter (total suspended solids). This may be removed by coagulation/flocculation and clarification processes. Additional metals removal, if needed, may be performed through chemical precipitation using iron co-precipitation and/or organosulfide addition (if mercury limitations apply that will require treatment), and filtration. However, implementation of multiple-step treatment for process wastewater will be very expensive, particularly when evaluated in a cost per pound of pollutant removal basis.

9

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