Technical Memorandum 700

Treatment Technology Selection

June 2011

King County

Department of Natural Resources and Parks
Wastewater Treatment Division

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Acronyms

AwwaRF	American Water Works Association Research Foundation
ACH	aluminum chlorohydrate
BCDMH	Bromochlorodimethylhydantoin
BOD	Biochemical oxygen demand
CEPT	Chemically enhanced primary treatment
ClO_2	Chlorine dioxide
COD	Chemical oxygen demand
CPVC	Chlorinated polyvinyl chloride
CSO	Combined sewer overflow
DAF	Dissolved air flotation
EFDC	Environmental fluid dynamics code
EPA	U.S. Environmental Protection Agency
EPDM	Ethylene propylene diene monomer
FTE	Full time equivalents
FRP	Fiber-reinforced plastic
gpd/sf	Gallons per day per square foot
HAA	Haloacetic acid
HDPE	High-density polyethylene
mgd	Million gallons per day
MPN	Most probable number
NaOCl	Sodium Hypochlorite
NTU	Nephelometric Turbidity Units
NWRI	National Water Research Institute
O&M	Operation and maintenance
PAA	Peracetic Acid
PAX	Polyaluminum chloride
PLC	Programmable Logic Controller
PPE	Personal protective equipment
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl chloride
PVDF	Polyvinylidene fluoride
SEPA	State Environmental Policy Act
SOR	Surface overflow rate
THM	Trihalomethane
TRC	Total residual chlorine
TSS	Total suspended solids
UV	Ultraviolet
UVT	Ultraviolet transmittance
WAC	Washington Administrative Code
WEF	Water Environment Federation
WERF	Water Environment Research Foundation
WWTP	Wastewater Treatment Plant

1.0. EXECUTIVE SUMMARY

King County's Wastewater Treatment Division is reviewing treatment technologies that can be used to treat combined sewer overflow (CSO) discharges. These treatment technologies are being considered for CSO locations where storage and/or flow reduction are not expected to achieve control, including the County's four Duwamish CSO treatment projects that were planned in the 1999 Regional Wastewater Services Plan (RWSP) (King/Kingdome, Hanford/Lander, Brandon and Michigan sites).

1.1 Background and History

King County's RWSP recommended that the County use conventional clarification for CSO treatment, which was the more cost-effective treatment technology at the time. The RWSP also recommended that the County continue to evaluate the development of new technologies, including alternative high-rate treatment technologies, based on the experience of other agencies. This was done as part of the *2000 CSO Plan Update* and the *2006 CSO Control Program Review*, and is being updated again as part of the *2012 CSO Control Program Review.* The 2006 Review identified several promising approaches which lacked operating data; thus, pilot testing was recommended. The County completed testing of high-rate clarification technologies at the West Point Wastewater Treatment Plant in 2009. The final report was issued in June 2010. The information from the pilot testing is included in the technology review for this *2012 CSO Control Program Review.*

1.2 Purpose

The goals of the treatment technology review are to gather the latest information on treatment technologies and their performance; better define the design conditions and operational issues associated with the technologies; and identify two technologies for incorporation into an alternatives development for the *2012 CSO Control Program Review.* At a minimum, the treatment technologies must be capable of meeting the following requirements, as well as applicable water quality and sediment quality standards:

- Treatment Technology Permit Requirements
    - Comply with Washington Administrative Code (WAC) 173-245
    - Annual average solids removal ≥ 50 percent
    - Annual average effluent settleable solids ≤ 0.3 milliliters per liter per hour, as well as a daily maximum limit set in some permits
    - Disinfection: fecal coliforms < 400 colony-forming units per 100 ml
    - A single event may be excluded from solids limit calculations as the one untreated event per year
- Discharge Requirements
    - Meet acute water quality standards at the edge of an approved mixing zone (WAC 173-201A)
    - Meet sediment quality standards (WAC 173-204).

1.3 Technology Narrowing

The evaluation started with a list of 14 treatment technologies that are currently in use or being marketed for use in CSO treatment. Based on an evaluation of considerations including performance, siting requirements, costs, and staffing requirements, this list was narrowed to the five most promising treatment technologies. These five technologies were then evaluated in more detail and were presented at a workshop on November 17, 2010. Table 1 summarizes how each technology was rated for key evaluation criteria.

Table 1. Technologies and Evaluation Criteria

	Evaluation Criteria					
	Performance					
Technology	Potential Treatment Performance	Adaptability	Reliability	Siting Requirements	Cost	Staffing Requirements
Conventional Clarification [1]	Marginal	Yes	Fair	Largest Site	Highest	Low
Clarification with Lamella Plates	Fair	Yes	Fair	Moderate	Moderate	Low
Chemically Enhanced Primary Treatment (CEPT)	Good	Yes	Good	Moderate	High	Moderate
CEPT with Lamella Plates	Better	Limited	Good	Moderate	High	Moderate
Ballasted Sedimentation	Best	Limited	Good	Moderate	High	Highest

1. Just prior to screening, Wastewater Treatment Division management reviewed the performance of existing conventional clarification CSO plants and the very different conditions of the Duwamish River and recommended that convention clarification be dropped from consideration. This information is presented for comparison purposes.

The five most promising treatment technologies were evaluated for their compatibility with disinfection technologies being considered. The recommendation of this evaluation was that ultraviolet (UV) disinfection be used only with the higher levels of treatment evaluated. Chemical disinfection technologies were considered effective for each of the clarification technologies identified, but are also expected to perform better with higher levels of treatment.

Based on the evaluation and the feedback received during the stakeholder workshop and subsequent evaluation, the following treatment technologies were eliminated from further consideration:

- Conventional Clarification—In addition to having the highest cost and largest site requirements, the potential treatment performance is marginal and cannot reliably meet the permit requirements unless a large amount of solids removal is accomplished through capture of wet-weather flow.
- Clarification with Lamella Plates—While this technology performs better than conventional clarification within a smaller footprint at lower cost, there is limited

performance data available to verify that it can reliably meet the permit requirements on a regular basis. If determined to be useful, the data could be obtained through further studies and pilot evaluations. Until the performance of this technology and its ability to consistently meet permit requirements are validated, it is not recommended for consideration during the alternatives development phase.

- Chemically Enhanced Primary Treatment (CEPT)—Because the overall performance of this technology can be improved and the footprint requirements can be reduced by adding lamella plates, the lamella plate option is recommended for consideration instead of CEPT alone.

1.4 Selected Treatment Technologies

The remaining two treatment technologies recommended under the alternatives development phase of the *2012 CSO Control Program Review* are described below.

1.4.1 Chemically Enhanced Primary Treatment with Lamella Plates

CEPT with lamella plates improves on conventional clarification by providing chemical feeds to enhance the coagulation, flocculation, and removal of suspended solids. Inclined plates near the top of the clarifier increase the sedimentation basin's effective settling area. This in turn reduces the footprint and land requirements and improves performance. Key advantages and disadvantages of this technology are as follows:

- Provides good treatment that reliably met permit requirements during County pilot-testing.
- Of the technologies considered, only ballasted sedimentation provides higher levels of treatment.
- Can provide enhanced removal of dissolved copper and other potential parameters of concern.
- Moderately complex process that requires additional staffing, primarily due to the additional chemical storage and feed facilities.
- Relatively high capital and operation and maintenance (O&M) costs.

Figure 1 is a sample process flow schematic for CEPT with lamella plates.

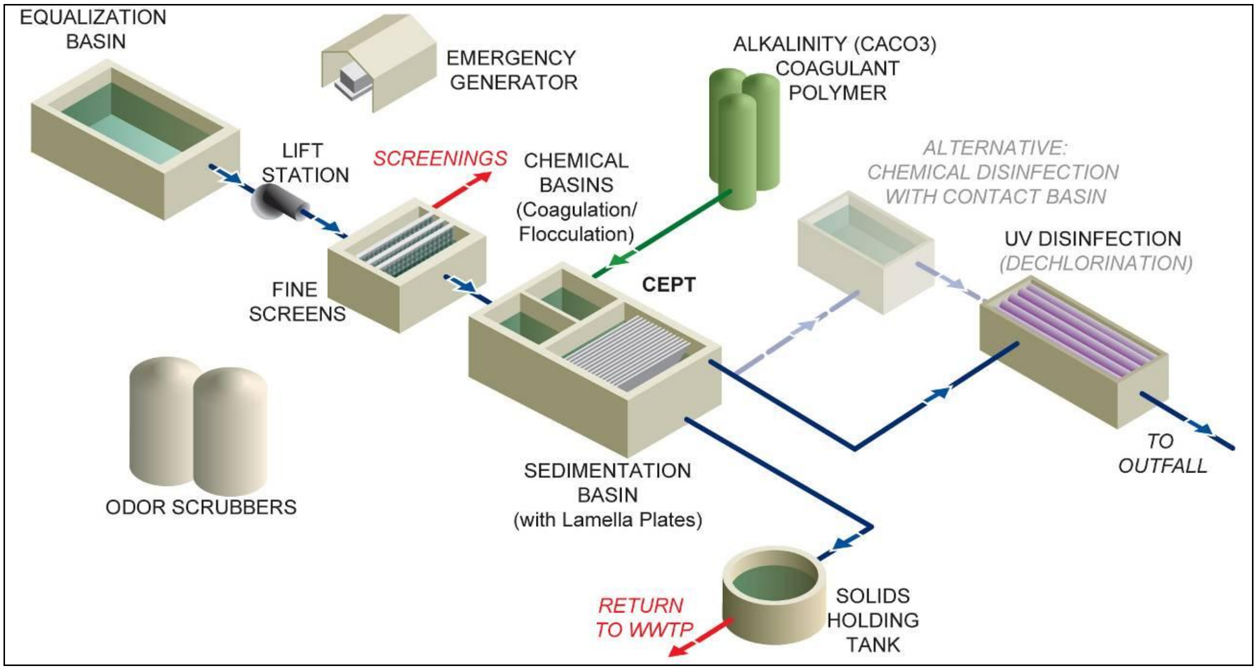

Figure 1 Sample Process Flow Schematic for CEPT with Lamella Plates

1.4.2 Ballasted Sedimentation

This technology uses CEPT with lamella plates in combination with a ballast material (microsand or recirculated sludge, depending on the proprietary process selected) to optimize settling and provide the best potential treatment within the smallest footprint. However, these facilities have high cost and are anticipated to require the greatest staffing levels. This process is currently in use at numerous U.S. and international wastewater treatment plants for wet-weather flow treatment, as well as in several wet-weather installations remote from a treatment plant. Key advantages and disadvantages of this technology are as follows:

- Supported by the greatest industry operating experience and performance data.
- Provides the best treatment performance of all technologies evaluated.
- Highest capital and O&M costs.
- More sophisticated process with the highest staffing requirements.

Figure 2 is a sample process flow schematic for ballasted sedimentation.

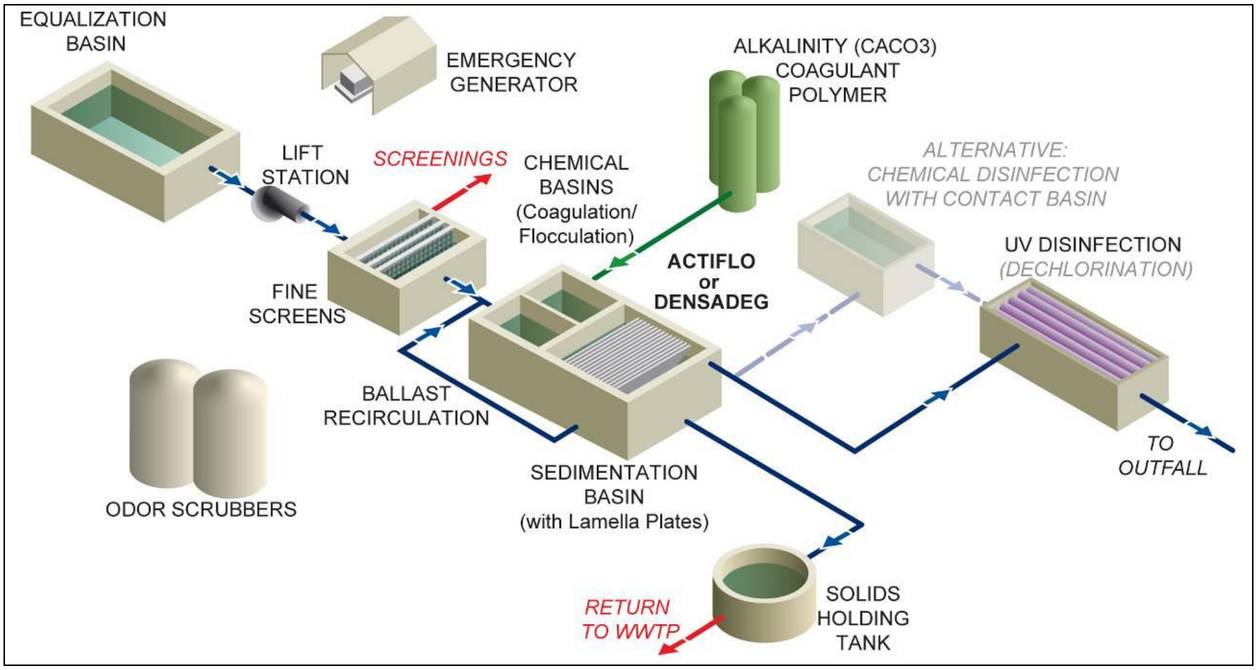

Figure 2 Sample Process Flow Schematic for Ballasted Sedimentation

2.0. INTRODUCTION

King County's Wastewater Treatment Division is reviewing treatment technologies that can be used to treat combined sewer overflow (CSO) discharges. These treatment technologies are being considered for CSO locations where storage and/or flow reduction is not expected to achieve control, including the County's four Duwamish CSO treatment projects that were planned in the 1999 Regional Wastewater Services Plan (RWSP) (King/Kingdome, Hanford/Lander, Brandon and Michigan sites).

King County's 1999 RWSP recommended that the County use conventional primary clarification for CSO treatment, which was the more cost-effective treatment technology at the time. The RWSP also recommended that the County continue to evaluate the development of new technologies, including alternative high-rate treatment technologies based on the experience of other agencies. This was done as part of the *2000 CSO Plan Update* and the *2006 CSO Control Program Review*, and is being updated again as part of the *2012 CSO Control Program Review*. The 2006 Review identified several promising approaches which lacked operating data; thus, pilot testing was recommended. The County completed testing of high-rate clarification technologies at the West Point Wastewater Treatment Plant in 2009. The final report was issued in June 2010. The information from the pilot testing is included in the technology review for this *2012 CSO Control Program Review*.

This report updates previous information from the *2000 CSO Plan Update* (Task 300 Technical Memorandum, *Alternative Technologies for CSO Control*) with newly available reference materials, pilot study data, and operational experience from full-scale facilities. Technologies are compared to identify potential differentiators between them, with the key evaluation criteria based on the most recent operating experience and regulatory requirements. The evaluation focuses on treatment and disinfection technologies; it does not include floatables control or source control.

2.1 Objectives

The objectives for this report are as follows:

- Gather and update available information for various treatment and disinfection technologies for CSO and wet-weather applications.
- Better define the design conditions and operational issues associated with the treatment and disinfection technologies.
- Identify two treatment technologies, combined with an appropriate disinfection technology, for incorporation in the alternatives development for the *2012 CSO Control Program Review*.

2.2 Regulatory Requirements

The selected treatment and disinfection technologies must comply with the requirements of Washington Administrative Code (WAC) 173-245:

- ≥ 50% solids removal (annual average)

- Settleable solids ≤ 0.3 milliliters per liter per hour (ml/L/hr) (annual average) as well as a daily maximum in some permits
- Effluent fecal coliform bacteria < 400 colony-forming units/100 ml (monthly geometric mean)

In addition, the CSO discharge must comply with the following requirements through a combination of source control, treatment, and outfall/mixing zone:

- Acute water quality standards in WAC 173-201A
- Sediment quality standards in WAC 173-204

2.3 Study Approach

The evaluation described in this technical memorandum consisted of the following elements:

- The study first identified a series of criteria to be used in evaluating treatment and disinfection technologies, as described in Chapter 4.
- Treatment and disinfection technologies were identified that are in use or are available as commercially available products and are applicable to CSO and wet-weather applications, as described in Chapter 3.
- Information was then gathered on these technologies, including a literature review, prior studies by King County (including pilot-testing), vendor information, and operating data from other agencies, as described in Chapter 3.
- This information was then used to evaluate the technologies, as described in Chapter 5, and those that performed poorly or were not considered to be feasible were screened out.
- The remaining technologies were further reviewed and evaluated relative to the overall treatment process, as described in Chapters 5 and 6, including the effectiveness of various combinations of treatment and disinfection technologies.
- At several stages during the review and evaluation process, collaborative workshops were held to solicit input from key stakeholders. Participants included other sewer and government agencies that interface with King County, environmental and community groups, community members and property owners, and the County's staff and operators. The workshops are described in Chapter 3.
- Based on this analysis and input received from the stakeholders, two treatment technologies, each combined with an appropriate disinfection technology, were selected for incorporation in the alternatives development for the *2012 CSO Control Program Review.*

Combined, these efforts provide a comprehensive overview of wet-weather treatment and disinfection technologies, with an emphasis on critical local factors that are specific to King County.

3.0. SELECTION OF TECHNOLOGIES AND DATA COLLECTION

3.1 Selection of Technologies

3.1.1 Treatment Technologies

A variety of CSO and wet-weather treatment technologies are in use or commercially available, most with existing full-scale installations in service. An initial list of treatment technologies was created based on the County's existing CSO treatment facilities (conventional clarification) and the technologies considered in the *2000 CSO Plan Update* (Task 300 Technical Memorandum, *Alternative Technologies for CSO Control*). All treatment technologies from the *2000 CSO Plan Update* were included except for constructed wetlands, which require large land areas (generally 1 to 2 percent of the tributary area for the wetland). The County's CSO sites are in urban areas with limited land available, so constructed wetlands are not a viable treatment technology for these sites.

The listing of treatment technologies was updated based on newly available information. In some cases, proprietary technologies have been sold to other companies which resulted in a change of the product name. In other cases, new technologies have been developed or existing technologies have been used in new applications.

3.1.2 Disinfection Technologies

An initial list of alternative disinfection technologies was created based on the County's existing CSO disinfection facilities (sodium hypochlorite followed by dechlorination) and the alternative technologies in the *2000 CSO Plan Update* Task 300 Technical Memorandum. However, this evaluation was expanded to include a review of multiple disinfection technologies. All disinfection technologies from the *2000 CSO Plan Update* were included except for high-voltage electron beam irradiation, which has not been used for CSO or wet-weather disinfection. Disinfection technologies were evaluated to ensure they are appropriately coupled with treatment technologies.

In addition, several new disinfection technologies were evaluated: ultraviolet (UV) light with hydrogen peroxide, peracetic acid, chlorine dioxide, and bromochlorodimethylhydantoin (BCDMH).

3.2 Data Collection

3.2.1 King County Studies

2000 CSO Plan Update

The *2000 CSO Plan Update* was submitted as part of the National Pollutant Discharge Elimination System (NPDES) permit renewal application for King County's West Point Wastewater Treatment Plant. Four treatment facilities using conventional clarification followed by chlorine-based disinfection to control six CSO sites were proposed in the plan. The *CSO Plan Year 2000 Update* reaffirmed the recommended conventional clarification for removal of total suspended solids (TSS). The design basis for sizing these treatment facilities was a surface overflow rate (SOR) of 4,000 gallons per day per square foot (gpd/sf) for peak flow rate conditions.

The update indicated that other agencies' experience using alternative primary settling processes ("enhanced") and particle separation processes ("vortex") should continue to be monitored. King County eliminated some treatment technologies from consideration, including filtration, dissolved air flotation (DAF), and wetlands.

The only recommended disinfection technology in the 2000 Update is chlorine disinfection using hypochlorite. However, the update indicates that King County should continue to consider alternative forms of chlorine disinfectant, alternative chemical disinfectants, and UV. King County eliminated some disinfection technologies from consideration, including ozone and high-energy electron beam irradiation.

2006 CSO Control Program Review

The *2006 CSO Control Program Review* evaluated technologies for CSO treatment, focusing on conventional clarification and assuming a SOR of 4,000 gpd/sf. At the time of the 2006 Review, high-rate sedimentation was considered a new technology and was not evaluated, but piloting of some promising technologies was recommended.

2010 CSO Treatment Systems Evaluation and Testing

King County's *2010 CSO Treatment Systems Evaluation and Testing, Phase 2, Subtask 340—Pilot Test Report* focused on two high-rate treatment technologies: chemically enhanced primary treatment (CEPT) and CEPT with lamella plates. In addition, the pilot study conducted a limited number of runs using the CEPT with lamella plates pilot unit with no chemical addition.

Figure 3 presents the percent removal of total suspended solids as a function of the surface overflow rate for the high-rate treatment configurations using the following chemical feed combinations:

- No chemical addition
- Polyaluminum chloride (PAX) and an anionic polymer (Nalco 7766)
- Ferric chloride and an anionic polymer (Nalco 7766)

The pilot-test results indicate that the combination of PAX and anionic polymer provide the highest TSS removal for both CEPT and CEPT with lamella plates. Based on these results, the pilot-test report recommended an average PAX dose of 12 mg/L as Al and an anionic polymer dose of 1.5 mg/L as the design criteria for both CEPT and CEPT with lamella plates.

Based on the TSS removal requirement (> 50 percent), the pilot-study report recommended a design SOR of 5,000 gpd/sf for CEPT and 20,000 gpd/sf for CEPT with lamella plates. Using the recommended chemical feeds, the corresponding TSS removals from the graph in Figure 3 are expected to be approximately 87 percent for CEPT and 90 percent for CEPT with lamella plates.

While the pilot-test report did not make any recommendations regarding clarification with lamella plates due to the limited data set, Figure 2-1 indicates that approximately 60-percent TSS removal can be achieved at a SOR in the range of 15,000 gpd/sf. TSS removal rates dropped below 50 percent at a SOR of approximately 20,000 gpd/sf.

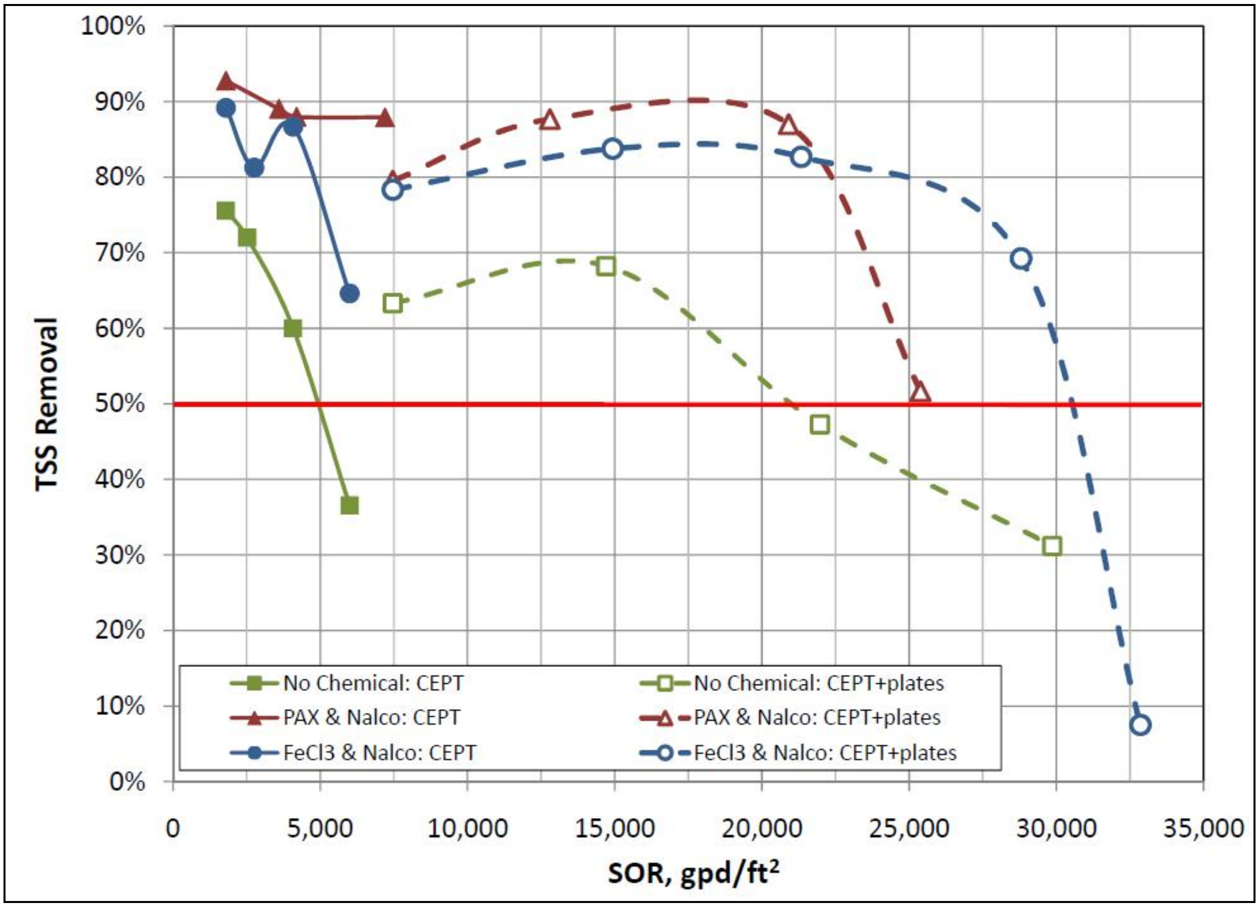

Figure 3 **TSS Removal Pilot Test Results With and Without Chemical Addition**

Conventional clarification typically achieves TSS removals between 50 percent and 70 percent at a maximum design SOR of 1,000 gpd/sf. This is consistent with the primary clarifiers at the County’s West Point Wastewater Treatment Plant, which are operated at typical SOR between 800 and 1,000 gpd/sf. The pilot test also operated the pilot units without chemical feed at a SOR that approximated the SOR of the West Point primary clarifiers and achieved comparable removal efficiencies.

The pilot test report also compared TSS removals with and without chemicals at the recommended design SOR. These results indicated that the addition of a coagulant and polymer increased the TSS removals to 70 percent to 80 percent at the recommended design SOR for CEPT and CEPT with lamella plates.

A study published in 2006 by the Water Environment Research Federation (WERF) included an evaluation of primary clarifier performance at the County’s South Treatment Plant and West Point Wastewater Treatment Plant, which indicated that the primary clarifier TSS removal efficiencies were 69.8 percent (South Plant) and 65.5 percent (West Point Wastewater Treatment Plant). The performance for a CSO treatment facility is expected to be less due to the challenges associated with treating wet-weather flows (see Chapter 5 for additional discussion). Therefore, a

TSS removal efficiency of 60 percent likely represents the upper end of the range of expected performance for wet-weather treatment using primary clarification without chemical addition (this includes both conventional clarification and clarification with lamella plates). This raises concerns about the reliability of any sedimentation process to accomplish the required solids removal of 50 percent for wet-weather applications on a consistent basis without chemical addition and without relying on flow capture for transfer to secondary treatment plants.

3.2.2 Literature Review

Literature, including peer-reviewed journal and conference papers, vendor information, and textbooks were consulted to determine the state-of-the-art in handling CSOs and update the literature reviews carried out for previous King County studies. Supplements were obtained from the U.S. Environmental Protection Agency (EPA), the Water Environment Federation (WEF), and the WERF. A complete list of references is presented at the end of this technical memorandum.

3.2.3 Other Agency Experience

Contacts were made with operational staff at selected project facilities that provide insight into CSO treatment processes similar to King County potential operations. These contacts were intended to gather general information on the facility performance and operational considerations.

Cincinnati, Ohio

Ali Bahar of the Cincinnati Metropolitan Sewage District was interviewed by project staff and provided an engineering report on the performance of a 15-million-gallon-per-day (mgd) ballasted sedimentation process unit that is used for a sanitary sewer overflow and is located remote from the District’s treatment plants. Prior to entering the ballasted sedimentation unit, the flow is equalized through approximately 3 million gallons of storage and screened. Due to the sizing of the influent pump station and the operation of the storage tanks, this provides approximately 2 hours (minimum) equalization prior to CSO treatment operation. The ballasted sedimentation system is fed at a relatively constant rate. There is a bypass provision around the unit when flows are high. Following treatment, flow is disinfected with UV.

In general, the facility is working well. Challenges with the facility are generally unrelated to the process and include level control settings associated with UV disinfection, poor performance of the selected brush screen and lack of understanding of system hydraulics prior to construction. The system hydraulic conditions prevented reliable discharge of wasted solids back to the interceptor, and recirculation of sludge through the unit resulted in poor performance. There were also some issues with foaming in the discharge. The Cincinnati Metropolitan Sewage District is making some modifications to the facility, including adding dedicated sludge storage. The District typically sends an operator to the facility about the time the treatment system begins operation and reports that one of the primary operation and maintenance functions for the process is sand replenishment.

Frankfort, Kentucky

Bill Scalf at the Frankfort, Kentucky wastewater treatment plant was interviewed relative to the plant’s use of peracetic acid for disinfection of secondary effluent. Frankfort had previously used an ozone system for its treatment plant (9.9 mgd average day, 28 mgd peak). During construction of upgrades to that system, the plant piloted the use of peracetic acid supplied by Solvay

Chemical. Mr. Scalf indicated that the plant was very satisfied with the product and would consider using it as an ongoing disinfectant. The product was supplied in 330-gallon pre-mixed totes, which the plant used at a rate of approximately two totes per week. The feed dose was between 0.75 and 1.25 parts per million. The primary concern about the product was that it is very corrosive, requiring protective clothing for staff and special materials for pumps, valves, and any other equipment that it comes in contact with.

Toledo, Ohio

Steve Hallett, senior engineer at the Toledo wastewater treatment plant, provided an overview of the wet-weather facilities at the treatment plant, including the ballasted sedimentation facility. This is a 185-mgd multi-train unit that receives screened influent during wet-weather events that exceed the plant's primary treatment capacity. Effluent from the process is primarily stored on-site until additional treatment plant capacity is available. During very large events, the equalization overflows are discharged to the receiving stream. During the recreational season, the equalization overflow is disinfected with sodium hypochlorite.

Mr. Hallett provided comments about the facility, mostly associated with ease of operation. There are multiple grit units upstream of the process and the distribution of grit to these units is poor, which was the most significant maintenance issue reported. A number of modifications were made to the facility following startup. Problems were experienced with the robustness of some of the installed equipment. Operator access was also an issue. Sensors and sampling equipment also required modifications, including providing weather protection. It was not clear if these items related to the manufacturer's selection of equipment or if the equipment of concern were specified by the design engineer.

Despite these concerns, the overall operation of the facility is reported to be satisfactory. The performance of the facility and the pilot-testing are reported in several of the reference papers.

Detroit, Michigan (Rouge River)

The Rouge River National Wet-Weather Demonstration Project included the construction of 10 CSO treatment facilities in the mid 1990s. These facilities are retention treatment basins and include screening, settling and disinfection as process elements. Operational reports and performance data were collected from these facilities and were summarized by the Rouge program in various reports and papers. Operational performance of these facilities was generally good, with the largest source of challenges being related to the disinfection systems. These systems were challenging to operate reliably in an intermittent mode. Difficulties included problems with system initiation during wet weather, strength of chemical, and challenges in appropriate dosing of chemicals due to flow metering that was ineffective.

Bremerton, Washington

The Bremerton CSO treatment facility is a remote wet-weather treatment facility consisting of a Ballasted Sedimentation system to treat CSOs from East Bremerton. The wet-weather treatment facility consists of ballasted sedimentation system designed to treat 15 mgd of combined sewer flows. Peak wet-weather flows are screened by a bar screen prior to entering the system followed by UV disinfection. Bremerton pilot tested two ballasted sedimentation manufacturers (Densadeg and Actiflo systems) and found better start-up performance with Actiflo. The City pre-purchased the UV disinfection and Actiflo system and in 2003, the first satellite CSO treatment facility began operating.

During wet weather periods, flows are first routed to a storage tank upstream of the treatment facility. CSOs are sent to the storage tank first, which is equipped with level sensors. The signal is sent to the programmable logic controller (PLC) to contact the operator to the facility. As the storage tank continues to fill, another level sensor sends a signal to activate the Actiflo system. As flows increase in the storage tank, flows are routed to the plant. Solids removed at this plant are also stored in the storage tank. When capacity becomes available in the sewer system, the solids are conveyed to the West Plant for removal and treatment.

Bremerton uses aluminum chlorohydrate (ACH) for the coagulant, which they order from a local representative for $5/gal. The coagulant dosage rate is approximately 5 to 10 mg/L. The City decided not to use Ferric because it would stain the UV lamps and impact disinfection performance. Alum was not used because of the short shelf life as well. The Actiflo system was initially installed with a liquid polymer feed, but later switched to a dry polymer system for cost efficiency. The polymer dosage rate is approximately 2 mg/L. Polymer is typically prepared prior to a large storm event.

The Bremerton facility has operated approximately 20 times since 2003 and has achieved between 90 percent to 95 percent TSS removal and effluent turbidity levels less than 3 Nephelometric Turbidity Units (NTU) . Treated effluent is passed through medium-pressure, high-output UV disinfection before it is discharged into the Puget Sound.

Gold Bar Wastewater Treatment Plant, Edmonton, Alberta

The Gold Bar Wastewater Treatment Plant in Edmonton, Alberta was expanded and improved to accommodate sanitary sewer overflows. The existing facility consisted of a secondary treatment facility followed by UV disinfection. In order to accommodate storm flows and comply with regulatory requirements, a new wet-weather treatment facility was added to operate in parallel with the existing treatment facility. The Gold Bar Wastewater Treatment Plant is the only full-scale CEPT with lamella plates installation for wet-weather flows. It is designed to treat 160 mgd of screened raw sewage during peak flow events. The wet-weather treatment facility consists of four CEPT with lamella plates basins, a chemical feed system, mixing and flocculation tanks. Peak wet-weather flows are screened via 8-mm fine bar screens prior to entering the CEPT basins. Treated flow from the CEPT basin is blended with the wastewater plant effluent, disinfected via the UV disinfection system and discharged at the existing outfall.

The CEPT basins are designed for SOR of 6,600 gpd/sf. Stainless steel lamella plates were installed at a 60-degree angle in the basins. Operating experience has demonstrated that the CEPT with lamella plates can produce high quality treated effluent prior to disinfection. Operators at the Gold Bar Wastewater Treatment Plant have found that simultaneous chlorination using 12.5-percent sodium hypochlorite at the influent to the CEPT process has been very effective. The UV transmittance of the sanitary sewer overflow has ranged from 40 percent to 60 percent.

The sludge produced from the CEPT with lamella plates has typically been at 3-percent TSS, compared to the conventional secondary treatment sludge at 4-percent TSS. The sludge has measured a lower pH (~6.0) than conventional primary sludge (~7.0), due to the addition of alum in the CEPT process, which consumes alkalinity and drops the pH.

Operational and maintenance issues described by the operator included potential hydrogen sulfide gas emitted during plate cleaning. Low-pressure air headers under the lamella plates scour built-up residue. During air scouring of the plates, hydrogen sulfide odors are emitted. Additional staff was required for the complex operation of the polymer chemical feed system. The facility uses both liquid and dry polymer to balance costs versus shelf life. Liquid polymer has a longer shelf life but is expensive compared to dry polymer. Although dry polymer is cheaper, it requires at least two hours of preparation prior to use.

3.3 Collaborative Workshops

3.3.1 Workshop on May 6, 2010 (Task 710—Technology Selection Criteria)

A workshop was held on May 6, 2010 to confirm the selection criteria to be used for screening and ranking the CSO treatment technologies. The workshop concluded by developing final selection criteria and related questions that would be used to evaluate the CSO treatment technologies. The screening criteria included: staffing requirements, treatment performance, reliability, costs, footprint, and acceptance by others.

3.3.2 Workshop on August 12, 2010 (Task 740—Technology Narrowing)

A workshop was held on August 12, 2010 to narrow the list of treatment and disinfection technologies to a smaller group for further analysis. A total of 5 CSO treatment processes alternatives were retained for further evaluation as discussed further in Chapter 7. The workshop first reviewed the previous studies and tasks completed, including the elimination of several technologies. Overviews of the remaining technologies were then presented and discussed, followed by a presentation of King County’s pilot test results. The remaining technologies were then compared relative to performance and the technology selection criteria, with any “fatal flaws” identified.

3.3.3 Workshop on November 17, 2010 (Task 770—Technology Selection)

A workshop with participation by invited stakeholders was held on November 17, 2010, to present and discuss the five shortlisted CSO treatment processes alternatives. An overview of the project was first presented, followed by a presentation of the technology selection process, including the background, pilot results, purpose and goals of the evaluation, and evaluation criteria. The results of the technology narrowing process were then presented, including schematics of the two CSO treatment/disinfection trains retained for detail evaluation. Outfall, effluent water quality considerations, and sediment impacts were then discussed. A work session was then conducted with the workshop attendees, during which questions were addressed and comments/feedback were solicited before closing the workshop.

3.3.4 Workshop on January 12, 2011 (Task 770—Technology Selection)

A workshop with the County’s operations and maintenance staff was held on January 12, 2011, to solicit input from this key stakeholder group. After an introduction and meeting overview, a previous site visit by staff to the ballasted sedimentation CSO treatment facility in Bremerton, Washington was discussed and feedback was solicited regarding impressions of the facility. This was followed by a summary of the technology narrowing workshop on November 17, 2010. Conceptual treatment trains were presented and discussed for the two CSO treatment/disinfection trains selected in the previous workshop on November 17, 2010.

4.0. EVALUATION CRITERIA

4.1 Preliminary List of Evaluation Criteria

Prior studies evaluated technologies according to cost (operation and maintenance (O&M) and capital), performance (operability and reliability), and applicability to the King County system. These criteria were further developed as part of the collaborative workshop on May 6, 2010, resulting in the following screening criteria:

- Staffing Requirements
    - O&M equipment requirements for routine staffing
    - Sampling requirements for offsite staff to collect samples following an event
    - Type of personnel for operating/maintaining technology during/after an event
    - Staffing levels required at different times: pre-event, during event, post-event
    - Training requirements
- Treatment Performance Flexibility
    - Ability and robustness to reliably meet water quality standards
    - Ability to reduce TSS and other pollutants (e.g., metals), relative to regulatory criteria
    - Effectiveness in conjunction with disinfection under widely varying flow conditions – hydraulic loadings and pollutant demand
    - Chemical interference with chlorination or UV
    - Performance on weak sewage (e.g., low influent concentration)
    - Effectiveness range from low to high flow rates and loadings
    - Isolation of unit processes in technology’s footprint
    - Ability to modify process in the future (e.g., add chemical feed capability)
    - Need/ benefit of upstream equalization
    - Startup time
    - Resiliency of system
    - Ability to operate after extended dry period.
    - Regulatory acceptance of performance/ trust in technology
- Design Condition Adaptability
    - Design for existing conditions, but accommodate future conditions
    - Pretreatment processes required prior to main treatment component (e.g., screening, grit removal, etc)
    - Solids handling facility requirements

  - Modular “scale up” consideration
  - Hydraulic feasibility with flow pattern, chemical addition and/or residual solids
  - Hydraulic loss through facility (pumping versus no pumping)
  - Underflow requirements (percent of influent flow stream)
  - Optimal flow range for the technology
  - Ability to fix/- adapt/-optimize the process
- Reliability
  - Equipment operation in an intermittent mode (startup, etc.)
  - Fail safe operation if units are non functional, automation complexity
  - Dependability under variant flow and loadings conditions
  - Is technology “permit compliant?” What is the confidence level?
  - Performance guarantee and/or warranty
  - Documented performance under similar conditions
  - Ability to operate after extended dry period
  - Ability to prepare for seasonal use (test without discharging)
- Cost
  - Capital cost
  - O&M cost (chemical, power, etc.)
  - Land acquisition
  - Greenhouse gas
- Ease of Siting
  - Size considerations
  - Footprint of treatment works + pretreatment and disinfection (stacking of units, etc.)
  - Adequate area and footprint to accommodate present/future flows and loadings
  - Is technology footprint expandable horizontal, vertical, and upward (“x-y-z”)?
  - Visual screening capability (single or multiple units, surface or subsurface, building height
  - Odor concerns
  - Publicly acceptable technology (perceived risk – e.g., chemical storage)
  - Truck traffic issues (chemical delivery)
  - Noise
  - Perceived acceptance in other communities (urban and rural)

4.2 Refined List of Evaluation Factors

Based on later workshops and the subsequent development and evaluation of technologies, the preliminary list of evaluation criteria was further developed to create lists of key evaluation factors, as listed below.

4.2.1 Evaluation Factors for Treatment Technologies

The list of key evaluation factors for the treatment technologies is as follows:

- Treatment Effectiveness – Removal efficiencies for the following constituents/parameters:
  - Total suspended solids
  - Settleable solids
  - Biochemical oxygen demand (BOD)
  - Chemical oxygen demand (COD)
  - Floatables
  - Future parameters of concern (e.g., Copper)
- Upstream treatment requirements
  - Equalization
  - Screening
  - Grit removal
- Existing installations
  - CSO or wastewater treatment plant facilities – United States
  - CSO or wastewater treatment plant facilities – International
  - Other applications or industries
- Design parameters
  - Solids/mass loading
  - Hydraulic loading
  - Hydraulic losses/head requirements
- Ancillary component requirements
  - Side streams or waste solids produced
  - Additional storage/treatment requirements for these streams
- Chemical addition
  - Is chemical addition required?
  - Bulk delivery or on-site generation
  - Shelf-life of chemicals used

- Chemical handling and storage requirements
  - Potential hazards
  - Personal protective equipment requirements
  - Special materials of construction required
- Compatibility with downstream disinfection technologies
  - Sodium hypochlorite
  - Ultraviolet (UV)
  - Peracetic acid
  - Chlorine dioxide
  - BCDMH
- Adaptability and flexibility
  - Performance over wide range of operating conditions
  - Ability to upgrade in the future in response to changing permit conditions/requirements
- Constructability
  - Footprint/area requirements
  - Single or multiple manufacturers/suppliers
- Operation and maintenance (O&M)
  - Reliability – performance
  - Reliability – equipment
  - Ease of operation/complexity
  - Operator attendance requirements
  - Preventive maintenance requirements
  - Equipment maintenance requirements
  - Odor potential
  - Noise potential
  - Non-chemical consumable materials used
- Public perception

4.2.2 Evaluation Factors for Disinfection Technologies

The list of key evaluation factors for the disinfection technologies is as follows:

- Disinfection effectiveness
  - Reduction of bacterial indicator organisms (fecal coliform, *e. coli*, *enterococcus*)

  - Reduction of viruses, crypto, giardia, and other pathogens
- Contact time requirements at peak design flows
- Existing installations
  - CSO or wastewater treatment plant facilities – United States
  - CSO or wastewater treatment plant facilities – International
  - Other applications or industries
- Additional potential treatment benefits
- Formation of disinfection by-products
  - Trihalomethanes (THMs)
  - Haloacetic acids (HAAs)
- Disinfection residuals
  - Potential for disinfection residuals
  - Need for addition of reducing agent
- Effluent toxicity
  - Potential toxicity impacts
  - Additional downstream treatment requirements
- TSS/particle shielding
  - Impact on disinfection effectiveness
  - Upstream treatment requirements
- Chemical addition
  - Is chemical addition required
  - Bulk delivery or on-site generation
  - Shelf-life of chemicals used
- Chemical handling and storage requirements
  - Potential hazards
  - Personal protective equipment requirements
  - Special materials of construction required
- Constructability
  - Footprint requirements
  - Single or multiple manufacturers/suppliers
  - Capital costs (based on facilities with peak design flows between 10 mgd and 100 mgd)

- Operation and maintenance (O&M)
  - Reliability – performance
  - Reliability – equipment
  - Ease of operation/complexity
  - Operator attendance requirements
  - Preventive maintenance requirements
  - Equipment maintenance requirements
  - Chemical and energy costs (based on facilities with peak design flows between 10 mgd and 100 mgd)
- Public perception.

5.0. TREATMENT TECHNOLOGIES

This chapter describes the treatment technologies that were initially considered for this study. Numerous treatment technologies for solids removal have been implemented in CSO and wet-weather applications. Several are commercially available as proprietary technologies. CSO treatment is a challenging application for treatment systems because the flow is intermittent and has variable quality, so the treatment system must perform reliably and consistently over a wide range of flows and concentrations that can vary rapidly. Wet-weather treatment facilities generally begin operation in a dry condition, function during an event, and then need to be returned to a cleaned condition following the event. This is significantly different operationally than continuously-operating wastewater facilities.

5.1 Conventional Clarification

5.1.1 Description

This technology uses primary sedimentation facilities for removal of suspended solids. It is well-established and has been used at wastewater treatment plants and wet-weather treatment facilities around the world for many years. As such, conventional clarification was identified in this study as the baseline technology for comparison with other CSO treatment technologies.

5.1.2 Installations

King County maintains and operates four CSO treatment facilities that use conventional clarification: Carkeek, Alki, Mercer/Elliott West and Henderson/MLK Way/Norfolk. Carkeek and Alki use primary sedimentation basins for solids removal. Mercer/Elliott West and Henderson/MLK Way/Norfolk use large-diameter tunnels for primary clarification and storage. All four depend on the credit for captured solids and flow that is drained to the associated secondary treatment plant. In this approach the removal efficiency of retreating the captured solids and flow is part of the TSS removal calculation.

Carkeek CSO Treatment Facility

The Carkeek CSO Treatment Facility is a former primary wastewater treatment plant that was converted into a 20-mgd wet-weather treatment facility. It consists of screening, degritting, primary sedimentation, disinfection and dechlorination. The primary sedimentation tanks were designed for a SOR of 5,500 gpd/sf at peak design flows. Hypochlorite is added to control odors and for effluent disinfection as flow enters the grit tanks. In the grit tank, the flow is aerated and grit is pumped into two primary sedimentation tanks. Flows are routed to the chlorine contact tank for disinfection and dechlorinated prior to discharge to Puget Sound. Solids and some flow are stored for drainage to the West Point Wastewater Treatment Plant when the storm passes. The facility was designed for the following permit conditions:

- Annual number of treated discharge events: 10
- Annual average settleable solids: 0.3 ml/L/hr
- Event maximum settleable solids: 1.9 ml/L/hr
- Annual average TSS removal: 50 percent

- Fecal coliform (monthly geometric mean): 400 most probable number (MPN)/100 ml
- Total residual chlorine (maximum of daily): 490 micrograms per liter (µg/L)

The Carkeek CSO Treatment Facility has achieved up to 90-percent TSS removal, when the load reduction associated with captured flow is considered. The daily maximum settleable solids and chlorine residual and fecal coliform limits have been met. Dechlorination via sodium bisulfite was added to the facility in 2005 to assist in achieving the total residual chlorine permit limit. According to King County staff, this facility has operated well from an operation and maintenance point of view. The facility is labor-intensive when the primary tanks need to be cleaned after an event. Improvements are being designed to automatically drain the tanks after a storm event.

Alki CSO Treatment Facility

Flows are pumped to the Alki CSO Treatment Facility from the 63rd Avenue Pump Station. The facility's treatment capacity is limited by its hydraulic capacity, which is 45 mgd to 67 mgd, depending on the tide level. Flows are routed through bar screens, Parshall flumes, and pre-aeration channels for maintaining solids in suspension. Six primary clarifiers provide settling of solids, and flows are sent to a chlorine contact tank for disinfection prior to discharging. The primary sedimentation tanks were designed for a SOR of 3,950 gpd/sf at peak design flows of 65 mgd. Solids are continually returned to the conveyance system during an event for transfer to West Point Wastewater Treatment Plant. The facility was designed for the following permit conditions:

- Annual number of treated discharge events: 29
- Annual average settleable solids: 0.3 ml/L/hr
- Event maximum settleable solids: 1.9 ml/L/hr
- Annual average TSS removal: 50 percent
- Fecal coliform (monthly geometric mean): 400 MPN/100 ml
- Total residual chlorine (maximum of daily): 230 µg/L

Alki has not consistently met the annual 50-percent TSS removal requirement. Operational strategies have been implemented to allow the plant to more consistently meet this requirement. The daily maximum settleable solids and fecal coliform limits have been met. The facility has not met the monthly and daily limits for chlorine residual due to operational issues with the dechlorination system. The 38-percent sodium bisulfite solution has crystallized in the piping and valves during cold weather, leading to high chlorine residual discharges. Improvements are being made to address freeze protection. Since 2008, the 38-percent solution was replaced with 25-percent solution due to its lower freezing temperature. Two new 12-gallon-per-minute bisulfite dechlorination pumps were also installed.

Mercer/Elliott West CSO Treatment Facility

The Mercer/Elliott West CSO Treatment Facility provides storage and primary treatment of CSOs in the 14-foot-diameter Mercer Tunnel, and treatment of settled flows up to 250 mgd that exceed the capacity of the tunnel at the Mercer/Elliott West CSO Treatment Facility. The Mercer/Elliott West CSO Treatment Facility was designed to provide screening and disinfection prior to discharge into Elliott Bay. The Mercer Tunnel provides up to 7.2 million gallons of storage and primary clarification for all flows and settled solids entering the tunnel. During the 2006-2007 season, the Mercer Tunnel operated for 28 wet weather events; final treatment at Mercer/Elliott West CSO Treatment Facility with discharge occurred for 14 events. The facility was designed for the following permit conditions:

- Annual number of treated discharge events: 10
- Annual average settleable solids: 0.3 ml/L/hr
- Event maximum settleable solids: 1.9 ml/L/hr
- Annual average TSS removal: 50 percent
- Fecal coliform (monthly geometric mean): 400 MPN/100 ml
- Total residual chlorine (maximum of daily): 104 µg/L

Assessment of the treatment performance of the Mercer/Elliott West CSO Facility has been hampered by a lack of reliable representative effluent quality data, particularly for suspended solids and settleable solids. There has been considerable improvement since November 2008 in the collection of wastewater samples from the facility. Up to 72-percent TSS removal has been achieved. However, the average and daily maximum settleable solids and fecal coliform limits have been exceeded. The facility has also exceeded the daily limits for chlorine residual due to operational issues with the chlorination and dechlorination system. King County has been working to implement solutions to achieve permit compliance.

Henderson/ML King CSO Control System

The Henderson/ML King CSO Control System was implemented to control CSOs into Lake Washington from the Henderson and Martin Luther King drainage basins and CSOs into the Duwamish River from the Norfolk drainage basin. This system provides storage and primary treatment in the 42nd Ave S Storage/Treatment Tunnel of wastewater during peak flow events. Hypochlorite is added to all flows entering the tunnel to control odors and for effluent disinfection. In the event that the tunnel is filled and wastewater continues to flow into the tunnel, the wastewater overflows and is screened and dechlorinated prior to discharge to the Duwamish River. Flows stored in the tunnel are discharged into the conveyance system when capacity is available and sent to the South Treatment Plant. The Henderson Tunnel provides storage for up to 4 million gallons and primary clarification. Solids and stored flows are drained to the South Treatment Plant in Renton when the storm passes. The treatment facility was designed for the following permit conditions

- Annual number of treated discharge events: 10
- Annual average settleable solids: 0.3 ml/L/hr
- Event maximum settleable solids: 1.9 ml/L/hr
- Annual average TSS removal: 50 percent
- Fecal coliform (monthly geometric mean): 400 MPN/100 ml
- Total residual chlorine (maximum of daily): 39 µg/L

This treatment facility has met all discharge permit conditions except for the maximum daily chlorine limit. The maximum daily chlorine limit was exceeded due to mechanical and monitoring problems related to the sodium bisulfite addition.

5.1.3 Discussion

Conventional clarification facilities are less complex to operate and maintain compared to many other CSO treatment technologies. However, conventional clarification provides marginal treatment performance, making it difficult to meet permit requirements for TSS removal in a flow-through mode of operation. Currently, the pollutant removal performance of County CSO treatment facilities has relied, at least in part, on volume capture to achieve TSS removal. This level of volume capture is not anticipated in future facilities. Based on experience with existing CSO treatment facilities that use conventional clarification technology, a SOR of 1,000 gpd/sf was assumed for this type of technology. The result is that conventional clarification has a large footprint requirement and correspondingly high capital costs due to the large sedimentation basins and land required.

In addition, County operations and maintenance staff have identified issues associated with chlorine disinfection downstream of the primary clarification facilities. Balancing environmental risks, chemical demands, and contact times using conventional chlorination/dechlorination has been challenging. As previously mentioned, CSO treatment facilities have been issued notice of violations for failure to comply with the fecal coliform and chlorine residual permit limits.

5.2 Primary Clarification with Concurrent Disinfection

5.2.1 Description

Primary clarification with concurrent disinfection is based on conventional clarification and provides disinfection concurrent with sedimentation by adding a chemical disinfectant (typically sodium hypochlorite) to the wastewater as it enters the sedimentation basin. The hydraulic retention time provided by the sedimentation basin therefore also serves as the contact time for the disinfectant. These systems are also referred to as retention treatment basins.

5.2.2 Installations

Retention treatment basins have been used at numerous CSO treatment facilities, primarily in Michigan, which has over 30 installations. Examples include the George W. Kuhn Retention Treatment Facility in Oakland County, Michigan and the Hubbell Southfield CSO Facility owned by the Detroit Water and Sewerage Department.

5.2.3 Discussion

The same O&M and performance considerations for conventional clarification also apply to retention treatment basins. By providing sedimentation and disinfection in the same basin, the footprint requirements and capital costs for retention treatment basins are reduced relative to conventional clarification followed by separate disinfection facilities. However, this configuration requires the disinfection system to operate under a wider range of conditions and additional disinfection chemical is required due to the presence of additional suspended solids in the retention treatment basin increases the overall chlorine demand.

5.3 Chemically Enhanced Primary Treatment

5.3.1 Description

Chemically enhanced primary treatment (CEPT) optimizes the removal of suspended solids by adding chemical coagulants and flocculants to form highly settleable solids. Commonly used chemical coagulants include ferric chloride, alum, and polyaluminum chloride. For CSO treatment applications, anionic polymers are typically used as flocculants in combination with one of the coagulants. In addition to optimizing the removal of suspended and settleable solids, CEPT can remove colloidal materials that would not be removed by conventional clarification. Depending on the chemical coagulants and flocculants that are used, there is also the potential for coagulation and precipitation of soluble copper and other metals.

5.3.2 Installations

CEPT is a well-established and proven treatment option to optimize primary treatment at wastewater treatment plants, with published performance data for several large facilities in California (City of San Diego, Orange County, Los Angeles County, and the City of Los Angeles) and Ontario, Canada (WEF et al., 2009; note that several of these facilities have since been replaced by full secondary treatment or are scheduled for replacement). However, there are no known CSO or wet-weather facilities using CEPT that are not located at a treatment plant. This technology has been pilot-tested for use in CSO applications by King County (King County, 2010).

5.3.3 Discussion

In addition to improving the removal efficiencies for suspended solids, settleable solids, biochemical oxygen demand (BOD) and chemical oxygen demand (COD), CEPT facilities can be operated at a higher SOR than conventional clarification facilities, which reduces the footprint requirement for the sedimentation basin. However, rapid mix and flocculation tanks are recommended for optimal performance of CEPT facilities, which offset some of the footprint reduction associated with the sedimentation component. In addition, chemical storage and feed facilities are required, which require space and increase the overall complexity of the process compared to conventional clarification. The increased removal efficiencies produce greater quantities of solids that must be managed, and the solids tend to have a lower solids concentration than those from conventional primary sludge, further increasing the sludge storage volume requirements.

5.4 Clarification With Lamella Plates

5.4.1 Description

This technology uses lamella plates to enhance the performance of conventional clarification. Lamella plates are inclined plates installed near the surface of a primary sedimentation basin that reduce the distance a particle must settle in order to be removed. Because each lamella plate settler provides an effective area equal to that of its horizontal projection, lamella plates increase a sedimentation basin's effective settling area. The removal efficiencies that can be achieved using clarification with lamella plates are comparable to conventional clarification, but at higher SORs.

5.4.2 Installations

This technology is comparable to plate-and-tube settlers that are widely used in Europe. While it is commonly used for industrial wastewater treatment, there is limited use at municipal facilities in the United States, with no known CSO facilities using clarification with lamella plates as a standalone technology.

5.4.3 Discussion

By increasing the SOR, the size and footprint for the sedimentation basins using clarification with lamella plates can be significantly reduced relative to conventional clarification, which also reduces the capital cost. Otherwise, the O&M and performance considerations for conventional clarification also apply to clarification with lamella plates.

5.5 CEPT with Lamella Plates

5.5.1 Description

This technology combines CEPT with the use of lamella plates to further optimize performance by increasing removal efficiencies and SORs.

5.5.2 Installations

One wastewater treatment plant that uses CEPT with lamella plates to treat wet-weather flows is the Gold Bar Wastewater Treatment Plant, which is operated by the City of Edmonton in Alberta, Canada. The Gold Bar Wastewater Treatment Plant uses screening followed by CEPT with lamella plates and UV disinfection to treat peak wet-weather wastewater flows that bypass the secondary wastewater treatment facilities. This technology was also pilot-tested for use in CSO applications by King County along with CEPT (King County, 2010).

5.5.3 Discussion

This technology provides the benefits of both CEPT and lamella plates, providing high removal efficiencies at high SORs. It is operationally complex, requiring greater staffing levels and O&M requirements than conventional clarification, retention treatment basins, and enhanced primary clarification. The King County CSO pilot test evaluated the performance of CEPT with lamella plates installed at a 55 degrees angle and a ratio of horizontal projected surface area to clarification surface area of 10.

5.6 Ballasted Sedimentation (CEPT with Lamella Plates and Microsand Ballast)

5.6.1 Description

A further variation on the CEPT with lamella plates technology is the Actiflo process by Krüger, which adds microsand as a seed for floc formation. In addition to providing more surface area for floc formation, the microsand acts as a ballast or weight. The microsand-ballasted floc that is formed has significantly improved settling characteristics compared to a conventional floc or chemical floc. Consequently, the Actiflo process is able to achieve even higher removal efficiencies at extremely high SORs relative to the other treatment technologies discussed.

5.6.2 Installations

The Actiflo process has been used at multiple wastewater treatment plants for wet-weather flow treatment, including Lawrence, Kansas; Greenfield, Indiana; and Port Clinton, Ohio. There are two known wet-weather treatment facilities using the Actiflo process that are remote from the treatment plant: Sanitary Sewer Overflow 700 in Cincinnati, Ohio and the CSO facility in Bremerton, Washington. There have been several pilot studies performed by other agencies that tested the Actiflo process for use in CSO or wet-weather applications, including studies in Columbus, Ohio (Landon et. al., 2005); Akron, Ohio (Frank and Smith, 2006); Milwaukee, Wisconsin; Toledo, Ohio; Hamilton, Ontario; and New York.

5.6.3 Discussion

The Actiflo process uses a sludge pump and hydrocyclone to separate and recover microsand from settled floc before returning it to the treatment process, adding another mechanical component to the treatment system that must be operated and maintained. Even with the microsand recovery process, some of the microsand remains in the solids and is wasted from the process along with the sludge, requiring a recurring O&M cost to replenish the microsand that is not recovered. In addition, the Actiflo process requires the wasting of a significant quantity of dilute sludge in order to operate properly. This can be accomplished by directing the flow back to the collection system. Because of concerns of capacity limitations in the King County system during CSO events, it is expected that separate storage tanks would be required for the waste solids from the hydrocyclones. CSO treatment technologies previously described are expected to store the settled solids in the sedimentation basin. This is not possible with this technology and so adds another component to the overall treatment system. Therefore, while providing the best overall performance and removal capabilities within the most compact footprint of the treatment technologies discussed so far, the Actiflo process is also the most complex process with the highest O&M and staffing requirements.

5.7 Ballasted Sedimentation (CEPT with Lamella Plates and Sludge Recycle Ballast)

5.7.1 Description

The DensaDeg process by Infilco Degremont is similar to the Actiflo process, with the primary difference being the type of ballast material used. Instead of adding microsand, the DensaDeg process uses a sludge recycle stream to enhance the flocculation process, relying on fine grit present in the influent wastewater to serve as the ballast material.

5.7.2 Installations

The DensaDeg process at the wastewater treatment plant in Toledo, Ohio is the largest, high-rate wet-weather installation in North America according to literature by Infilco Degremont. In addition, many of the published pilot studies that tested the Actiflo process also tested the

DensaDeg process for use in CSO or wet-weather applications, including the studies in Columbus, Ohio (Landon et. al., 2005); Akron, Ohio (Frank and Smith, 2006); Milwaukee, Wisconsin; Hamilton, Ontario; and New York.

5.7.3 Discussion

Because it does not use microsand, the DensaDeg process does not require a hydrocyclone to separate and recover microsand. This eliminates some of the O&M costs associated with replenishment of the microsand, but it also provides less operational control over the ballasted sedimentation process. It also allows the DensaDeg process to produce a thicker waste sludge, with solids concentrations in the 2- to 4-percent range, which is comparable to CEPT and CEPT with lamella plates. The waste solids concentration for the Actiflo process is typically much less concentrated, in the 0.15- to 0.25-percent range. The DensaDeg process requires sludge wasting during operation, although volumes are significantly less than for the Actiflo process. For King County facilities, separate waste sludge storage tanks are assumed. In general, the DensaDeg process is considered to be comparable to the Actiflo process regarding overall performance, removal capabilities, footprint requirements, complexity, O&M, staffing and costs.

5.8 Vortex and Screening (Hydrodynamic Separation)

5.8.1 Description

Hydrodynamic or vortex separation uses the incoming energy in the influent wastewater to induce a vortex flow pattern in a cylindrical tank, which helps to flocculate solids and accumulates the settleable solids at the center bottom of the unit for removal. There are several commercially available vortex separation processes, including the Storm King by Hydro International and the Hydrovex Fluidsep Vortex Separator by John Meunier/Veolia Water Solutions and Technologies. The Storm King unit also uses a self-cleaning, non-powered screening device for the removal of gross solids and floatables. A design by the U.S. EPA is also available and is non-proprietary.

5.8.2 Installations

Hydrodynamic separators have been used extensively for CSO and wet-weather treatment and floatables removal, including the Columbus, Georgia, Advanced Demonstration Facility and multiple installations in New York, Illinois and Michigan.

5.8.3 Discussion

At high hydraulic loading rates, vortex separation units with screens are typically only effective at removing floatables and dense grit particles. In order to achieve the required suspended solids removal efficiencies, vortex separation units must be designed and operated at hydraulic loading rates and SORs comparable to conventional clarification facilities. In addition, the available solids storage volume in vortex separation units is limited and solids must be wasted on a continuous basis and either stored in tanks or returned to the sewer. Therefore, based on the requirements for CSO treatment by King County, vortex separation units with screens do not offer any significant benefits or advantages relative to conventional clarification as a standalone CSO treatment technology.

5.9 Compressed Media Filters

5.9.1 Description

The Fuzzy Filter offered by the Schreiber Corporation and the WWETCO Filter offered by WWETCO, LLC are high-rate filters that use compressible synthetic fiber spheres in a media bed contained between two horizontal, perforated plates. The compression and porosity of the media bed are adjusted to suit the influent wastewater characteristics. The filter uses influent water combined with air scour for backwash, which effectively cleans the media with very little wash water and no loss of media as the media is physically retained during backwash by the perforated plates. These properties make compressed media filters effective at treating CSOs at filtration rates that are five to six times higher than high-rate sand filters.

5.9.2 Installations

The Fuzzy Filter is included in the Columbus, Georgia, Advanced Demonstration Facility, which included vortex separation units for grit, debris, and floatables removal upstream of the Fuzzy Filter. Units have also been installed in Atlanta, Georgia downstream of more traditional solids removal process components. Pilot studies have been performed in Akron, OH, and there is a pending installation in Springfield, Ohio.

5.9.3 Discussion

Pretreatment is required upstream of compressed media filters to remove grit, debris, and floatables that would otherwise plug and foul the filter media. Testing of compressed media filtration by King County for primary influent resulted in unreliable performance. However, when combined with adequate pretreatment, compressed media filters can reliably achieve suspended solids reductions of 50 percent or greater. In existing installations, compressed media filtration is not a standalone treatment process and is therefore considered as an add-on process to improve removal efficiencies in combination with other treatment processes. Operation of the filters also requires a regular backwash operation which produces a significant waste stream.

5.10 Continuous Deflective Separation

5.10.1 Description

The SanSep process offered by Process Wastewater Technologies LLC uses a continuous deflective separation fine-screening technology for solids removal. It is a passive screening process that converts a portion of the incoming hydraulic gradient into velocity energy that continually cleans the screen, which is typically a metal screen with openings of 1 to 5 mm. Flow is channeled into the interior of the screen, where it forms a circulating flow that sweeps the screen clean. The captured solids are concentrated inside of the screen, with the heavier solids settling to the bottom of the unit and lighter materials floating near the surface. When the solids build up to sufficient levels inside the screen, they are cleaned out and removed by mechanical means (vacuum trucks, clamshells, etc.) or with a sump pump. CSO applications typically use an underflow sump pump for solids removal, which monitors the solids inventory in the unit and periodically pumps the captured solids back to an interceptor, downstream of the overflow regulator. This pumped underflow is usually in the range of 1 percent to 2 percent of the treated flow. The SanSep process can also be used for pre-treatment prior to other CSO treatment technologies, removing coarse sediment and other solids that may otherwise negatively impact the performance of those technologies by plugging recirculation pumps, pipes, or lamella plates.

5.10.2 Installations

The process was originally developed in Australia, and there are multiple SanSep facilities in operation around the world, including CSO facilities in Louisville, Kentucky and Fort Wayne, Indiana. The process has been pilot tested for CSO applications in Louisville, Kentucky and Rockland County, New York.

5.10.3 Discussion

The SanSep process is very effective at removal of coarse solids, removing essentially all solids larger than 1 mm. Because the screen has a raised surface, solids are deflected away from the openings, allowing the screen to reject solids that are much smaller than the aperture in the screen, removing solids below 0.1 mm. The manufacturer reports good removals of solids materials in stormwater applications. It is difficult to translate this potential to a CSO application and without independent evaluation. While the screen has no moving parts, CSO applications typically include a submersible underflow pump for solids handling that must be maintained and could be subject to plugging from the collected debris. The unit has a very small footprint and can be operated at SORs as high as 150 gallons per minute per square foot. However, by converting some of the incoming hydraulic gradient into velocity energy to clean the screen, the SanSep process also creates head loss that must be accounted for in the system hydraulics. For King County, this process likely cannot meet the CSO discharge standards and requirements on a consistent basis as a standalone process, but could be used as a pre-treatment process combined with other treatment technologies, including but not limited to compressed media filters, CEPT with lamella plates, and Ballasted Sedimentation.

5.11 Salsnes Filter

5.11.1 Description

The Salsnes filter is a continuous-loop fine mesh screen that is distributed in the United States by Blue Water Technologies, Inc. As the screen moves, it carries captured solids out of the flow and drops them into a hopper, where an auger press dewaters the solids as they are conveyed to a dumpster for disposal. An air-blower system forces the retained screenings off the mesh and into the hopper, which is followed by a hot water wash for removal of grease and any remaining solids that may adhere to the mesh.

5.11.2 Installations

The Salsnes filter has been installed in over 240 facilities in a variety of applications, including primary wastewater treatment; membrane pretreatment; the food, fishing and dairy industries; pulp and paper industry; hog and beef manure treatment; and poultry rendering facilities. However, there are no known CSO applications using the Salsnes filter.

5.11.3 Discussion

TSS removal efficiencies of 40 to 70 percent can be achieved using the Salsnes filter within a footprint requirement that is approximately 10 percent of the footprint required for conventional clarification. The waste solids produced are also dewatered, with cake solids of 25 to 40 percent. While the high cake solids are beneficial at wastewater treatment facilities, reducing the disposal costs for the waste solids, the high cake solids creates additional solids handling issues at CSO facilities, which typically store the waste solids and return them to the sewer system after each event. In addition, the units have a limited flow capacity—the largest standard unit that is currently available (6,000 square feet) has a maximum hydraulic capacity of 3.7 mgd. While multiple units can be provided to treat higher flows, this is not considered practical for large CSO facilities with design flows of 100 mgd or greater, which would require over 25 of the largest standard Salsnes filter unit.

5.12 Dissolved Air Flotation

5.12.1 Description

In the dissolved air flotation (DAF) process, a portion of the flow is supersaturated with air under pressure and is mixed with the incoming flow after adding polymers and/or coagulants. When the supersaturated liquid is released into the tank, very small air bubbles are formed, which attach to the suspended solids and floc that were formed by the polymer and/or coagulant addition. The air bubbles cause the solids to rise to the surface, where they are skimmed and removed from the surface of the unit.

5.12.2 Installations

DAF units are used extensively for industrial wastewater treatment. DAF units were pilot-tested for CSO applications in the 1970s by the U.S. EPA and were implemented in San Francisco for CSO treatment. DAFs were also included as part of the hydrodynamic separators installed in the Columbus, Georgia, Advanced Demonstration Facility. The San Francisco facility was abandoned due to difficulties with the process. In Columbus, the process has not proved to increase performance.

5.12.3 Discussion

The process is complex, with high operation and maintenance costs. Based on the operational experience and poor performance history at the installations in San Francisco and Columbus, this process is not considered reliable and is not recommended for use in CSO applications.

5.13 Membrane Filtration

5.13.1 Description

Due to advancements in membrane technologies in recent years, membrane filtration is becoming increasingly feasible as a wastewater treatment technology in membrane bioreactors or as a tertiary treatment process. Depending on the pore size, membranes can be used to provide the following levels of filtration:

- Microfiltration, which separates particles from 0.1 to 10.0 microns
- Ultrafiltration, which rejects materials from 0.01 to 0.1 microns
- Nanofiltration, which rejects materials from 0.001 to 0.01 microns

- Reverse osmosis, ranging in molecular size up to 0.001 microns.

Microfiltration and ultrafiltration are classified as low-pressure membranes, with typical operating pressures in the range of 10 to 25 psi. Nanofiltration and reverse osmosis are classified as high-pressure membranes, with typical operating pressures between 50 and 225 psi for nanofiltration and 200 to 1,000 psi for reverse osmosis. Based on the very small pore sizes involved, membrane filtration processes are capable of achieving very high levels of solids capture and removal efficiencies. However, the membranes are also subject to plugging and fouling in wastewater applications, requiring a very high level of upstream pre-treatment in order to work effectively in wastewater applications.

Wastewater treatment processes such as membrane bioreactors, typically use low-pressure microfiltration or ultrafiltration membranes. Where extremely high-levels of tertiary treatment are required, high-pressure membranes (nanofiltration or reverse osmosis) may be used, often preceded by a low-pressure membrane as a pre-treatment step to minimize plugging of the high-pressure membrane.

5.13.2 Installations

Many wastewater treatment plants use membrane bioreactors or membranes for tertiary wastewater treatment, but there are no known installations using membrane filtration for CSO treatment.

5.13.3 Discussion

Currently, the high levels of treatment provided by membrane filtration are not required for CSO discharges. In addition, the intermittent nature of treating wet-weather flows, combined with the associated extreme peaking factors and rapid changes in flow rates, are generally not compatible with membrane treatment processes, which work best with continuous flow and much more moderate peaking factors. Therefore, while membrane filtration could be considered as an add-on process to achieve improved removal efficiencies in combination with other treatment processes, it is not practical for CSO applications based on the high levels of upstream treatment and flow equalization that would be required.

5.14 Electrocoagulation

5.14.1 Description

Electrocoagulation is an electro-chemical process that can precipitate and remove heavy metals, suspended solids, emulsified organics, and many other contaminants from wastewater using electricity and sacrificial plates instead of chemical reagents to form insoluble oxide and hydroxide floc, which are then removed using a conventional solids separation process (conventional clarification, enhanced primary clarification, etc.).

5.14.2 Installations

Electrocoagulation is used to treat many types of industrial wastewaters, including metal wastes, electroplating wastes, oily wastes, emulsions from heavy equipment wash bays, ship bilge water, and confined animal wash water waste. However, there are no known installations treating domestic wastewater, CSO, or wet-weather flows with electrocoagulation.

5.14.3 Discussion

Studies have indicated that electrocoagulation can achieve high levels of suspended solids reduction (90 percent or greater) without any chemical addition. However, the commercially available units tend to be smaller units geared toward the industrial wastewater market, with maximum reported capacities less than 4 mgd. While multiple units could be provided to treat higher flows, this is not considered practical for large CSO facilities with design flows of 100 mgd or greater, which would require over 25 units. The cost associated with this process is also prohibitive. Therefore, based on sizing considerations and the lack of full-scale operational experience with domestic or CSO wastewaters, electrocoagulation is not considered to be a feasible CSO treatment technology at present.

5.15 Initial Screening of Treatment Technologies

Based on an initial screening, the following treatment technologies were eliminated from further consideration as not being able to achieve the necessary level of treatment for King County CSO treatment facilities in a reliable manner:

- Primary clarification with concurrent disinfection
- Vortex and screening
- Salsnes filter
- Dissolved air floatation
- Membrane filtration
- Electrocoagulation.

Screening also eliminated the following treatment technologies from consideration as standalone treatment processes:

- Continuous deflective separation (SanSep)
- Compressed media filters.

While these treatment technologies could be combined with each other or used in combination with other treatment technologies to meet the County's CSO treatment needs and requirements, this would add an additional level of complexity and cost to the overall treatment process. Since the other remaining treatment technologies can meet County requirements as standalone processes, these two technologies were also eliminated from further consideration.

Based on further review, the ballasted sedimentation systems (Actiflo and DensaDeg processes) were considered similar enough to be evaluated as a single treatment technology for the purposes of this study. Thus five treatment technologies were carried forward for further evaluation, as described in Chapter 7:

- Conventional Clarification[1]

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[1] Just prior to initial screening, Wastewater Treatment Division management reviewed the performance of existing conventional clarification CSO plants and the very different conditions of the Duwamish River and recommended

- Clarification w/ Lamella Plates
- Chemically Enhanced Primary Treatment (CEPT)
- CEPT w/ Lamella Plates
- Ballasted Sedimentation.

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that conventional clarification be dropped from consideration. This information is presented for comparison purposes.

6.0. DISINFECTION TECHNOLOGIES

This chapter describes the disinfection technologies that were considered for use by King County. The challenges associated with disinfection of CSOs include effectively dealing with high concentrations of organic materials, suspended solids, and various other pollutants, including oil and grease, oxygen-demanding compounds, chemicals, nutrients, heavy metals, bacteria, and viruses. In addition, CSOs are also characterized by variable temperatures and variable concentrations of microorganisms. This variability makes disinfection difficult, as it requires a disinfectant that can be applied at a high rate with a strong capacity for bacterial reduction (at least 99.9 percent) under a wide variety of operating conditions.

Available technologies for disinfection of CSOs and other wet-weather flows can generally be characterized as one of the following:

- Chemical disinfection
- Irradiation
- Combination of chemical disinfection with irradiation.

Chlorine is an example of a chemical disinfectant that has been widely used in the water and wastewater industry. Chlorine is available in several forms for disinfection applications, with liquid sodium hypochlorite a commonly used form for wastewater disinfection. Other forms of chlorine are also effective disinfectants and have been used to treat water and wastewater, including chlorine dioxide. Other chemicals that are powerful oxidants have also been used as disinfectants, including ozone, peracetic acid, and bromine-based compounds (BCDMH).

As an alternative to chemical disinfectants, irradiation may be used, typically using ultraviolet light. UV is a well-established disinfection technology that is currently in use at facilities around the world, with multiple suppliers offering a variety of systems for water and wastewater disinfection. While electron beam irradiation has also been tested for disinfection, it has not been embraced as an effective disinfection technology and continues to be unproven for long-term use. Therefore, UV is the only form of irradiation considered in this evaluation.

In some cases, a chemical disinfectant may also be used in combination with UV irradiation. For example, UV can be used in combination with hydrogen peroxide, a chemical oxidant, to provide enhanced disinfection.

6.1 Sodium Hypochlorite

6.1.1 Description

Most remote wet-weather facilities that use chlorine for disinfection, including those owned and operated by King County, use liquid sodium hypochlorite. Therefore, for this evaluation, sodium hypochlorite will be used as the baseline chlorination technology for disinfection of CSOs.

Hypochlorite in some form has long been used as a disinfectant for water, wastewater, and wet-weather flow treatment. It uses the same disinfecting chemical as obtained from chlorine gas, but in a non-gaseous form. While hypochlorite may be provided as solid tablets of sodium hypochlorite or calcium hypochlorite with a binding agent for smaller facilities, it is most commonly supplied in bulk for CSO applications as a liquid solution of sodium hypochlorite at an initial concentration of 12.5 percent.

Hypochlorite is generally an effective disinfectant when it is present in sufficient concentrations with an adequate contact time. For CSO applications, which typically have very high peak design flows, the contact time is often limited and relatively short. Therefore, hypochlorite is usually fed at dosages that are sufficiently high to provide a significant chlorine residual in the CSO discharge in order to provide adequate disinfection. As a result, dechlorination following chlorination by hypochlorite may be needed to meet chlorine permit limits. Dechlorination is typically accomplished with sulfur dioxide gas, sodium bisulfite, or sodium metabisulfite; the last two are available in both solid and solution forms.

6.1.2 Installations

Chlorination/dechlorination is considered to be the standard CSO disinfection technology and is currently installed in King County and in numerous installations around the United States.

6.1.3 Discussion

Hypochlorite is generally easy to use and safe to store. Both liquid and solid forms can lose potency over time, depending on temperature and storage conditions, with the solid form being somewhat more stable over time. For liquid hypochlorite, this results in a reduction in the active concentration of the hypochlorite solution over time to something less than the initial 12.5 percent. This can result in having to replace unused hypochlorite with fresh stock if it is not used quickly enough, or increasing the dosage to compensate for the reduction in potency. Otherwise, the technology is very reliable at obtaining desired reductions in pathogenic organisms.

Hypochlorite can also result in the formation of trihalomethanes (THMs) or other disinfection byproducts. In addition, it is often required to use a second chemical for dechlorination, essentially doubling the facilities and system complexity while increasing the O&M costs. Like hypochlorite, solutions of bisulfite or metabisulfite can lose potency over time, requiring that the stock be rotated or the dosage increased to compensate for the loss in potency. Freezing of the more concentrated bisulfite solutions has resulted in interruptions of dechlorination and, thus, chlorine permit violations, at County facilities. Finding the appropriate balance of hypochlorite to bisulfate in the rapidly varying flows has also proved challenging.

6.2 UV Light

6.2.1 Description

Irradiation with ultraviolet light has become a common method for achieving inactivation of pathogens in wastewater and stormwater. The wastewater stream passes by banks of UV lamps (wavelengths of 220 to 320 nanometers (nm)) emitting at sufficient intensity to achieve the desired inactivation. The most effective wavelength is 260 nm, and UV lamps used for wastewater disinfection typically emit the majority of their light energy at around 254 nm. In addition to bacteria, UV is highly effective against viruses, *Cryptosporidium*, and *Giardia*.

The UV light inactivates pathogenic organisms by penetrating the cell wall and altering the DNA, which prevents the organism from replicating or functioning. The wastewater must have sufficient transmittance of UV for this to work. Turbidity and TSS concentrations must be relatively low because solids or particulates in the wastewater can scatter or absorb the UV light, blocking or shielding the organisms from exposure to the UV light. For CSO applications, this requires a high degree of upstream treatment in order for UV to be an effective disinfectant.

While turbidity and TSS are important parameters to consider for UV disinfection, they are not the only parameters that influence UV performance. Some soluble compounds in wastewater can absorb UV light, including sun block, coffee, pharmaceuticals, and other constituents. UV transmittance (UVT) accounts for the effects of both particulates and soluble compounds and is the primary parameter that impacts the performance of UV disinfection systems.

A relationship exists between the applied UV dose (typically expressed as milliwatt-second per square centimeter, or mW-s/cm^2) and the corresponding reduction in pathogenic organisms. The performance of a UV disinfection system is directly related to the concentration of fecal coliforms in the effluent. Process performance is measured in terms of “log reduction” in coliform concentrations. Each increment in “log reduction” represents a factor of 10 reduction in the residual coliform concentration; for example, 1-log reduction removes 90 percent and 2-log removes 99 percent.

In 2003, the National Water Research Institute (NWRI) and the American Water Works Association Research Foundation (AwwaRF) published *Ultraviolet Disinfection Guidelines for Drinking Water and Reuse*, which recommended UV design dose guidelines for wastewater reuse applications as cited in WEF MOP-8: 100 mW-s/cm^2 and 55-percent UVT for effluent treated with media filtration. The 2005 WERF study for disinfecting wet-weather flows used a UV dose between 65 and 220 mW-s/cm^2 during the pilot-testing phase, with an assumed design dose of 100 mW-s/cm^2 for the conceptual cost estimates.

For the reasons listed above, UV is generally not recommended for use with conventional clarification without sufficient pilot studies or testing that demonstrate its reliable and effective use in this application.

CEPT with lamella plates and CEPT are both considered to be more appropriate for use with UV, based on the greater TSS removal efficiencies for these treatment technologies. However, the reliability of both with UV is still questionable, and further testing is recommended before using UV in combination with either of these treatment technologies.

UV is most effective when combined with high levels of upstream treatment, including CEPT with lamella plates and ballasted sedimentation. One consideration with the use of both of these treatment technologies in combination with UV is the type of chemical coagulant used. Ferric chloride, which is a commonly used coagulant, can also foul the downstream UV lamp sleeves, reducing the effective UVT and negatively impacting the disinfection performance. Therefore, alternative chemical coagulants are recommended for use with UV systems, including alum or polyaluminum chloride.

An advantage of UV over chemical disinfection methods is that no chemicals are required to be stored, and no residual chemicals such as THMs or disinfection byproducts are formed. UV disinfection also requires a very short contact time, typically between 5 and 10 seconds, which results in a very small footprint compared to chemical disinfection technologies, which require minimum contact times in the range of 2 to 15 minutes depending on the chemical disinfectant used.

6.2.2 Installations

A number of facilities have implemented UV for wastewater treatment. By 2007, it was estimated that approximately 21 percent of all major publicly owned treatment works used UV for disinfection (WEF MOP-8), so UV disinfection is a well-established and proven wastewater disinfection technology. However, UV has typically been used with highly treated waste streams with low concentrations of TSS and turbidity, so wet-weather applications have been fewer and typically associated with high levels of treatment such as CEPT or ballasted sedimentation. Wet-weather facilities using UV disinfection include Bremerton, Washington; Cincinnati, Ohio; and Columbus, Georgia. All of these wet weather facilities include a relatively high level of treatment prior to the UV application.

6.2.3 Discussion

UV systems are relatively easy to maintain, especially if they are used intermittently, as would be the case for CSO treatment. The lamps require occasional wiping, unless a wiper system is built in, and occasional cleaning using prescribed chemicals. Upstream use of ferric chloride can contribute to lamp fouling, so alternative chemical coagulants are recommended for use with UV systems, including alum or polyaluminum chloride.

The King County pilot study evaluated the UV transmittance (UVT) of effluent from CEPT and CEPT with lamella plates, and reported UVT over 66 percent for the influent and effluent for both technologies. However, the influent for the pilot test unit was a combination of primary effluent diluted with secondary effluent from a treatment plant, and it appeared that the test results were influenced by the presence of the secondary effluent. Consequently, the pilot test results are not conclusive regarding the UVT that is expected to be associated with the effluent from these treatment technologies when treating actual CSOs.

In comparison, as cited in the pilot test report, columnated beam testing at pilot scale wet-weather treatment in Toronto (CEPT with lamella plates) and full-scale facilities at Bremerton (ballasted sedimentation) have produced results with UVT ranges from 40 to 60 percent, indicating that fecal coliform levels of 200 coliform-forming units/100 ml can be achieved at a UV dose of 30 mW-s/cm^2. This is a relatively low UV dose when compared to the NWRI-AwwaRF recommended UV doses for wastewater effluent reuse applications and the assumed design dose from the 2005 WERF wet-weather disinfection study (100 mW-s/cm^2).

As long as the transmittance of the water stream is adequate, the reliability of UV systems is generally outstanding. For remote CSO operation, it may be necessary to have higher intensity lamps to ensure acceptable operation. UV systems have a larger power requirement than most chemical disinfection technologies, requiring larger back-up emergency power supply facilities (generator or uninterruptible power supply).

6.3 UV Light with Hydrogen Peroxide

6.3.1 Description

A possible enhancement of a UV irradiation system is the use of UV in combination with an oxidant such as hydrogen peroxide, with produces a hydroxyl ion radical that is an extremely powerful oxidant. Such a combined system has been shown to potentially be more effective in achieving pathogen reduction than either technology alone. A combined system has also been found to be effective at removing certain recalcitrant chemicals from water streams. The system works by introducing liquid hydrogen peroxide into the wastewater upstream of a UV system. A portion of the UV light reacts with the hydrogen peroxide to form the hydroxyl ion radical, which then rapidly oxidizes most compounds that it comes into contact with.

Like hypochlorite, hydrogen peroxide can lose its potency over time, meaning that replacement of stock could be required if the chemical is not used quickly enough. Also, because the oxidant reacts with other compounds in the wastewater, the chemical demand for wet-weather applications will be extremely high in order to effectively improve disinfection. This process would be most applicable to very dilute waste streams with low concentrations of recalcitrant compounds or wastewater effluent that has received advanced levels of wastewater treatment, such as biological wastewater treatment followed by tertiary filtration.

6.3.2 Installations

There are no known wet-weather facilities using UV with hydrogen peroxide for disinfection.

6.3.3 Discussion

Because of the high chemical demands that would be required for this process to be effective in wet-weather applications, it is not recommended for further consideration. Comparable results can be achieved by designing a conventional UV system to provide higher UV doses as required.

6.4 Ozone

6.4.1 Description

The strong oxidant ozone has been studied and used in a number of water and wastewater disinfection applications. Ozone itself is unstable, meaning that it must be generated on-site at the time of application. The technology involves a means of generating pure oxygen by separating molecular oxygen from air, passing that oxygen through an ozone generator, then bubbling the ozone into the water stream. The advantages of ozone are that it is a strong disinfectant that leaves no residual, and that it does not create trihalomethanes. The primary drawbacks are the production process, which is complicated compared to other disinfection technologies.

6.4.2 Installations

Pilot-testing of ozone for wet-weather disinfection has been reported by the U.S. EPA in New York City (Wojtenko and Stinson, 2003) and the WERF in Syracuse, New York (Moffa et. al. (b), 2005). However, there are no known wet-weather facilities using ozone for disinfection.

6.4.3 Discussion

The requirements for pure oxygen and high electrical power to form ozone mean that the overall process is extremely energy intensive. The WERF pilot study reported no measurable formation of disinfection byproducts associated with the use of ozone; nor was the ozone effluent found to be toxic. However, the same study found that compared to other disinfectants tested (chlorination, chlorine dioxide, and UV), ozone had the highest average effluent bacteria concentrations and the lowest average log reductions, which indicates that ozone was the least effective disinfectant tested for wet-weather applications. This difference in effectiveness could have been due to challenges associated with accurately measuring ozone residuals and hence dose, or to the fact that ozone was readily consumed by constituents in the wastewater.

Based on the high energy requirements and limited effectiveness compared to other disinfection technologies as reported in the 2005 WERF report, ozone is not considered to be a viable disinfection alternative for CSOs at this time. These findings are consistent with those of the 2003 EPA report, which found ozone not to be feasible for CSO applications.

6.5 Peracetic acid

6.5.1 Description

Peracetic acid is obtained by combining glacial acetic acid with hydrogen peroxide. It is available from Solvay Chemicals, which is marketing its use for disinfection of wastewater treatment plant effluent and wet-weather flows under the brand name Proxitane WW-12, which is a 12-percent solution of peracetic acid that was recently approved by the EPA for wastewater disinfection applications. FMC Corporation is also marketing a proprietary 15-percent peracetic acid formulation (VigorOx® WWTII) for use in wastewater disinfection applications, which has also received EPA approval.

Peracetic acid is an excellent bactericide that decomposes into non-harmful byproducts (water, oxygen, and acetic acid), so no reducing agent is required to treat any remaining residual concentrations prior to discharge. Because it is non-halogenated, it does not produce THMs. It is a liquid that can be stored for extended periods (over 12 months) in cool, dry, well-ventilated locations with the addition of a stabilizing compound. However, it is thermally unstable and can decompose, becoming explosive at high temperatures (greater than 122 degrees Fahrenheit). Peracetic acid reacts rapidly when fed to the waste stream, so relatively short contact times are required compared to chlorine. Because it is a powerful oxidant with a $pH < 2$, it requires special handling, storage and safety considerations.

6.5.2 Installations

Peracetic acid has a proven record as a safe sanitizer in the food industry. Solvay Chemical recently started marketing its use for wastewater disinfection, including wet-weather applications, with a known installation at a wastewater treatment plant in Frankfort, Kentucky. FMC Corporation has also published the results of a full-scale demonstration test at the WWTP in St, Augustine, FL, where peracetic acid was tested side-by-side with chlorination/dechlorination for disinfection of the plant's effluent (Keogh and Tran, 2011).

6.5.3 Discussion

Peracetic acid offers several potential advantages for wet-weather applications compared to chlorination using sodium hypochlorite:

- A longer shelf-life
- No formation of THMs
- No need for additional reducing agents to treat residuals
- A potentially smaller footprint requirement due to shorter contact time requirements.

However, it is currently only being marketed for use in wastewater applications by two suppliers in the United States (Solvay Chemical and FMC Corporation). It also requires extreme caution in handling, storage, and safety considerations to protect workers.

6.6 Chlorine Dioxide

6.6.1 Description

Chlorine dioxide is a powerful oxidizing agent, which theoretically has 2.5 times the oxidizing power of chlorine. It is also more soluble, a broader bactericide, and a more effective viricide than chlorine. Chlorine dioxide is a more effective disinfectant than chlorine and is capable of achieving comparable levels of bacterial reduction at lower doses or shorter contact times. It also does not react with ammonia and does not produce THMs. However, other disinfection byproducts may be formed by the generation and use of chlorine dioxide, including residual concentrations of chlorine dioxide, chlorite or chlorate.

Because of its oxidation properties, chlorine dioxide is used to treat for a variety of compounds and parameters in water and wastewater applications: taste and odor control; phenols; sulfides; iron; manganese; THM precursors; pesticides; and algae control.

Chlorine dioxide is unstable and must be generated on-site and used on an as-needed basis. A variety of chlorine dioxide generation technologies are available. Due to safety considerations, generation of chlorine dioxide using chlorine gas is not considered to be a viable alternative. Instead, only generation technologies that use liquid solutions with either sodium chlorite or sodium chlorate as a base feed chemical, with the addition of a strong acid (such as hydrochloric acid or sulfuric acid), are recommended for this application. The feed stock chemicals are relatively stable and can be stored for up to 6 months.

The use of a reducing agent will likely be required to treat any residual of chlorine dioxide, chlorite, or chlorate. Special handling, storage and safety considerations apply to chlorine dioxide systems, although these requirements are not as stringent as for peracetic acid.

6.6.2 Installations

Several studies that pilot-tested ozone for wet-weather disinfection also pilot-tested chlorine dioxide, including the EPA study in New York City (Wojtenko and Stinson, 2003) and the WERF study in Syracuse (Moffa et. al. (b), 2005). There are no known wet-weather facilities using chlorine dioxide for disinfection, but multiple facilities use it for applications other than wastewater disinfection.

6.6.3 Discussion

Chlorine dioxide is a stronger disinfectant than hypochlorite, allowing lower dosages or less contact time. It also does not produce THMs and requires a relatively small footprint for the generation equipment. However, it will likely produce disinfection residuals and disinfection byproducts, requiring the use of a reducing agent post-disinfection. It also requires special handling, storage, and safety measures.

6.7 Bromochlorodimethylhydantoin

6.7.1 Description

Bromochlorodimethylhydantoin (BCDMH) is a chemical in powdered form that can be dissolved in water to form a powerful disinfectant, which can achieve greater bacterial reductions than a comparable dose of chlorine. The combination of active biocides that are formed (hypobromous acid and hypochlorous acid), which are also powerful oxidizing agents, can achieve better bacterial reductions at lower doses or reduced contact times, with lower concentrations of disinfection byproducts than sodium hypochlorite.

In its powdered form, BCDMH is highly stable and can be stored for extended periods with negligible degradation of oxidation strength. According to the manufacturer of BCDMH (Ebara of Tokyo, Japan), it can be stored for over a year without a decrease in effectiveness using relatively simple storage and feed systems. Ebara is the only known supplier of BCDMH for the wastewater industry in the United States.

Because of these properties, BCDMH is a disinfection technology that has the potential to be well-suited for use in the intermittent treatment of wastewater, including CSO disinfection. However, because it uses halogenated compounds, BCDMH still produces THMs and disinfection byproducts.

6.7.2 Installations

BCDMH is currently in use in Japan for CSO disinfection, but there are no known full-scale operational CSO or other wastewater facilities in the United States using BCDMH. However, it is used in other disinfectant applications in the United States, including the pool and hot-tub industries. Pilot and bench-scale testing of BCDMH for CSO disinfection was performed by the City of Akron, Ohio, in October and November of 2005 (Moffa et. al. (a), 2006).

6.7.3 Discussion

BCDMH provides a stronger disinfectant than hypochlorite, requiring potentially lower dosages or less contact time. It also requires a relatively compact footprint for the storage and feed equipment, which is relatively simple. The dry powder is very stable and can be stored for periods as long as a year without losing effectiveness. However, it still produces THMs and disinfection byproducts, requiring the addition of a reducing agent post-disinfection.

6.8 Initial Screening of Disinfection Technologies

An initial screening of the disinfection technologies described above eliminated UV light with hydrogen peroxide and ozone from further consideration, as they are not viable wet-weather disinfection technologies at this time. The remaining disinfection technologies were all considered to be viable disinfection technologies, each with potential merits as well as potential drawbacks. Further evaluation of the remaining disinfection technologies is described in Chapter 7.

7.0. FINAL EVALUATION OF TECHNOLOGIES

This chapter presents facility cost estimates for the treatment and disinfection technologies remaining after the initial screening processes described in Chapters 5 and 6. The cost estimates, along with the qualitative assessments of the technologies presented in Chapters 5 and 6, were then used to evaluate the remaining technologies against the criteria described in Chapter 4. This final evaluation led to the identification of two selected treatment technologies and two selected disinfection technologies.

7.1 Summary of Screened Treatment Technologies

Table 2 summarizes the treatment technologies advanced for final evaluation, and the design SORs for each.

Table 2. Screened Treatment Technologies and Design Overflow Rates

Process	Description	SORs for 50% TSS Removal (gpd/sf)
Conventional Clarification[1]	Rectangular settling tank	1,000
Clarification with Lamella Plates	Conventional clarification with plates to improve settling by providing a more uniform, quiescent flow in the downward flow direction, which increases the amount of particulates that reach the bottom of the tank	15,000
CEPT	Conventional clarification with the addition of polymer to promote coagulation	5,000
CEPT with Lamella Plates	Conventional clarification with the addition of polymer to promote coagulation, and addition of lamella plates to increase effective solids settling area	20,000
Ballasted Sedimentation	Conventional clarification with settling plates, chemicals and a ballast such as sand to clarify and filter solids	57,600

1. Just prior to screening, Wastewater Treatment Division management reviewed the performance of existing conventional clarification CSO plants and the very different conditions of the Duwamish River and recommended that conventional clarification be dropped from consideration. This information is presented for comparison purposes

7.2 Cost Data

7.2.1 Construction Cost Estimates

The *Technical Memorandum 620, Cost Estimating Methodology for CSO Control Facilities* presents the project cost estimating methodologies used to develop project and life-cycle costs for CSO treatment facilities. Planning-level construction costs were estimated using cost curves (developed from the Omaha CSO cost model) for the CSO treatment facilities and King County cost model (Tabula Rasa) for conveyance systems.

Table 3 summarizes the cost elements included in the estimates for each CSO treatment technology. Conveyance (influent and effluent piping) and outfall costs are not included because those costs would be the same for all alternatives. The following sections describe the included cost elements.

Table 3. Wet-Weather Treatment Facility Cost Components

	CSO Treatment Technologies				
Cost Elements	**Conventional Clarification**	**Clarification with Lamella Plates**	**CEPT**	**CEPT with Lamella Plates**	**Ballasted Sedimentation**
CSO Treatment[a]	√	√	√	√	√
Influent Pump Station	√	√	√	√	√
Regulator Station Upgrades	√	√	√	√	√
Grit Removal					√
Solids Handling[b]		√		√	√
Lamella Plates		√		√	√
Property Acquisition[c]	√	√	√	√	√

a. CSO treatment includes screening, disinfection, and ancillary facilities (odor control and standby generator).
b. Solids handling costs assumes a separate solids handling facility.
c. Property cost based on average cost per square foot for industrial building and land in the Duwamish area.

CSO Treatment

The CSO treatment cost estimates assume a wet-weather treatment process along with screening, disinfection, and ancillary facilities that include odor control and standby generator. Estimates for each treatment technology were developed as follows:

- **Conventional Clarification**—These treatment costs were developed using the ballasted sedimentation treatment costs as the base costs, removing the cost associated with the Actiflo process, and adding cost for a conventional clarifier settling basin with an overflow rate of 1,000 gpd/sf (from Tabula Rasa).
- **Clarification with Lamella Plates**—These treatment costs were developed using the ballasted sedimentation treatment costs as the base costs, removing the cost associated with the Actiflo process, and adding cost for a settling basin with an overflow rate of 15,000 gpd/sf (from Tabula Rasa) and lamella plates (from Meurer Research vendor quote).
- **CEPT**—These treatment costs were developed using the ballasted sedimentation treatment costs as the base costs, removing the cost associated with the Actiflo process but retaining costs associated with the chemical feed system and storage. Added cost for a settling basin with a SOR of 20,000 gpd/sf (from Tabula Rasa). Additional costs were added for chemical mixing basins, assuming a design detention time of 8 minutes for both coagulation and flocculation.

- **CEPT with Lamella Plates** —These treatment costs were developed using the ballasted sedimentation treatment costs as the base costs, removing the cost associated with the Actiflo process but retaining costs associated with the chemical feed system and storage. Added costs for a settling basin with lamella plates with a SOR of 20,000 gpd/sf (from Tabula Rasa). Additional costs were added for chemical mixing basins, assuming a design detention time of 8 minutes for both coagulation and flocculation.
- **Ballasted Sedimentation**—The Omaha tool provided a cost curve for treatment including the following components: 4-mm fine screens, Actiflo system (chemical injection tank, flocculation tank, settling tank), sump pumps for dewatering, UV disinfection, polymer feed system, coagulant feed system, and microsand storage. The ballasted sedimentation cost component is approximately 35 to 55 percent of the wet-weather treatment facility costs.

Influent Pump Station

Costs for each treatment technology include an influent pump station to lift flows to the treatment facility. The Tabula Rasa cost tool for pump stations assumes an excavation depth of 30 feet and a total design head of 35 feet.

Regulator Station Upgrades

Costs for each treatment technology include upgrades to the existing regulator station to route flows to and from the treatment facility. The Tabula Rasa cost tool for regulator station was used assuming an above-grade structure would be required.

Grit Removal

Per manufacturer recommendations, grit removal costs were added only to the ballasted sedimentation facility to protect the equipment from plugging. Costs were obtained from planning-level unit costs ($/mgd) obtained from facilities with different types of grit removal systems, including vortex structures.

Solids Holding Basin

Separate solids handling facility costs were included for facilities where the CSO treatment settling basin would not provide sufficient solids storage. Influent (TSS) loads were calculated using 32 years of King County overflow data from storm events. Total solids was estimated using the influent TSS loads, assuming 85% TSS removal, and 2.5% solids concentration. The 85% TSS removal is representative of the average TSS removal performance of the Clarification with lamella plates, CEPT with lamella plates, and ballasted sedimentation treatment processes. TSS removal efficiencies of the each treatment process is discussed further in Section 7.2.3. The total solids calculated were compared to the settling basin area calculated assuming the CSO peak flow rate (not equalized peak flow rate).

Conventional clarification and CEPT treatment technologies provide settling basins with sufficient volume to store the solids generated during treatment, due to their lower SORs requiring larger settling basin areas. Clarification with lamella plates, CEPT with lamella plates, and ballasted sedimentation will require a separate solids holding basin due to the smaller settling basin area available with those technologies’ higher SOR.

Lamella Plates

For planning level cost estimating, lamella plate costs were obtained from the manufacturer assuming stainless steel lamella plates installed at a 55-degree angle with a ratio of horizontal projected surface area to clarification surface area of 11.5, similar to the King County CSO pilot tests.

Property Acquisition

Property acquisition costs are included based on footprint curves developed for each treatment technology. Land cost of $114.47 per square foot was used, based on the average land cost of property in the Duwamish area, where CSO treatment facilities are most likely.

Cost Summary

Figure 4 shows construction and property acquisition cost estimates for the five treatment technologies.

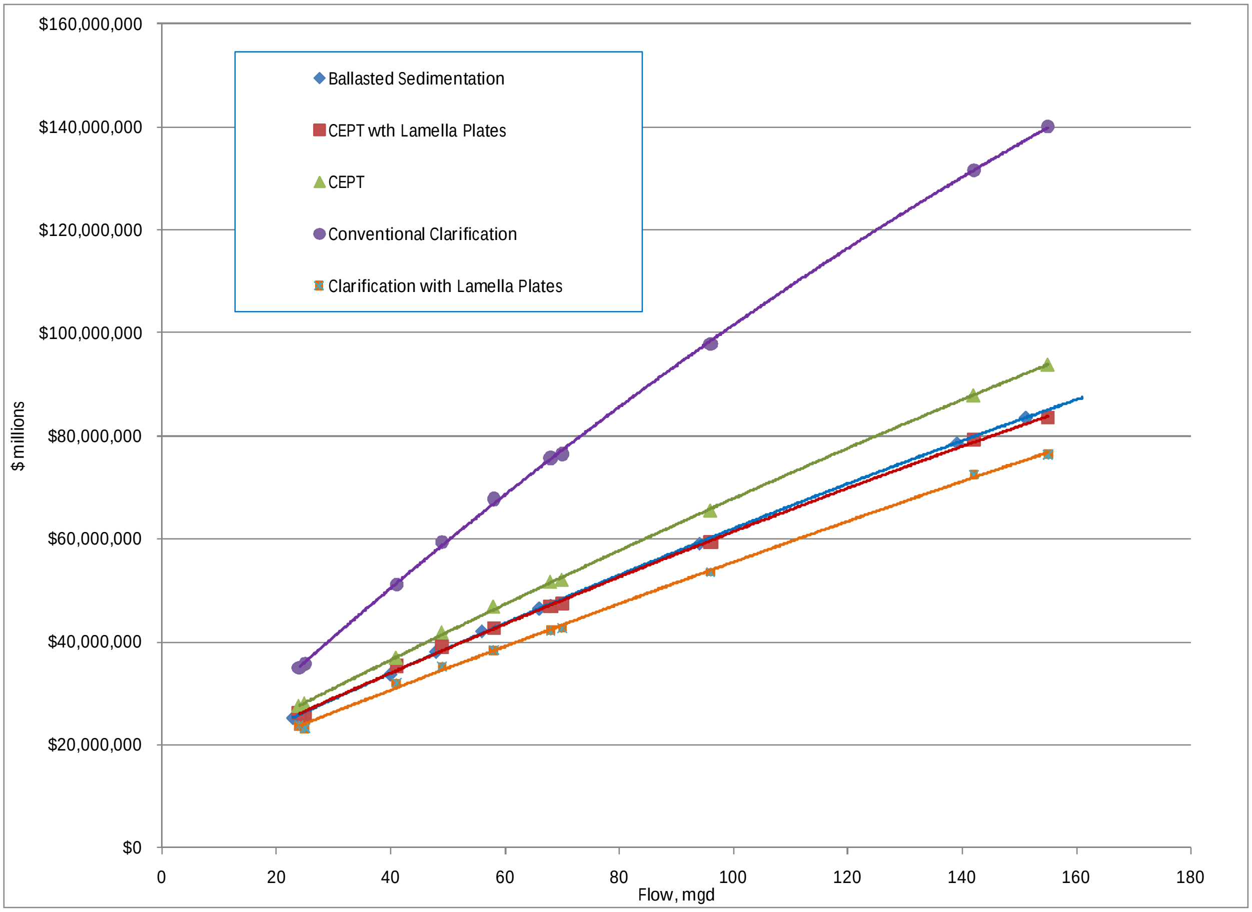

Figure 4 **Construction Costs Comparison (ENR CCI: 8645.35, Seattle, January 2010)**

The results can be summarized as follows:

- Conventional clarification has the highest estimated cost, associated with a larger settling basin and land acquisition.

- CEPT facilities are the second highest in construction cost, due to costs associated with a larger settling basin, chemical mixing basins, and land acquisition.
- Ballasted sedimentation and CEPT with lamella plates are similar in total construction cost, but the costs for ballasted sedimentation are due to equipment costs and those for CEPT with lamella plates are associated with settling basin size, chemical mixing basins and land acquisition.
- Clarification with lamella plates is the least expensive technology due to the lack of chemical mixing basins and moderate land acquisition requirements.

7.2.2 Operating Costs

Operating costs for the CSO treatment facilities were not developed as part of this technical memorandum but are evaluated in the *Technical Memorandum 620, Cost Estimating Methodology for CSO Control Facilities*. The following operation and maintenance costs are considered:

- **Staffing**—Staffing during normal operations will consist of major preventive work before and after CSO events. Staffing directly related to storm events will consist of sampling and monitoring during the events and preparing the facility for the next event.
- **Power**—Ballasted sedimentation, CEPT and CEPT with lamella plates will have higher power costs associated with sludge pumps and chemical feed systems. Equipment associated with conventional clarification and clarification with lamella plates treatment processes do not have power requirements.
- **Chemicals**—Ballasted sedimentation, CEPT and CEPT with lamella plates will have costs associated with chemical feed of polymer and coagulant. Costs will depend on the feed rates required to meet performance requirements.

Operating costs for the Lawrence, Kansas Wet-weather Treatment Facility were collected over a period of two years. The costs included chemical costs (ferric chloride and polymer), operations labor (1 FTE during an event), and maintenance labor (0.25 FTE). Total operating cost was estimated to be $93.21 per million gallons of treated flow.

7.2.3 Unit Costs Based on Treatment Performance

Unit Cost per Pound of TSS Removed

A comparative analysis of the construction cost and TSS removal efficiency of the five CSO treatment technologies was performed as follows:

- Calculate annual average TSS influent load:
    - Use 32 years of King County overflow volume from storm events in 10 King County CSO basins where treatment will be considered.
    - Assume a TSS concentration of 120 mg/L.
- For each technology, calculate a minimum and maximum TSS removal (pounds per year) based on the following TSS removal efficiencies:
    - Conventional Primary—50 percent to 70 percent

  - Clarification with Lamella Plates—50 percent to 70 percent
  - CEPT—60 percent to 90 percent
  - CEPT with Lamella Plates—60 percent to 90 percent
  - Ballasted Sedimentation—75 percent to 90 percent.
- Divide the construction cost shown on Figure 4 by the range of annual average TSS removal for each treatment technology.

Figure 5 shows the results, which may be summarized as follows:

- Ballasted sedimentation is the most cost-effective because it has the highest TSS removal efficiency and a construction cost comparable to the other treatment technologies.
- Conventional clarification has the highest unit cost per pound of annual average TSS removed, due to its high construction costs and low removal rate.
- The unit construction cost per pound of annual average TSS removed is similar for CEPT, CEPT with lamella plates and clarification with lamella plates.
- The unit construction cost per pound of annual average TSS removed is highly sensitive to the range of TSS removal efficiency.

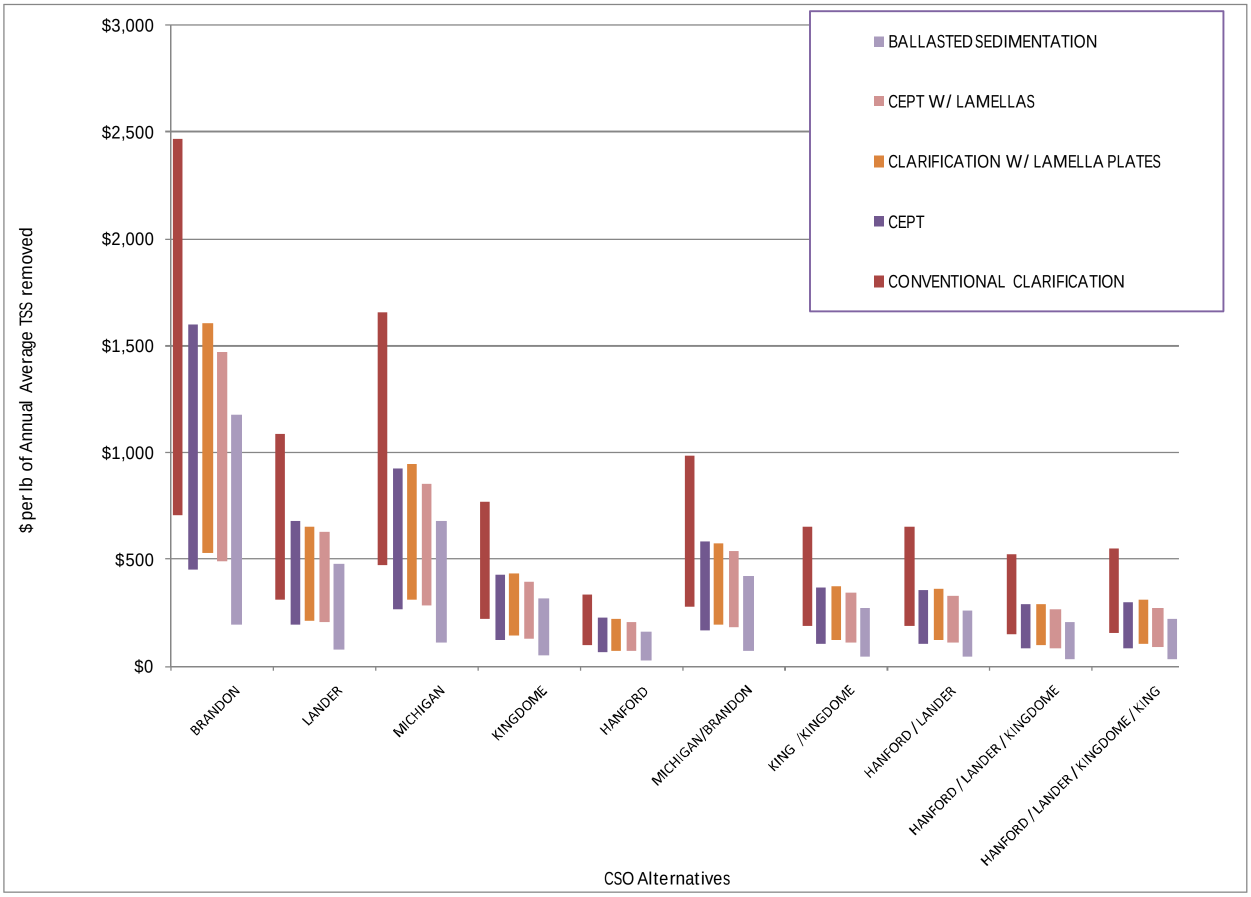

Figure 5 **Unit Construction Costs per Pound of Annual Average TSS Removed (ENR CCI: 8645.35, Seattle, January 2010)**

Unit Cost per Pound of Copper Removed

A comparative analysis was performed of the construction cost and amount of copper removed for the five treatment technologies. At this time, the Washington Department of Ecology has not imposed specific requirements for the removal of metals. However, as water quality standards become more stringent, removal of metals will likely need to be addressed. Copper concentrations in CSOs discharged to receiving waters would need to meet the acute water quality standards identified in the Washington Administrative Code, which states that 1-hour average concentrations at the edge of an approved mixing zone may not be exceeded more than once every three years on average (WAC 173-201A, Table 240(3)).

In 2006, King County conducted a water quality review for parameters of concern at Duwamish area outfalls identified as potential locations for CSO treatment facilities. The assessment assumed the use of conventional clarification for treatment, which provides little removal of dissolved copper. Thus, the results of the assessment indicated potential to exceed dissolved copper limits at these locations.

Clarification with lamella plates also does not provide any dissolved copper removal and will not meet water quality limits for dissolved copper. The CSO treatment technologies using chemical addition (CEPT, CEPT with lamella plates, ballasted sedimentation) will improve removal of dissolved copper – this was a factor in the County's decision to recommend these technologies. Operating experience with full-scale facilities will be needed to determine actual copper removals. During the pilot testing, King County investigated Metclear, a specialty polymer designed and marketed to enhance metals removal. It was seen to be particularly effective for dissolved copper removal, with 81% to 90% removal of dissolved copper for CEPT and CEPT with lamella plates, respectively. If operating experience shows the need for additional removal of dissolved copper levels, chemicals such as Metclear could be added to the process.

7.3 Final Evaluation of Treatment Technologies

The five treatment technologies remaining after the initial screening were presented at the workshop on November 17, 2010. Appendix A provides detailed results of the evaluation of these technologies based on the key evaluation criteria. Table 4 summarizes these results.

Table 4. Selected Treatment Technologies and Key Evaluation Criteria

	Evaluation Criteria					
	Performance					
Technology	Potential Treatment Performance	Adaptability	Reliability	Siting Requirements	Cost	Staffing Requirements
Conventional Clarification	Marginal	Yes	Fair	Largest Site	Highest	Low
Clarification w/ Lamella Plates	Fair	Yes	Fair	Moderate	Moderate	Low
Chemically Enhanced Primary Treatment (CEPT)	Good	Yes	Good	Moderate	High	Moderate
CEPT w/ Lamella Plates	Better	Limited	Good	Moderate	High	Moderate
Ballasted Sedimentation	Best	Limited	Good	Moderate	High	Highest

Based on the analysis performed at the workshop, the following technologies were removed from further consideration:

- Conventional Clarification—Per the recommendation of County management this technology was not carried forward. In addition to having the highest cost of the settling technologies (as a result of the size required) and the largest site/land requirements, the potential treatment performance for conventional clarification is considered to be marginal for the Duwamish River. Consequently, conventional clarification does not meet one of the County's basic goals and objectives, which is to consistently and reliably comply with all effluent permit limits, water quality standards, and sediment quality standards.
- Clarification with Lamella Plates—While clarification with lamella plates improves on the performance of conventional clarification, reducing costs and site requirements, there are still concerns regarding its ability to consistently and reliably comply with all effluent permit limits, water quality standards, and sediment quality standards in wet-weather applications without some form of chemical addition or without relying on flow capture. Limited King County pilot test runs indicated that TSS removals of 60 percent could be achieved using clarification with lamella plates. Further testing and evaluation would be required to verify that these results can be consistently and reliably achieved in full-scale wet-weather applications. Therefore, this technology was screened out from the current evaluation.
- CEPT—This technology was screened from further consideration only because CEPT with lamella plates offers the same benefits with the potential for improved settling performance at minimal additional cost.

The following treatment technologies remain for detailed evaluation:

- CEPT with lamella plates
- Ballasted Sedimentation.

Ballasted sedimentation and CEPT with lamella plates are comparable in construction costs and provide the highest levels of treatment, with TSS removal rates from 50 to 90 percent.

7.4 Final Evaluation of Disinfection Technologies

A more detailed evaluation of each disinfection technology remaining after the initial screening was performed based on the following key evaluation factors, which are summarized in Appendix B:

- Disinfection effectiveness
- Contact time requirements
- Existing installations
- Additional potential treatment benefits
- Formation of disinfection byproducts
- Disinfection residuals

- Effluent toxicity
- TSS and particle shielding
- Chemical addition
- Chemical handling and storage requirements
- Constructability
- Operation and maintenance
- Public perception.

Based on this secondary evaluation, UV is the recommended disinfection technology if used in combination with one of the two selected treatment technologies (ballasted sedimentation or CEPT with lamella plates), which provide adequate levels of upstream treatment for use with UV. Clarification with lamella plates and CEPT would likely provide adequate levels of treatment for use with UV, but further evaluation is recommended if these treatment technologies are selected. Only conventional clarification is considered to provide marginal or inadequate levels of treatment for use with UV.

Should a treatment technology be selected that is not fully compatible with UV, then chlorination with sodium hypochlorite is the recommended disinfection technology. While peracetic acid, chlorine dioxide, and BCDMH all offer potential advantages relative to sodium hypochlorite, they all also present significant disadvantages, with limited experience treating wet-weather flows in the United States (primarily based on pilot studies and testing to date). Therefore, these three disinfection technologies are not recommended for use by King County in wet-weather applications at the current time. However, continued monitoring of these technologies is recommended as they continue to be developed and implemented in full-scale wet-weather applications.

8.0. ASSESSMENT OF SELECTED TECHNOLOGIES

8.1 Summary Description

The treatment and disinfection technologies selected for the alternatives development phase of the *2012 CSO Control Program Review* are summarized below.

8.1.1 CEPT with Lamella Plates

CEPT with lamella plates improves on conventional clarification by providing chemical feeds to enhance the coagulation, flocculation, and removal of suspended solids. Inclined plates near the top of the clarifier increase the sedimentation basin's effective settling area. This in turn reduces the footprint requirements and improves performance. Figure 6 is a sample process flow schematic for CEPT with lamella plates.

Key advantages and disadvantages of this technology are as follows:

- Provides good treatment that reliably met permit requirements during County pilot-testing.
- Can provide enhanced removal of copper and other potential parameters of concern.
- Moderately complex process that requires additional staffing, primarily due to the additional chemical storage and feed facilities.
- Relatively high capital and O&M costs.

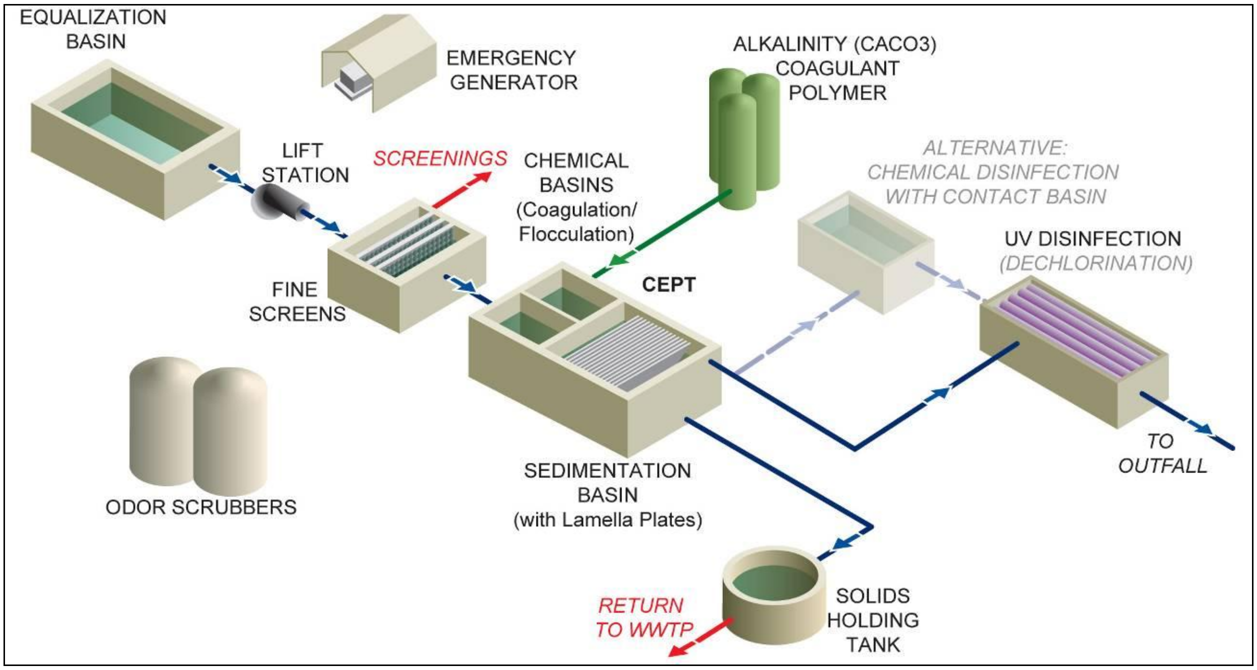

Figure 6 Sample Process Flow Schematic for CEPT with Lamella Plates

8.1.2 Ballasted Sedimentation

This technology uses CEPT with lamella plates in combination with a ballast material (microsand or recirculated sludge, depending on the proprietary process selected) to optimize settling and provide the best potential treatment within the smallest footprint. However, these facilities have the highest cost of the assessed technologies and are anticipated to require the greatest staffing levels. This process is currently in use at numerous U.S. and international wastewater treatment plants for wet-weather flow treatment, as well as in several wet-weather installations remote from a treatment plant. Key advantages and disadvantages of this technology are as follows:

- Provides the best treatment performance of all technologies evaluated.
- Highest capital and O&M costs of assessed technologies.
- More sophisticated process with the highest staffing requirements.

Figure 7 is a sample process flow schematic for ballasted sedimentation.

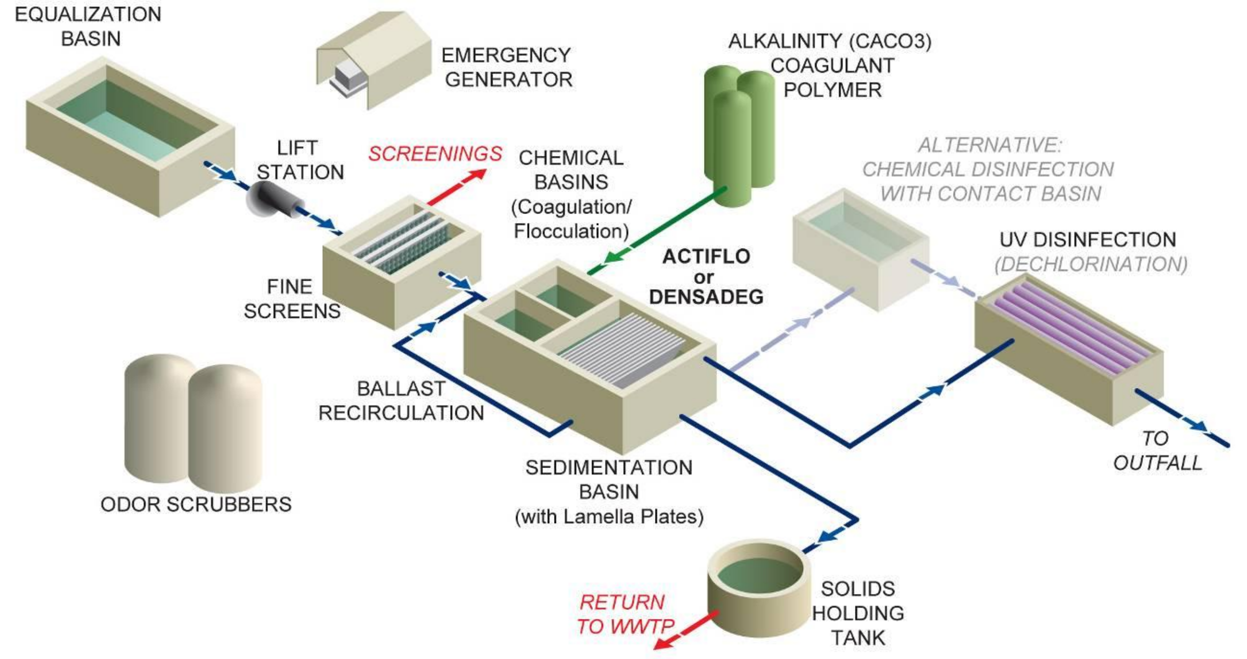

Figure 7 Sample Process Flow Schematic for Ballasted Sedimentation

8.2 Treatment Performance

8.2.1 Removal Efficiencies

CEPT with lamella plates can achieve TSS removals between 60 and 90 percent at SORs greater than 5,000 gpd/sf. The King County pilot-test report recommended a design SOR of 20,000 gpd/sf for CEPT with lamella plates, which can provide TSS removals up to 90 percent based on the pilot-test results. Ballasted sedimentation can typically achieve TSS removals between 75 and 90 percent—similar to CEPT with lamella plates at the upper end of the range and higher than CEPT with lamella plates at the lower end of the range. This indicates that ballasted sedimentation is generally a more consistent treatment process with more uniform results.

Removal rates for other parameters are as follows for the two selected treatment technologies:

- Settleable Solids—Both technologies achieve high levels of settleable solids removal (greater than or equal to 90 percent).
- BOD and COD—BOD and COD removal efficiencies can be as high as 70 percent for both technologies. The minimum expected BOD and COD removal is slightly higher for ballasted sedimentation than for CEPT with lamella plates (55 percent versus 40 percent).
- Free Oil, Grease, and Floatables—Both selected technologies can provide removal of these parameters via scum removal devices.

The King County pilot test measured removal percentages for CEPT with lamella plates for the following parameters (it is expected that ballasted sedimentation can achieve comparable removal efficiencies):

- PCB—90-percent removal based on the recommended design SOR and feed chemicals (PAX).
- Nitrogen—Some removal of organic nitrogen was observed (around 10 percent), which was attributed to the removal of solids. However, no removal of ammonia or inorganic nitrogen was observed, which is expected.
- Phosphorus—Total phosphorus removal greater than 80 percent was reported.
- Copper—Using the recommended feed chemical (PAX), up to 49-percent removal of total copper was reported (29 percent removal of dissolved copper). This removal was further enhanced with the addition of MetClear, a specialty polymer designed and marketed to enhance metals removal. Using MetClear in combination with PAX increased the total copper removal to 80 percent, with 90 percent removal of dissolved copper.
- Other Metals—Significant removal (>50 percent) of several other metals was reported when using MetClear at various SORs. This included arsenic, cadmium, chromium, iron, lead, mercury, and silver.
- Phthalates-Using the recommended feed chemical (PAX), up to 31-percent removal of Bis(2-Ethylhexyl)Phthalate was reported for CEPT. The addition of Metclear in combination with PAX further enhanced removals, increasing the percent removal to 85-percent for CEPT with lamella plates.
- Polycyclic Aromatic Hydrocarbons (PAHs)-Up to 37-percent removal was reported for Phenanthrene, a PAH, when using PAX alone. While the pilot study did not test for removal efficiencies using PAX with Metclear, the results for Bis(2-Ethylhexyl)Phthalate indicate the potential to further enhance removal efficiencies for Phenanthrene and other PAHs by using PAX in combination with Metclear or other specialty polymers.

Based on these removal efficiencies, both technologies are compatible with the use of UV disinfection. If used with chemical disinfection technologies, these enhanced removal efficiencies are also expected to positively benefit disinfection performance.

8.2.2 Surface Overflow Rates

The most significant difference between ballasted sedimentation and CEPT with lamella plates is the design SORs: 57,600 to 86,400 gpd/sf for the DensaDeg process and 72,000 to 115,200 gpd/sf for the Actiflo process compared to 20,000 gpd/sf for CEPT with lamella plates. Ballasted sedimentation will generally achieve solids removal efficiencies up to 90 percent at design SORs that are 3 to 5 times greater than those for CEPT with lamella plates, with more uniform and consistent performance.

8.3 Hydraulic Performance

Both selected treatment technologies have comparable hydraulic profiles. Based on the hydraulic profile for the ballasted sedimentation process at Bremerton, Washington, where the head loss at the peak design flow is 3.3 feet, the expected hydraulic profile for both selected technologies is expected to be in the range of 3 to 4 feet, depending on the specific hydraulic design of each facility.

8.4 Sediment Recontamination Risks

The potential for the CSO effluent to deposit sediment and create an area in exceedence of Washington State's sediment quality standards (SQS) was evaluated using a 3-Dimensional hydrodynamic transport model (Environmental Fluid Dynamics Code, EFDC). CSO discharge locations within the Lower Duwamish Waterway, East Waterway, and Elliott Bay were modeled with discharge hydrographs developed from hydrological modeling. Chemical concentrations were assigned to particles in the CSO effluent based on the mean concentration of previous CSO characterization sampling. The sediment modeling results can be found in the *Technical Memorandum 750, Sediment Deposition and Contamination Potential from Treated CSO Discharges*.

Ambient sedimentation rates were taken from conceptual site models and sedimentation rates measured in cores collected in the Lower Duwamish Waterway, East Waterway and Elliott Bay. Ambient sedimentation concentrations were taken from existing surface sediment samples.

Both selected treatment technologies have relatively high levels of TSS removal, reducing the loading rate of solids relative to the existing CSO discharges. The expected loading rates from both of the selected treatment alternatives are sufficiently low that no sediment quality exceedences were predicted in any of the conditions modeled.

8.5 Greenhouse Gas Emissions

Infrastructure projects require a Washington State Environmental Policy Act (SEPA) checklist (WAC 197-11-960) that identifies, among other potential project impacts, the likely sources of greenhouse gas emissions. The checklist must identify air emissions expected during construction and when the project is completed.

King County has developed a worksheet for estimating greenhouse gas emissions for most types of buildings, including CSO treatment facilities. The worksheet was used to estimate greenhouse gas emissions for the ballasted sedimentation CSO treatment process. The methodology is as follows:

- Estimate footprint of proposed CSO treatment facility, including equalization basin, influent pump station, CSO treatment process (ballasted sedimentation) and disinfection (UV).
- Using footprint calculations, estimate total excavation quantities and construction material quantities (concrete, aggregate, steel).
- Using footprint calculations, estimate square footage of conditioned spaces for energy usage.
- Calculate total emissions in metric tons of carbon dioxide (MT CO_2) over the lifespan of the facility (assumed to be 62.5 years) for each of the following:
  - Embodied Emissions—Emissions created through transportation, construction and disposal of building materials and soil excavation during construction.
  - Energy Emissions— Emissions related to energy consumption (electricity and natural gas), based on energy consumption at existing King County CSO treatment facilities (Mercer/Elliott West and Alki CSO Treatment Plant) and estimated footprint of CSO treatment facility.
  - Transportation Emissions—Emissions related to transportation of staffing to the CSO treatment facilities, based on existing King County CSO treatment facilities O&M estimates where staff requirements range from 1.8 to 2.7 full time equivalents (FTE), assuming staffing of 2 FTE per 5,000 square feet of facility footprint.

The greenhouse gas emissions were estimated for three treatment and equalization design capacities for the CSO treatment facilities assuming a ballasted sedimentation CSO treatment process. Table 5 summarizes that estimated gas emissions. The spreadsheets used to develop the estimates are provided in Appendix C.

Table 5 Greenhouse Gas Emissions Estimates

	Estimated Greenhouse Gas Emissions (MT CO_2)		
	Equalization: 0.89 MG, Treatment: 66 mgd	**Equalization: 0.97 MG, Treatment: 94 mgd**	**Equalization: 1.71 MG, Treatment:151 mgd**
Total Emissions	14,990	20,235	30,770

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Appendix A

Evaluation Factors for Treatment Technologies

Key Evaluation Factors	Conventional Clarification	Clarification w/ Lamella Plates	Chemically Enhanced Primary Treatment (CEPT)		Ballasted Sedimentation
			Without Lamella Plates	With Lamella Plates	
1. Treatment Effectiveness – Removal Efficiencies for the following constituents / parameters: a. Total Suspended Solids (TSS) b. Settleable Solids c. Biochemical Oxygen Demand (BOD) d. Chemical Oxygen Demand (COD) e. Floatables f. Future Parameters of Concern (Copper)	• TSS Removal = 50-70% • Settleable Solids Removal = 80-95% • BOD or COD Removal = 25-40% • Provides removal of free oil, grease, and other floatables via scum removal devices. • Negligible Removal of Soluble Copper; Removal of Particulate or Precipitated Copper Compounds Will Be Comparable to TSS Removal.	• Performance is comparable to conventional clarification but at higher SORs.	• TSS Removal = 60-90% • Settleable Solids Removal > 95% • BOD or COD Removal = 40-70% • Provides removal of free oil, grease, and other floatables via scum removal devices. • Can also result in the chemical precipitation and removal of colloidal material. • Potential for removal of copper and other heavy metals, including the coagulation and precipitation of soluble forms/compounds. Removal of soluble copper/metals will be dependent on the specific chemicals used.		• TSS Removal = 75-90% • Settleable Solids Removal > 95% • BOD or COD Removal = 55-70% • Provides removal of free oil, grease, and other floatables via scum removal devices. • Potential for removal of copper and other heavy metals, including the coagulation and precipitation of soluble forms/compounds. Removal of soluble copper/metals will be dependent on the specific chemicals used.
2. Upstream Treatment Requirements a. Equalization b. Screening c. Grit Removal	• Equalization is recommended to control peak hydraulic loading and optimize performance. • Screening is recommended to remove the larger rags, debris, and floatables, which will improve the overall performance and reduce O&M. • Grit removal is optional, as most of the grit will be removed along with the TSS and Settleable Solids.	• Equalization is recommended to control peak hydraulic loading and optimize performance. • Fine screening and grit removal are recommended to reduce the potential for fouling or plugging of the lamella plates with rags, debris, grease, and solids. Otherwise, O&M requirements will be greater and/or performance will decrease.	• Equalization is recommended to control peak hydraulic loading and optimize performance. • Screening comparable to conventional clarification. • Grit removal is recommended to optimize performance and reduce O&M, particularly if lamella plates are included.	• Equalization is recommended to control peak hydraulic loading and optimize performance. • Fine screening is recommended. • Grit removal is recommended to optimize performance and reduce O&M, particularly if lamella plates are included.	• Equalization is recommended to stabilize hydraulic loading and optimize performance. • Coarse or fine screening (dependent on manufacture recommendation) and grit removal are required to prepare the wastewater for the treatment process and optimize performance.
3. Existing Installations a. CSO or Wastewater Treatment Plant (WWTP) Facilities – United States b. CSO or WWTP Facilities – International c. Other Applications or Industries	• Widely used at CSO and WWTP facilities throughout the world.	• Comparable to plate-and-tube settlers that are widely used in Europe. • Limited use at municipal facilities in the United States. • Commonly used at industrial wastewater facilities.	• Several large scale WWTPs in the United States and Canada have used CEPT. • No specific installations for CSO applications. • Commonly used at industrial wastewater treatment facilities.		• Used at multiple WWTPs for wet-weather flow treatment. • Two known locations for CSO or wet-weather treatment remote from WWTPs. • Additional installations at industrial sites and drinking water facilities.
4. Design Parameters a. Solids / Mass Loading b. Hydraulic Loading c. Hydraulic Losses / Head Requirements	• Typically not designed based on solids or mass loading. • Hydraulic loading based on Surface Overflow Rate (SOR) = 1,000 gpd/sf. • Minimal hydraulic losses; typically less than 2 feet of head required.	• By increasing the effective surface area by a factor of 6 to 12 times, the SOR can be increased by a comparable amount relative to conventional clarification. • Hydraulic losses and head requirements are comparable to conventional clarification.	• SOR up to 5,000 gpd/sf can be used. • Hydraulic losses and head requirements are comparable to conventional clarification.	• Lamella plates can be used to further increase SOR by increasing the effective surface area. • Hydraulic losses and head requirements are comparable to conventional clarification.	• SOR for settling area = 57,600 to 86,400 gpd/sf for DensaDeg; 72,000 to 115,200 gpd/sf for ACTIFLO. • For best performance, hydraulic loading rates should remain stable. Multiple parallel treatment components should be considered. • Hydraulic losses and total head requirements are in the range of 3 to 4 feet, which are slightly greater than conventional clarification. .

Key Evaluation Factors	Conventional Clarification	Clarification w/ Lamella Plates	Chemically Enhanced Primary Treatment (CEPT)		Ballasted Sedimentation
			Without Lamella Plates	With Lamella Plates	
5. Ancillary Component Requirements a. Side Streams or Waste Solids Produced b. Additional Storage / Treatment Requirements for these streams	• Scum removal produces a waste stream with oil, grease, and floatables. • Settled solids with a concentration between 3 and 6% solids. • Provide storage for these waste streams and discharge back to the SS during periods of dry weather. Settled solids can be stored in the basin by oversizing the sump.	• Same as conventional clarification.	• By increasing the TSS removal efficiencies and precipitating colloidal materials, additional settled solids will be produced. This can increase the storage requirements by an additional 50 to 100%. Settled solids can be stored in the basin by oversizing the sump and increasing the side-water depth. • Chemical waste sludge tends to be lighter than conventional primary sludge due to the chemical floc, with solids concentrations in the range of 2 to 3%.		• Scum removal produces a waste stream with oil, grease, and floatables. • Wasting of sludge from ballasted systems differs in terms of rate and percent (5% wasting rate for DensaDeg at 3-6% solids versus 5% wasting rate at 0.15-0.25% solids for ACTIFLO). • Waste sludge cannot be stored in process units but must be returned to interceptor or stored/thickened on site prior to discharge. • Recommended to provide storage for these waste streams in separate storage/thickening tanks and discharge back to the SS during periods of dry weather.
6. Chemical Addition a. Is Chemical Addition Required b. Bulk Delivery or On-Site Generation c. Shelf-Life of Chemicals Used	• No chemical addition required.	• No chemical addition required.	• Iron salts are the most common coagulant used. Lime and alum can also be used. • Polymers can also be added as flocculant aids. Anionic polymers are most effective for CEPT. • Chemicals are delivered and stored in bulk. • Chemicals can be stored for extended periods.		• Potential coagulants include ferric chloride, alum, and polyaluminum hydroxychloride. • Polymers can also be added as flocculant aids. • Chemicals are delivered and stored in bulk. • Chemicals can be stored for extended periods. • Some ballasted systems require additional materials management (ballast), during and between events
7. Chemical Handling and Storage Requirements a. Potential Hazards b. Personal Protective Equipment (PPE) Requirements c. Special Materials of Construction Required	• Not Applicable	• Not Applicable	Based on 35-45% Ferric Chloride: • Corrosive liquid solution that can cause redness, pain, or severe burns in contact with the skin or eyes. • Recommended PPE includes impervious boots, rubber gloves, and coveralls to prevent skin contact and chemical safety goggles or full face shield for eye protection. • Corrosive to most metal; avoid contact with aluminum, carbon steel, stainless steel and copper alloys. Compatible with HDPE, FRP, PVC, CPVC, Viton, and EPDM.		• Comparable to CEPT.

Key Evaluation Factors	Conventional Clarification	Clarification w/ Lamella Plates	Chemically Enhanced Primary Treatment (CEPT)		Ballasted Sedimentation
			Without Lamella Plates	With Lamella Plates	
8. Compatibility with Downstream Disinfection Technologies a. Sodium Hypochlorite (NaOCl) b. Ultra Violet (UV) c. Peracetic Acid (PAA) d. Chlorine Dioxide (ClO_2) e. BCDMH (Bromine)	- Compatible with chemical disinfection technologies (NaOCl, PAA, ClO_2, and BCDMH). - Less compatible with UV, which works best with more advanced levels of treatment.	- Same as conventional clarification.	- Compatible with chemical disinfection technologies (NaOCl, PAA, ClO_2, and BCDMH). - Higher levels of treatment provided makes CEPT more compatible with UV. - Use of ferric for coagulation may impact use of UV. Alternative coagulant should be considered if UV preferred disinfection approach.		- Sufficiently treats flows for use of preferred disinfectant; compatible with either chemical or UV disinfection. - Use of ferric chloride for coagulation may impact use of UV. Alternative coagulant should be considered if UV preferred disinfection approach
9. Adaptability and Flexibility a. Performance over wide range of operating conditions b. Ability to Upgrade in the Future in Response to Changing Permit Conditions / Requirements	- Performance and removal efficiencies decrease at higher flows and hydraulic loadings. - Performance decreases with colder wastewater temperatures below 68 degree F. - Can be upgraded by adding lamella plates or chemical addition in the future. Provisions for future chemical addition would include space for a future mixing/coagulation chamber and chemical storage/feed systems.	- The greater effective surface area can be used to improve performance at peak flows and loadings while minimizing the hydraulic residence time, reducing the odor potential. - Can be upgraded by adding chemical addition in the future. Provisions for future chemical addition would include space for a future mixing/coagulation chamber and chemical storage/feed systems.	- Chemical feed capability provides greater flexibility and improved performance over a wide range of operating conditions. - Additional chemical feeds, including polymers and other coagulant aids, can be used to upgrade performance to meet particular treatment requirements in the future.		- Chemical feed capability provides greater flexibility and improved performance over a wide range of operating conditions. - Additional chemical feeds, including polymers and other coagulant aids, can be used to upgrade performance to meet particular treatment requirements in the future.
10. Constructability a. Footprint / Area Requirements b. Single or Multiple Manufacturers/Suppliers	- Largest footprint / area requirements. - Multiple manufacturers and suppliers	- Footprint requirements can be reduced by a factor of 6 to 12 compared to conventional clarification. - Fewer manufacturers and suppliers than conventional clarification.	- Smaller footprint / area requirements than conventional clarification. - Multiple manufacturers of chemical storage and feed systems.	- Footprint / area requirements can be further reduced by adding lamella plates.	- Smallest footprint / area requirements. - Two primary manufacturers in the market today: o ACTIFLO o DensaDeg

Key Evaluation Factors	Conventional Clarification	Clarification w/ Lamella Plates	Chemically Enhanced Primary Treatment (CEPT)		Ballasted Sedimentation
			Without Lamella Plates	With Lamella Plates	
11. Operation and Maintenance (O&M) a. Reliability – Performance b. Reliability—Equipment c. Ease of Operation / Complexity d. Operator Attendance Requirements e. Preventive Maintenance Requirements f. Equipment Maintenance Requirements g. Odor Potential h. Noise Potential i. Non-Chemical Consumable Materials Used	• Performance is variable and is a function of the influent wastewater characteristics, flows, and temperature. • Equipment is very reliable. • Very simple to operate. • Minimal operator attendance required. • Minimal preventive maintenance is required, primarily periodic checks of the clarifier mechanism drive gear and lubrication. • Minimal equipment maintenance required. • Odor potential. • Very low noise potential. • No consumable materials used.	• Comparable to conventional clarification with the exception of the following: o Reduced odor potential. o Additional maintenance required for additional pretreatment (fine screens and grit removal) or additional cleaning of the lamella plates.	• Performance is more reliable and can be better controlled than conventional clarification. • Additional complexity of the chemical feed systems reduces the overall equipment reliability. • Operator attendance is required to monitor and control the chemical feed systems. • Additional preventive and equipment maintenance is required for the chemical storage tanks and feed systems. • Reduced odor potential. • Greater noise potential associated with chemical deliveries.		• Best performance of identified technologies. • Most complex of various systems identified. Chemical feed and ballast systems result in the highest number of systems to be maintained. • Operator attendance is required to monitor and control the chemical feed and ballast systems. • Additional preventive and equipment maintenance is required for the chemical storage tanks and feed systems. Ballast systems involve pumps, valves and other equipment. • Reduced odor potential. • Greater noise potential associated with chemical deliveries; additional equipment. • For ACTIFLO system, sand ballast must be stocked and replenished. Maintenance or cleaning of sand ballast between events necessary to prevent "set up."
12. Public Perception	• Potential negatives include large footprint / area requirements and more risk of odor. • Facilities are more amenable to being located below grade with minimal surface building and alternative surface use (e.g. park space)	• Expected to be more positive than conventional clarification due to reduced footprint / area requirements and reduced odor potential. • Would likely involve more above grade facilities	• Delivery and storage of chemicals may negatively impact public perception. • Reduced footprint / area requirements and reduced odor potential are expected to enhance public perception. • Would likely involve more above grade facilities		• Delivery and storage of chemicals may negatively impact public perception. • Reduced footprint / area requirements and reduced odor potential are expected to enhance public perception. • Would likely involve more above grade facilities

Appendix B

Evaluation Factors for Disinfection Technologies

Key Evaluation Factors	Sodium Hypochlorite (NaOCl)	Ultra Violet (UV)	Peracetic Acid (PAA)	Chlorine Dioxide (ClO_2)	BCDMH
1. Disinfection Effectiveness a. Reduction of Bacterial Indicator Organisms (Fecal coliform, *E. coli*, *Enterococcus*) b. Reduction of Viruses, Crypto, Giardia, and Other Pathogens	• Up to 99.998% bacterial reductions. • Limited effectiveness against viruses, Crypto, and Giardia.	• Up to 99.998% bacterial reductions. • Highly effective against viruses, Crypto, Giardia, and other infectious bacteria.	• Over 99.99% reduction of fecal coliform. • No data in the literature regarding viruses or other pathogens.	• Up to 99.999% bacterial reductions • Also an effective viricide. • More effective than chlorine against Crypto, Giardia, and other infectious bacteria.	• Over 99.99% reduction of fecal coliform. • No data in the literature regarding viruses or other pathogens.
2. Contact Time Requirements @ Peak Design Flows	• 5 to 15 Minutes	• 5 to 10 Seconds	• 2 to 5 Minutes	• ≥ 5 Minutes	• 3 to 5 Minutes
3. Existing Installations a. CSO or WWTP Facilities – United States b. CSO or WWTP Facilities – International c. Other Applications or Industries	• Very well established disinfection technology used at numerous CSO and WWTP facilities around the world.	• Most commonly used alternative disinfection technology for WWTP facilities after chlorination and dechlorination, with numerous installations in the US and internationally. • CSO facilities in Bremerton, WA; Cincinnati, OH; and Columbus, GA.	• No CSO facilities in the US. • WWTP facility in Frankfort, KY. • Used in Europe for disinfection for a number of years.	• No known CSO disinfection installations • Used in multiple other treatment and disinfection applications	• No known CSO or WWTP facilities in the US. • CSO facilities in Japan. • Used in the pool and hot-tub industry in the US.
4. Additional Potential Treatment Benefits	• Limited additional treatment benefits; may provide some color removal.	• None known.	• None known.	• Used for treatment of color, odors, phenols, THM precursors, and pesticides.	• No data in the available literature regarding treatment benefits other than disinfection.
5. Formation of Disinfection By-Products a. Trihalomethanes (THMs) b. Haloacetic Acids (HAAs)	• Produces THMs • Produces HAAs	• Produces no disinfection by-products.	• Non-halogenated, so forms no THMs or HAAs.	• Does not produce THMs • Formation of HAAs is not expected, but could occur due to formation of total residual chlorine (TRC).	• Produces THMs. • Produces HAAs.
6. Disinfection Residuals a. Potential for Disinfection Residuals b. Need For Addition of Reducing Agent	• Total Residual Chlorine (TRC) includes hypochlorous acid, hypochlorite ions, and chloramines. • Use of reducing agent is typically required to meet effluent TRC limits.	• Produces no disinfectant residuals. • No need for reducing agent.	• Naturally decomposes into water, oxygen, and acetic acid over time. • No need for a reducing agent.	• Disinfection residuals may include ClO_2, TRC, chlorite, or chlorate (depending on the generation technology used). • Use of reducing agent may be required.	• Disinfection residuals may include TRC and bromamines. • Use of reducing agent may be required.
7. Effluent Toxicity a. Potential Toxicity Impacts b. Additional Downstream Treatment Requirements	• TRC is toxic to aquatic organisms. • The use of a reducing agent may be required to meet effluent toxicity limits.	• No toxicity impacts. • No additional downstream treatment required.	• Toxicity impacts are expected to be minimal, but further evaluation is required to verify. • No additional downstream treatment is expected to be required.	• Potentially toxic to aquatic organisms due to disinfection residuals. • May require the addition of reducing agent.	• Potentially toxic to some test species (Daphnia). • May require the addition of reducing agent.

Key Evaluation Factors	Sodium Hypochlorite (NaOCl)	Ultra Violet (UV)	Peracetic Acid (PAA)	Chlorine Dioxide (ClO_2)	BCDMH
8. TSS / Particle Shielding a. Impact on Disinfection Effectiveness b. Upstream Treatment Requirements	• Limited Impact • Minimal upstream treatment required (screening and grit removal) • Additional treatment improves performance.	• Particle shielding by particulates / TSS will negatively impact performance. • Performance is also directly related to UV transmittance (UVT). • Higher levels of upstream treatment are therefore recommended for TSS removal, turbidity removal, and maximum UVT.	• Limited Impact • Minimal upstream treatment required (screening and grit removal) • Additional treatment improves performance.	• Limited Impact • Minimal upstream treatment required (screening and grit removal) • Additional treatment improves performance.	• Limited Impact • Minimal upstream treatment required (screening and grit removal). • Additional treatment improves performance.
9. Chemical Addition a. Is Chemical Addition Required b. Bulk Delivery or On-Site Generation c. Shelf-Life of Chemicals Used	• Chemical Addition Required. • Bulk Delivery. • Limited shelf-life that begins to lose strength after 30 days for a 12.5% solution.	• No chemical addition required. • No chemical deliveries. • No chemical shelf-life issues.	• Chemical Addition Required. • Bulk Delivery. • Includes a stabilizer to increase shelf-life to over 12 months.	• Chemical Addition Required. • On-site generation. • Feed stock chemicals can be stored for up to 6 months.	• Chemical Addition Required. • On-site generation of feed solution using dry powder. • Powder can be stored as long as a year.
10. Chemical Handling and Storage Requirements a. Potential Hazards b. PPE Requirements c. Special Materials of Construction Required	• Nonflammable and noncombustible liquid with a pH of 11.2 to 11.4 that will react with ammonia compounds. Eye and skin irritant; vapors may cause irritation to upper respiratory tract if inhaled. • Recommended PPE includes goggles or face shield with rubber gloves. • HDPE or FRP Storage Tanks with PVC piping.	• No chemical handling or storage requirements.	• Strong oxidizer with a pungent odor and a pH < 2. Severe eye and skin irritant that will cause redness, swelling, and potentially blindness or severe burns. Inhalation or ingestion will cause severe irritation and burns of the mouth and throat, breathing difficulties, and risk of chemical pneumonitis or toxic oedema. Potential for exothermic hazard. To avoid thermal decomposition, storage temperature not to exceed 122 F. • Recommended PPE includes chemically resistant eye protection, gloves, hard hat with face shield, acid suit and boots, and respiratory protection. • Suitable materials include high-purity aluminum, stainless steel, PTFE, or PVDF. Not compatible with brass, copper, nickel, steel, bronze, zinc, or synthetic rubbers.	• Uses acidic feed chemicals that cause skin and eye irritation, potentially causing blindness. ClO_2 solution is pale green in color with a pungent odor; causes skin redness and moderate irritation, strong irritant to the eyes that may cause corneal injuries and burns, and irritation of the mucous membranes if inhaled that may cause coughing, breathing difficulties, and pulmonary edema. Avoid elevated temperatures to reduce evolution of ClO_2 gas. • Recommended PPE includes chemically resistant eye protection, gloves, full-working clothes, and respiratory protection. • Storage not recommended – generate and feed “on demand” using CPVC piping. Corrosive to steel, stainless steel, and copper alloys and therefore not compatible with these materials.	• White, water soluble powder that causes skin irritation and eye irritation/acute burn as well as irritation of the respiratory tract and lungs if inhaled. • Recommended PPE includes impermeable gloves, boots, apron, face shield with chemical splash goggles, and respiratory protection. • Uses dry chemical storage and feed equipment. Avoid contact with strong acids and strong oxidizers which can generate heat, fires, explosions, and the release of toxic fumes. Not compatible with copper and iron.

Key Evaluation Factors	Sodium Hypochlorite (NaOCl)	Ultra Violet (UV)	Peracetic Acid (PAA)	Chlorine Dioxide (ClO_2)	BCDMH
11. Constructability a. Footprint Requirements b. Single or Multiple Manufacturers/Suppliers c. Capital Costs (Based on Facilities with Peak Design Flows Between 10 mgd and 100 mgd)	• Largest footprint requirements based on contact basin volume required and bulk storage requirements. • Multiple manufacturers and suppliers. • Typically has the lowest capital costs, which are used as the baseline for comparison purposes.	• Smallest footprint requirement due to extremely short contact time requirement and no chemical storage/feed facilities. • Multiple manufacturers. • Capital costs between 2.7 and 3.0 times a comparable NaOCl chlorination and dechlorination facility.	• Potential smaller footprint compared to NaOCl. • Two suppliers in the US (Solvay Chemicals and FMC Corporation) • No data on capital costs for comparison against NaOCl.	• Potentially smaller footprint requirement compared to NaOCl. • Multiple manufacturers and suppliers. • Capital costs between 1.2 and 1.8 times a comparable chlorination and dechlorination facility using NaOCl.	• Potentially smaller footprint compared to NaOCl and ClO_2 systems. • Single manufacturer and supplier (Ebara). • Capital costs approximately 1.5 times a comparable chlorination and dechlorination facility using NaOCl
12. Operation and Maintenance (O&M) a. Reliability – Performance b. Reliability—Equipment c. Ease of Operation / Complexity d. Operator Attendance Requirements e. Preventive Maintenance Requirements f. Equipment Maintenance Requirements g. Chemical and Energy Costs (Based on Facilities with Peak Design Flows Between 10 mgd and 100 mgd)	• Performance is generally reliable, but is influenced by pH, temperature, and the chlorine demand of the wastewater. • Feed pumps can be prone to air binding due to off-gassing from the NaOCl solution, particularly if idle for extended periods due to intermittent operation, which is typical for CSO applications. • Systems are simple and easy to operate. • Operator attendance required during operation. • Rotate chemical feed stocks and regularly operate/exercise the feed pumps. • Maintain chemical feed pumps. • Typically has the lowest chemical and energy costs, which are used as the baseline for comparison purposes against other technologies.	• Performance and reliability are strongly influenced by effluent quality, and is therefore more reliable with higher levels of upstream treatment. • UV equipment (lamps and ballasts) are considered highly reliable. • Simplest disinfection system to operate due to the lack of mechanical equipment (pumps or on-site generation equipment). • Operator attendance not required during operation. Systems can be remotely monitored. • Routine lamp cleaning is required, which can also be automated. • Lamp replacement is the primary equipment maintenance required. • Chemical and energy costs approximately 1.5 times a comparable NaOCl chlorination and dechlorination facility.	• Reliability requires further evaluation in CSO applications. • More complex to operate compared to NaOCl due to special handling requirements. • Operator attendance required during operation. • Rotate chemical feed stocks and regularly operate/exercise the feed pumps. • Maintain chemical feed pumps. • No data on O&M costs for comparison against NaOCl.	• Performance is expected to be consistent and reliable. • On-site generation equipment is considered to be slightly less reliable than NaOCl equipment due to additional complexity. • On-site generation systems are relatively simple and easy to operate, but are slightly more complex than NaOCl systems. • Operator attendance required during operation. • Rotate chemical feed stocks and regularly operate/exercise on-site generation equipment. • Maintain chemical feed pumps for on-site generation equipment. • Chemical and energy costs approximately 2.4 times a comparable chlorination and dechlorination facility using NaOCl.	• Performance is expected to be consistent and reliable. • Dry powder storage and feed equipment is considered to be slightly less reliable than NaOCl equipment due to additional complexity. • Storage and feed systems are relatively simple and easy to operate, but are slightly more complex than NaOCl systems. • Operator attendance required during operation. • Minimal preventive maintenance expected. • Maintain dry chemical feed and dissolution equipment. • Chemical and energy costs approximately 3.2 times a comparable chlorination and dechlorination facility using NaOCl.
13. Public Perception	• Footprint requirements and frequent chemical deliveries may negatively impact public perception. • Otherwise, a well established and relatively safe technology, which should aid in public perception.	• Expected to have the highest public perception due to the small footprint and lack of chemical deliveries/storage. • Also forms no disinfection residuals or disinfection by-products.	• The special handling requirements may negatively impact public perception.	• Expected to be comparable to NaOCl. • May benefit from reduced footprint requirements and less frequent chemical deliveries.	• Stability of the dry feed powder may reduce chemical deliveries to only once or twice a year, which may enhance public perception. • The compact footprint may also enhance public perception.

Appendix C

Greenhouse Gas Emission Worksheets

DESIGN CONDITIONS

EQUALIZATION 0.89 MGAL
TREATMENT 66 MGD

Section I: Buildings						
			Emissions Per Unit or Per Thousand Square Feet (MTCO2e)			
Type (Residential) or Principal Activity (Commercial)	# Units	Square Feet (in thousands of square feet)	Embodied	Energy	Transportation	**Lifespan Emissions (MTCO2e)**
Offsite Wastewater Facility..........................		4.8	0	2,693	123	**13541**

Section II: Pavement................................						
Pavement..		1.00				**50**

Section III: CSO Treatment Specific........						
Total Excavation...	14,261	cu yd	0.0018			**25**
Concrete Required.....................................	4,055	cu yd	0.24			**984**
Rebar Required..	369,446	kg	0.001027			**379**
Aggregate Required...................................	598	cu yd	0.000003			**0.0020**
Sodium Hypochlorite..................................	0	lbs		0.0570		**0**
Sodium bisulfate...	0	lbs		0.0125		**0**
UV Disinfection...	330	kWh		0.0227		**8**

Total Project Emissions:	**14987**

Assumptions

1. Square feet of CSO facility includes conditioned spaces only (CSO treatment process & pump station)
2. 62.5 years = life span of facility
3. Energy emissions based on historical energy usage (electricity & natural gas) of existing CSO facility (Mercer/Eliott West & Alki CSO)
4. Transportation emissions associated with transportion (vehicle usage) of plant staff, assuming 2 FTE for a footprint of 5000 sq ft
5. Estimate 50 MTCO2e/thousand square feet of pavement (over the facility's life cycle) as the embodied emission factor for pavement

DESIGN CONDITIONS

EQUALIZATION	**0.97**	**MGAL**
TREATMENT	**94**	**MGD**

Section I: Buildings

Type (Residential) or Principal Activity (Commercial)	# Units	Square Feet (in thousands of square feet)	Emissions Per Unit or Per Thousand Square Feet (MTCO2e) Embodied	Energy	Transportation	**Lifespan Emissions (MTCO2e)**
Education		0.0	39	646	361	**0**
Office		0.0	39	723	588	**0**
Warehouse and Storage		0.0	39	352	181	**0**
Other		0.0	39	1,278	257	**0**
Vacant		0.0	39	162	47	**0**
Offsite Wastewater Facility		6.6	0	2,693	123	**18578**

Section II: Pavement................................

Pavement...		1.00				**50**

Section III: CSO Treatment Specific........

Total Excavation...	17,009	cu yd	0.0018			**30**
Concrete Required.....................................	4,652	cu yd	0.24			**1129**
Rebar Required..	425,786	kg	0.001027			**437**
Aggregate Required...................................	705	cu yd	0.000003			**0.0024**
Sodium Hypochlorite..................................	0	lbs		0.0570		**0**
Sodium bisulfate...	0	lbs		0.0125		**0**
UV Disinfection...	470	kWh		0.0227		**11**

Total Project Emissions:	**20235**

Assumptions

1. Square feet of CSO facility includes conditioned spaces only (CSO treatment process & pump station)
2. 62.5 years = life span of facility
3. Energy emissions based on historical energy usage (electricity & natural gas) of existing CSO facility (Mercer/Eliott West & Alki CSO)
4. Transportation emissions associated with transportion (vehicle usage) of plant staff, assuming 2 FTE for a footprint of 5000 sq ft
5. Estimate 50 MTCO2e/thousand square feet of pavement (over the facility's life cycle) as the embodied emission factor for pavement

DESIGN CONDITIONS

EQUALIZATION	**1.7**	**MGAL**
TREATMENT	**151**	**MGD**

Section I: Buildings						
			Emissions Per Unit or Per Thousand Square Feet (MTCO2e)			
Type (Residential) or Principal Activity (Commercial)	# Units	Square Feet (in thousands of square feet)	Embodied	Energy	Transportation	**Lifespan Emissions (MTCO2e)**
Education		0.0	39	646	361	**0**
Office		0.0	39	723	588	**0**
Warehouse and Storage		0.0	39	352	181	**0**
Other		0.0	39	1,278	257	**0**
Vacant		0.0	39	162	47	**0**
Offsite Wastewater Facility		10.1	0	2,693	123	**28470**

Section II: Pavement................................						
Pavement...		1.00				**50**

Section III: CSO Treatment Specific........						
Total Excavation..	25,656	cu yd	0.0018			**46**
Concrete Required.....................................	6,462	cu yd	0.24			**1568**
Rebar Required...	599,647	kg	0.001027			**616**
Aggregate Required...................................	1,060	cu yd	0.000003			**0.0036**
Sodium Hypochlorite..................................	0	lbs		0.0570		**0**
Sodium bisulfate...	0	lbs		0.0125		**0**
UV Disinfection...	755	kWh		0.0227		**17**

Total Project Emissions:	**30767**

Assumptions

1. Square feet of CSO facility includes conditioned spaces only (CSO treatment process & pump station)
2. 62.5 years = life span of facility
3. Energy emissions based on historical energy usage (electricity & natural gas) of existing CSO facility (Mercer/Eliott West & Alki CSO)
4. Transportation emissions associated with transportion (vehicle usage) of plant staff, assuming 2 FTE for a footprint of 5000 sq ft
5. Estimate 50 MTCO2e/thousand square feet of pavement (over the facility's life cycle) as the embodied emission factor for pavement