6-I
EFFLUENT QUALITY EVALUATION FOR THE MEMBRANE BIOREACTOR AND ADVANCED PRIMARY SYSTEM

FINAL
ENVIRONMENTAL
IMPACT STATEMENT

Brightwater
Regional Wastewater
Treatment System

APPENDICES

King County Brightwater TREATMENT SYSTEM

Final

Appendix 6-I

Effluent Quality Evaluation

Membrane Bioreactor and Advanced Primary System

October 2003

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King County
Department of Natural Resources and Parks
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Table of Contents

List of Tables

List of Figures

1.0 INTRODUCTION

King County has prepared a Draft Environmental Impact Statement (Draft EIS) and Final Environmental Impact Statement (Final EIS) on the Brightwater Regional Wastewater Treatment System. The Final EIS is intended to provide decision-makers, regulatory agencies and the public with information regarding the probable significant adverse impacts of the Brightwater proposal and identify alternatives and reasonable mitigation measures.

King County Executive Ron Sims has identified a preferred alternative, which is outlined in the Final EIS. This preferred alternative is for public information only, and is not intended in any way to prejudge the County's final decision, which will be made following the issuance of the Final EIS with accompanying technical appendices, comments on the Draft EIS and responses from King County, and additional supporting information. After issuance of the Final EIS, the King County Executive will select final locations for a treatment plant, marine outfall and associated conveyances.

The County Executive authorized the preparation of a set of Technical Reports, in support of the Final EIS. These reports represent a substantial volume of additional investigation on the identified Brightwater alternatives, as appropriate, to identify probable significant adverse environmental impacts as required by the State Environmental Policy Act (SEPA). The collection of pertinent information and evaluation of impacts and mitigation measures on the Brightwater proposal is an ongoing process. The Final EIS incorporates this updated information and additional analysis of the probable significant adverse environmental impacts of the Brightwater alternatives, along with identification of reasonable mitigation measures. Additional evaluation will continue as part of meeting federal, state and local permitting requirements.

Thus, the readers of this Technical Report should take into account the preliminary nature of the data contained herein, as well as the fact that new information relating to Brightwater may become available as the permit process gets underway. It is released at this time as part of King County's commitment to share information with the public as it is being developed.

King County proposes to build the Brightwater treatment plant to serve the residents of north King and south Snohomish County. The plant, as described in the DEIS, would be at one of two locations: the Unocal site in Edmonds or the Route 9 site in unincorporated Snohomish County. By 2010 the plant would have the capacity to treat an average of 36 million gallons per day (MGD) of wastewater. By 2040 the plant would be expected to provide secondary treatment capacity of 54 MGD. These capacities are for average wet weather flow (AWWF). The plant must be able to accommodate a peak hourly flow of 130 MGD by 2010 and 170 MGD by 2040 (Goetz & Allen 2003).[1]

The purposes of this report are to determine (1) whether the changes to proposed treatment processes change the conclusions of a water quality investigation that has been conducted for three potential locations for the Brightwater marine outfall (King County 2002a), (2) evaluate how the Brightwater outfall discharge will affect dissolved oxygen concentrations in Puget Sound, and (3) evaluate the current risks of a subsistence shellfish diet and how these risks are influenced by the Brightwater discharge. The water quality investigation estimated potential future risks to aquatic life and people from discharging Brightwater effluent to Puget Sound,

[1] A sub-alternative being considered for the Unocal site would redirect wastewater flows from treatment facilities currently operated by the cities of Edmonds and Lynnwood to the Brightwater plant, requiring an expansion of the plant's capacity to 72 MGD AWWF and peak hourly flows of 235 MGD.

assuming that Brightwater used the treatment process units proposed in the DEIS. This report evaluates whether the quality of blended MBR and APT effluent would at least equal the quality of effluent from conventional secondary treatment (i.e., CAS effluent). If so, it is reasonable to conclude that the proposed treatment process changes are at least as protective of aquatic life and people as the treatment processes that were assumed in the DEIS.

The principle findings of this report are as follows:

- The changes to proposed treatment processes would not change the conclusions of the water quality investigation conducted for three potential Puget Sound marine outfall locations; the available information indicates that effluent quality would be at least as good. Effluent quality would by significantly better for metals, PAHs and phenol, with the changes to the proposed treatment processes.
- Reductions in dissolved oxygen concentrations resulting from Brightwater discharges would be less than the 0.2 mg/L that is allowed under state water quality standards.
- Cancer risk estimates for a subsistence shellfish diet are similar to the fish-based evaluation presented in King County (2002a) and within the 10^{-6} to 10^{-4} range that National Contingency Plan (NCP) range the USEPA generally considers acceptable.

1.1. TREATMENT PROCESS COMPARISONS

Brightwater treatment processes were proposed in the DEIS. Subsequently, two areas of the treatment process changed based on evaluations conducted during ongoing predesign activities (Goetz & Allen 2003, King County 2003a).

- Split Flow MBR. In the DEIS, a full flow conventional activated sludge process (CAS) was proposed. The treatment plant process units were sized to handle the peak hourly flow at buildout of 170 MGD with a buildout AWWF of 54 MGD. During predesign, various alternatives for the secondary process were considered and a split flow membrane bioreactor (MBR) was selected as the preferred alternative. The MBR process is a split flow process due to the limited peaking capacity of the membrane system. Flows above the designed threshold would be split downstream of preliminary treatment and treated by ballasted sedimentation, an advanced primary treatment (APT) system. The split flows would be recombined for discharge to Puget Sound via a deep-water marine outfall. Effluents would be disinfected prior to recombination at the Unocal site and after recombination at the Route 9 site (Goetz & Allen 2003).
- Filtration. The DEIS included facilities for effluent filtration for reuse using granular filtration of a portion of the CAS effluent. This is no longer needed because the MBR produces filtered effluent and no additional filtration is required to produce Class A reclaimed water (Goetz & Allen 2003).

Concurrent with these changes in the proposed treatment processes, reviewers of the DEIS have asked for further evaluations of biochemical oxygen demand and the risks from consuming a subsistence shellfish diet. As both of these evaluations are dependent on the projected concentrations to be discharged from the future plant, they are included in this technical memorandum.

1.2. DISSOLVED OXYGEN IMPACTS

The original analysis in the DEIS of the effect of future Brightwater effluent on dissolved oxygen (DO) concentrations involved two approaches – estimating the increase in BOD by diluting effluent with ambient water and calculating the increase phytoplankton growth that would result from increases in nutrients discharged from the Brightwater plant. This analysis concluded that Brightwater effluent would not exceed the state narrative standard of no greater than a 0.2 mg/L decrease in dissolved oxygen resulting from human activities. This analysis was made assuming summer conditions in the Central basin of Puget Sound, where maximum effluent dilution will occur.

Reviewers have proposed using an alternate method of directly combining the effect of the two components of BOD – carbonaceous biochemical oxygen demand (CBOD) and nitrogenous biochemical oxygen demand (NBOD) – to gain a more inclusive estimate of the effect of effluent on dissolved oxygen levels. As the CBOD and NBOD levels are likely to change with the change in treatment processes at the future plant, this analysis is presented here with the evaluation of MBR/APT processes to evaluate the potential for failing to meet state dissolved oxygen standards. Additionally, reviewers have also requested an evaluation of the biochemical oxygen demand at mesoscale distances from the outfall. In the modeling effort supporting DEIS, this distance would correspond to the near bottom exposure scenario.

1.3. THERMAL IMPACTS

Reviewers have asked about the potential thermal impacts resulting from the future discharge of Brightwater effluent. A conservative analysis is presented here.

1.4. SHELLFISH SUBSISTENCE DIET

The original evaluation of risks associated with consuming seafood from the Brightwater study area focused on the patterns recorded in a human use recreation survey conducted in support of the Brightwater project (King County 2002b). This one-year survey documented that 71% of the people collecting and consuming seafood from the Brightwater study area ate finfish only. An additional 10% consumed a mixture of finfish and shellfish. Based on this site-specific evaluation and data availability, it was decided that an evaluation of finfish consumption only would adequately address the population cancer and non-cancer risks. However, DEIS reviewers requested an analysis of a shellfish subsistence diet be included in any evaluation of Brightwater treatment plant discharges. Therefore, this technical memorandum addresses the cancer and non-cancer risks from eating a subsistence diet of shellfish.

2.0 COMPARING TREATMENT PROCESSES

This section presents two different kinds of comparisons of effluent quality produced by different wastewater treatment processes. First, it presents direct comparisons of effluents produced by different treatment processes from the same influent. Second, it estimates future Brightwater effluent quality for split stream MBR-APT and CAS treatment processes, and compares the MBR-APT estimates against the CAS estimates.

Several types of information were needed to compare treatment processes. For the direct comparisons, we needed data on effluents produced by CAS, MBR and APT from the same influent. For the MBR-APT vs. CAS comparisons, we needed:

- Brightwater effluent quality estimates for CAS, MBR and APT processes. To get the effluent quality estimates, we needed estimates of Brightwater influent quality and CAS, MBR and APT removal efficiencies.
- Hydrographs so we could determine how much of the plant's flow would be treated by MBR and how much by APT.

The remainder of this section is organized as follows: Section 2.1 provides background information on membrane bioreactors and advanced primary treatment processes. Section 2.2 discusses data needs and describes what data were available for this study. Section 2.3 presents the effluent quality comparisons.

2.1. Proposed Treatment Processes

Following are brief descriptions of the MBR and APT technologies proposed for Brightwater.

2.1.1. Membrane Bioreactors

MBRs use a biological reactor and microfiltration (filters with nominal pore sizes of 0.1-0.4 mm) as a unit operation for secondary wastewater treatment. Microfiltration replaces the solids separation function of both secondary clarification and effluent filtration. MBRs provide several advantages over CAS:

- Mixed-liquor suspended solids (MLSS) concentrations are no longer limited by secondary clarifier solids loading limitations, so MBRs can operate at higher MLSS than CAS systems (Metcalf & Eddy 2003).
- MBRs require shorter reactor hydraulic retention times, which permits higher loading rates (Metcalf & Eddy 2003).
- MBRs have longer sludge retention times (SRTs), so the amount of sludge requiring disposal is reduced (Metcalf & Eddy 2003). Longer SRTs may also allow engineers to create activated sludges that are more effective at removing chemicals that are resistant to biological treatment in CAS systems.
- MBRs can operate at low dissolved oxygen concentrations (0.5 – 1.0 mg/L) and have the potential for simultaneous ammonia oxidation and NOx reduction in long SRT designs (Metcalf & Eddy 2003).

- MBRs avoid floc-settling and clarification problems associated with secondary clarifiers. This results in higher effluent quality (Metcalf & Eddy 2003).
- MBRs eliminate the need for secondary clarifiers and effluent filters, so they require less land and can reduce a wastewater treatment plant's footprint (Metcalf & Eddy 2003).

The disadvantages of MBRs include higher capital costs, limited data on membrane life, potential high cost of periodic membrane replacement, higher energy costs, and the need to control membrane fouling (Metcalf & Eddy 2003).

2.1.2. Advanced Primary Treatment

Enhanced flocculation and ballasted sedimentation are primary treatment processes in that the objective is to clarify wastewater by settling suspended solids. They are referred to as advanced primary treatment (APT) because they use a flocculation aid to enhance particle flocculation and a ballasting agent to achieve faster settling (high-rate clarification). A chemical coagulant (typically an iron salt) is used to destabilize colloids and allow flocculation to occur.

Ballasted sedimentation involves adding an inert ballasting agent (usually a silica "microsand" or a recycled chemically conditioned sludge) and a polymer to a coagulated and partially flocculated suspension. The polymer acts as the "glue" that binds floc to ballast. The ballasted particles settle faster because they are denser, smoother and more spherically shaped than conventional floc particles.

The advantages of enhanced flocculation/ballasted sedimentation units over conventional primary treatment systems are threefold. They are compact so space requirements are reduced, they are able to quickly achieve peak efficiency upon startup, and they remove solids more effectively and so produce a more highly clarified effluent. High operating costs due to polymer and coagulant requirements are the principal disadvantage, but when APT is used for treating peak flows the effect on a plant's annual operating costs are minimal (Hun 1998).

2.2. DATA SOURCES

2.2.1. King County Pilot Testing Program

Between June 2001 and March 2002, King County conducted a pilot testing program at the West Point Treatment Plant to assess the performance of emerging wastewater treatment technologies for water reuse applications (http://dnr.metrokc.gov/WTD/reuse/alternatives.htm). APT processes and MBRs were among the technologies tested as part of that program. This subsection briefly describes these tests.

The APT processes tested included US Filter/Krüger's Actiflo process and Ondeo Degremont's Densadeg® 4D process. Both of these processes provide enhanced flocculation and ballasted sedimentation. The MBR tests included a unit manufactured by Zenon. A second MBR pilot plant, manufactured by Enviroquip, was tested after the completion of the water reuse pilot testing program. A brief description of that project is included in this section as well.

2.2.1.1. APT Pilot Projects

Actiflo

The Actiflo APT pilot plant was at West Point from August 27-October 5, 2001. The performance goals for this project were (King County 2002c):

- total suspended solids (TSS) removal efficiency > 80%
- chemical oxygen demand (COD) removal efficiency > 60%
- total phosphorous (TP) removal efficiency > 80%
- sand recovery > 95%

Testing was conducted to determine optimal operating conditions (polymer and coagulant types and doses); collect long-term performance data at optimum and sub-optimum doses; evaluate the impact of operating challenges (wet and dry start-ups and loss of chemical feed); and to collect data on metals removal.

Two full-time US Filter/Krüger operators operated the unit, collected data and laboratory samples and prepared pilot project reports. The operators analyzed pH and turbidity samples and the King County Environmental Laboratory analyzed metals samples. The West Point Process Laboratory analyzed all other samples.

The results of the pilot project indicated that the Actiflo pilot plant met performance goals in optimized continuous run trials, as well as outperforming conventional primary clarification in average TSS, COD and TP removal efficiencies and performance variability. These conclusions were based on comparisons of pilot results and West Point primary clarification data for October 2001. The Actiflo metals removal data are discussed in Section 2.3.2.2 in comparison to CAS data.

Densadeg®

The Densadeg® APT pilot plant was at West Point from October 22, 2001-February 8, 2002 (King County 2002d). The performance goals for this project were:

- TSS removal efficiency > 80%
- COD removal efficiency > 60%
- TP removal efficiency > 80%

There was no performance goal for sand recovery because the Densadeg® process does not require sand for ballast, using dense solids produced by the process instead.

Testing was conducted to determine optimal operating conditions (polymer and coagulant types and doses); collect long-term performance data at optimum and sub-optimum doses; evaluate the impact of operating challenges (wet and dry start-ups and loss of chemical feed); and to collect data on metals removal.

King County Technology Assessment Program and West Point staff operated the unit, collected laboratory samples and recorded field data. The West Point Process Laboratory analyzed a majority of the samples collected. The King County Environmental Laboratory conducted metals analyses.

The results of the pilot project indicated that the Densadeg® pilot plant met performance goals in optimized continuous run trials, as well as outperforming conventional primary clarification in average TSS, COD and TP removal efficiencies and performance variability. These conclusions were based on comparisons of pilot results and West Point primary clarification data for February 2002. The Densadeg® metals removal data are discussed in Section 2.3.2.2 in comparison to CAS data.

2.2.1.2. MBR Pilot Projects

Enviroquip

Testing of the Enviroquip MBR pilot plant began at West Point on July 27, 2002 and ran through March 2003. King County Technology Assessment Program and West Point staff operated the unit, collected laboratory samples and recorded field data. The West Point Process Laboratory and King County Environmental Laboratory analyzed a majority of the samples collected. Influent and effluent concentrations were available for samples collected on August 26, September 23, October 28 and November 25, 2002.

Zenon

The Zenon MBR operated at West Point between August 29, 2001 and March 25, 2002. The unit was fed with primary effluent from the plant. During the six months of operation, different conditions were tested (King County 2002e). The specific goals for this project were:

- Achieve 90th percentile effluent ammonia concentration < 1 mg/L
- Achieve 90th percentile effluent nitrate concentration < 8 mg/L
- Achieve 50th percentile effluent nitrate concentration < 5 mg/L
- Achieve 90th percentile effluent turbidity < 0.2 NTU
- Achieve 90th percentile effluent TP < 0.1 mg/L
- Meet Class A reclaimed water standards

Process performance data were collected on solids, BOD, COD and TOC, nutrients, microbes, metals organic chemicals and hydraulic parameters. MBR effluent was sampled four times for a range of metals (Al, Sb, As, Ba, Be, Cd, Cr, Co, Cu, Fe, Pb, Hg, Mo, Ni, Se, Ag, Tl, V and Zn). Effluent quality data were reported as summary statistics (minimum, average, 90th percentile and maximum values) for conventionals and metals, and as single values for organics.

King County Technology Assessment Program and West Point staff operated the unit, collected laboratory samples and recorded field data. The West Point Process Laboratory and King County Environmental Laboratory analyzed the samples collected.

2.2.2. City of Tacoma APT Pilot Testing Program

The City of Tacoma conducted an APT pilot testing program at its Central Treatment Plant (CTP) between February 15 and March 4, 1999. The purpose of the program was to evaluate ballasted sedimentation as an effective means to increase treatment plant peak hydraulic capacity, while also meeting effluent water quality standards during storm flow events (City of Tacoma 2001a).

The APT systems evaluated by the City of Tacoma employed US Filter's Microsep process and Krüger's [2] Actiflo process. Both provide enhanced flocculation and ballasted sedimentation. Testing protocols for process optimization runs, system stability test runs, start-up efficiency test runs and long-term operational runs were developed (City of Tacoma 2001b) to compatibly evaluate the two systems under representative flow and loading conditions at the Tacoma CTP.

The two pilot units were run side by side to evaluate their performance under identical loading conditions. Raw, degritted primary wastewater served as the pilot unit influent. Flow control into the Krüger-Actiflo pilot unit provided some additional screening prior to entering the pilot unit.

Influent samples were collected from the primary clarifier adjacent to the pilot unit influent wastewater submersible pumps. Pilot unit effluent samples were collected from both pilot units immediately downstream of their overflow weirs.

A total of six autosamplers were operated on a daily basis by Tacoma CTP staff for the duration of the pilot study. Two autosamplers each were located at the influent channel of the primary tank for pilot unit influent analysis and at each of the pilot units for effluent sampling analysis. One autosampler was designated for hourly composited samples while the second was used to collect discrete hourly samples. Hourly composited 24-hour samples were analyzed for TSS, total Biochemical Oxygen Demand (t-BOD), soluble BOD and COD. Discrete hourly samples were analyzed for TSS and COD. Influent and effluent discrete hourly samples corresponding to the lowest influent COD value during a 24-hour run period were also analyzed for t-BOD. These samples were used to compare BOD/COD ratios at low loading conditions. In two long-term runs, 24-hour composited samples and two grab samples were also analyzed for heavy metals and semi-volatile organics. The pilot unit operators collected turbidity, pH, and waste sludge grab samples. The turbidity data were not presented in the pilot study report.

All sampling analyses for TSS, COD, BOD, and waste sludge TS and volatile solids were conducted using EPA approved methods by certified Tacoma Public Works laboratory personnel at the CTP Operations Lab. The Tacoma Utility Services Laboratory conducted semi-volatile and inorganic metal analyses.

The results of the pilot project indicated that consistently high TSS and BOD removal efficiencies well below the CTP's permitted weekly and even monthly average concentration limits were achieved by ballasted sedimentation as a stand alone process.

2.2.3. King County WWTP Operations Data

2.2.3.1. Data Requirements

The King County MBR and APT pilot testing program data will be used for two types of effluent quality comparisons. Both types of comparison require operations data from the King County wastewater treatment plants. The first type of comparison looks at effluents produced by different treatment processes from the same influent. For this, West Point secondary-treated effluent data are needed for making comparisons to the King County Pilot Testing Program results, because those pilot projects were done at West Point.

The second type of comparison involves comparing estimates of future Brightwater effluent quality, assuming split stream MBR-APT treatment, to estimates of future Brightwater effluent

[2] Both firms are now US Filter subsidiaries.

quality assuming CAS treatment. Both South Treatment Plant and West Point data are needed for the split stream-CAS comparisons:

- West Point influent quality data are needed to calculate removal efficiencies for the MBR and APT pilot plants.
- South Treatment Plant influent data are used as a surrogate for Brightwater influent because both are separated systems with similar service areas.
- South Treatment Plant effluent data are needed to serve as a surrogate for what Brightwater effluent quality would be, if Brightwater were to use CAS for secondary treatment.

The remainder of this section describes the WWTP operations data used for these comparisons.

2.2.3.2. Data Availability

The West Point and South Plant influent and effluent quality data were obtained from a recent water quality effects assessment (WQE) report (King County 2001). King County completed this report in support of an incidental take permit application, as provided for under Section (10)(a)(1)(B) of the Endangered Species Act. King County needed to understand the potential for constituents in its discharges of secondary treated effluent to negatively affect fish species that would be covered under the permit. That required a thorough review of the data on chemical concentrations in the influents and effluents from the county's wastewater treatment plants.

King County's influent and secondary treated effluent data were obtained from the following locations:

- The process laboratories at the South and West Point Treatment Plants provided daily conventional, nutrient and coliform data from a custom database (South Treatment Plant) and Excel workbooks (West Point).
- Everything except the daily conventional, nutrient and coliform data came from the King County Environmental Laboratory's Laboratory Information Management System (LIMS), an Oracle©-based database.

South Treatment Plant influent and secondary-treated effluent data were compiled for the date range November 1, 1995 through December 31, 1999. The start of this date range represents completion of several major upgrades to facilities and treatment processes at the South Treatment Plant (e.g., construction of a new aeration tank, two new clarifiers and new dewatering filtrate storage facilities; installation of new diffusers).

West Point influent and secondary-treated effluent data were compiled for the date range August 1, 1996 through December 31, 1999. The earlier end of this range represents the approximate start date for discharge of secondary-treated effluent at West Point. Prior to this, West Point provided only primary treatment. Details of the data requests (e.g., specific sample locator IDs, matrices, etc) from the LIMS database are presented in Attachment 1 of the WQE data characterization appendix (King County 2001).

2.2.3.3. Data Review

Data obtained from the LIMS database were combined into a new Access 97 database developed specifically for the WQE project. Data obtained from the South and West Point Treatment Plants process laboratories were evaluated using Excel. Data were reviewed to ensure that only data of

appropriate quality were used. The WQE database design ensures the ability to trace all data summaries and statistical calculations back to the original raw data.

The data review filtered out any inappropriate data that were included in the data packages obtained from the source databases. Data records having the following properties were excluded from further evaluation:

- All data for analytical constituents flagged as “deleted.”
- Tentatively identified compound (TIC) results. Chemicals identified as TICs were not reviewed because of the large uncertainty associated with (1) correct identification of non-target analytes, and (2) correct estimation of the concentration of non-target analytes.
- Data records where insufficient information was reported (e.g., results for which neither a chemical concentration nor a sample-specific method detection limit were available).
- Analytical results rejected by the analytical lab during QA/QC review (i.e., results qualified with an "R" for rejected).
- All data records for constituents that represent quality control analytes (e.g., surrogates) and data from QC samples (e.g., field blanks).
- Data records for West Point reclaimed water “Sample 1” collected 07/02/1997 that were analyzed by Edge Analytical, Inc. using USEPA Method 515.1. USEPA Method 515.1 target analytes detected in this sample were not followed up by confirmational GC/MS-SIM analysis (confirmational follow-up analyses were conducted for detected target analytes in all subsequent reclaimed water samples analyzed by USEPA Method 515.1).

A total of 33,503 influent data records and 17,911 secondary-treated effluent data records were retained in the WQE database.

2.2.4. City of Tacoma CTP Operations Data

The Tacoma APT pilot testing program report (City of Tacoma 2001a) provides paired metals data on raw primary influent quality and APT effluent quality, but it does not provide data on CAS effluent quality. These data were provided to King County by the City of Tacoma (City of Tacoma 2003) in order to assist the county with its treatment process comparisons. Specifically, the city provided King County with its NPDES data on influent and effluent quality for ten metals and ammonia for the period January 2, 1996-August 30, 2001. Sample dates were provided as well, so the data could be paired for calculating chemical removal efficiencies for the Tacoma CTP.

The Tacoma data are used for both of the types of comparison described in Section 2.2.3:

- For the type 1 comparison, APT effluent quality data from the City of Tacoma pilot project are compared to CAS effluent quality data from the Tacoma CTP.
- For the type 2 comparison, the APT effluent quality data and CTP influent quality data are used to estimate removal efficiencies for the Tacoma APT process.

2.2.5. Additional Chemistry Data

Data searches did yield other MBR and APT effluent quality data, but provided neither the CAS data nor the removal efficiencies that would be needed to make them useful for quantitative comparisons. Nonetheless, these other data are useful for providing some general information about effluent quality. This subsection identifies the additional data sources.

A search of the Water Environment Research Foundation's MBR database (http://www.werf.org/products/MembraneTool/home/default.asp) identified seven plants that are using MBRs for full-scale municipal wastewater treatment in the United States. The database did not provide effluent quality data for these plants, so U.S. Environmental Protection Agency's Enforcement and Compliance History Online (ECHO) database (http://www.epa.gov/echo/) was consulted to obtain the effluent quality data. A literature review revealed that pilot MBRs have been evaluated across the United States, but data were unavailable for most of the projects.

Effluent quality data also were obtained for three organic chemicals (bis(2-ethylhexyl)phthalate, chloroform and trichloroethylene) from a full-scale APT process that has been in operation for over 10 years at the Hyperion Treatment Plant in Los Angeles, California (Shao *et al.* 1996). Neither influent nor CAS effluent concentrations were available for the Hyperion plant.

In addition to the APT data obtained for the Hyperion plant, APT concentrations in effluent were estimated using removal efficiencies from the U.S. EPA's Risk Reduction Engineering Laboratory (RREL) treatability database (USEPA 1993). Removal efficiency data for various treatment systems are available in the database (http://www.epa.gov/ORD/NRMRL/treat.htm); data for chemically assisted clarification treatment systems were used to estimate APT removal efficiency. Municipal wastewater treatment data were used preferentially. Removal efficiencies for industrial wastewater treatment processes were used when municipal data were unavailable. Removal efficiencies from wastewater treatment processes at Superfund sites were used if and only if both municipal and industrial data were unavailable. The estimated APT removal efficiencies were compared to removal efficiencies calculated for King County's South Plant as a direct comparison. In the absence of pilot project data, APT removal efficiencies estimated from the RREL database also were used for split stream-CAS comparisons.

Data were found on the removal efficiency for one endocrine disrupter by a MBR. Wintgens *et al.* (2002) report a nonylphenol removal efficiency of greater than 90 percent with an effluent level of 0.03 mg/L.

2.2.6. Brightwater Hydrographs

Estimating effluent quality from the split stream MBR-APT process requires an estimate of the flow into the Brightwater plant. To get that, King County's sewer model was used to simulate flow. The model was run for 2002 land use conditions in the Brightwater service area, and a 51-year history of rainfall data from Seattle-Tacoma International Airport. The simulation provided a continuous record (hydrograph) of the predicted flow rate to the Brightwater plant. The modeled hydrograph was scaled to future conditions with scaling factors based on the anticipated AWWF (36 MGD for Phase I, 54 MGD for Phase II and 72 MGD for Phase II under the sub-alternative in which Edmonds and Lynnwood would redirect wastewater flows to the Brightwater plant). The hydrographs used for this analysis were produced as part of the Brightwater Predesign Initial Dilution Assessment (King County 2003b). They are presented in Figure 1.

2.3. EFFLUENT QUALITY COMPARISONS

As stated previously, this report presents two types of effluent quality comparisons. The first type of comparison is looking separately at the components that would make up the blended effluent discharged from Brightwater. This provides information about the effectiveness of MBR and APT relative to CAS. When looking at these "direct comparisons," it is important to keep in mind that APT is primary treatment that by itself does not necessarily produce a higher quality effluent than CAS. However, APT would be used at Brightwater only in combination with MBR.

This leads us to the second type of effluent quality comparison presented in this memo, which is the comparison of future Brightwater effluent quality estimates for split stream MBR-APT treatment and CAS treatment. The second type of comparison is looking at the blended MBR-APT effluent instead of the individual components. It takes into account the frequency distribution of discharge flow rates and, therefore, the proportions of MBR and APT effluent in the blended discharge.

2.3.1. Mathematical Description of Comparisons

This subsection mathematically describes the effluent quality comparisons presented in this report. Some readers will find this explanation useful, especially for the blended effluent comparisons to CAS. However, understanding the equations is not essential for understanding the results that follow, and some readers may wish to just skim the equations, or skip them altogether.

2.3.1.1. Direct Comparisons

The first type of comparison is relatively straightforward and is described by equations 1-3:

$$C_{WP_{MBR}} \overset{?}{<=>} C_{WP_{CAS}} \quad (1)$$

$$C_{WP_{APT}} \overset{?}{<=>} C_{WP_{CAS}} \quad (2)$$

$$C_{CTP_{APT}} \overset{?}{<=>} C_{CTP_{CAS}} \quad (3)$$

where C_{X_Y} is the concentration of any particular consituent in effluent Y from plant X. These equations simply state that we compared effluents produced by different treatment processes in the same plant.

Different quantities of data were available for each of the variables in equations 1-3. Only a few samples of MBR and APT effluents were available because the pilot projects operated for a limited period of time. Therefore, point estimates based on the sampled MBR and APT effluent concentrations were used for the left sides of equations 1-3. The CAS data for West Point and Tacoma were more extensive, as described in Sections 2.2.3 and 2.2.4. In these cases, it was possible to estimate how effluent concentration varied over time and we did so. These concentration distributions were used for the right side of equations 1 and 2. For Tacoma CTP, we did have the raw data on CAS effluent quality for the dates the pilot project samples were collected, so we used those concentrations for the right side of equation 3.

Statistical Methods for Estimating West Point CAS Effluent Concentration Distributions

We assumed that the West Point CAS effluent concentrations were lognormally distributed with means and standard deviations estimated by the sample means and standard deviations in the

summary data sets. The data for five COPCs (chromium, nickel, silver, di-N-butyl phthalate and phenol) were mostly below method detection limits (BDL). These constituents were also assumed to have lognormally distributed effluent concentration distributions, but alternate parameter sets were required to define the distributions. The details of how these five distributions were estimated are provided in the remainder of this subsection. Readers not interested in the statistical details may wish to skip ahead to subsection 2.3.1.2.

Statistical Methods for Highly Censored Data Sets

Effluents discharged from King County's wastewater treatment plants are regulated under the Washington State Department of Ecology's Wastewater Discharge Permit Program. This program administers National Pollution Discharge Elimination System (NPDES) permits. NPDES permits contain effluent limitations, which are set to cause the regulated discharge to meet state water quality standards. Effluent monitoring, recording and reporting requirements also are included in NPDES permits to verify that effluent limitations are being achieved. The NPDES monitoring requirements stipulate the laboratory methods and procedures that are used to measure chemical concentrations in effluent samples, in order to ensure that they can verify that effluent limitations are being achieved. If effluent quality is consistently better than required by effluent limitations, a chemical might be undetected in most effluent samples. The fact that the chemical is undetected (i.e., BDL) is acceptable because the NPDES permit conditions are designed to ensure that BDL samples occur only if the discharge is meeting effluent limitations and state water quality standards.

In addition to monitoring compliance with NPDES permit conditions, there are other uses the effluent monitoring data collected under the Wastewater Discharge Permit Program. The direct comparisons presented in this section are a case in point. The NPDES monitoring data are used here as a basis for comparing the quality of CAS effluent to MBR and APT effluents. For this it is useful to be able to estimate chemical concentrations in BDL effluent samples, especially when most of the samples are BDL, because those estimates provide a better basis for quantitatively comparing treatment processes.

Data sets with high proportions of BDL data are called highly censored data sets. The proportions of BDL samples in the five highly censored data sets used here were: chromium (four detects in 175 NPDES effluent monitoring samples = 97.7% BDL), nickel (one detect in 175 samples = 99.4% BDL), silver (eight detects in 175 samples = 95.4% BDL), di-N-butyl phthalate (three detects in fourteen samples = 78.6% BDL) and phenol (one detect in fourteen samples = 92.9% BDL).

Lognormal distributions were used to estimate the concentrations in the five highly censored data sets. The lognormal concentration distributions were not intended to be precise models. A high level of precision generally was not needed to determine whether a combination of MBR and APT was more effective at removing a constituent than CAS.

The lognormal distribution is used to model many kinds of environmental concentration data. The lognormal distribution is defined by two parameters. Typically, the mean and standard deviation are used. When the data are highly censored, the standard deviation cannot be estimated reliably so a percentile may be used instead. A second percentile may be used for the second parameter in place of the mean.

The lognormal model for di-N-butyl phthalate was estimated using two percentiles as parameters. The ninetieth percentile of the data was used to estimate the ninetieth percentile of the distribution, and the detection limit (specifically the laboratory method detection limit or MDL) was used to estimate the 100*(1-fod) percentile, where (1-fod) is the fraction of non-detects in the

censored data set. Since 100*(1-fod) percent of the data were below the MDL, it made sense to use the MDL as the estimate of the 100*(1-fod) percentile. In the case of di-N-butyl phthalate, this was the 78.6th percentile.

The lognormal distributions for chromium, nickel, silver and phenol were estimated using a percentile and the mean as parameters. As for di-N-butyl phthalate, the MDL was used to estimate the 100*(1- fod) percentile. In the case of di-N-butyl phthalate, about 23 percent of the data were detects, so it was possible to use the 90th percentile of the data set to estimate the 90th percentile of the lognormal distribution. In the other four cases, the fraction of detects was less than ten percent so the method used for di-N-butyl phthalate did not apply. In these cases, we used the estimated mean concentration as the second parameter of the lognormal distribution. The mean was estimated to be equal to one-half the MDL. This is analogous to assuming that the concentration distribution was not highly skewed, and if anything would overestimate actual BDL concentrations.

Statistical Methods for Estimating Tacoma CTP CAS Effluent Concentration Distributions

Unlike West Point, for which we had summary data sets, we had raw data on Tacoma CTP CAS effluent quality. Therefore, instead of assuming the form of the distribution (i.e., lognormal) and fitting with sample means and standard deviations, we simply fit distributions to the raw data. We used the commercial software @RISK Professional, version 4.0.1 (http://www.palisade.com). The software was used to fit various types of distributions to the raw data (e.g., lognormal, gamma, Weibull, etc.), and determine the "goodness-of-fit" of each distribution to the data by three statistics (Chi-Squared, Kolmogorov-Smirinov and Anderson-Darling). We looked at all the fitted distributions for a particular metal, performed sensitivity analyses by varying the fitting assumptions, and tried to find situations in which selecting a different distribution or changing assumptions would change our conclusions about whether the APT effluent quality was as good as, better or worse than CAS effluent quality. In all cases, our conclusions, which are reported below in subsection 2.3.2.3, are robust.

One particular issue we examined by sensitivity analysis was data censoring. We found that data censoring was not a significant issue for our analysis of metals concentrations in Tacoma CTP CAS effluent. In all cases, the percentage of censored data was low. For distribution fitting, we started by setting the BDL data equal to half the detection limit, and then conducted sensitivity analyses if there was a question about whether BDL data handling might affect our conclusions. There were a few cases (chromium, copper and silver) where, with lower detection limits, one might have found that the APT removal efficiencies were higher than CAS, but in each of these cases, we made the conservative interpretation of the data, which was that APT removal efficiencies were as high as CAS removal efficiencies, but not higher (see subsection 2.3.2.3).

2.3.1.2. Blended Effluent-CAS Comparisons

The equations for blended effluent comparisons to CAS are somewhat more complicated than the equations for the direct comparisons. This is because:

- They have to account for the proportions of the influent that get treated by MBR and APT, which is a function of flow through Brightwater as described by the Brightwater hydrographs (see subsection 2.2.6)
- They have to appropriately combine data from different wastewater treatment plants, for example, MBR removal efficiencies calculated with influent and effluent data from West Point, APT removal efficiencies from the RREL database and influent concentrations from South Treatment Plant.

- They have to provide for different ways of calculating parameters; for example, APT removal efficiencies can be calculated with Tacoma CTP, West Point or RREL data.

Equations 4-9a explain how the data described in Section 2.2 are used in the split stream-CAS comparisons. The South Treatment Plant effluent data are compared to South Treatment Plant influent concentrations that have been multiplied by MBR and APT removal efficiencies calculated from the West Point influent and pilot project data, and the South Treatment Plant effluent concentration so calculated is used as the surrogate for Brightwater effluent concentration:

$$C_{BW_{eff}} = C_{STP_{eff}} \overset{?}{<=>} C_{STP_{\inf}} \cdot r \tag{4}$$

where r is the overall removal efficiency of the split stream process:

$$r = \frac{r_{MBR} \cdot V_{MBR} + r_{APT} \cdot V_{APT}}{V_{MBR} + V_{APT}} \tag{5}$$

V_{MBR} and V_{APT} are the volumes treated by the MBR and APT processes, respectfully, and r_{MBR} and r_{APT} are the MBR And APT removal efficiencies. The data used to estimate the volumes treated by MBR and APT processes were described in Section 2.2.6. Equation 5 is actually solved for 98 different flow volumes, corresponding to the 1st-99th percentiles of the hydrograph, for each of the three Brightwater hydrographs (36, 54 and 72 MGD AWWF). The removal efficiencies on the right hand side of equation 5 are:

$$r_{MBR} = \frac{C_{MBR_{\inf}} - C_{MBR_{eff}}}{C_{MBR_{\inf}}} = 1 - \frac{C_{MBR_{eff}}}{C_{MBR_{\inf}}} \tag{6}$$

and:

$$r_{APT} = \frac{C_{APT_{\inf}} - C_{APT_{eff}}}{C_{APT_{\inf}}} = 1 - \frac{C_{APT_{eff}}}{C_{APT_{\inf}}} \tag{7}$$

Equation 6 is solved with West Point data. Equation 7 is solved three different ways: with West Point data, with Tacoma CTP data and with RREL data. Plant influent data, rather than primary-treated effluent data, are used for the MBR and APT influent concentrations for the pilot projects conducted at West Point and Tacoma CTP:

$$C_{APT_{\inf}} = C_{MBR_{\inf}} = C_{WP_{\inf}} \tag{8a}$$

$$C_{APT_{\inf}} = C_{MBR_{\inf}} = C_{CTP_{\inf}} \tag{8b}$$

This is appropriate because the removal efficiencies are multiplied by plant influent concentrations from the South Treatment Plant. The RREL removal efficiencies are calculated in the EPA database and used as representative of APT removal efficiencies:

$$r_{APT} = r_{RREL} \tag{9}$$

Combining equations 4-7 and 8a gives equation 10a, which is the equation for split stream-CAS comparisons with King County MBR and APT data:

$$C_{STP_{eff}} \overset{?}{<=>} C_{STP_{\inf}} \cdot \frac{\left(1 - \frac{C_{MBR_{eff}}}{C_{WP_{\inf}}}\right) \cdot V_{MBR} + \left(1 - \frac{C_{APT_{eff}}}{C_{WP_{\inf}}}\right) \cdot V_{APT}}{V_{MBR} + V_{APT}} \tag{10a}$$

Substituting equation 8b for 8a gives equation 10b, which is the equation for split stream-CAS comparisons using King County MBR data and Tacoma APT data:

$$C_{STP_{eff}} \overset{?}{<=>} C_{STP_{\inf}} \cdot \frac{\left(1 - \frac{C_{MBR_{eff}}}{C_{WP_{\inf}}}\right) \cdot V_{MBR} + \left(1 - \frac{C_{APT_{eff}}}{C_{CTP_{\inf}}}\right) \cdot V_{APT}}{V_{MBR} + V_{APT}} \tag{10b}$$

Substituting equation 9 for 8b gives equation 10c, which is the equation for split stream-CAS comparisons using King County MBR data and RREL data:

$$C_{STP_{eff}} \overset{?}{<=>} C_{STP_{\inf}} \cdot \frac{\left(1 - \frac{C_{MBR_{eff}}}{C_{WP_{\inf}}}\right) \cdot V_{MBR} + r_{APT_{RREL}} \cdot V_{APT}}{V_{MBR} + V_{APT}} \tag{10c}$$

Each of these equations (10a-10c) is solved at the 1st through 99th percentiles of the Brightwater hydrographs (36, 54 and 72 MGD AWWF), producing concentration distributions that describe the temporal variability in Brightwater effluent quality. The average influent concentration was used in equations 10a-10c, although the data do provide information about variability in influent concentration. We expect influent concentration and flow volume to be correlated, so it would be incorrect to model the variability in influent concentration without also modeling the correlation. Using the average influent concentration instead of the distribution is a way of addressing the uncertainty about the flow-concentration correlation.

2.3.2. Results of Direct Comparisons

This subsection presents the results of direct comparisons of effluents produced from the same influent by different treatment processes: specifically, MBR-CAS and APT-CAS comparisons for West Point, and APT-CAS comparisons for Tacoma CTP.

2.3.2.1. Comparison of West Point MBR and CAS Effluent Quality

West Point pilot-scale MBR data were available for 173 water quality constituents. West Point CAS effluent quality data were available for 28 previously identified COPCs (King County 2001). Twelve COPCs were detected in both MBR and CAS effluents. These included eight metals, ammonia-nitrogen, two phthalates and phenol.

Qualitative comparisons of effluent quality from the two West Point MBR pilot projects to West Point CAS effluent are presented in Table 1. In all cases, the MBR effluent quality was found to be as good as or better than CAS effluent quality. Differences in ammonia removal efficiencies are due to differences in operating conditions across the pilot projects rather than differences in the MBRs (Sukapanpotharam and Bucher 2003). The difference in metals removal effectiveness is an interesting result. One might expect some enhancement in the removal efficiency for metals because they would sorb to fine floc, which carries through CAS systems but would be filtered by MBRs. One hypothesis is that enhanced efficiency was not observed for copper, mercury, nickel and zinc in the pilot projects because these metals entered the MBR predominately in a particulate form, and so did not sorb to floc. Data for Kubota membrane bioreactor systems operating in the U.K. reportedly show results for copper, mercury and zinc similar to what has been observed in the West Point pilot projects, i.e., little or no improvement by MBR over CAS.

Details about the data and analyses conducted to reach the conclusions presented in Table 1 can be found in Figures 2-13. These figures show the lognormal distributions fit to the West Point CAS effluent quality data, and they show the MBR effluent quality data. They provide a brief summary of the analysis of the goodness-of-fit of the CAS distributions and the robustness of the conclusions to uncertainty about the variability in CAS effluent quality.

Table 1. Comparison of West Point MBR and CAS Effluent Quality.

Constituent	MBR	
	Enviroquip	Zenon
Aluminum	=	>
Barium	=	>
Chromium	>	>
Copper	=	=
Mercury	=	=
Nickel	=	=
Silver	>	>
Zinc	=	=
Ammonia-nitrogen	=	>
Bis(2-ethylhexyl)phthalate	no data	>
Di-N-butyl phthalate	no data	=
Phenol	no data	>

= MBR effluent quality as good as CAS effluent quality

> MBR effluent quality better than CAS effluent quality

2.3.2.2. Comparison of West Point APT and CAS Effluent Quality

West Point pilot-scale APT data were available for 19 water quality constituents (iron, aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, molybdenum, nickel, selenium, silver, thallium, vanadium, zinc and mercury). West Point CAS effluent quality data were available for the 28 COPCs (King County 2001). Seven COPCs were detected in both APT and CAS effluents. These included aluminum, barium, chromium, copper, nickel, silver and zinc. Qualitative comparisons of effluent quality from the two West Point APT pilot projects to West Point CAS effluent are presented in Table 2. In all cases, the APT effluent quality was found to be at least as good as CAS effluent quality. Details about the data and analyses conducted to reach the conclusions presented in Table 2 can be found in Figures 2-9. These figures show the lognormal distributions fit to the West Point CAS effluent quality data, and they

show the APT effluent quality data. They provide a brief summary of the analysis of the goodness-of-fit of the CAS distributions and the robustness of the conclusions to uncertainty about the variability in CAS effluent quality.

Table 2. Comparison of West Point APT and CAS Effluent Quality.

Constituent	APT	
	Actiflo	Densadeg®
Aluminum	=	=
Barium	=	=
Chromium	=	=
Copper	=	=
Nickel	=	=
Silver	=	=
Zinc	=	=

= APT effluent quality as good as CAS effluent quality

2.3.2.3. Comparison of Tacoma APT and CAS Effluent Quality

Tacoma CTP pilot-scale APT data were available for eight metals: arsenic, chromium, copper, lead, molybdenum, nickel, silver and zinc. CAS effluent quality data were available for all eight. In one case (copper), CAS and APT effluent quality data were available for the same dates. Qualitative comparisons of effluent quality from the two Tacoma CTP APT pilot projects to Tacoma CTP CAS effluent are presented in Table 3. In all cases, the APT effluent quality was found to be at least as good as CAS effluent quality.

Table 3. Comparison of Tacoma APT and CAS Effluent Quality.

Constituent	APT	
	Actiflo	Microsep
Arsenic	=	=
Chromium	=	=
Copper[1]	=	=
Lead	=	=
Molybdenum	=	=
Nickel	=	=
Silver	=	=
Zinc	=	=

= APT effluent quality as good as CAS effluent quality

[1] For copper, CAS samples were available from the same dates as the APT samples. On day 1 (March 1-2, 1999), the 24-hour composite APT effluent copper concentrations were 6.4 and 3.1 μg/L. The March 1, 1999 CAS effluent copper concentration was 4 μg/L.. On day 2 (March 2-3, 1999), the APT effluent copper concentrations were <2.0 and 2.0 μg/L. The March 3, 1999 CAS effluent copper concentration was 9 μg/L. 2 μg/L is below the 5th percentile of CAS effluent copper concentrations for the period January 1996-August 2001. Considering the 9 μg/L CAS effluent sample and the variability distribution of CAS effluent copper concentration, one could conclude that on March 2-3, the APT removed copper more effectively than CAS.

2.3.3. Results of Blended Effluent Quality Comparisons

This subsection presents the results of comparing blended MBR-APT effluent quality to CAS effluent quality as described above in equation 10a-10c. Flows that are split and treated in parallel MBR and APT processes would be blended before they were discharged to Puget Sound. The question presented is, whether the quality of blended effluent be better or worse than the quality of CAS effluent at the point of discharge to Puget Sound. This question was previously addressed for biochemical oxygen demand (BOD) and total suspended solids (TSS) so the current analysis focuses on toxic constituents of potential concern (COPCs) (Goetz and Allen 2003). Goetz and Allen (2003) found that split flow treatment would reduce the annual discharge of BOD and TSS 75 percent or more when compared to a full flow CAS process.

The Brightwater water quality investigations conducted in support of the DEIS (King County 2002a) identified twelve COPCs that it estimated would be present at or above ten percent of an aquatic toxicity threshold concentration (HQ > 0.1) for either acute or chronic exposure durations at the edge of the mixing zone. These COPCs were 2,4-dichlorophenol, 4,4'-DDT, chlorpyrifos, copper (total), diazinon, fluoranthene, heptachlor, malathion, manganese (total), phenol, pyrene and silver (total). Of the twelve COPCs with an HQ > 0.1, ten had sufficient data for estimating blended effluent quality. The two COPC exceptions are chlorpyrifos and malathion.

For the ten remaining COPCs, blended effluent quality was estimated by assuming that all flow up to the designed MBR capacity would be treated by MBR, and all surplus flow by APT. Blended effluent quality was estimated for the minimum to maximum flows estimated the Brightwater hydrograph at percentile intervals (minimum, 1st percentile, 2nd percentile, 3rd percentile, …, 98th percentile, 99th percentile, maximum).

Blended effluent quality was estimated by taking the weighted average of the MBR and APT effluent quality estimates, where the weighting factors were the percentages of the total flow treated by each process. For example, the Phase I MBR design capacity is 38 MGD, so at a flow of 50 MGD the weighting factors would be 0.76 for MBR (38/50) and 0.24 for APT ((50-38)/50). For these calculations, any CAS, MBR and APT concentrations that were below the method detection limit (MDL) for a COPC were set equal to that COPC's maximum reported MDL and calculated concentration was reported as less than the calculated value. CAS effluent quality was assumed to be independent of flow.

Blended effluent quality was compared to CAS effluent quality in three ways. First, we determined the flow rate at which enough of the blended effluent would have received advanced primary treatment for blended effluent quality to be worse than CAS effluent quality. Second, we compared CAS and blended effluent quality under average flow conditions. Third, we compared the quality of CAS and blended effluents under high (95th percentile) flow conditions.

2.3.3.1. Flow

The estimated flows for 36, 54 and 72 MGD AWWF were shown in Figure 1. The average and 95th percentile flows are summarized in Table 4, along with the planned MBR capacity for Phases I and II (base case and 72 MGD sub-alternative) of the Brightwater plant.

Table 4. Brightwater Flow Statistics and MBR Capacity.

Phase	AWWF (MGD)	Average Flow (MGD)	95%ile Flow (MGD)	MBR Capacity (MGD)
I	36	34.8	39.8	38
II (Base Case)	54	52.3	59.7	56
II (Sub-Alternative)	72	69.7	79.6	76

Looking at Table 4, one can see that at the average flow, 100 percent of Brightwater effluent would receive MBR treatment (because average flow is less than MBR capacity). At the 95th percentile flow, 94-95 percent of the effluent would receive MBR treatment (MBR capacity divided by 95%ile flow), with the remaining five to six percent receiving APT.

2.3.3.2. Effluent Quality

The data needed to estimate blended effluent quality include South Plant influent and effluent concentrations; percentiles of the Brightwater hydrographs for 36, 54 and 72 MGD AWWF; West Point influent concentrations and MBR effluent concentrations (which are used to estimate MBR removal efficiencies); and data for estimating APT removal efficiencies. These can be West Point influent and West Point APT effluent data, or Tacoma CTP influent and APT effluent data, or removal efficiency estimates from the RREL treatability database (USEPA 1993). The RREL option was only used when neither West Point nor Tacoma data were available for estimating APT removal efficiency. The hydrographs were presented in Figure 1. The rest of the data needed for blended-CAS effluent comparisons are provided in Table 5.

Table 5. South Plant Influent and Effluent and West Point Influent Concentrations.

COPC	Units	South Plant Influent	South Plant CAS Effluent	West Point Influent
2,4-Dichlorophenol	µg/L	<0.94	<0.95	<1
4,4'-DDT	µg/L	<0.047	<0.048	<0.047
Chlorpyrifos	µg/L	0.018	<0.032	n/an
Copper, total	mg/L	0.1167	0.0290	0.0530
Diazinon	µg/L	n/an	0.055	<0.049
Fluoranthene	µg/L	<0.57	<0.57	1
Heptachlor	µg/L	0.13	<0.048	0.19
Malathion	µg/L	n/an	<0.95	n/an
Manganese, total	mg/L	0.22	0.10	0.13
Phenol	µg/L	26.47	13.9	15.31
Pyrene	µg/L	<0.57	<0.57	0.97
Silver, total	mg/L	0.0078	0.012	0.0064

n/an = not analyzed

South Plant Influent and Effluent

Table 5 provides South Plant influent and effluent concentrations for the twelve COPCs:

- **2,4-Dichlorophenol** was undetected in 31 samples of South Plant influent taken between January 31, 1996 and August 19, 1999 (method detection limit (MDL) = 0.94 µg/L), and in 42 samples of South Plant CAS effluent taken between the same dates (min MDL = 0.24 µg/L, max MDL = 0.95 µg/L).

- **4,4' DDT** was undetected in 33 influent samples and 33 CAS effluent samples over the same period of time. Reported MDLs ranged from 0.0013-0.047 μg/L for the influent samples, and from 0.024-0.048 μg/L for the CAS effluent samples. n = 2, fod = 1, MDL = 0.004 μg/L.

- **Chlorpyrifos** was not analyzed for routinely but it was detected at an average concentration of 0.018 μg/L in two of two influent samples from a special study conducted August 2-9, 1999 (MDL = 0.004 μg/L). It was undetected in seven of seven CAS effluent samples taken during a March 31-April 6, 1998 special study (MDL = 0.032 μg/L).

- **Copper** was detected in all 1,536 influent samples taken between November 1, 1995 and December 31, 1999. The minimum and maximum measured concentrations were 0.02 and 1.11 mg/L. The sample average and standard deviation were 0.117 and 0.058 mg/L. The tenth, fiftieth and ninetieth percentile concentrations were 0.0795, 0.111 and 0.1485 mg/L. Copper also was detected in all 733 CAS effluent samples taken between November 1, 1995 and November 17, 1999. The minimum and maximum measured concentrations were 0.012 and 0.208 mg/L. The sample average and standard deviation were 0.029 and 0.014 mg/L. The tenth, fiftieth and ninetieth percentile concentrations were 0.018, 0.027 and 0.040 mg/L.

- **Diazinon** was not analyzed for routinely, but it was detected in one of seven CAS effluent samples taken during a March 31-April 6, 1998 special study. The measured concentration was 0.055 μg/L. The other six samples were below the MDL of 0.041 μg/L.

- **Fluoranthene** was undetected in 31 influent and 42 CAS effluent samples taken between January 31, 1996 and August 19, 1999. The MDL for the influent samples was 0.057 μg/L. The CAS effluent MDL ranged from 0.014-0.057 μg/L.

- **Heptachlor** was detected once in 33 South Plant influent samples taken between January 31, 1996 and August 19, 1999. (MDL = 0.002-0.047 μg/L). It was undetected in 33 CAS effluent samples taken over the same time period (MDL = 0.024-0.048 μg/L).

- **Malathion** was not analyzed for in South Plant influent samples, and it was undetected in 42 CAS effluent samples taken between January 31, 1996 and August 19, 1999. (MDL = 0.24-0.95 μg/L).

- **Manganese** was detected in 22 of 22 influent samples taken between January 31, 1996 and April 12, 1999. The minimum and maximum measured concentrations were 0.154 and 0.369 mg/L. The sample average and standard deviation were 0.220 and 0.056 mg/L. The tenth, fiftieth and ninetieth percentile concentrations were 0.162, 0.215 and 0.288 mg/L. Manganese also was detected in and 23 of 23 CAS effluent samples taken between the same dates. The minimum and maximum measured concentrations were 0.0532 and 0.175 mg/L. The sample average and standard deviation were 0.102 and 0.028 mg/L. The tenth, fiftieth and ninetieth percentile concentrations were 0.066, 0.1.4 and 0.128 mg/L.

- **Phenol** was detected in 30 of 31 samples collected between January 31, 1996 and August 19, 1999 (MDL = 3.8 μg/L). The minimum and maximum measured concentrations were <3.8 and 139 μg/L. The sample average and standard deviation were 26.47 and 27.63

μg/L. It was detected only once in 42 CAS effluent samples (MDL = 0.94-3.8 μg/L). The detected concentration was 13.9 μg/L.

- **Pyrene** was undetected in 31 influent and 42 CAS effluent samples taken between January 31, 1996 and August 19, 1999. The MDL for the influent samples was 0.057 μg/L. The CAS effluent MDL ranged from 0.014-0.057 μg/L.
- **Silver** was detected in 71 percent of 1,266 South Plant influent samples (MDL = 0.004 mg/L) taken between November 1, 1995 and the end of 1999. The minimum and maximum concentrations were <0.004 and 0.0248 mg/L. The average and standard deviation were 0.0064 and 0.0037 mg/L. The tenth, fiftieth and ninetieth percentile concentrations were <0.004, 0.0078 and 0.013 mg/L. It was detected in 43 of 733CAS effluent samples (MDL = 0.0002-0.004 mg/L) collected between November 1, 1995 and November 17, 1999. The maximum concentration measured in South Plant CAS effluent was 0.012 mg/L.

West Point Influent

Table 5 also provides West Point influent concentrations for the twelve COPCs:

- **2,4-Dichlorophenol** was undetected in 15 samples of West Point influent taken between January 28, 1997 and August 18, 1999 (MDL = 0.94-1 μg/L).
- **4,4' DDT** was undetected in 14 influent samples taken between January 28, 1997 and August 18, 1999 (MDL = 0.024-0.047 μg/L).
- **Chlorpyrifos** was not analyzed for in West Point influent.
- **Copper** was detected in all 1,266 influent samples taken between August 1, 1996 and December 31, 1999. The minimum and maximum measured concentrations were 0.0073 and 0.245 mg/L. The sample average and standard deviation were 0.053 and 0.0197 mg/L. The tenth, fiftieth and ninetieth percentile concentrations were 0.0328, 0.0499 and 0.0759 mg/L.
- **Diazinon** was not routinely analyzed for in West Point influent, but it was analyzed for in a West Point influent sample collected as part of the Zenon MBR pilot project. The concentration in that influent sample was less than the MDL of 0.049 μg/L.
- **Fluoranthene** was detected once in fifteen samples of West Point influent taken between January 28, 1997 and August 18, 1999 (MDL = 0.57-0.6 μg/L).
- **Heptachlor** was detected six times in fourteen West Point influent samples taken between January 28, 1997 and August 18, 1999 (MDL = 0.024-0.047 μg/L. The maximum measured concentration was 0.0186 μg/L. The sample average and 90th percentile concentrations were 0.052 and 0.114 μg/L respectively.
- **Malathion** was not analyzed for in West Point influent.
- **Manganese** was detected in 37 of 37 influent samples taken between October 16, 1996 and August 18, 1999 (MDL = 0.002 mg/L). The minimum and maximum measured concentrations were 0.072 and 0.317 mg/L. The sample average and standard deviation were 0.129 and 0.043 mg/L. The tenth, fiftieth and ninetieth percentile concentrations were 0.098, 0.12 and 0.159 mg/L.

- **Phenol** was detected in fourteen of fifteen samples collected between January 28, 1997 and August 18, 1999 (MDL = 3.8-4.0 μg/L). The minimum and maximum measured concentrations were <4.0 and 42 μg/L. The sample average and standard deviation were 15.3 and 11.3 μg/L.

- **Pyrene** was detected in one of fifteen West Point influent samples taken between January 28, 1997 and August 18, 1999 (MDL = 0.57-0.6 μg/L). The measured concentration was 0.972 μg/L.

- **Silver** was detected in 895 of 1,266 West Point influent samples (MDL = 0.004 mg/L) taken between August 1, 1996 and November 17, 1999. The minimum and maximum concentrations were <0.004 and 0.0248 mg/L. The average and standard deviation were 0.0064 and 0.0037 mg/L. The tenth, fiftieth and ninetieth percentile concentrations were <0.004, 0.0063 and 0.011 mg/L.

MBR Removal Efficiencies

Table 6 provides estimates of MBR removal efficiencies for the COPCs. Three of the COPCs (chlorpyrifos, malathion and manganese) were not analyzed for in the MBR pilot projects. In the absence of MBR data, we have conservatively assumed that MBR would be no more efficient than CAS for these COPCs. The only COPCs analyzed for in the Enviroquip pilot were copper and silver. The Zenon pilot analyzed for fluoranthene, manganese, phenol and pyrene, in addition to copper and silver.

Enviroquip MBR effluent was sampled on August 26, September 23, October 28 and November 25, 2002. The measured copper concentrations in Enviroquip MBR effluent were 0.00203, 0.00436, 0.0016 mg/L and 0.00163 mg/L. All silver samples were below the MDL of 0.0002 mg/L. West Point primary influent was sampled concurrently with the MBR effluent. The copper influent concentrations were on August 26, September 23, October 28 and November 25, 2002 were 0.145, 0.0658, 0.0283 and 0.0282 mg/L. The silver concentrations in West Point primary influent on these dates were 0.00215, 0.00293, 0.00172 and 0.00127 mg/L. Based on these data, the average copper removal efficiency was 95 percent. Setting the silver MBR effluent concentration equal to the MDL gives the lowest estimated removal efficiency (i.e., the silver concentration in MBR effluent could be lower, in which case the removal efficiency would be higher). Assuming that the MBR effluent concentration equals the MDL gives an average silver removal efficiency of 89 percent, which is the lower limit on the possible ranges of values.

The Zenon MBR data were used for estimating fluoranthene, manganese, phenol and pyrene removal efficiencies. Phenol was reported detected at a concentration of 0.0521 μg/L. Fluoranthene, manganese and pyrene were all below MDLs. Concurrent West Point influent concentrations data were not available with the Zenon effluent concentrations, so we used the average influent concentrations.

APT Removal Efficiencies

West Point Pilot Projects

Copper and silver were the only COPCs analyzed for in West Point APT pilot effluents. Concentrations were reported as single-valued estimates. Each pilot project was run with three different coagulants: alum, polyaluminum chloride (PACl) and ferric chloride ($FeCl_3$). The copper and silver removal efficiencies for all three coagulants are given in Table 7.

Table 6.
MBR Removal Efficiencies

COPC	Removal Efficiency (%)	Explanation
2,4-Dichlorophenol	=CAS	Zenon MBR effluent concentration <MDL 0.024 µg/L. Concurrent West Point influent concentration <MDL of 0.12 µg/L. These data are insufficient for estimating removal efficiency so assumed same removal efficiency as CAS.
4,4'-DDT	=CAS	Zenon MBR effluent concentration <MDL 0.0025 µg/L. Concurrent West Point influent concentration <MDL of 0.0024 µg/L. These data are insufficient for estimating removal efficiency so assumed same removal efficiency as CAS.
Chlorpyrifos	=CAS	No data on MBR removal efficiency so assumed same removal efficiency as CAS.
Copper, total	92	MBR effluents (one Zenon and four Enviroquip samples) and West Point primary influent sampled concurrently on five occasions. Took the average the five removal efficiencies (i.e., the average, across the five paired samples, of one minus the ratio of the MBR effluent concentration and the influent concentration).
Diazinon	=CAS	Zenon MBR effluent concentration <MDL 0.0097 µg/L. Concurrent West Point influent concentration <MDL of 0.049 µg/L. These data are insufficient for estimating removal efficiency so assumed same removal efficiency as CAS.
Fluoranthene	>98	Analyzed for but undetected in Zenon MBR effluent (MDL = 0.0097 µg/L). Concurrent West Point influent concentration = 0.389 µg/L. Used these data for calculating a lower limit on the removal efficiency (i.e., one minus the ratio of the MBR MDL and the influent concentration).
Heptachlor	>37	Zenon MBR effluent concentration <MDL of 0.0025 µg/L. Concurrent West Point influent concentration <MDL of 0.0024 µg/L. These data are insufficient for estimating removal efficiency so assumed same removal efficiency as CAS. CAS removal efficiency found using South Plant primary influent concentration (0.13 µg/L) and secondary effluent concentrations (<MDL of 0.048 µg/L). Used these data for calculating a lower limit on the removal efficiency (i.e., one minus the ratio of the CAS effluent MDL and the influent concentration).
Malathion	=CAS	No data on MBR removal efficiency so assumed same removal efficiency as CAS.
Manganese, total	45	No data on MBR removal efficiency so assumed same removal efficiency as CAS. CAS removal efficiency found by taking the one minus the ratio of South Plant secondary effluent concentration (0.10 mg/L) and primary influent concentration (0.22 mg/L).
Phenol	99	Zenon MBR effluent concentration = 0.0521 µg/L. Concurrent West Point influent concentration = 6.29 µg/L.
Pyrene	>87	Zenon MBR effluent concentration <MDL 0.0097 µg/L. Concurrent West Point influent concentration = 0.074 µg/L. Used these data for calculating a lower limit on the removal efficiency (i.e., one minus the ratio of the MBR MDL and the influent concentration).
Silver, total	>90	MBR effluents (one Zenon and four Enviroquip samples) and West Point primary influent sampled concurrently on five occasions. Silver was detected in all five influent samples, but below the MDL of 0.002 mg/L in all five MBR effluent samples. Used these data for calculating a lower limit on the removal efficiency (i.e., the average, across the five paired samples, of one minus the ratio of the MBR MDL and the influent concentration).

Table 7. West Point APT Removal Efficiencies.

COPC	Actiflo Pilot (*from* King County 2002c, Table 12)			Densadeg® Pilot (*from* King County 2002d, Table 13)		
	Alum	PACl	$FeCl_3$	Alum	PACl	$FeCl_3$
Copper	96%	89%	86%	88%	n/r	79%
Silver	94%	93%	94%	91%	n/r	82%

n/r = removal efficiency not reported (King County 2002d)

Tacoma Pilot Projects

Copper and silver were the only COPCs analyzed for in Tacoma CTP APT pilot effluents. Concentrations were reported in two 24-hour composite samples taken on consecutive days. The values reported in Table 8 are averages of the two composites. The coagulant used for the test runs was PACl.

Tacoma CTP influent data were provided to King County by the City of Tacoma (2003).

- **Copper** was detected in 38 of 41 samples collected between January 11, 1996 and July 6, 2001. The minimum and maximum measured concentrations were 0.032 and 0.188 mg/L. The sample average and standard deviation were 0.192 and 0.042 mg/L. The median concentration was 0.0985 mg/L.
- **Silver** was detected in 39 of 41 samples collected between January 11, 1996 and July 6, 2001. The minimum and maximum measured concentrations were 0.001 and 0.018 mg/L. The sample average and standard deviation were 0.0065 and 0.0040 mg/L. The median concentration was 0.0065 mg/L.

The APT copper and silver removal efficiencies for the Tacoma pilot projects are reported in Table 8.

Table 8. Tacoma APT Removal Efficiencies.

COPC	Actiflo Pilot	Microsep Pilot	Explanation
Copper	95%	97%	Tacoma CTP influent concentration = 0.092 (City of Tacoma 2003); Actiflo ATP effluent = 0.0042 and Microsep effluent = 0.0026 mg/L (City of Tacoma 2001a, Table 3-4).
Silver	>94%	>94%	Tacoma CTP influent concentration = 0.0065 mg/L (City of Tacoma 2003). Actiflo and Microsep APT effluent concentration both <MDL of 0.00097 mg/L (City of Tacoma 2001a, Table 3-4). Used these data for calculating a lower limit on the removal efficiency (i.e., one minus the ratio of the APT MDL and the influent concentration).

RREL Database

The RREL database was used for COPCs other than copper and silver, for which the pilot project data were considered more reliable estimators. RREL removal efficiencies were available for six of the twelve COPCs. These removal efficiencies are values reported by the U.S. EPA (1993) for chemically assisted clarification (CAC) of municipal or industrial wastewaters. The RREL removal efficiencies are presented in Table 9.

Table 9. RREL Estimates of APT Removal Efficiencies (USEPA 1993).

COPC	Removal Efficiency
2,4-Dichlorophenol	53%
Flouranthene	88%
Heptachlor	64%
Manganese	55%
Phenol	28%
Pyrene	88%

Summary of APT Removal Efficiency Estimates

Table 10 gives an overall summary of APT removal efficiencies estimated from the various available sources. Removal efficiencies were unavailable for four of the twelve COPCs: 4,4'-DDT, chlorpyrifos, heptachlor and malathion. In the absence of appropriate data, the APT removal efficiencies for these four COPCs were conservatively assumed to be zero, even though some removal would be expected to occur.

Table 10. Overall Summary of APT Removal Efficiencies.

COPC	Removal Efficiency	Source
2,4-Dichlorophenol	53%	RREL data
4,4'-DDT	0	n/d
Chlorpyrifos	0	n/d
Copper	90%	average of seven pilot projects
Diazinon	0	n/d
Fluoranthene	88%	RREL
Heptachlor	64%	RREL
Malathion	0	n/d
Manganese, total	55%	RREL
Phenol	28%	RREL
Pyrene	88%	RREL
Silver	92%	average of seven pilot projects, using 94% for the Tacoma pilots

n/d = no data

Effluent Quality Comparisons

The data reported in Figure 1 and Table 4,5, 6 and 10 were used to estimate and compare blended and CAS effluent qualities. Results are presented in Tables 11-13. The analysis found that blended MBR-APT effluent would be of at least equal quality to CAS effluent. In several cases blended MBR-APT effluent would be of significantly higher quality than CAS effluent, even at high flows. Annual mass loadings of the COPCs analyzed would decline by up to 98 percent, and average effluent quality improved by a comparable amount. These improvements would be observed even at the 95th percentile flow (close to worst case).

One COPC (2,4-dichlorophenol) shows effluent quality improving as flow increases, an indication that APT effluent quality is better than MBR effluent quality. This occurred because we had inadequate data to estimate the MBR removal efficiency for 2,4-dichlorophenol, so it was assumed to be no better than CAS. On top of that, the CAS removal efficiency estimate was zero because 2,4-dichlorophenol was measured below MDLs in influent and effluent. We did have data for estimating the APT removal efficiency for 2,4-dichlorophenol, though, so some removal was predicted when flow was high enough to use APT.

Table 11. Summary Comparison of Blended (MBR/APT) and CAS Effluents, Phase I (36 MGD AWWF)

Constituent	Annual Mass Loading (kg/yr)		Effluent Concentration (μg/L)					
	CAS	MBR-APT	CAS	Average Flow MBR-APT Blend[1]	95th %ile Flow MBR-APT Blend	Estimated % Time MBR-APT Effluent Concentration>CAS	Estimated Effluent Quality Improvement at Average Flow	Estimated Effluent Quality Improvement at 95th %ile Flow
2,4-Dichlorophenol	< 46	< 45	< 0.95	< 0.95	< 0.93	0%	0%	2%
4,4'-DDT	< 2	< 2	< 0.05	< 0.05	< 0.05	0%	0%	0%
Copper, total	1397	451	29	9.3	9.4	0%	68%	67%
Diazinon	3	3	0.06	0.06	0.06	0%	0%	0%
Flouranthene	< 27	< 1	< 0.57	< 0.01	< 0.01	0%	98%	98%
Heptachlor	< 2	< 2	< 0.048	< 0.05	< 0.05	0%	0%	0%
Manganese, total	4817	4816	100	100	100	0%	0%	0%
Phenol	670	24	13.9	0.3	1.1	0%	98%	92%
Pyrene	< 27	< 4	< 0.57	< 0.07	< 0.07	0%	87%	87%
Silver	578	37	12	1	1	0%	94%	94%

[1] Average flow is less than the MBR capacity of 38 MGD (see Table 4), so in this case “MBR-APT Blend” is 100% MBR effluent.

Table 12. Summary Comparison of Blended (MBR/APT) and CAS Effluents, Phase II Base Case (54 MGD AWWF)

Constituent	Annual Mass Loading (kg/yr)		Effluent Concentration (μg/L)					
	CAS	MBR-APT	CAS	Average Flow MBR-APT Blend[1]	95th %ile Flow MBR-APT Blend	Estimated % Time MBR-APT Effluent Concentration>CAS	Estimated Effluent Quality Improvement at Average Flow	Estimated Effluent Quality Improvement at 95th %ile Flow
2,4-Dichlorophenol	< 69	< 68	< 0.95	< 0.95	< 0.92	0%	0%	3%
4,4'-DDT	< 3	< 3	< 0.05	< 0.05	< 0.05	0%	0%	0%
Copper, total	2095	677	29	9.3	9.5	0%	68%	67%
Diazinon	4	4	0.06	0.06	0.06	0%	0%	0%
Flouranthene	< 41	< 1	< 0.57	< 0.01	< 0.01	0%	98%	97%
Heptachlor	< 3	< 3	< 0.048	< 0.05	< 0.05	0%	0%	0%
Manganese, total	7225	7225	100	100	100	0%	0%	0%
Phenol	1004	37	13.9	0.3	1.4	0%	98%	90%
Pyrene	< 41	< 5	< 0.57	< 0.07	< 0.07	0%	87%	87%
Silver	867	56	12	1	1	0%	94%	94%

[1] Average flow is less than the MBR capacity of 56 MGD (see Table 4), so in this case “MBR-APT Blend” is 100% MBR effluent.

Table 13. Summary Comparison of Blended (MBR/APT) and CAS Effluents, Phase II 72 MGD Sub-Alternative

Constituent	Annual Mass Loading (kg/yr)		Effluent Concentration (μg/L)					
	CAS	MBR-APT	CAS	Average Flow MBR-APT Blend[1]	95th %ile Flow MBR-APT Blend	Estimated % Time MBR-APT Effluent Concentration>CAS	Estimated Effluent Quality Improvement at Average Flow	Estimated Effluent Quality Improvement at 95th %ile Flow
2,4-Dichlorophenol	< 92	< 91	< 0.95	< 0.95	< 0.93	0%	0%	2%
4,4'-DDT	< 5	< 5	< 0.05	< 0.05	< 0.05	0%	0%	0%
Copper, total	2794	902	29	9.3	9.4	0%	68%	67%
Diazinon	5	5	0.06	0.06	0.06	0%	0%	0%
Flouranthene	< 55	< 1	< 0.57	< 0.01	< 0.01	0%	98%	98%
Heptachlor	< 5	< 5	< 0.048	< 0.05	< 0.05	0%	0%	0%
Manganese, total	9634	9633	100	100	100	0%	0%	0%
Phenol	1339	47	13.9	0.3	1.1	0%	98%	92%
Pyrene	< 55	< 7	< 0.57	< 0.07	< 0.07	0%	87%	87%
Silver	1156	75	12	1	1	0%	94%	94%

[1] Average flow is less than the MBR capacity of 76 MGD (see Table 4), so in this case “MBR-APT Blend” is 100% MBR effluent.

3.0 IMPLICATIONS OF TREATMENT PROCESSES FOR DISSOLVED OXYGEN IMPACTS

Potential reduction of dissolved oxygen (DO) concentrations in the receiving water resulting from the effluent discharge could result from two sources. These include increased biochemical oxygen demand (BOD), as well as decay of phytoplankton populations that may have been augmented by increased nutrients in the effluent. As noted above, the influence of Brightwater treatment plant effluent on BOD in Puget Sound was evaluated for the DEIS for a specific set of conditions in the Sound.

> *"Minimum DO concentrations in the Central Basin occur in the late summer (King County 2002f); therefore, the corresponding plant flows would likely be relatively low. For example, the average dry-weather flow of the plant would be about four-fifths of the average wet weather flow. However, to avoid under estimating potential impacts to DO from the discharge, the average wet-weather flow of 54 MGD was assumed" (King County 2002f).*

Thus this scenario examined the influence of Brightwater treatment plant effluent on BOD throughout the entire Central Basin during the time period likely to produce the lowest dilution over this spatial scale.

The DEIS evaluation scenario examined relatively large-scale, long-term potential effects of effluent BOD on Central Basin dissolved oxygen levels. To complement this effort, two additional scenarios—the near-bottom environment and Possession Sound—are evaluated here. The near-bottom environment represents the area were the plume could make contact with sediment after completing the initial dilution process (where differences in density and temperature dominate the dilution process). This scenario is more conservative than that evaluated in the DEIS as the plume has undergone some initial mixing, but has not yet achieved long-term equilibrium with the Puget Sound (King County 2002f). (With these lower dilutions meaning higher BOD concentrations and a greater potential for adversely affecting DO levels in this environment.) Further, the near-bottom environment is of particular interest as it an area where geoducks could be present in large numbers (King County 2002f). The second scenario addresses the potential affects of effluent BOD on Possession Sound, which is an area of particular concern based on a historical record of low dissolved oxygen numbers (low being defined as being greater than 3.0 mg/L and less than 5.0 mg/L) (see data trends presented in WDOE 2002).

3.1. BOD Methods

The influence of Brightwater treatment plant effluent on near-bottom environment BOD was analyzed using the following approach:

- BOD measurements from the King County Environmental Laboratory were determined to be Total BOD_5 or $TBOD_5$ (oxygen demand generated by biological processes in 5 days). $TBOD_5$ is composed of approximately 50% carbonaceous BOD ($CBOD_5$) and

approximately 50% nitrogenous BOD ($NBOD_5$). For the purposes of this analysis, it will be assumed that the relationship is 1:1.

- The $TBOD_5$ value does not represent the maximum oxygen demand present in treatment plant effluent (referred to as $T_{ultimate}$ or $TBOD_u$). USEPA (2000) reports a range of factors that have been used for converting $tBOD_5$ to $TBOD_u$. For the purposes of this analysis, we used equation 11 (USEPA 2000) to express the maximum oxygen demand present in Brightwater treatment plant effluent:

$$TBOD_u = 2.84 * tBOD_5 \quad (11)$$

- $CBOD_u$ was then estimated by equation 12:

$$CBOD_u = tBOD_5 * 0.5*2.84 \quad (12)$$

- Total Kjeldahl Nitrogen (TKN) concentrations in blended MBR/APT effluent were estimated from the MBR pilot plant studies, and applying estimate removal efficiencies for the APT process to measured mean concentrations measured in South Plant influent. The predicted blended concentration of MBR/APT TKN is 5.6 mg/L

- NBODu (ultimate nitrogenous biochemical oxygen demand or the complete amount of oxygen consumed to completely convert ammonia in biological processes) is calculated as 4.57* TKN.

- The direct potential influence of discharging effluent from Brightwater in each scenario is the sum of $CBOD_u$ and $NBOD_u$ divided by the approximate dilution. Near bottom dilutions during the same summer scenario as used in the initial BOD evaluation range from 584:1 to 863:1 depending on the number of days post-release (King County 2002f). In this evaluation, 700:1 was selected as a representative dilution for the near-bottom exposure scenario. Possession Sound dilutions were selected to be equal to the basin-scale model lower level steady state dilution of 2,890:1, as this model result best represented the likely contribution of Brightwater effluent to this water body (King County 2002f).

- Total BOD_5 in blended MBR/APT effluent was calculated to be 6.0 mg/L annual average during an extreme year (and 4.0 mg/L in an average year) (Krugel, et al. 2002). Total BOD_5 was set equal to 6.0 mg/L for this analysis.

- The change in dissolved oxygen resulting from discharge of BOD from the Brightwater treatment plant effluent is the sum of ($CBOD_u$+$NDOB_u$) divided by the scenario specific dilution factor.

3.2. PHYTOPLANKTON DECAY METHODS

Nutrients released in the effluent may stimulate phytoplankton growth, whose decaying matter consumes oxygen as it is decomposed. The potential increase in phytoplankton growth can be estimated by assuming that all Total Kjeldahl Nitrogen (TKN) discharged from the plant is used by the phytoplankton and converted to carbon. All of this carbon is then assumed to be converted back to CO_2, consuming DO from the surrounding water. In addition, any O_2 produced by phytoplankton was not considered in this estimate, which also reduces the chance of underestimating the potential impact on phytoplankton growth.

Using the predicted blended MBR/APT TKN concentrations of 5.6 mg/L, and a Redfield ratio of 106 C: 16 N: 1 P (Wetzel 2001), the impact of nutrients discharged by the plant on DO concentrations can be estimated. Assuming that two oxygen molecules are used to convert each carbon molecule to CO2, the theoretical maximum total, undiluted DO demand from nutrients in the effluent discharge is 84.8 mg/L.

$$DO\ demand \quad = \quad 5.6\ mg/L\ TKN \times \frac{1N}{14\ g} \times \frac{106C}{16N} \times \frac{2O}{1C} \times \frac{16g}{1O} \quad = \quad 84.8\ mg/L\ DO$$

If this theoretical maximum total reduction in DO resulting from phytoplankton decay is diluted using the basin-scale model lower level steady state dilution of 2,890:1, the resulting DO demand is 0.029 mg/L

$$\frac{84.8\ mg/L}{2{,}890} \quad = \quad 0.029\ mg/L$$

3.3. Results

A worst-case scenario would combine the impacts on DO from both BOD and phytoplankton decay. Combining the DO demand from these two sources results in a maximum reduction of 0.078 mg/L, which is below the 0.2 mg/L allowed by state standards. This value is less than half of the allowable change in marine water dissolved oxygen (WAC 2003). Similarly, these methods predict a change in Possession Sound dissolved oxygen levels of 0.041 mg/L resulting from the combined contribution of BOD present in Brightwater effluent and the theoretical maximum phytoplankton decay. This value is less than one quarter of the allowable decrease in dissolved oxygen attributable to human activities (WAC 2003).

3.4. Impact of Discharges on Sediment Oxygen Demand

Sediment Oxygen Demand (SOD) is the total of all ongoing biological and chemical processes in sediment that consume oxygen in the overlying water column (USEPA 2003). SOD can significantly impact dissolved oxygen (DO) levels in nutrient enriched waters and stratified water bodies such as lakes and slow-moving rivers (USEPA 2003; Lee, *et al*. 2003). While a number of methods have been developed to measure SOD in both the field and laboratory (Lee and Jones, 1999; USEPA 2003), it is possible to deduce whether or not SOD could impact Puget Sound sediments through (1) examining effluent quality, (2) receiving environment characteristics, and (3) the benthic community present at other currently functioning King County outfalls.

Sediments could be impacted through increased oxygen demand through three basic effects: (1) local deposition of solids with a measurable biochemical oxygen demand (BOD) load, (2) long-range transport of sediments first deposited locally and then moved to other areas (such as Possession Sound), and (3) partitioning of BOD constituents to sediments after long-range transport of water column BOD. Overall, the Membrane Bioreactor (MBR) process that will be used at the Brightwater Treatment Facility will remove between 99 and 100% of the settleable solids. Coupled with the dynamic, turbulent nature of the diffuser zone (rising effluent, local currents, mixing of freshwater with saltwater), this should prevent deposition of any remaining settleable solids in the local area surrounding the diffuser. That is to say, the energy in the outfall to create the mixing action will prevent any of the material to settle out around the outfall.

Therefore, we would conclude that there would be no significant deposition or buildup of BOD containing sediments in the outfall environment. This conclusion is supported by an examination of current sediment conditions at existing King County outfalls (Striplin and DNR, 2001), which concluded that - "*The sedimentary environment surrounding the South TP Outfall appears to be in good condition with no chemical exceedances. The sediment type and benthic community is indicative of a long-term community with little or no disturbances that may result in adverse impacts."* This report further states that there was no detectable gradation in species distributions in the samples collected in 2000 that would indicate that there was no increase in pollution tolerant species (i.e., species tolerant of low DO) directly adjacent to the South TP Outfall.

Overall, long range transport of sediments would not be a significant problem as it is very unlikely that there would be any discernable buildup of sediments in the local environment to transport to other locations within Puget Sound. Additionally, in contrast with other more persistent effluent constituents, BOD5 is the amount of oxygen consumed over a five-day period (which likely represents 80-90% of the ultimate BOD). Any transport that took longer than this would have little remaining oxygen demand once those sediments were re-deposited at some removed location. Lastly, the potential impact on sediments from BOD constituents partitioning from the water column has basically been addressed in the initial analysis. That is, the initial estimate accounted for the total BOD load that could be attributable to effluent discharged for the future Brightwater Treatment Facility. Any partitioning to sediments in the outfall vicinity would be negligible as supported by the observation of a functioning and diverse benthic community in the sediments adjacent to the South Treatment Plant Outfall. The expected oxygen demand, for example, in Possession Sound would be no more than that calculated in the water column, 0.078 mg/L. This drop would not significantly affect benthic organisms.

4.0 IMPLICATIONS OF TREATMENT PROCESSES FOR TEMPERATURE

Effluent temperature is highly dependent upon treatment processes utilized at the plant. Therefore, temperatures at the regulatory mixing zones cannot be accurately determined until treatment processes at the plant have been determined. An effluent temperature of 15.5 C (based on typical effluent temperature at other treatment plants) was assumed for diffuser hydraulic performance modeling in order to estimate the difference in density between effluent and receiving water. Assuming an effluent temperature of 15.5 C, the temperature difference between effluent and receiving water would be, at most, 10 C. Assuming a minimum dilution of 100:1 at the chronic mixing zone boundary, the incremental temperature increase would be 0.1 C, which is below state water quality standards for temperature.

5.0 IMPLICATIONS OF TREATMENT PROCESSES FOR SHELLFISH SUBSISTENCE DIET

The Phase 3 WQI did not evaluate potential chemical risks from shellfish consumption because human use surveys suggested that finfish are the predominant type of seafood consumed from the study area. However, given that shellfish consumption may increase as current shellfish harvesting bans are lifted, potential chemical risks from shellfish consumption were assessed using shellfish consumption rates for the Suquamish Indian Tribe. These consumption rates were assumed to be representative of a subsistent diet, or at least representative of a highly exposed population in the study area.

5.1. Methods

The following describes the methods for compiling shellfish chemistry data for the study area and development of a shellfish consumption rate based on surveys of the Suquamish Indian Tribe. As discussed in detail below, shellfish chemistry data were only available for Littleneck clams in the study area. These data were assumed to be representative of all shellfish species consumed by the Suquamish.

Chemistry data for shellfish in Puget Sound were identified in DOH (1996). This study analyzed metals and organics in littleneck clams (*Protothaca staminae*) at 29 locations in Puget Sound. Of these, four locations were assumed to be reasonably representative of the proposed Brightwater outfall sites. These locations were Carkeek Park, Edmonds oil dock, Mukilteo, and Picnic Point. Data were available from 1992 and 1993 and assumed to be representative of existing conditions. All data were pooled for each detected parameter and the 95 percent confidence limit on the mean was calculated[3] (Table 14).

Shellfish ingestion rates were derived from a fish consumption survey of the Suquamish Indian Tribe (The Suquamish Tribe 2000). There were 92 respondents to the survey and eight bivalve species consumed by the respondents were identified: littleneck clams, horse clams, butter clams, geoducks, cockles, oysters, mussels, and scallops. Although shellfish chemistry data were only available for littleneck clams, it was assumed that concentrations in these clams would be, on average, similar to those in other bivalves. This is an uncertain assumption because variability in species' habitat preferences, feeding strategies, and lipid contents influence tissue chemical concentrations. However, there is greater uncertainty in the chemical exposure estimates if the contribution from other bivalve species is not accounted for.

For each bivalve species, summary statistics on the mean number of servings per year and portion size (grams) per serving were supplied. These are presented in Table 15.

[3] Non-detected parameters and their associated detection limits were not reported, so it was not possible to determine whether detection limits were below concentrations that may pose risk.

Table 14. Summary Statistics for Parameter Concentrations in Native Littleneck Clams

Parameter	Units	Mean	SD	n	95 UCL on Mean
Arsenic	mg/kg ww	1.3	0.27	4	1.6
Cadmium	mg/kg ww	0.14	0.037	4	0.18
Copper	mg/kg ww	1.09	0.34	4	1.50
Lead	mg/kg ww	0.068	0.010	4	0.079
Mercury	mg/kg ww	0.010	0	4	0.010
Zinc	mg/kg ww	13.2	1.67	4	15.2
Benzoic acid	µg/kg ww	2,008	1,104	4	3,308
bis(2-ethylhexyl)phthalate	µg/kg ww	1,436	1,378	2	7,588
Butyl benzyl phthalate	µg/kg ww	36	-	1	36

SD = Standard deviation
n = Sample size
ww = Wet weight

Table 15. Summary Statistics for Consumption of Bivalves

Shellfish	# of Servings per Year					
	Mean	Median	90th %ile	Min	Max	n
Littleneck clams	24	11	68	1	208	84
Horse clams	9	4	29	1	52	51
Butter clams	14	6	36	1	120	71
Geoducks	13	8	36	1	80	82
Cockles	13	6	30	1	140	60
Oysters	13	8	46	2	52	60
Mussels	8	2	24	1	48	25
Scallops	7	4	22	1	52	52

Shellfish	Portion Size (g) per Serving					
	Mean	Median	90th %ile	Min	Max	n
Littleneck clams	326	196	800	15	2268	84
Horse clams	216	138	441	57	1588	51
Butter clams	428	375	750	33	2268	71
Geoducks	376	272	900	45	2720	82
Cockles	564	448	1120	56	2240	60
Oysters	271	180	477	30	1361	60
Mussels	256	128	806	32	1134	25
Scallops	137	72	432	24	720	51

The mean number of servings per year was multiplied by the mean portion size per serving to estimate the mean grams of each bivalve species consumed per year (Table 16). The same calculation was done using the 90th percentile data (Table 16). This latter calculation is likely a conservative estimate of the 90th percentile consumption rate because the number of servings and portion per serving are not necessarily correlated. The mean and 90th percentile consumption rates for each species were then normalized for the percentage of respondents that consume each species. This step was necessary because consumption rates for each bivalve species should not contribute equally to the total bivalve ingestion rate. For example, on average, 84 of the respondents eat 24 littleneck clam meals per year, while 25 respondents eat eight meals per year. By considering the number of respondents that do not eat a given species, the consumption rates for each species can be calculated:

$$\text{sample population } CR = \frac{CR \times \text{number of positive responses}}{\text{total number of responses}} \qquad (13)$$

where CR = consumption rate (kg/yr)

Table 16. Estimated Annual Consumption Rates of Bivalves

Shellfish	Consumption Rate – Positive Respondents Only (kg/yr)		Consumption Rate - All Respondents (kg/yr)	
	Mean	90th %ile	Mean	90th %ile
Littleneck clams	7.8	54.4	7.1	49.7
Horse clams	1.9	12.8	1.1	7.1
Butter clams	6.0	27.0	4.6	20.8
Geoducks	4.9	32.4	4.4	28.9
Cockles	7.3	33.6	4.8	21.9
Oysters	3.5	21.9	2.3	14.3
Mussels	2.0	19.3	0.56	5.3
Scallops	0.96	9.5	0.54	5.4
Totals	**34.5**	**211**	**25.4**	**153**

This calculation was conducted on both the mean and 90th percentile data and the consumption rates for all species were summed (Table 16). Using this approach, the final mean and 90th percentile shellfish consumptions rates for the Suquamish Tribe sample population were 25 and 153 kg/year. The final step for estimating chemical doses from shellfish was to determine the fraction of shellfish consumed from the outfall siting area. The Suquamish survey asked for the harvest locations of the different bivalve species. Unfortunately, the reporting area (defined as Area 26) encompassing the proposed outfall sites included all of Puget Sound from the southern portion of Whidbey Island to Tacoma. Nevertheless, these data were used to develop a conservative estimate of the fraction of shellfish collected from the outfall sites. The fractions for each bivalve species was then weighted using the same approach described above for weighting the bivalve consumption rates. These data and results of this analysis are provided in Table 17. As shown, it was assumed that 69-70% of all bivalves consumed were to be harvested from the outfall siting areas. Thus, exposure concentrations were estimated using the consumption rates based on all shellfish combined, the fractions of shellfish conservatively assumed to be collected form the study area, and chemical concentrations measured in native littleneck clams.

Table 17.
Fraction of Shellfish Harvested from Puget Sound Zone Containing the Proposed Outfall

Shellfish	# of Positive Respondents Harvesting from Area 26	Total # of Positive Respondents	% of Positive Respondents Harvesting from Area 26	Weighted % of Positive Respondents Harvesting from Area 26 (Mean)	Weighted % of Positive Respondents Harvesting from Area 26 (90th %ile)
Clams, geoducks	64	90	71%	48%	49%
Cockles	46	57	81%	15%	12%
Oysters	28	60	47%	4%	4%
Mussels	8	13	62%	1%	2%
Scallops	5	12	42%	1%	1%
Averages				**70%**	**69%**

The exposure scenarios evaluated were the same as those evaluated in King County (2002a) and are summarized in Table 18. Thus, scenarios 120, 121, 122, 126, and 127 represent future scenarios. The associated dilution factors for each of these scenarios, as well as the equation for estimating future concentrations of outfall constituents, can also be found in King County (2002a).

Table 18.
Shellfish Consumption Exposure Scenarios for Human Health

Scenario[1]	Condition	Zone	Flows (MGD)
117	Ambient	Zone 6 & 7S	–
119	Ambient	Zone 6 & 7S	–
120	Ambient + Effluent	Zone 6	36
121	Ambient + Effluent	Zone 6	54
122	Ambient + Effluent	Zone 6	72
126	Ambient + Effluent	Zone 7S	35
127	Ambient + Effluent	Zone 7S	54

[1]Scenarios 118, 123, 124, and 125 for outfall zone 7N is no longer being considered.

MGD = Million Gallons per Day

5.2. Results

Cancer risks and non-cancer hazard quotients were calculated as described in King County (2002a). Cumulative cancer risks and hazard quotients were the same for all scenarios (current conditions without Brightwater and with Brightwater) (Table 19). Approximately 70 percent of the cumulative cancer risk was driven by arsenic, with the remainder resulting from bis(2-ethylhexyl)phthalate. These cancer risk estimates are similar to the fish-based evaluation presented in King County (2002a) and within the 10^{-6} to 10^{-4} National Contingency Plan (NCP) range the USEPA generally considers acceptable when characterizing the magnitude of risks related to Superfund sites. The cumulative hazard quotient of six was also driven by arsenic (37 percent), bis(2-ethylhexyl)phthalate (26 percent), as well as cadmium (26 percent). In summary, the analysis indicates that the addition of Brightwater effluent to Puget Sound would not cause the health risks of a subsistence shellfish diet to increase.

Table 19.
Human Health Risk Estimates for Shellfish Subsistence Diet.

Scenario[1]	Condition	Cancer Risk	Hazard Quotient
117	Ambient	$6*10^{-4}$	6
119	Ambient	$6*10^{-4}$	6
120	Ambient + Effluent	$6*10^{-4}$	6
121	Ambient + Effluent	$6*10^{-4}$	6
122	Ambient + Effluent	$6*10^{-4}$	6
126	Ambient + Effluent	$6*10^{-4}$	6
127	Ambient + Effluent	$6*10^{-4}$	6

6.0 CONCLUSIONS

6.1. Treatment Process Comparisons

The purpose of this report is to determine whether the changes to proposed treatment processes for the Brightwater Treatment Plant change the conclusions of a water quality investigation conducted for three potential Puget Sound marine outfall locations (King County 2002a). The water quality investigation estimated potential future risks to aquatic life and people from discharging Brightwater effluent to Puget Sound, assuming that Brightwater used the treatment process units proposed in the DEIS. This report evaluates whether MBR and APT effluent qualities would be at least equal to the quality of filtered CAS effluent.

Side-by-side comparisons of MBR and CAS effluents produced from the same influent were possible for twelve chemicals: aluminum, barium, chromium, copper, mercury, nickel, silver, zinc, ammonia-nitrogen, bis(2-ethylhexyl)phthalate, di-N-butyl phthalate and phenol. In all cases, MBR effluent quality was equal to or better than CAS effluent quality. These results were presented in Tables 1-3 and Figures 2-13.

Blended MBR-APT effluents were compared to CAS effluent under a range of flow conditions. This analysis was conducted for constituents that previously were shown to be of the greatest potential concern for their effects on aquatic life. The analysis confirmed that blended effluent quality will be significantly better than CAS effluent quality. It is estimated that annual mass loads to Puget Sound will be reduced by up to 98 percent, depending on the chemical. In all cases, even at high flow rates, switching to the blended MBR-APT process improves effluent quality. These results were presented in Tables 11-13.

6.2. Dissolved Oxygen Impacts

The initial evaluation of DO impacts conducted for the DEIS indicated that Brightwater treatment plant effluent was unlikely to reduce dissolved oxygen concentrations more than the 0.2 mg/L reduction allowed by state water quality standards. This alternative approach to estimating the potential reduction in dissolved oxygen in the near-bottom environment reaches the same conclusion. The most significant factor contributing to this conclusion is the reduced levels of tBOD5 and TKN produced by the MBR and APT treatment processes.

6.3. THERMAL IMPACTS

Even given conservative assumptions for the difference in temperature between the discharge and the receiving water, and the expected dilution, no significant temperature impacts are predicted.

6.4. Subsistence Shellfish Diet

Cumulative cancer risks and non-cancer hazard quotients were the same for all scenarios (cancer risk = $6x10^{-4}$ and hazard quotient = 6). The parameter contributing most to both the cancer risks and non-cancer hazard quotients was arsenic, with bis(2-ethylhexyl)phthalate contributing the

second most. The cancer risk estimates are similar to the fish-based evaluation presented in King County (2002a) and within the 10^{-6} to 10^{-4} National Contingency Plan (NCP) range the USEPA generally considers acceptable when characterizing the magnitude of risks related to Superfund sites. Overall, the health risks from consuming a subsistence shellfish diet are not expected to increase above current conditions with the addition of Brightwater effluent to Puget Sound.

7.0 REFERENCES

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Figures

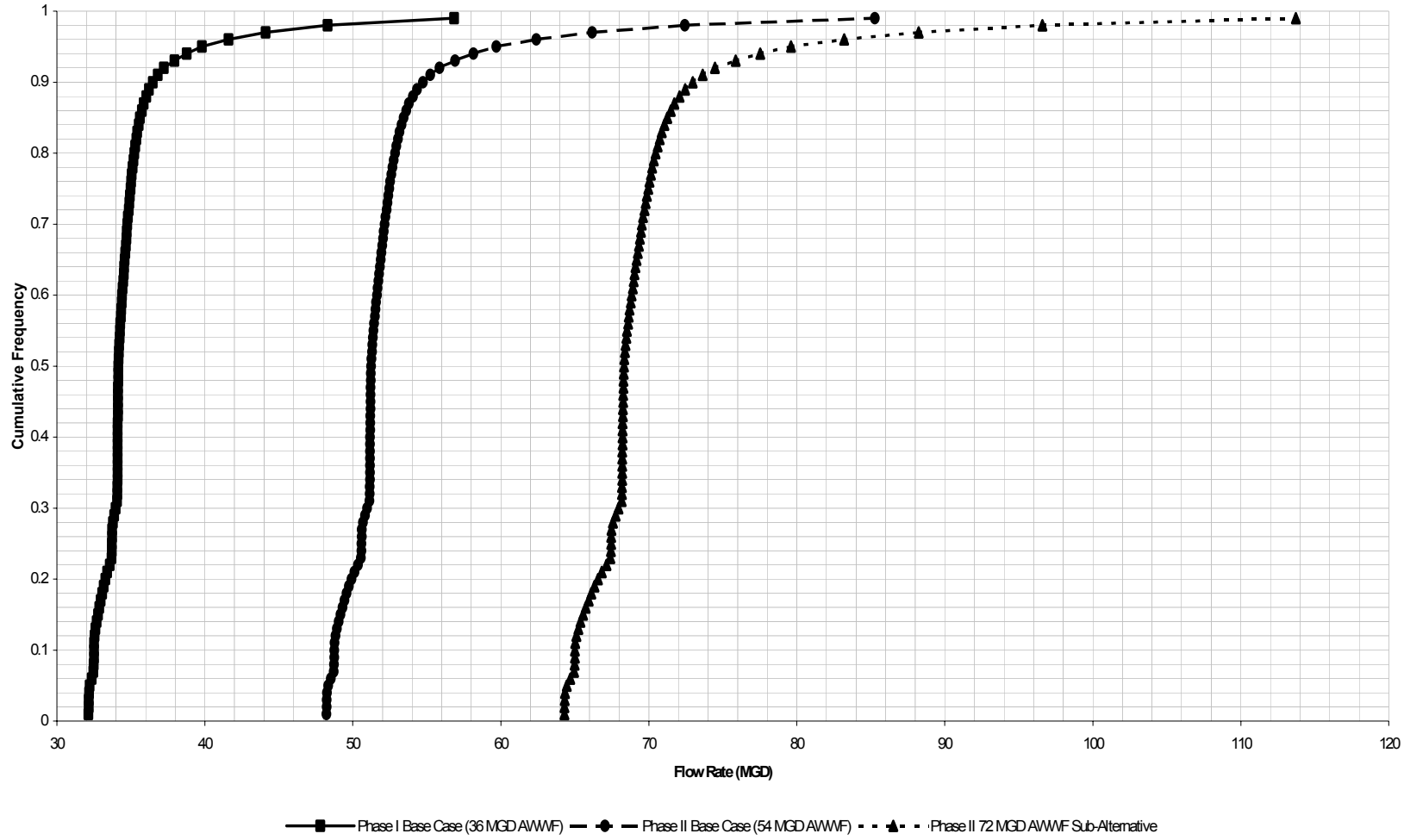

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Figure 1

Brightwater Hydrographs for Phase 1 (36 MGD AWWF), Phase II Base Case (54 MGD) and Phase II

BRIGHTWATER REGIONAL WASTEWATER TREATMENT SYSTEM

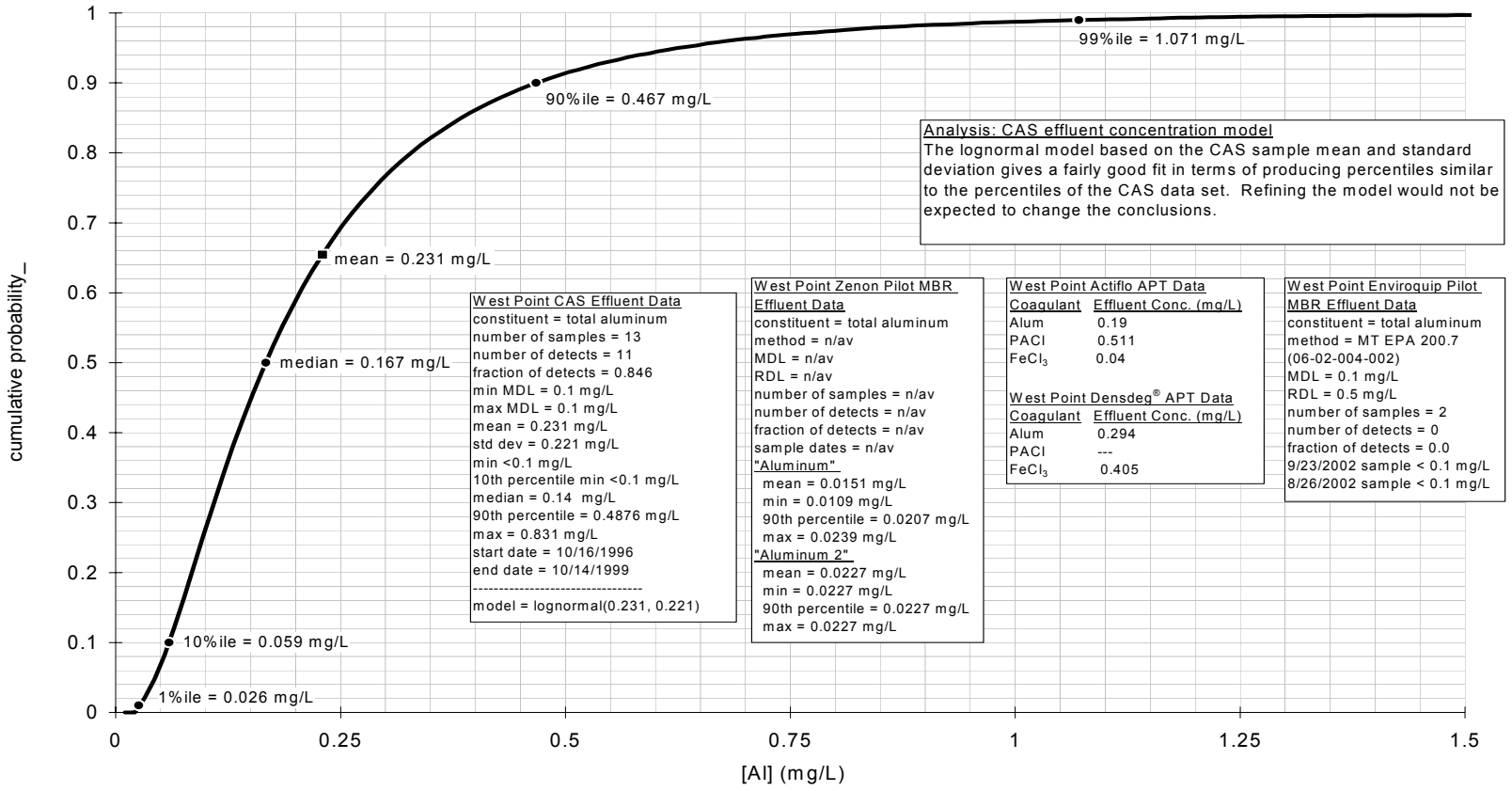

Figure 2

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Comparison of MBR Pilot Project Effluent Quality Data to West Point Secondary Effluent Quality, Aluminum

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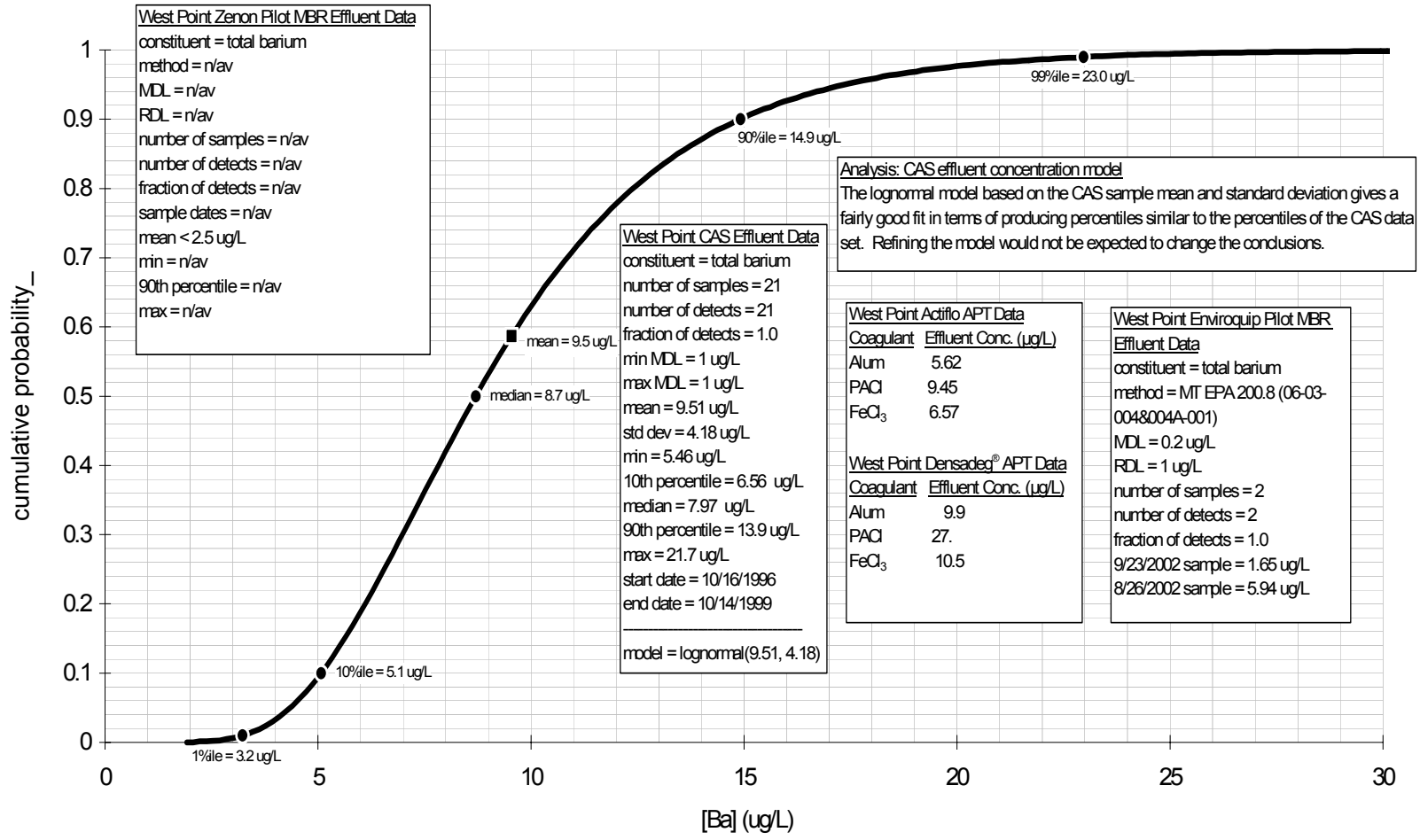

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Figure 3

Comparison of MBR Pilot Project Effluent Quality Data to West Point Secondary Effluent Quality, Barium

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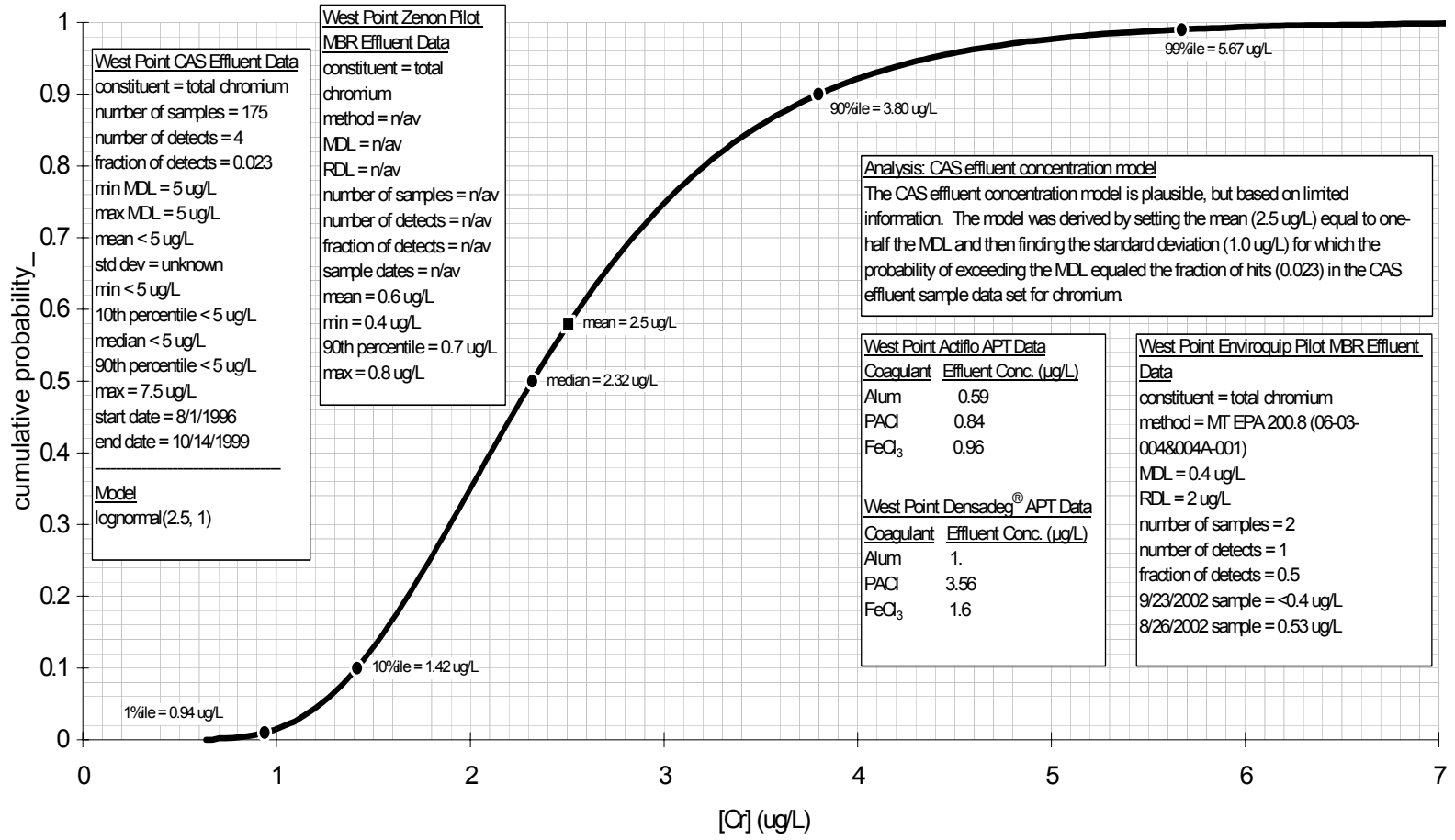

Figure 4

Comparison of MBR Pilot Project Effluent Quality Data to West Point Secondary Effluent Quality, Chromium

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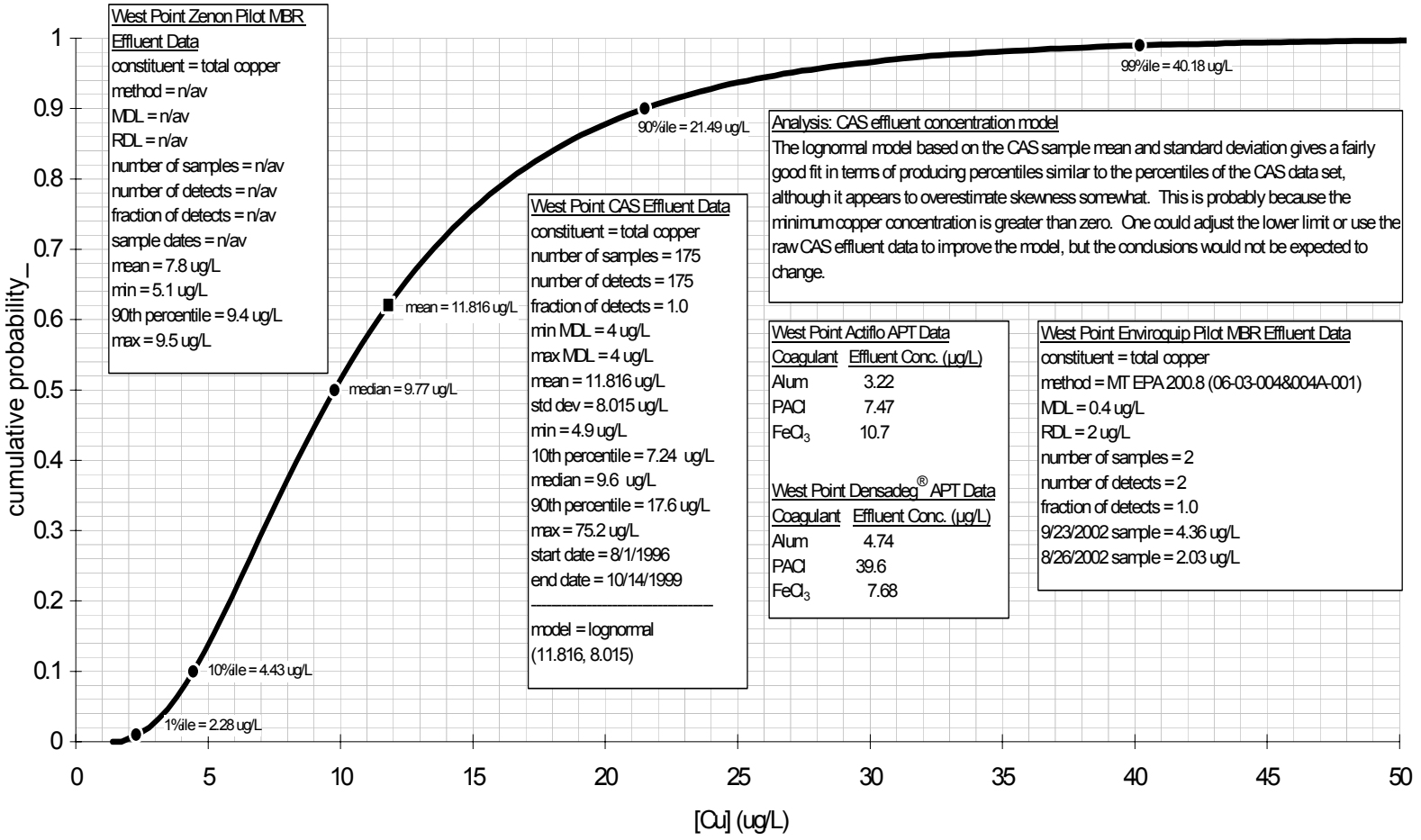

Figure 5

Comparison of MBR Pilot Project Effluent Quality Data to West Point Secondary Effluent Quality, Copper

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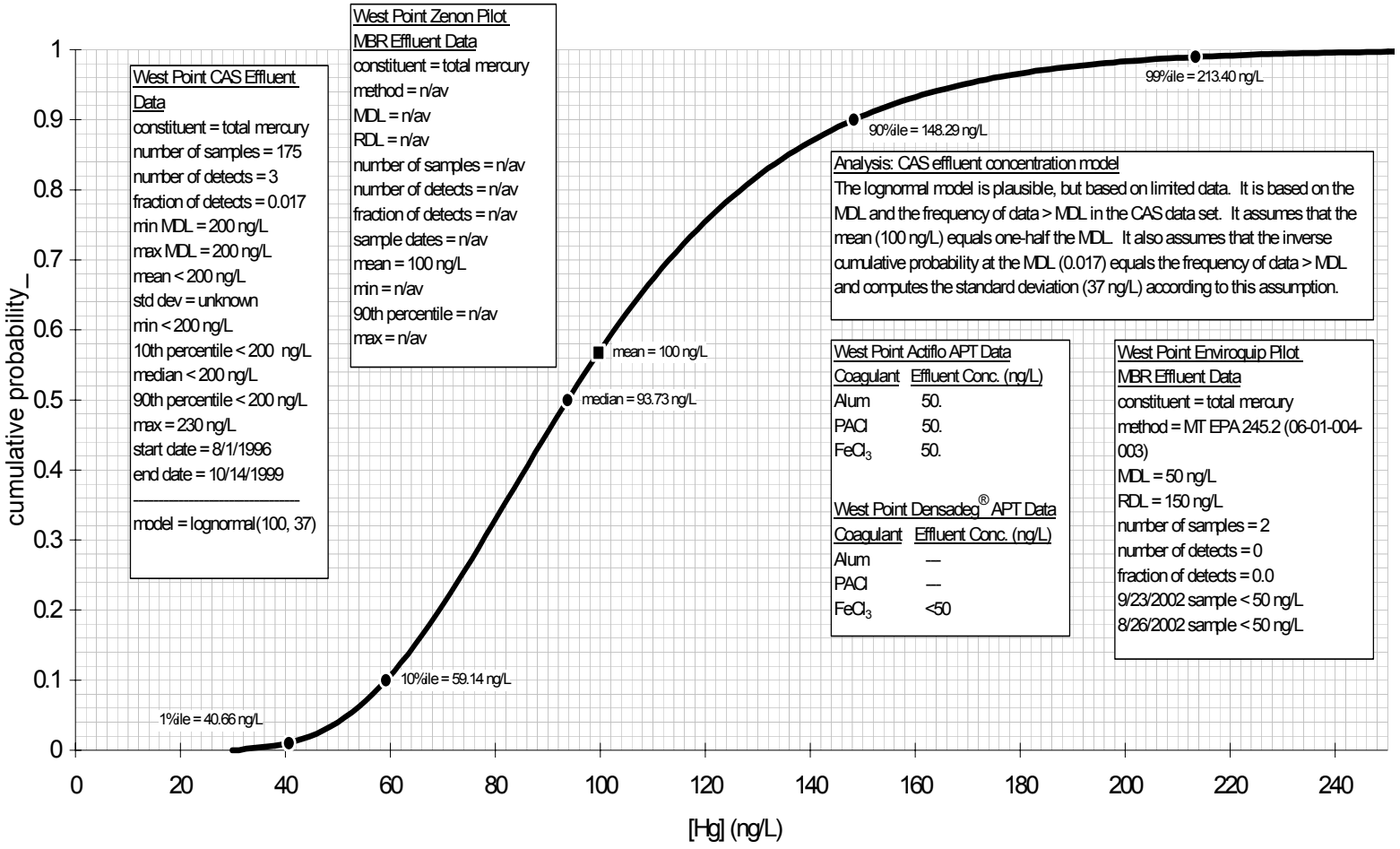

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Figure 6

Comparison of MBR Pilot Project Effluent Quality Data to West Point Secondary Effluent Quality, Mercury

BRIGHTWATER REGIONAL WASTEWATER TREATMENT SYSTEM

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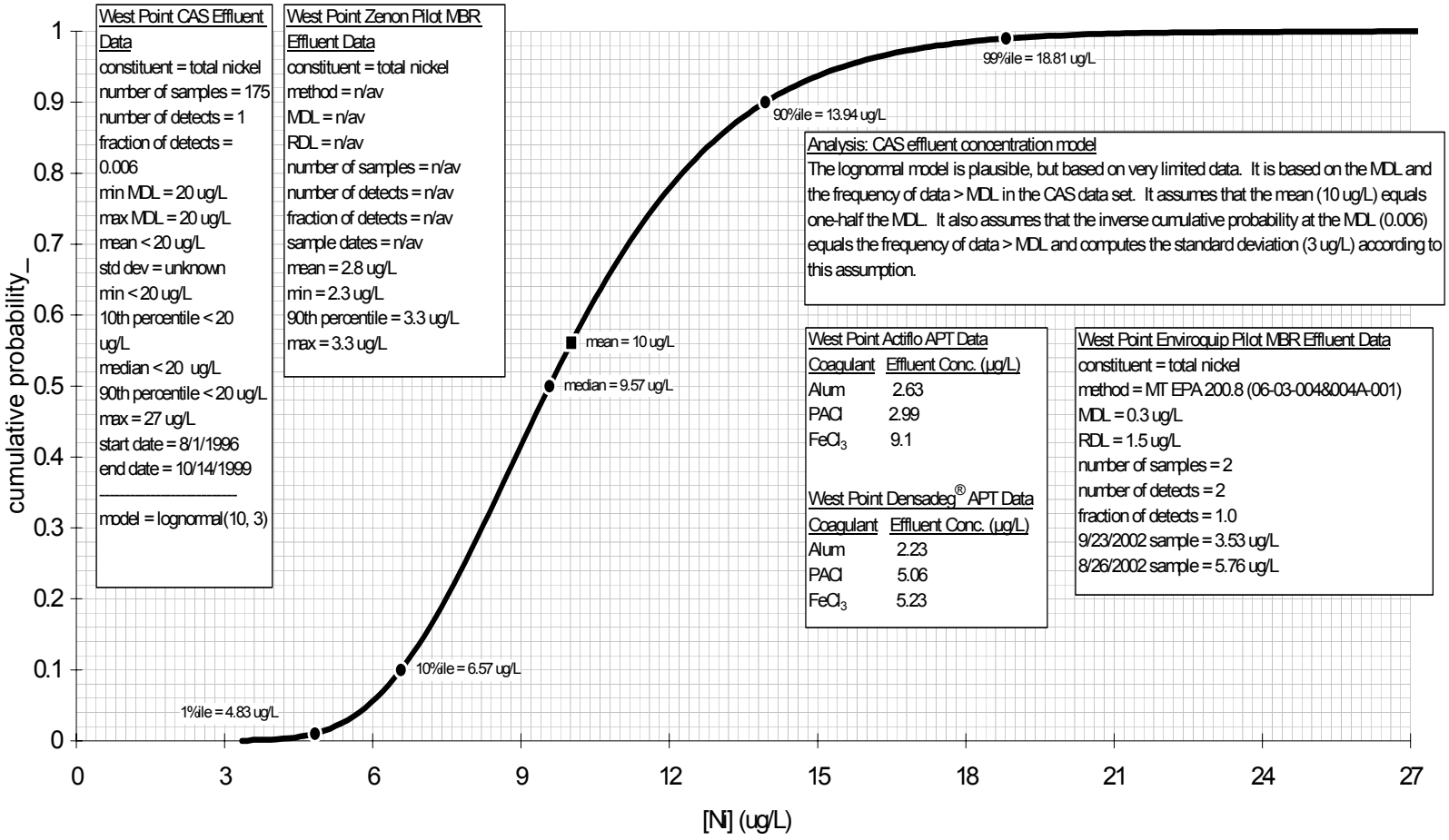

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Figure 7

Comparison of MBR Pilot Project Effluent Quality Data to West Point Secondary Effluent Quality, Nickel

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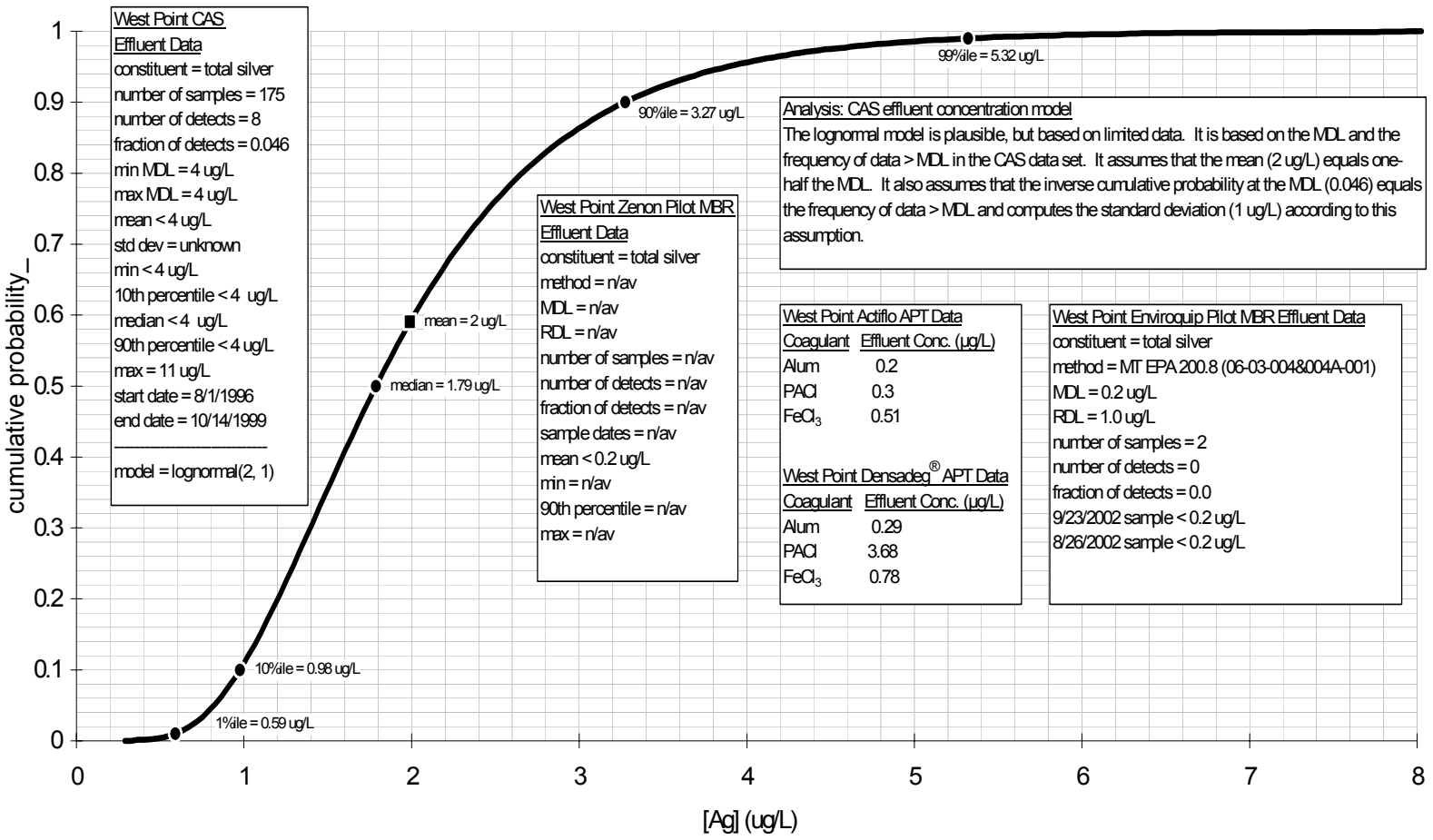

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Figure 8

Comparison of MBR Pilot Project Effluent Quality Data to West Point Secondary Effluent Quality, Silver

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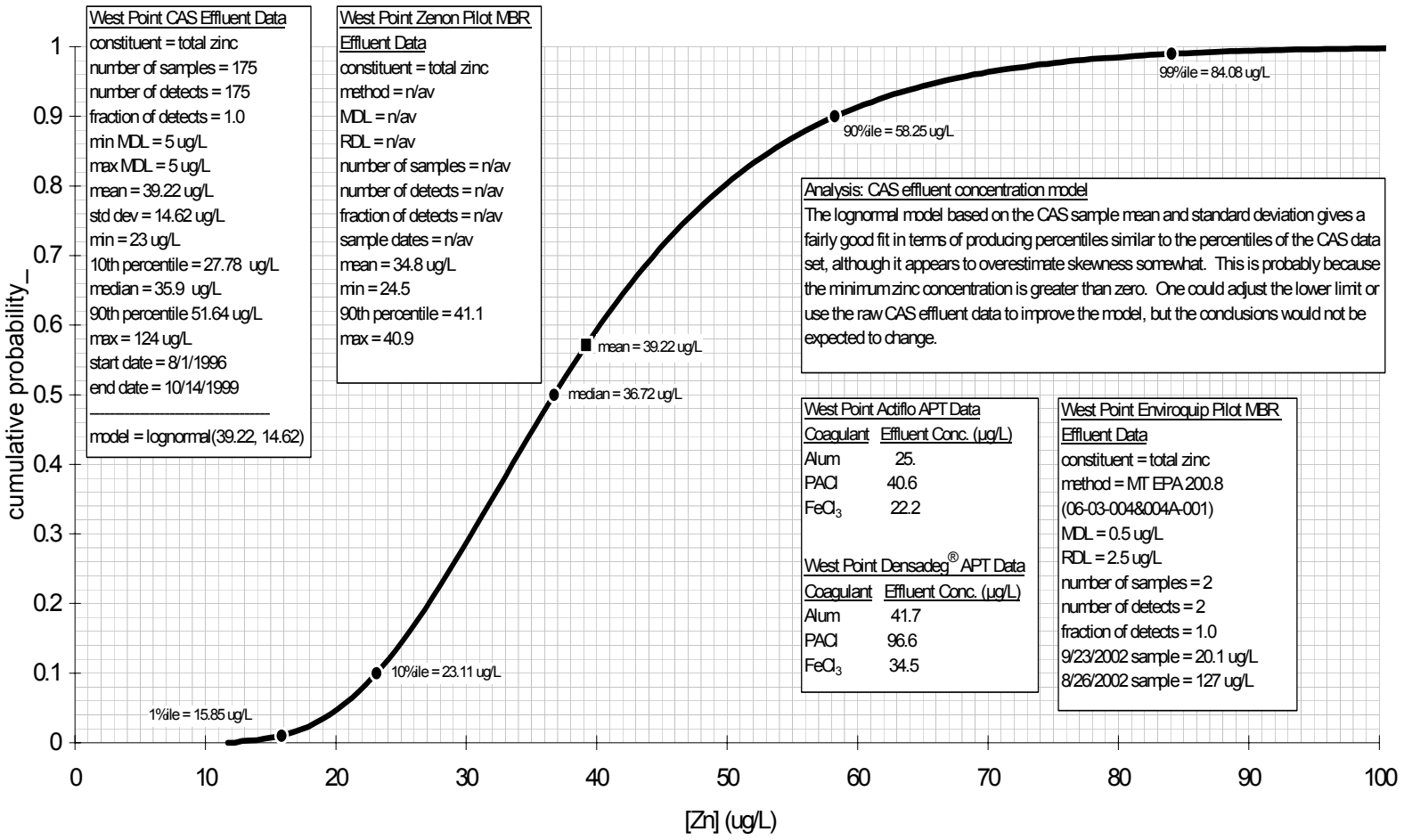

Figure 9

Comparison of MBR Pilot Project Effluent Quality Data to West Point Secondary Effluent Quality, Zinc

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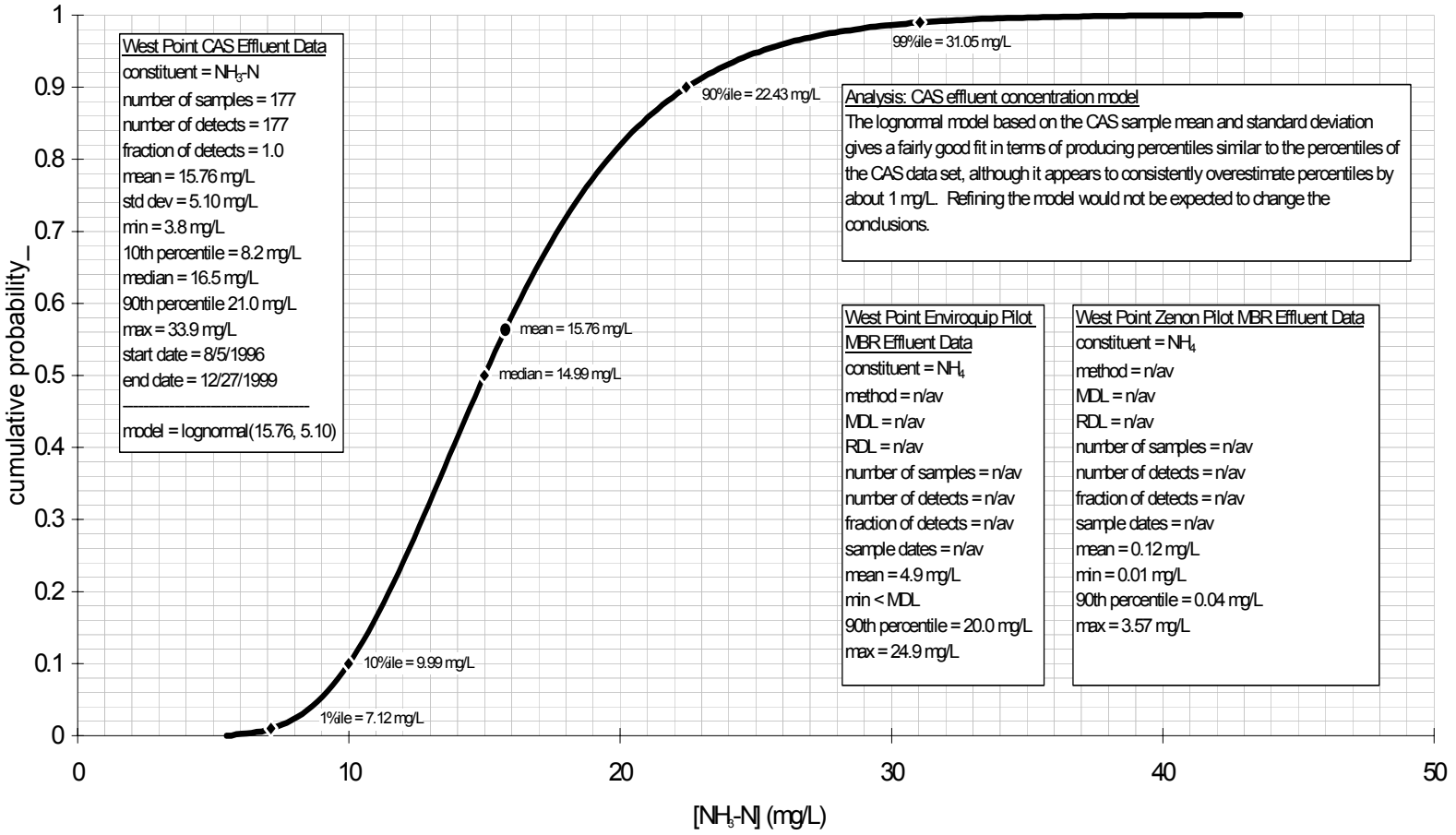

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Figure 10

Comparison of MBR Pilot Project Effluent Quality Data to West Point Secondary Effluent Quality, Ammonia-Nitrogen

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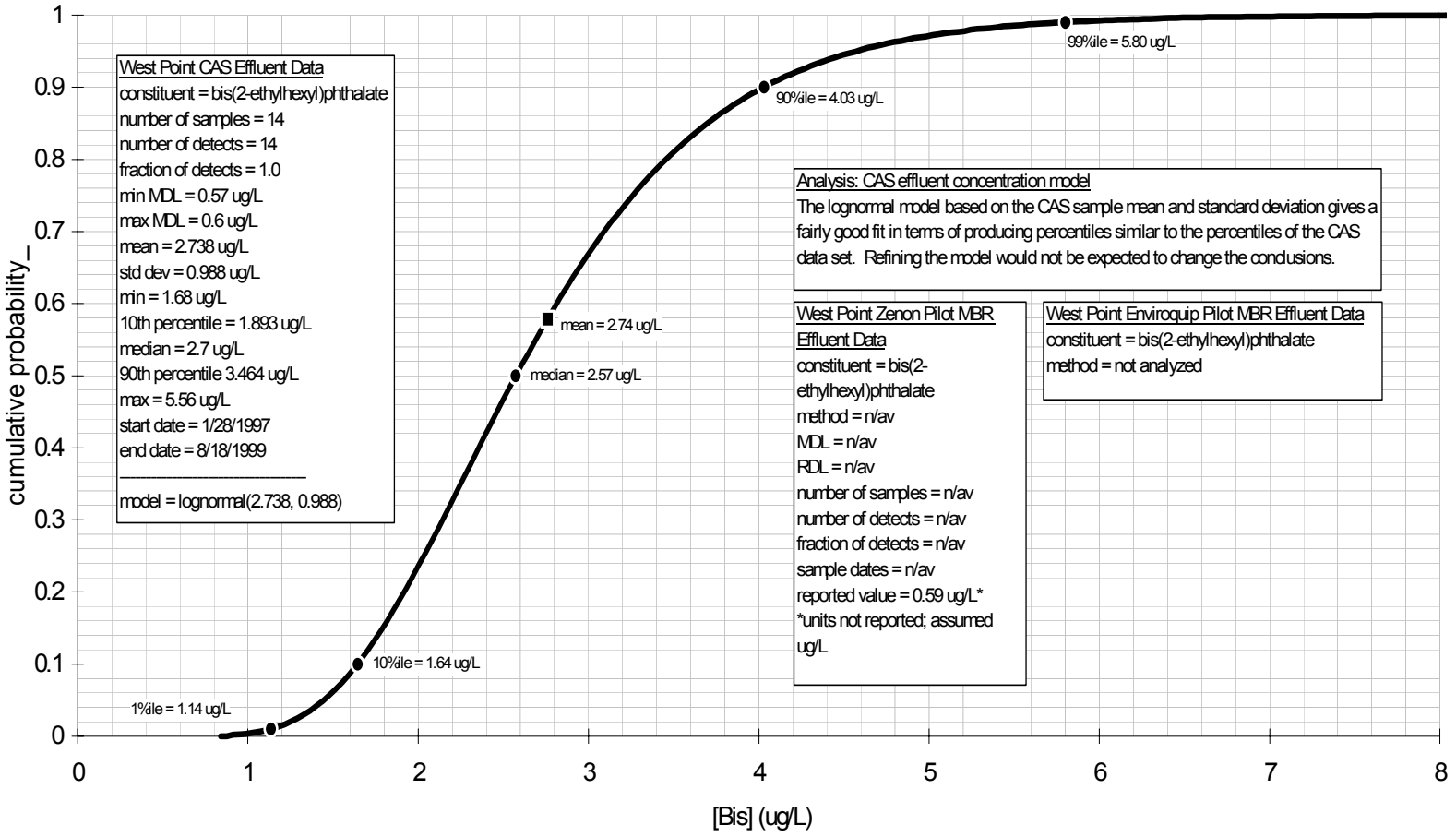

Figure 11

Comparison of MBR Pilot Project Effluent Quality Data to West Point Secondary Effluent Quality, Bis(2-Ethylhexyl)Phthalate

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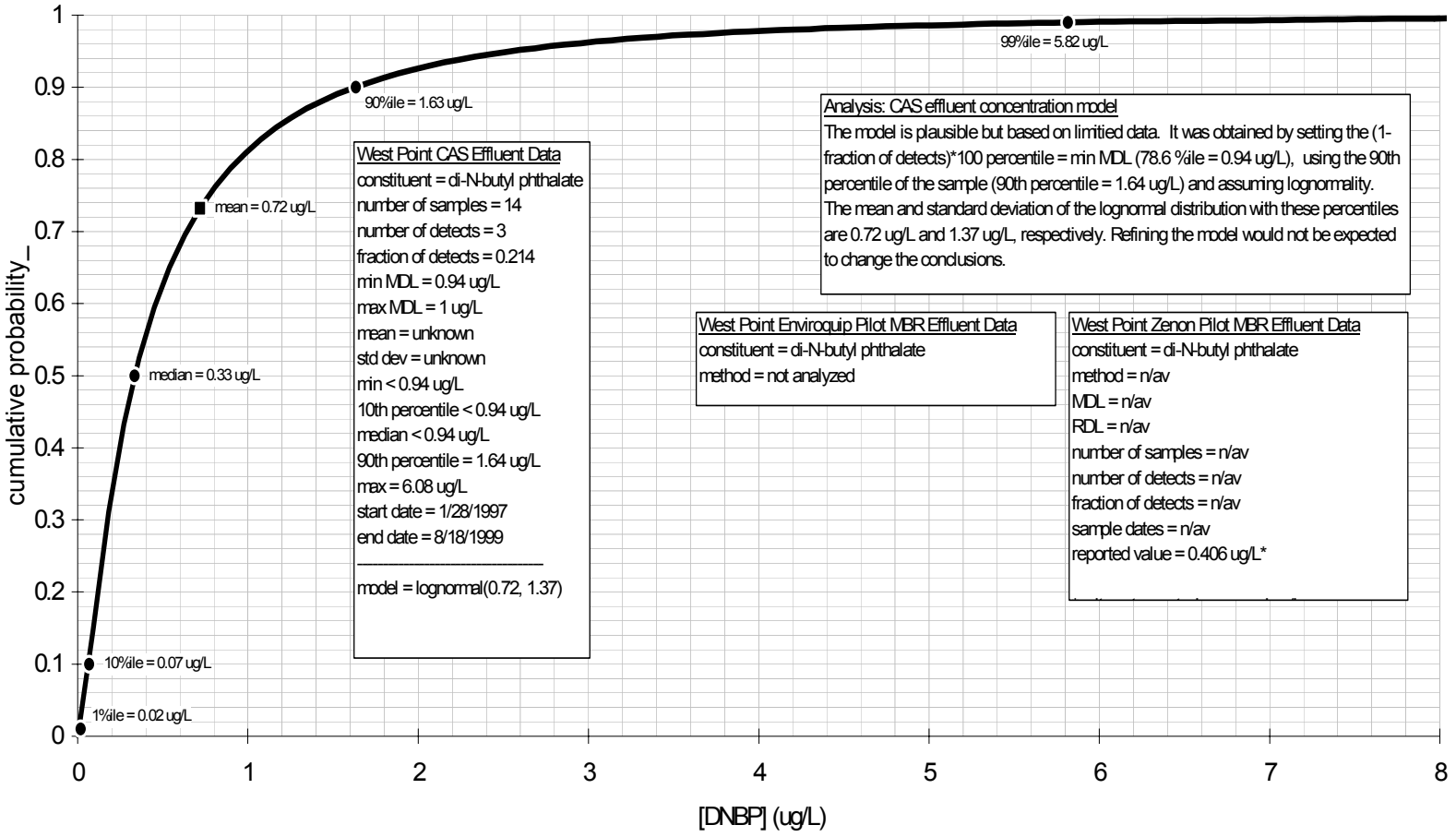

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Figure 12

Comparison of MBR Pilot Project Effluent Quality Data to West Point Secondary Effluent Quality, Di-N-Butyl Phthalate

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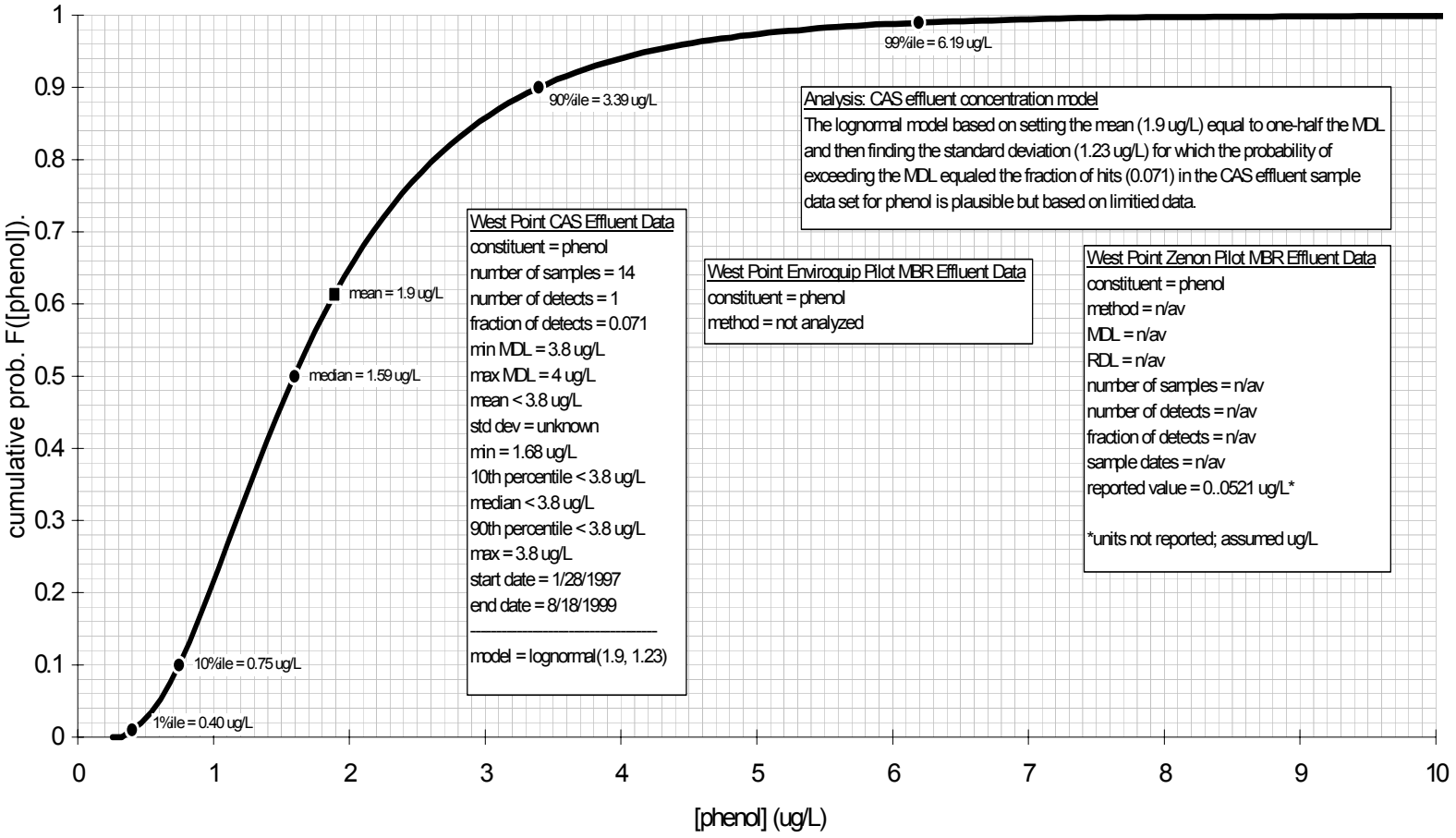

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Figure 13

Comparison of MBR Pilot Project Effluent Quality Data to West Point Secondary Effluent Quality, Phenol

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