CITY OF COOS BAY CITY COUNCIL
Agenda Staff Report

MEETING DATE	AGENDA ITEM NUMBER
April 26, 2016	

TO: Mayor Shoji and City Councilors

FROM: Jim Hossley, Public Works Director

THROUGH: Rodger Craddock, City Manager

ISSUE: Work Session to Discuss the Proposed Empire and North Spit Option for Wastewater

BACKGROUND:

To date the City of Coos Bay has spent approximately $3.8M on design for the proposed Wastewater Treatment Plant 2 project (Empire Option). On April 18, 2016 the City received an approval from the Department of Environmental Quality (DEQ) for the final plans and specifications for the Empire Option. Additionally, staff has been working with the DEQ and finalized a Clean Water State Revolving Fund (SRF) loan agreement for the construction of Plant 2 at a rate of 1%.

At the April 5, 2016 Council meeting it was voted 3-2 to not accept the SRF loan. Council requested a work session to discuss this issue further. At this work session there will be experts related to wastewater treatment and membrane technology along with DEQ Staff. Staff has also compiled information related to the history of the Plant 2 project, the alternatives that were analyzed, explanation of Membrane Bioreactor and Sequencing Batch Reactor (SBR) treatments, funding options, equivalent dwelling unit (EDU) cost comparisons, life cycle cost information, DEQ information, groundwater injection information, and Empire Option and North Spit Option comparisons.

Attachment
Work Session Information Related to the Proposed Empire Option and North Spit Option for Wastewater, dated April 22, 2016

Work Session Information Related to the Proposed Empire Option and North Spit Option for Wastewater

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April 22, 2016

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ACRONYM LIST

BHSD	Bunker Hill Sanitary District
CIP	Capital Improvement Project
CMGC	Construction Manager and General Contractor
CSD	Charleston Sanitary District
DBWT	DB Western Texas
DEQ	Department of Environmental Quality
EDU	Equivalent Dwelling Unit
EPA	Environmental Protection Agency
FPA	Facility Plan Amendment
HP	Horse Power
IFA	Infrastructure Finance Authority
I/I	Inflow and Infiltration
NPDES	National Pollutant Discharge Elimination System
O&M	Operation and Maintenance
SBR	Sequencing Batch Reactor
SRF	State Revolving Fund
STA	Short Term Assets
UGB	Urban Growth Boundary
UV	Ultraviolet
VA	Value Analysis
VE	Value Engineering
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

The City of Coos Bay has been working towards updating the Empire Wastewater Treatment Plant Number 2 (WWTP2) since 2003 when they entered into a Mutual Agreement Order with the Department of Environmental Quality (DEQ). On April 18, 2016, the City received approval of the final plans and specifications for the proposed WWTP 2 Empire Option project. The plant is being relocated, approximately one block east from its current location, to the north east corner of Fulton Avenue and Empire Boulevard. The approved plans proposed a Sequencing Batch Reactor (SBR) for wastewater treatment and Ultraviolet (UV) disinfection. In addition, the City has qualified for a DEQ Clean Water State Revolving Fund (SRF) loan with an interest rate of 1% if they perform $2M of stormwater projects (also at a loan rate of 1%).

Several steps and analyses had to be completed and approved prior to DEQ's final approval. After the MAO was negotiated a Facility Plan was prepared. Then alternatives were analyzed, one of which was relocating the plant on the North Spit. Alternative methods of treatment were also analyzed, including Membrane Filtration. In total, nearly 20 alternatives were analyzed and vetted. In addition, the City completed a value analysis and value engineering for the Facility Plan/Facility Plan Amendment and the Predesign Report (30% Design), respectively. This "value" process brought in a group of engineers and wastewater experts, that were not currently on the design team and went through the documents, proposed alternatives, and verified that the course that that the City was taking was in the best interest of the City (SBR treatment and UV disinfection on the proposed site in Empire). Once the value process was completed, final design was performed and the City obtained state and federal environmental approvals. In total, this process took 13 years.

As of late, a company named DB Western Texas (DBWT), Oregon based company, has made a proposal to the City to construct a Membrane Filtration plant on the North Spit. This proposal does not have environmental approval, stakeholder's approval, land acquired, approved DEQ plans, or funding. This option has already been analyzed by the City and the Port of Coos Bay. All of the reports stated the same finding: A facility on the North Spit is not economically feasible.

DBWT has provided construction and lifecycle costs. Based on the information that they have provided, if the City wishes to move forward with the North Spit Option, it will cost the rate payers significantly more money per equivalent dwelling unit (EDU). In addition, the rate payers will still have costs for the City's collection system (the North Spit option does not include maintaining and operating the City's infrastructure).

While there is no questions that a Membrane Filtration plant will produce a higher quality of treated effluent than an SBR plant (please note that both plants are proposing UV disinfection), the simple truth is that Membrane Filtration is not required by DEQ (at this time) and is expensive. The City has been approved for a low interest loan for the Empire Option project. If this or any other project had to be funded privately it will cost additional money. If the Empire Option project was privately funded it would cost up to an additional $9M in interest.

The following information has been provided to allow Council to make an informed decision regarding the City's future wastewater path. Information has been provided that explains the project's history, the alternatives that are analyzed, explanation of what Membrane Filtration and SBR treatment is, funding options, EDU cost comparisons, life cycle cost information, DEQ information, and Empire Option and North Spit Option comparisons.

I. EMPIRE OPTION TIME LINE

The Oregon Department of Environmental Quality (DEQ) has a required course of action for communities to follow when doing planning and design for wastewater treatment facilities if they want to qualify for grants and loans from DEQ. The course of action involves three major efforts: Facility Plan, Pre-design Report and Final Design Plans. Each of these major efforts has particular actions, criteria and information the community must complete and or provide.

2004 - The City of Coos Bay contracted with West Yost and Associates who started preparation of a Facility Plan for Wastewater Treatment Plant 2 (WWTP 2).

2008 – The Facility Plan is approved by DEQ. The City hired a financial consultant (Steve Donovan) to prepare rate and cost of service study to ensure City's wastewater fees/rates are adequate to pay for capital improvements needed for WWTP2 and other waste water infrastructure.

2009 – Pre-design report preparation starts by Civil West. During the Pre-design we learned that the selected alternative identified in the Facility Plan, and approved by DEQ, will not work on the property we had available.

2010 – Council authorized funding to perform a Feasibility Study to determine if relocation of WWTP2 operations to the North Spit was a viable alternative. The report was prepared by the design team of SHN and Civil West. Other options were also explored that included, pumping all the waste to WWTP 1, and expanding the current WWTP2 site into property located east of South Empire Boulevard. After evaluating other alternatives, our consultants determined that moving the current WWTP2 to larger nearby property would be the best option (Empire Option).

As these alternatives and the best option had not been fully vetted by the Facility Plan process and approved by DEQ, DEQ required that the City complete a Facility Plan Amendment (FPA) to include evaluation of the alternatives and best option.

2011 – The City contracted with a Civil West to prepare the FPA. Within this FPA, the City investigated several alternatives related to influent facilities, treatment, and disinfection.

The City, per the direction of DEQ, performed a value analysis (VA) of the FPA by a third party consultant. The VA was performed to confirm if the recommendation of the FPA was the correct path forward for the City. The third party consultant was CH2M (at the time that this analysis was performed they were not part of the design team). In addition to CH2M, City Staff, Charleston Sanitary District representatives, and a DEQ representative also contributed to the VA. The VA confirmed the most cost effective solution for the City was a Sequencing Batch Reactor (SBR) with Ultraviolet (UV) disinfection.

2012 - After the VA, the FPA was finalized. A Request for Qualifications (RFQ) for the design of the proposed Plant 2 (Empire Option) was advertised. A contract was awarded to SHN/CH2M Hill to complete a preliminary design report for WWTP2.

2013 – Preliminary design report is completed to 90%.

2013 - The City Council approved the construction manager and general construction (CMGC) delivery method for construction of the WWTP2. Mortenson Construction was selected to perform the CMGC services

2013 – Performed VE. The VE is a requirement if the project is to qualify for the DEQ Clean Water State Revolving Fund program. The VE is a process to be performed at the end of pre-design and before final design to ensure that the path forward is the best path for a jurisdiction and to potentially flush out any fatal flaws. A RFQ was advertised for a third party VE and Robinson Stafford and Rude was selected. The VE consisted of 12 wastewater engineers from Robertson Stafford and Rude, City Staff, the CMGC contractor, Charleston Sanitary District, and a representative from DEQ. The VE analyzed many options (see Section II) and concluded that the most cost effective solution for the City was a Sequencing Batch Reactor (SBR) with Ultraviolet (UV) disinfection.

2013 - State Revolving Fund (administered by DEQ) loan application submitted to DEQ.

2014 – Completed pre-design.

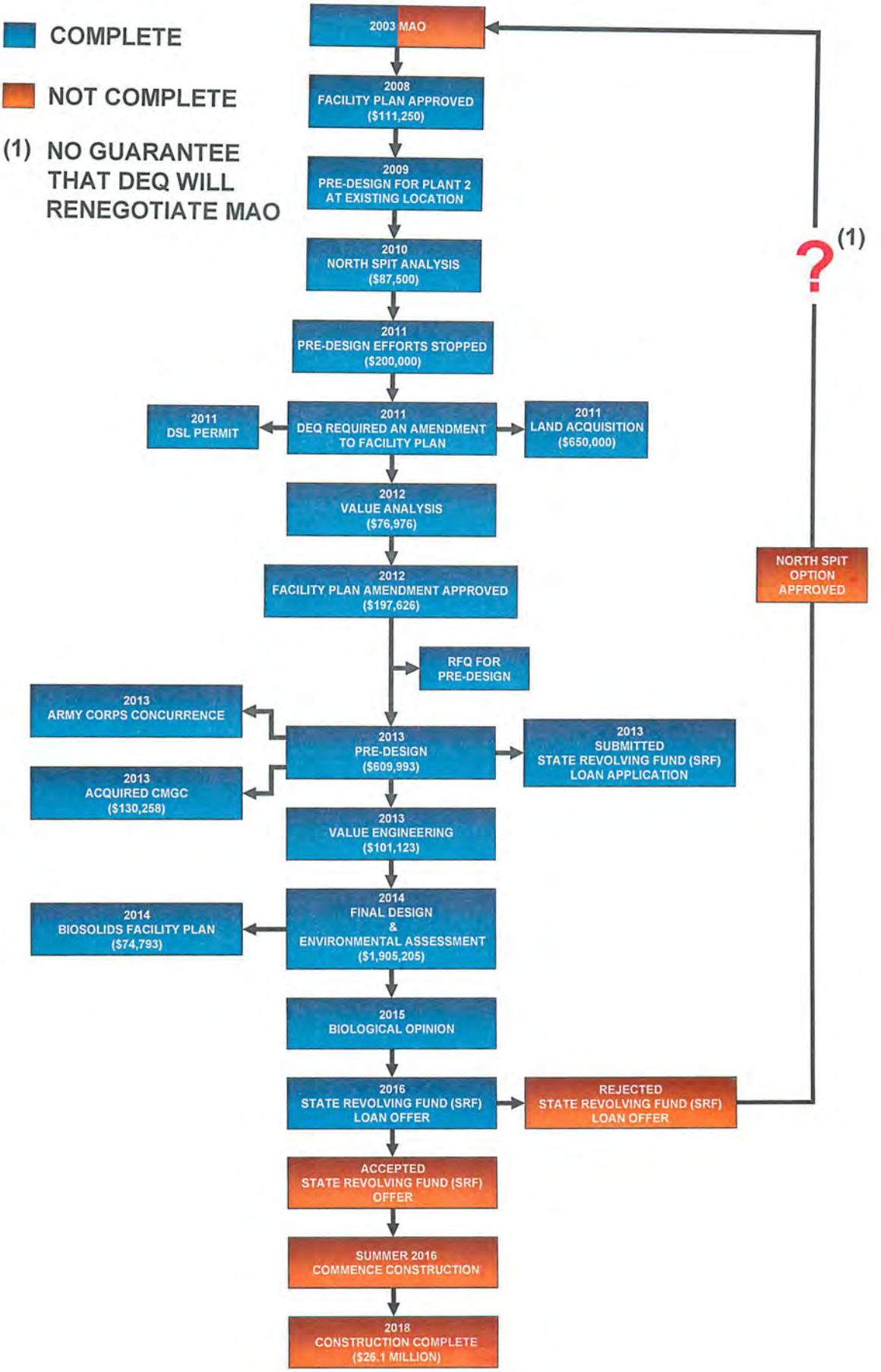
2014 - The final design of WWTP2 was started (SHN/CH2M) and completed.

2014 - Environmental permit application submitted to US EPA.

2015 – Received guaranteed maximum price from the CMGC in March. Received Environmental approvals in December.

2016 – Received approval of Final Design Plans and Specifications in April from DEQ.

HISTORIC & FUTURE PATH FOR WWTP 2



II. ALTERNATIVES ANALYZED

Using engineering consultant's specializing in municipal wastewater treatment, the City evaluated nearly twenty (20) alternatives for the upgrade of WWTP2. The consultants evaluated the various alternatives in preparation of the Facility Plan for WWTP2 (October 2007), the North Spit Analysis (2010), preparation of Facility Plan Amendment (FPA) for WWTP2 (November 2012), and in performing the Value Analysis prepared in October 2012. All of these alternatives were reviewed by the senior Oregon DEQ Wastewater Engineer. The evaluated alternatives included Membrane Bioreactor (MBR) technologies among many others (D.B. Western Texas' latest North Spit proposal uses the MBR technology). The estimated construction cost, operation & maintenance cost, and life cycle cost for MBR technologies were higher than some of the other technologies. The preferred and recommended alternative is a Sequencing Batch Reactor (SBR). This technology was selected as it provides necessary performance to meet water quality standards, has a lesser adverse impact to rate payers, and if necessary, can be easily modified to accommodate MBR technology should new water quality standards dictate the need at a later date.

Following is a description of the alternatives that were included in these documents:

Activated Sludge, Conventional -A conventional activated sludge plant will require numerous separate clarifiers, aeration vessels, and other facilities to treat wastewater in Coos Bay.

Oxidation Ditch -The oxidation ditch requires significant concrete structures in the multi-ring system along with two large clarifiers following the process. It is a proven and effective technology.

Sequencing Batch Reaction (SBR) - A traditional SBR, operating in a true batch operation and the ICEAS process (allows for constant flow during operation of the SBR process) offer viable treatment alternatives for the City of Coos Bay. An SBR allows for a compact footprint with efficient operating costs due to the use of fine bubble aeration. Because of the small footprint, concrete costs and other construction costs may be lower than other similar alternatives.

Packaged Activated Sludge Process -The packaged activated sludge process is a process making use of common wall construction and compact basins to reduce overall plant footprint and construction costs. The system has the ability to utilize long-life and low maintenance coarse bubble diffusers or more efficient (in terms of energy cost) fine bubble diffusers though maintenance and replacement issues must be considered for the fine bubble option. The packaged activated sludge treatment process includes aeration vessels, clarifiers, and digesters all in one tank.

Membrane Bio Reactor (MBR) -The MBR process, while perfect for smaller installations such as golf courses, casinos, and resorts, does not stack up well on small municipal projects where **I&I** and peak hydraulic capacity issues are paramount. While the MBR system can provide unparalleled effluent quality, the costs of providing capacity and redundancy in these systems simply make them impractical for this project.

MBR + ACTIFLO- The MBR process does produce a high quality effluent, but is not cost effective for a municipal system with large seasonal flow variations. The MBR/microsand combination takes advantage of the MBR benefits for summer flows and provides a more cost effective treatment method for high winter flows.

Packaged Fine Bubble Aerated Lagoon- Due to site restrictions, a conventional lagoon is not an option for the City of Coos Bay. Even the aerated lagoon system utilizing fine bubble aeration and clarification is not a viable option for the City of Coos Bay because of site constraints. The fine bubble aerated lagoon process is proving itself to be a cost effective alternative to SBR's, Ditches, and other mechanical treatment processes, when land is available.

IFAS +Bypass, on Existing Site, Value Analysis Option 2- The IFAS process can produce a good quality effluent, but is not cost effective for a system with large seasonal flow variations. To minimize the size of the IFAS, the VA report proposed a wet-weather, peak event bypass of flows exceeding the design flow. The bypass would convey excess flows from the primary clarifier to the secondary clarifier for secondary treatment. This alternative would also use existing tanks on the existing treatment plant site to reduce the cost of the project. Concerns remain about the hydraulic grade resulting from converting the existing secondary clarifiers to primary clarifiers. Additionally, maintaining continuous operation of the existing treatment plant throughout construction may not be feasible with this alternative.

MBR +Chemically Enhanced Primary Treatment Bypass, on Existing Site, Value Analysis Option 1 -The MBR process produces the highest quality effluent of the alternatives considered. However, the membrane filter is not cost effective for a municipal system with high seasonal flow variations. The bypass from chemically-enhanced primary clarifiers may not meet the EPA guidelines, as outlined in the EPA policy 68 Fed. Reg 63,042 (Nov. 7, 2003) and 40 CFR 122.41(m). In order to meet the EPA requirements and policy statement, the plant would need to go through an extensive 'no feasible alternative' analysis now and every NPDES permit renewal cycle. Further, hydraulic gradient concerns and constructability issues remain.

North Spit Option - During preliminary alternative investigations in 2010, the City of Coos Bay expressed an interest in utilizing the existing lagoon facility located on the north spit, across the bay and northwest of the existing treatment plant. In order to make use of this facility, the wastewater would have to be pumped under the bay and along the north spit access road to the lagoon site.

At the request of the City, Civil West and SHN teamed to prepare a study to investigate the design options and costs associated with the north spit treatment option. It was determined that the most feasible design would include an 18" High Density Poly Ethylene (HDPE) force main bored beneath the bay from the existing treatment plant to a point on the north spit near the retired salmon hatchery. From that point, 18" HDPE would be installed in an open trench along the north spit road to the treatment lagoon. To transmit the wastewater to the lagoon, a relatively large pump station at, or near, the existing treatment plant site would be required.

New headworks would be required similar to what would be required for treatment at the existing WWTP site. Two small primary cells would be created outside the footprint of the existing lagoon to treat the wastewater prior to introduction into the existing lagoon. The existing lagoon would be modified to include baffling to create an aerated partial mix/facultative

system. Disinfection requirements would also be similar to those evaluated for other treatment alternatives.

The existing lagoon has an ocean outfall which would be used to discharge the treated effluent into the Pacific Ocean. The outfall is thought to be in serviceable condition but would likely require a new diffuser. The system would also need a new effluent pump station.

Based on preliminary cost estimates, the improvement requirements to make use of the north spit lagoon were estimated to be over $18 million. This cost does not include any land acquisition or legal costs associated with the project. There are also concerns regarding the legal aspects of the City operating a plant which is outside of the City limits and the Urban Growth Boundary.

There were discussions with the Port of Coos Bay, who currently owns the site, for the port to continue to own and also to operate the treatment plant and charge the City a fee. Early negotiations on this option indicated an unfavorable position for the City and discussions were not continued.

Based on high costs, relatively high risk, and unknown legal issues, this option will not be further developed as a viable option for the purposes of this report.

Combined Plant Option - A cursory review of the possibility of pumping wastewater from Treatment Plant #2 to Treatment Plant #1 was requested by the City of Coos Bay.

Transmitting the full amount of wastewater from Treatment Plant #2 would require a combination of a 30" force main and sections of 42" gravity main. The total length of new main line would be nearly six miles. Depending on the selected alignment, three or four pump stations would be required.

Costs for transmission of the wastewater alone quickly surpassed $30 million. In addition to the transmission costs, Plant #1 would have to be completely rebuilt to handle the additional flows. This option was found to be expensive and will not be discussed further.

Value Analysis (VA) - The Value Analysis (October 2012) was completed before finalization of the Facility Plan Amendment. The VA looked over a dozen alternatives. The next table is from the Value Analysis document and shows the estimated capital costs for the two alternatives.

Table 1: Capital Costs of Alternatives for Coos Bay WWTP No.2 (in $2012 Dollars)

	SBR	MBR
Project Cost (exclude contractor markups)	$11,517,000	$14,428,000
Construction Cost (include contractor markups)	$17,774,000	$21,874,000
Capital Cost (include contractor markups and non-construction cost)	$22,219,000	$27,344,000

The construction costs for the MBR plant were about 20% higher than those for the SBR plant. Operations and Maintenance (O&M) costs for the MBR plant were about 25% higher than the SBR plant. The analysis by the consultants, and confirmed by DEQ, was that the membrane alternative was not recommended due to the higher cost.

These costs were estimated in 2012 dollars. Escalating the SBR costs to 2018 dollars (estimated project completion date), the estimate would be $26.5 million, which is in line with the current costs for the Empire Option.

III. COMPARISON OF PRIVATE FUNDING AND DEQ FUNDING (ESTIMATED DEBT SERVICE)

The City's Financial Advisor, Jim Stricklin at Wedbush Securities Inc., advised that a full faith and credit direct bank placement wastewater loan for a term of 20 years is difficult, but could be done due to the City's high credit rating (a grade of A+ per the Standard and Poor's grading system). The City of Carlton, Oregon completed a 20 year bank placement in August of 2015 with two bidders at a rate of 3.77%. Mr. Stricklin advised that the current climate is similar to that time period and advised the City of Coos Bay might conservatively expect a range of rates from 3.25% to 4%. A 10 year direct bank placement can generally expect to receive five to eight bidders because financial institutions like shorter repayment periods.

The table below shows the private options at 3.25% and 4% and compares it to the current SRF loan provided by DEQ (at 1%) for the Plant 2 Empire Option. As you can see, a project that is funded by a private institution will cost the City's rate payers up to an additional $9.4M. This analysis was based on the CMGC's guaranteed maximum price of $26.1M.

Table 2: Comparison of a 20-YearTerm Loan for $26.1M

Interest Rate	Approx. Annual Payment	Total Payments	Original Loan Amount	Total Interest	Additional Interest Paid
1%	$1,446,340	$28,926,794	$26,100,000	$2,826,794	-
3.25%	$1,795,129	$35,902,577	$26,100,000	$9,802,577	$6,975,783
4%	$1,920,484	$38,409,674	$26,100,000	$12,309,674	$9,482,879

SRF Loan
Private Loan

IV. Equivalent Dwelling Unit (EDU) Cost Comparison

An Equivalent Dwelling Unit (EDU) helps planners figure out the total load on a water or sewer system. An EDU is calculated by taking the average of all the residential users and using it to represent a typical single family home. The average water use for a residence in Coos Bay is 440 hundred cubic feet (CCF) per month (this information was provided to the City by the Coos Bay North Bend Water Board), which gives an average monthly sewer bill of just under $50 based on current operating costs and loan payments. The City of Coos Bay, Charleston Sanitary District, and Bunker Hill Sanitary District have 9835, 2199, and 400 EDUS, of which approximately half of these are commercial and industrial. ***It is important to note that the calculated cost per EDU is not the sewer rate, but is used to calculate the sewer rate and will be close to the actual rate given that all of the capital construction projects have been financed and the loan repayment is underway.***

Coos Bay sewer rates consist of two parts, the costs to operate the collection system and the costs to run the treatment plants. The collection system only serves residents of the City and so all costs are paid only by City residents. The treatment system also serves Charleston Sanitary District and Bunker Hill Sanitary District, so their flow is monitored to the treatment plants and they pay their share of running the treatment plants. The data presented in the following table breaks the rates into collection and treatment costs per EDU so that you can see the impact on the average family home of the costs of the proposed improvements.

Please note that all costs for the North Spit option were obtained directly from the DBWT reports submitted on February 12, 2016 and December 2, 2015, in addition to the DBWT's website, advertisements and flyers. The DBWT reports stated that construction costs are $88 million, interest rates are 3.5%, the project life is 20 years, and the life cycle cost of the 20-year Operations and Maintenance costs are $100 million. Putting all these values into a life cycle cost table produced a rate for a regional plant (assuming North Bend and Jordan Cove participate) of just under $58 per month for treatment only, which is a bit less than the $65 that DBWT claims. The difference could be attributed to the assumption of EDUs by Jordan Cove or it could be DBWT's profit margin. The City requested a breakdown of the DBWT rate calculation, but was not provided any additional information by them.

The Option 2 analysis assumes that all participants pay a proportionate share of the construction costs. Note that the December 2, 2015 DBWT Figure 10 shows Jordan Cove paying $10 million and Coos Bay paying $78 million and getting reimbursed by North Bend in several years for $9 million. Coos Bay's net share of the costs would be $69 million. It should also be noted that neither Charleston Sanitary nor the Bunker Hill Sanitary districts have notified the City that they are supportive of this option and that they are willing to pay their proportionate share.

If North Bend and Jordan Cove do not join the project, the treatment cost jumps to just under $84 per month per EDU. Note that the DBWT rate cost is for treatment only and City residents would continue to pay the collection cost also. To date we don't have a single regional partner willing to sign on as a stakeholder (The City has talked with North Bend, Port, County, and Jordan Cove).

Costs for building the new WWTP2 were taken from the contractor's offer with engineering and construction management added in. Costs for upgrading WWTP1 were escalated for inflation from the facilities plan with biosolids improvements added and a contingency factor. Loan costs

were estimated at 1% based on the current SRF funding offer. Operations costs for WWTP2 were obtained from the CH2M predesign report and for WWTP1 from the City Budget. Short term asset

replacement costs are from the facilities plans and staff estimates. These costs were put into a life cycle cost table and produced a rate for treatment of $38.94. Again, collection system costs would be in addition to this rate.

The calculated the cost of the collection system was made using the current City Budget, the existing loan payments and the estimated cost of loan payments for completing the projects in the City Capital Improvement Plan. The collection system cost per EDU is estimated at $38.48 per EDU per month if the City accepts the SRF Sponsorship Option loan at 1%. If that loan is not accepted, the City would need to finance the culvert replacements using other funds at an estimated 2.9% interest rate, which would raise the collections system costs to $38.74, as reflected in the North Spit options.

Table3: Comparison of EDU Costs

	Participants		
	Coos Bay CSD/BHSD	**Coos Bay, North Bend Jordan Cove CSD/BHSD**	**Coos Bay CSD/BHSD**
Option Number	1	2	3
Location	North Spit Option	North Spit Option	WWTP1 & 2 (Empire Option)
Treatment Cost per Month per EDU	$83.83	$57.58	$38.94
Collection System Costs for Coos Bay Residents	$38.74	$38.74	$38.48
Treatment + Collection Costs for Coos Bay Residents	**$122.57**	**$96.31**	**$77.42**[(1)]

CSD = Charleston Sanitary District
BHSD = Bunker Hill Sanitary District

This table presents estimated costs per equivalent dwelling unit (EDU) for three options:

- Option 1 - Abandon the Empire Option and convey flows that are tributary to Plant 1 and Plant 2 to a regional membrane plant on the North Spit. This Option assumes that only Coos Bay, Charleston Sanitary District, and Bunker Hill Sanitary District will partner on this venture.
- Option 2 – Abandon the Empire Option and convey flows that are tributary to Plant 1 and Plant 2 to a regional membrane plant on the North Spit. This Option assumes that Coos Bay, Charleston Sanitary District, and Bunker Hill Sanitary District will partner with Jordan Cove and North Bend on this venture.
- Option 3 – Construct the Empire Option and perform a major upgrade to Plant 1.

(1) Note: EDU costs reflect operating costs and loan payments at completion of current planned wastewater projects which will occur over 2 to 20 years. The costs presented are not proposed sewer rates, but are the costs that would be used in a rate study to propose rates.

V. LIFE CYCLE COST INFORMATION

Both of the existing City wastewater plants are in need of upgrades. The City has a construction cost (guaranteed maximum price) from their Construction Manager and General Contractor (CMGC), Mortenson Construction, for Wastewater Treatment Plant No. 2 (WWTP2). Facility plans were completed and approved for WWTP1 by West Yost in 2011, for WWTP2 by West Yost in 2008, for biosolids by the Dyer Partnership in 2015. DBWT has provided a series of briefs on construction of a regional plant on the North Spit. Information from these sources was used to produce the table below, which is for costs for wastewater treatment only and does not include the collection system. A detailed description of the derivation of the totals is included below:

WWTP1

The West Yost Plan was based on 2008 construction costs, so these were escalated to an estimated start date of 2020, the biosolids improvements from the Dyer 2015 study were added and $3.8 million was added for making it through the regulatory planning and permit process. A 10% contingency and 15% contractor overhead and profit were added. Please note the contingency will become less after the regulatory process is complete. Operations and Maintenance (O&M) costs were obtained from the current City Budget for 2016 and escalated 2.7% per year based on the past 10-year trends. Short term asset (STA) replacement costs were developed by staff with assistance from OMI. STA replacement costs were broken down into an average required annual reserve cost and the Present Value was calculated based on 3% interest and a 20-year life cycle. O&M Present Value costs were calculated based on 3% interest and a 20-year life cycle.

WWTP2

Construction costs were taken directly from the Mortenson Construction guaranteed maximum price. The cost of Engineering & CM was based on the current design and Construction Management (CM) fee by CH2M with administrative costs and the resident Project Representative (RPR) cost added. O&M costs were obtained from a variety of sources, including the CH2M Predesign Report, the Dyer Biosolids Study, and calculations by Kerbo Engineering. The STA replacement costs were developed by Kerbo Engineering for USDA. O&M and STA Present Values were calculated in the same manner as those for WWTP1.

NORTH SPIT

Construction costs were taken from the DBWT February 12, 2016 summary report as was the Present Value of the O&M costs. No changes or calculations were made on these figures. It is assumed that the construction cost in the report includes all Engineering and Construction Management. It is assumed that the O&M present value cost includes all short term asset replacement costs.

Table 4: Life Cycle Cost Comparison

COSTS	WWTP1 (1)	WWTP2	CB SUBTOTAL	NORTH SPIT
CONSTRUCTION COST	$28,225,000	$25,121,555	$53,346,555	$88,000,000
ENGINEERING & CONSTRUCTION MANAGEMENT	$5,325,000	$5,150,000	$10,475,000	Assume included in Construction
SUBTOTAL CONSTRUCTION COSTS	$33,550,000	$30,271,555	$63,821,555	$88,000,000
ANNUAL O&M 20 YEAR PRESENT VALUE	$24,556,311	$13,978,329	$38,534,640	$100,000,000
SHORT TERM ASSETS - 20 YEAR PRESENT VALUE	$474,305	$312,636	$786,941	Assume included in O&M
TOTAL LIFE CYCLE COST	**$58,580,617**	**$44,625,520**	**$103,143,136**	**$188,000,000**

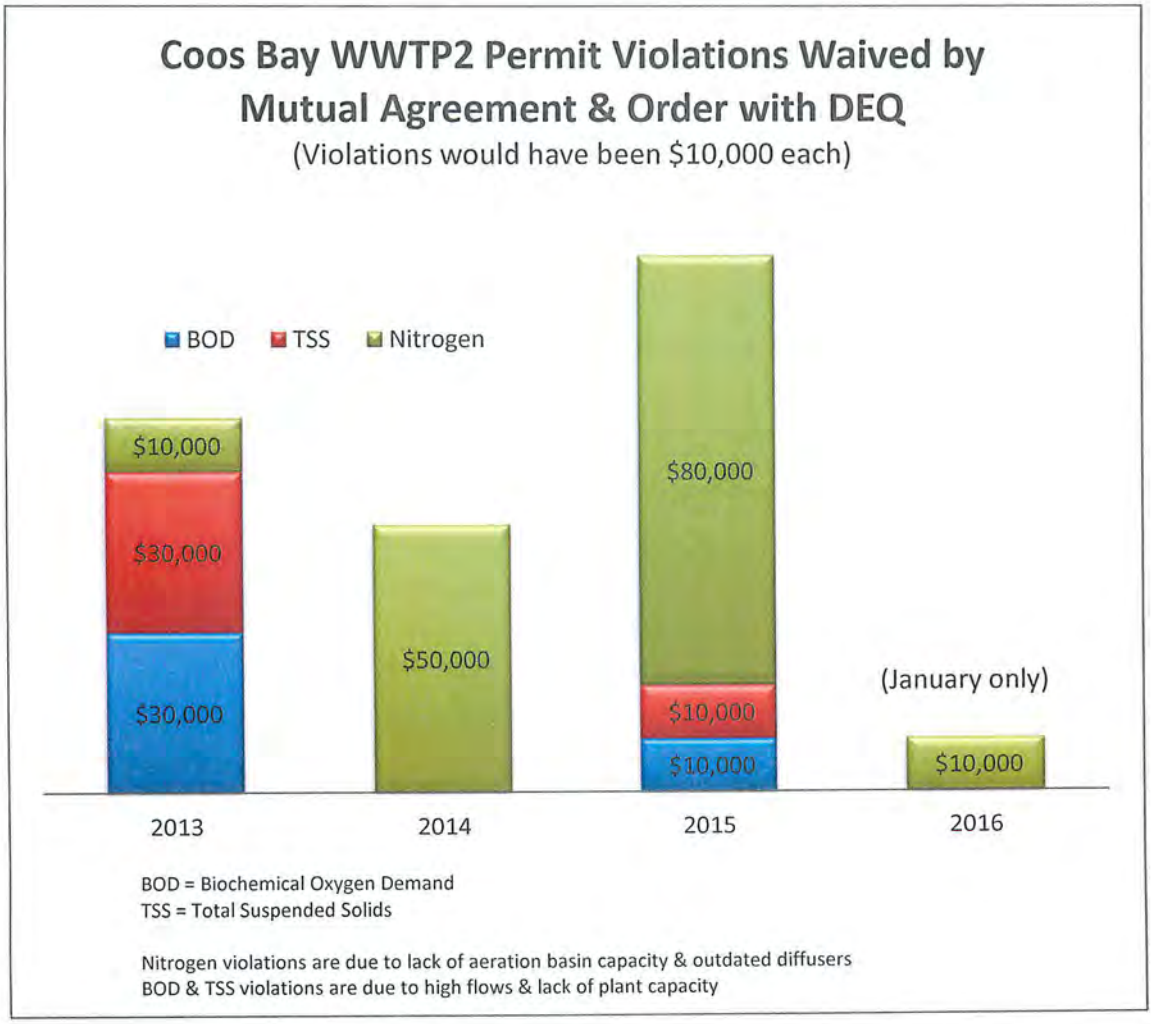
VI. ADDITIONAL INFORMATION

MAO COVERAGE

The City entered into an MAO (A copy of the MAO has been included in Attachment 7). with DEQ in 2003 to resolve violations of the National Pollutant Discharge Elimination System (NPDES) Permit for Plant 2. The MAO overrode permit limits and provided temporary effluent limits that the plant could meet while the City planned and constructed plant improvements. The City received several extensions of the MAO expiration deadline from DEQ only because DEQ observed that the City was moving forward with the planning for Plant 2.

The MAO allows 60 days to advertise bids for Plant 2 after approval by DEQ of the construction plans. That approval was received April 18, 2016, so to keep the MAO valid the City must advertise the Plant 2 project for bid no later than Friday, June 17, 2016.

If the MAO is revoked, the existing NPDES permit limits will take effect. The MAO was instated because the plant was unable to consistently meet the permit's effluent requirements. For each permit violation, the City may be fined $10,000/day/violation under the NPDES permit terms. Staff looked at the Discharge Monitoring Reports for the last three years and found an average of seven violations per year that the MAO overrode.



DEQ Information

DEQ is the regulating authority that oversees and enforces the City's National Pollutant Discharge Elimination (NPDES) permits for both plants. Staff has been working with DEQ throughout this entire process. Representatives from DEQ have consistently stated that the course of action that the City has taken with respect to proposing a new treatment plant in Empire is the appropriate course of action.

Staff asked DEQ to respond to questions that might help Council make their decision regarding the path forward for wastewater. The questions ranged from the status of the approved Empire Option final design plans to Membrane Filtration to infiltrating effluent to MAO and NPDES permits to SRF funding to other options. DEQ has submitted responses to these questions and provided them via email. A copy of the email is in Attachment 4.

Groundwater Injection

In the latest proposal from DBWT, they are proposing to inject treated effluent (Membrane Filtration) to recharge the groundwater on the North Spit. A memorandum was provided to the City (See Attachment 5) by GSI Water Solution Inc., who is a third party consultant that specializes in this type of work. This memorandum provides a summary of the basic permitting and technical considerations for using recycled wastewater to recharge groundwater in Oregon. However, in a conversation with Jon Gasik of DEQ, he stated that all groundwater in the state of Oregon is considered drinking water. As such, per the OAR 340-044-0015 (see Attachment 5) activities, which include the injection of treated wastewater into groundwater, is prohibited.

VII. Staff Recommendation

Understanding that there is a great deal of information associated with this topic and that this is a major decision that will be made by Council, staff would like to propose a recommendation. This Empire Option has been vetted and approved through the many necessary steps required for a design of this magnitude (along with the steps required for the DEQ funding). The Empire option is the most economically feasible and meets today's regulatory requirements. It is staff's recommendation to accept the SRF loan, bid the project, and construct the Empire Option.

Attachment 1

Backup for EDU Cost Comparison

TABLE 2: RATES ANALYSIS FOR WASTEWATER TREATMENT OPTIONS

Comparison of Upgrading VS. Moving to North Spit

Coos Bay Only		WWTP1 & WWTP2		North Spit
Construction Costs	1	$ 61,401,555	A	$ 88,000,000
Annual Operations &Maintenance	2	$ 2,113,354	B	$ 6,525,797
Short Term Asset Replacement	3	$ 84,275	C	
Estimated CIP Loan Payment	4	$ 3,613,054	D	$ 5,982,391
Total Annual Cost	5	$ 5,810,682	E	$ 12,508,188
Total EDUs	6	$ 12,434	F	$ 12,434
Treatment Cost per EDU	7	$ 38.94	G	$ 83.83
Collection System Cost per EDU	8	$ 38.48	8	$38.74
Total Cost for Coos Bay per Month/EDU	9	$ 77.42	9	$ 122.57

Comparison of Upgrading VS. Moving to North Spit with Partners

Coos Bay, North Bend & Jordan Cove		WWTP1 & WWTP2		North Spit
Construction Costs	1	$ 61,401,555	A	$ 88,000,000
Annual Operations &Maintenance	2	$ 2,113,354	B	$ 6,525,797
Short Term Asset Replacement	3	$ 84,275	C	$ -
Estimated CIP Loan Payment	4	$ 3,613,054	D	$ 5,982,391
Total Annual Cost	5	$ 5,810,682	E	$ 12,508,188
Total EDUs	6	$ 12,434	H	$ 18,104
Treatment Cost per EDU	7	$ 38.94	I	$ 57.58
Collection System Cost per EDU	8	$ 38.48	8	$ 38.74
Total Cost for Coos Bay per Month/EDU	9	$ 77.42	9	$ 96.31

Source of numbers:

A North Spit construction cost from DBWT 2/12/16 Cost Comparison

1 WWTP1 cost from draft Facilities Plan. WWTP2 cost from Mortenson construction cost

B North Spit O&M cost from DBWT 2/12/16 Cost Comparison converted into annual cost at 3%

2 WWTP1 & WWTP2 O&M costs from Facilities Plans with escalation to 2018

C North Spit Short Term Asset Replacement - no info available, may be in O&M costs

3 WWTP1 & WWTP2 Short Term Asset Replacement Costs by staff

D North Spit Estimated CIP Loan Payment calculated based on capital cost and interest from

4 WWTP1 & WWPT2 Estimated CIP Loan Payment based on rates in current SRF loan offer

E Sum of B-D Above

5 Sum of 2-4 Above

F Total Coos Bay, CSD & Bunker Hill equivalent dwelling units from facilities plans

6 Total Coos Bay, CSD & Bunker Hill equivalent dwelling units from facilities plans

G Total annual cost divided by EDUs divided by 12 to calculate cost per home per month

7 Total annual cost divided by EDUs divided by 12 to calculate cost per home per month

H EDUs from "F" plus estimated North Bend EDUs from Bob Dillard plus 2,000 people/2.3 for LNG

I Total annual cost divided by EDUs divided by H to calculate cost per home per month

8 Monthly sewer rate from Table A.

9 Sum of the two lines above

TABLE 3: SUMMARY OF COOS BAY WASTEWATER COLLECTION SYSTEM ANNUAL COSTS

Table A: Calculation of Collection System Costs

Debt Service IFA Loan 1	$146,221	From Table B
Debt Service IFA Loan 2	$193,896	From Table B
CIP 20-year Plan Loan Cost	$ 2,399,604	Table B - Based on 20-year 3% Loan
Collections Operations Cost	$ 997,641	From 2016 Budget
Stormwater Operations	$ 550,033	From 2016 Budget
Stormwater 2017 Construction Project	$ 98,906	From Table B
Annual Short Term Asset Costs	$ 76,124	From Table C
Administrative Costs	$ 79,119	1/3 of Wastewater Admin Budget
Total	**$4,541,543**	
EDUs (Coos Bay only)	9,835	From Facilities Plan
Monthly cost per EDU	**$38.48**	
Monthly cost per EDU W/O SRF	$38.74	

Table B: Existing and Anticipated Loan Costs for Capital Collection Improvements

Capital Project Amortization & Loans	Total	Payment
IFA Loan 1	$ 3,075,085	($146,221)
IFA Loan 2	$ 3,886,275	($193,896)
SRF Sponsorship Stormwater Project	$ 2,200,000	($98,906)
Above Stormwater Project without SRF	$ 2,200,000	($128,969)
Collection	$36,771,043	($2,399,604)

Table C: Short Term Asset Replacement Cost Calculation

Total Quant	Short term assets	Life years	Cost	Quant	Annual Cost
9	Pumps 0-10hp	10	20000	9	18000
3	Pumps 12-15 hp	15	30000	2	4000
6	Pumps 15-30 hp	15	40000	7	18667
2	Large pumps	15	75000	3	15000
8	Small genset major service	5	2500	8	4000
6	Large Genset major service	5	3000	6	3600
	Genset replacement	15	30000	2	4000
17	Building repaint	7	2000	17	4857
23	Electrical control panels	10	5000	8	4000
	Recommended Short term Asset Budget				**$ 76,124**

Note: The following information was a figure from the DBWT's December 2, 2015 proposal regarding the proposed Regional Plant (North Spit Option)

Figure 10

North Spit Regional WWTP ($ Millions)

Coos Bay Plants 1 and 2 (CB1 & CB2) - North Bend (NB) - LNG and North Spit Industry (NSI)
New 40 inch Ocean Outfall --- Resulting in **NO more waste to the Estuary**

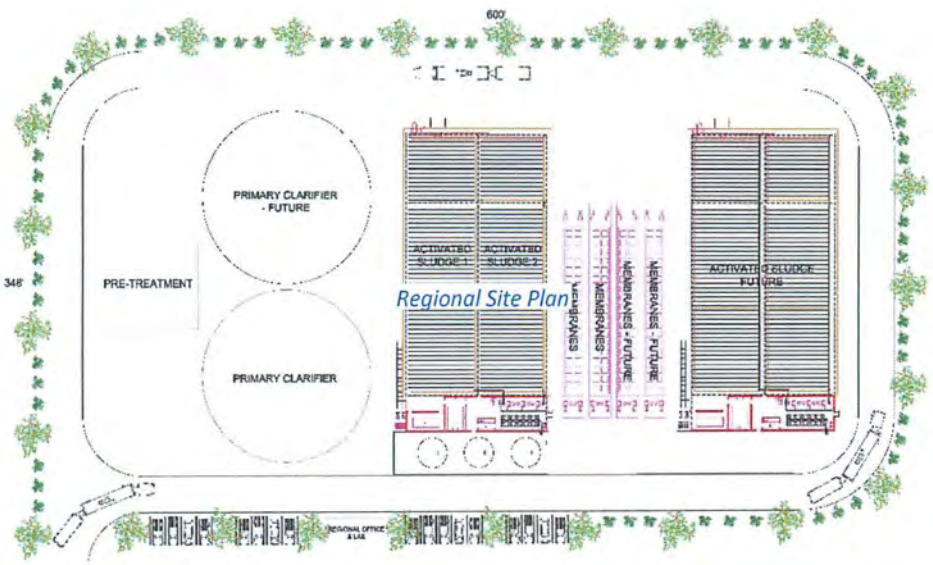
No.	Item	Regional	NB Only	LNG
1	CB1 Pump Station Modification	2		
2	Pipe (36 in) to Central Pump Station (CPS) - 3.2 miles	6		
3	Central Pump Station (CPS) - Aerated Grit Removal	6		
4	CB2 Pump Station	5		
5	CB2 Pipe to NB - 3 miles	5		
6	NB Pump Station Modification		2	
7	NB to CPS - 1.5 miles	3	2	
8	CPS Pipe (40 inch) under Bay to North Spit (NS) - 4,500 ft.	2		
9	NS to Regional WWTP	1		
10	WWTP Pipe to Ocean Outfall - 2.5 miles	3		3
11	Ocean Outfall	7		7
12	CB2 WWTP on North Spit	16		
13	CB1 WWTP on North Spit	32		
14	NB WWTP on North Spit		16	
15	NB Capital Cost Sharing to Join Regional WWTP		9	
16	**Capital Cost (No Credits) Estimate by DBWT**	**88**	**29**	**10**
	Savings (No Credits)			
17	Capital Estimate- CB1 & CB2	138		
18	Coos Bay Interest on Capital	56		
19	**City of Coos Bay Total**	**194**		
20	DBWT Capital	88		
21	DBWT Interest on Capital	36		
22	**DBWT Total (without credits)**	**124**		
23	***Total Savings (without credits)***	***70***		
	Potential Credits			
24	LNG Credit to Regional WWTP Capital	-10		
25	DBWT Capital	88		
26	DBWT Capital (with credits)	78		
27	DBWT Interest on Capital (with credits)	32		
28	**DBWT Total (with credits)**	**110**		
29	***Total Savings (with credits)***	***84***		
	Additional Savings			
30	Regional WWTP Lower O+M 20 yr Savings	20		
31	LNG Credit to Regional WWTP 20 yr Revenue	3		
32	Added horsepower over 20 years	-8		
33	NB Capital Cost Sharing to Join Regional WWTP	9		

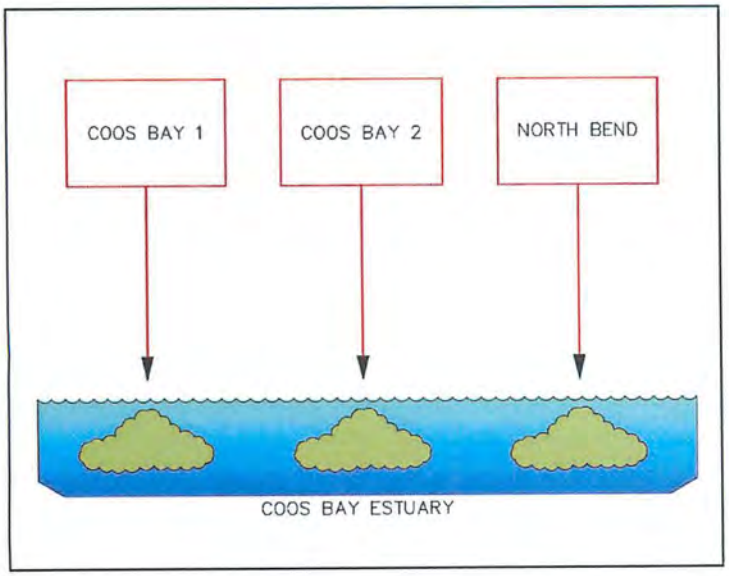
Note: The following information was an exhibit in DBWT's February 12, 2016 letter regarding the proposed Regional Plant (North Spit Option)

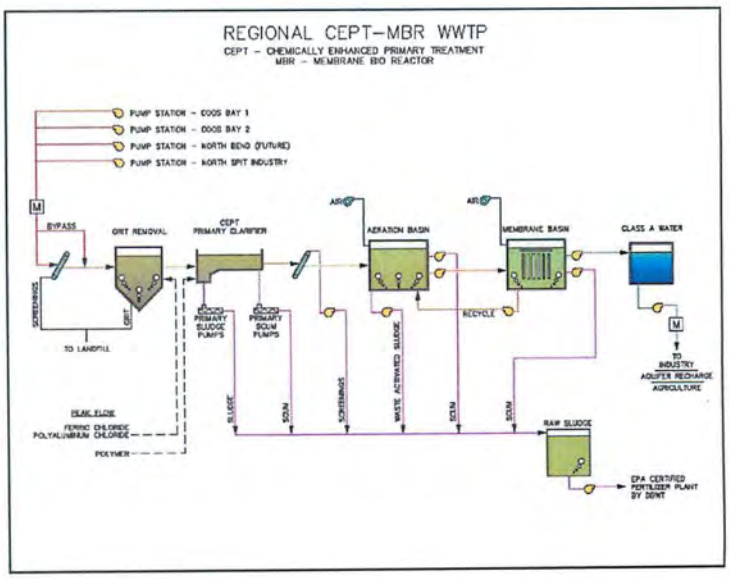
Cost Comparison

($ Millions)

No.	Description	Regional	Coos Bay		North Bend		LNG
			CB1	CB2	Existing	Upgrades	
1	***Plant Lifecycle***	***2021-41***	***2025-45***	***2017-37***		***2020-40***	
2	Capital	$88	$103	$35		$15	$10
3	Interest - 3.5% over 20 yrs.	$32	$42	$14		$6	$4
4	O&M Cost	$100	$80	$40	$30	$5	$10
5	20 Year Cost	$220	$225	$89	$30	$26	$24
	Total 20 Year	$220	$394				
6	**Regional WWTP Savings**	**$174**					







Attachment 2

Comparison of Empire Option and North Spit Option

COMPARISON OF EMPIRE SITE AND NORTH SPIT OPTIONS	
EMPIRE SITE SEQUENCING BATCH REACTOR (SBR)	**NORTH SPIT MEMBRANE BIOREACTOR**
Environmental	
Reduces viruses, chemicals and drugs	Better Reduces viruses, chemicals and drugs
Viruses, chemicals and drugs may pass through treatment	Viruses, chemicals and drugs may pass through treatment
Produces low ammonia levels in effluent	Produces lowest ammonia levels in effluent
Discharges to the lower estuary of Coos River	Potential to discharge to the bay, ocean or groundwater aquifer
Meets DEQ discharge requirements	Cleaner effluent than DEQ discharge requirements
Produces stable sludge that is easy to dewater	Lower sludge quantities, but harder to dewater
Economic	
Lowest cost option to build ($26M)	Highest construction cost ($88M)
Lower cost to operate	Higher cost to operate
Public funding offer is in place	Source of funding is unclear
Commitment for 1% interest offer is on the table and $2M in SRF Stormwater Funds	3.25% or higher estimated interest rate and city pays for stormwater projects out of rates
Planning and Site Issues	
Planning documents complete and approved by DEQ	No planning documents are required with private funding, but DEQ must approve final plans
Environmental Assessment approved by agencies	No Environmental Assessment has been approved
All plans are complete and approved by DEQ	Final plans have not been submitted to DEQ for review
Ready to bid and break ground by July 2016	Estimated 5-years needed to break ground
Land is already owned by City	Land has not been obtained and is not for sale
Empire site is in a commercial/residential area	North Spit is an industrial area with no residential
Facility within City Limits	Facility outside City Limits, may impact response time
Plans enhance & protect wetlands	Sensitive habitat may be impacted
SBR vs Membrane	
Flexible in responding to changes in flow	Very sensitive to high flows, may require surge basin
Requires grit removal and coarse screening	Requires grit removal and fine screening
Grit and sharp objects that get past headworks go to sludge	Grit & sharp objects that pass headworks may damage membranes
Aeration diffusers inexpensive to replace every 10 years	Membranes expensive to replace every 5-7 years
Produces stable sludge that is easy to dewater	Lower sludge quantities, but harder to dewater
Uses moderate amounts of electricity	Uses high levels of electricity
Requires a moderate amount of land to build	Requires a fairly small amount of land to build

Attachment 3

EPA Fact Sheets for Sequencing Batch Reactors and Membrane Filtration

United States Environmental Protection Agency | Office of Water Washington, D.C. | EPA 932-F-99-073 September 1999

EPA

Wastewater Technology Fact Sheet Sequencing Batch Reactors

DESCRIPTION

The sequencing batch reactor (SBR) is a fill-and-draw activated sludge system for wastewater treatment. In this system, wastewater is added to a single "batch" reactor, treated to remove undesirable components, and then discharged. Equalization, aeration, and clarification can all be achieved using a single batch reactor. To optimize the performance of the system, two or more batch reactors are used in a predetermined sequence of operations. SBR systems have been successfully used to treat both municipal and industrial wastewater. They are uniquely suited for wastewater treatment applications characterized by low or intermittent flow conditions.

Fill-and-draw batch processes similar to the SBR are not a recent development as commonly thought. Between 1914 and 1920, several full-scale fill-and-draw systems were in operation. Interest in SBRs was revived in the late 1950s and early 1960s, with the development of new equipment and technology. Improvements in aeration devices and controls have allowed SBRs to successfully compete with conventional activated sludge systems.

The unit processes of the SBR and conventional activated sludge systems are the same. A 1983 U.S. EPA report, summarized this by stating that "the SBR is no more than an activated sludge system which operates in time rather than in space." The difference between the two technologies is that the SBR performs equalization, biological treatment, and secondary clarification in a single tank using a timed control sequence. This type of reactor does, in some cases, also perform primary clarification. In a conventional activated sludge system, these unit processes would be accomplished by using separate tanks.

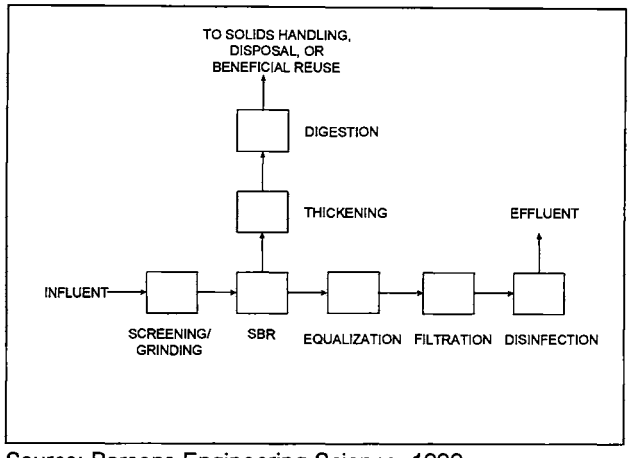
A modified version of the SBR is the Intermittent Cycle Extended Aeration System (ICEAS). In the ICEAS system, influent wastewater flows into the reactor on a continuous basis. As such, this is not a true batch reactor, as is the conventional SBR. A baffle wall may be used in the ICEAS to buffer this continuous inflow. The design configurations of the ICEAS and the SBR are otherwise very similar.

Description of a Wastewater Treatment Plant Using an SBR

A typical process flow schematic for a municipal wastewater treatment plant using an SBR is shown in Figure 1. Influent wastewater generally passes through screens and grit removal prior to the SBR. The wastewater then enters a partially filled reactor, containing biomass, which is acclimated to the wastewater constituents during preceding cycles. Once the reactor is full, it behaves like a conventional activated sludge system, but without a continuous influent or effluent flow. The aeration and mixing is discontinued after the biological reactions are complete, the biomass settles, and the treated supernatant is removed. Excess biomass is wasted at any time during the cycle. Frequent wasting results in holding the mass ratio of influent substrate to biomass nearly constant from cycle to cycle. Continuous flow systems hold the mass ratio of influent substrate to biomass constant by adjusting return activated sludge flowrates continually as influent flowrates, characteristics, and settling tank underflow concentrations vary. After the SBR, the "batch" of wastewater may flow to an equalization basin where the wastewater flowrate to

additional unit processed can be is controlled at a determined rate. In some cases the wastewater is filtered to remove additional solids and then disinfected.

As illustrated in Figure 1, the solids handling system may consist of a thickener and an aerobic digester. With SBRs there is no need for return activated sludge (RAS) pumps and primary sludge (PS) pumps like those associated with conventional activated sludge systems. With the SBR, there is typically only one sludge to handle. The need for gravity thickeners prior to digestion is determined



Source: Parsons Engineering Science, 1999.

FIGURE 1 PROCESS FLOW DIAGRAM FOR A TYPICAL SBR

on a case by case basis depending on the characteristics of the sludge.

An SBR serves as an equalization basin when the vessel is filling with wastewater, enabling the system to tolerate peak flows or peak loads in the influent and to equalize them in the batch reactor. In many conventional activated sludge systems, separate equalization is needed to protects the biological system from peak flows, which may wash out the biomass, or peak loads, which may upset the treatment process.

It should also be noted that primary clarifiers are typically not required for municipal wastewater applications prior to an SBR. In most conventional activated sludge wastewater treatment plants, primary clarifiers are used prior to the biological system. However, primary clarifiers may be recommended by the SBR manufacturer if the total suspended solids (TSS) or biochemical oxygen demand (BOD) are greater than 400 to 500 mg/L. Historic data should be evaluated and the SBR manufacturer consulted to determine whether primary clarifiers or equalization are recommended prior to an SBR for municipal and industrial applications.

Equalization may be required after the SBR, depending on the downstream process. If equalization is *not* used prior to filtration, the filters need to be sized in order to receive the batch of wastewater from the SBR, resulting in a large surface area required for filtration. Sizing filters to accept these "batch" flows is usually not feasible, which is why equalization is used between an SBR and downstream filtration. Separate equalization following the biological system is generally not required for most conventional activated sludge systems, because the flow is on a continuous and more constant basis.

APPLICABILITY

SBRs are typically used at flowrates of 5 MGD or less. The more sophisticated operation required at larger SBR plants tends to discourage the use of these plants for large flowrates.

As these systems have a relatively small footprint, they are useful for areas where the available land is limited. In addition, cycles within the system can be easily modified for nutrient removal in the future, if it becomes necessary. This makes SBRs extremely flexible to adapt to regulatory changes for effluent parameters such as nutrient removal. SBRs are also very cost effective if treatment beyond biological treatment is required, such as filtration.

ADVANTAGES AND DISADVANTAGES

Some advantages and disadvantages of SBRs are listed below:

Advantages

- Equalization, primary clarification (in most cases), biological treatment, and secondary clarification can be achieved in a single reactor vessel.
- Operating flexibility and control.
- Minimal footprint.
- Potential capital cost savings by eliminating clarifiers and other equipment.

Disadvantages

- A higher level of sophistication is required (compared to conventional systems), especially for larger systems, of timing units and controls.
- Higher level of maintenance (compared to conventional systems) associated with more sophisticated controls, automated switches, and automated valves.
- Potential of discharging floating or settled sludge during the DRAW or decant phase with some SBR configurations.
- Potential plugging of aeration devices during selected operating cycles, depending on the aeration system used by the manufacturer.
- Potential requirement for equalization after the SBR, depending on the downstream processes.

DESIGN CRITERIA

For any wastewater treatment plant design, the first step is to determine the anticipated influent characteristics of the wastewater and the effluent requirements for the proposed system. These influent parameters typically include design flow, maximum daily flow BOD_5, TSS, pH, alkalinity, wastewater temperature, total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), and total phosphorus (TP). For industrial and domestic wastewater, other site specific parameters may also be required.

The state regulatory agency should be contacted to determine the effluent requirements of the proposed plant. These effluent discharge parameters will be dictated by the state in the National Pollutant Discharge Elimination System (NPDES) permit. The parameters typically permitted for municipal systems are flowrate, BOD_5, TSS, and Fecal Coliform. In addition, many states are moving toward requiring nutrient removal. Therefore, total nitrogen (TN), TKN, NH_3-N, or TP may also be required. It is imperative to establish effluent requirements because they will impact the operating sequence of the SBR. For example, if there is a nutrient requirement and NH_3-N or TKN is required, then nitrification will be necessary. If there is a TN limit, then nitrification and denitrification will be necessary.

Once the influent and effluent characteristics of the system are determined, the engineer will typically consult SBR manufacturers for a recommended design. Based on these parameters, and other site specific parameters such as temperature, key design parameters are selected for the system. An example of these parameters for a wastewater system loading is listed in Table 1.

TABLE 1 KEY DESIGN PARAMETERS FOR A CONVENTIONAL LOAD

	Municipal	Industrial
Food to Mass (F:M)	0.15 - 0.4/day	0.15 - 0.6/day
Treatment Cycle Duration	4.0 hours	4.0 - 24 hours
Typically Low Water Level Mixed Liquor Suspended Solids	2,000-2,500 mg/L	2,000 - 4,000 mg/L
Hydraulic Retention Time	6 - 14 hours	varies

Source: AquaSBR Design Manual, 1995.

Once the key design parameters are determined, the number of cycles per day, number of basins, decant volume, reactor size, and detention times can be calculated. Additionally, the aeration equipment, decanter, and associated piping can then be sized.

Other site specific information is needed to size the aeration equipment, such as site elevation above mean sea level, wastewater temperature, and total dissolved solids concentration.

The operation of an SBR is based on the fill-and-draw principle, which consists of the following five basic steps: Idle, Fill, React, Settle, and Draw. More than one operating strategy is possible during most of these steps. For industrial wastewater applications, treatability studies are typically required to determine the optimum operating sequence. For most municipal wastewater treatment plants, treatability studies are not required to determine the operating sequence because municipal wastewater flowrates and characteristic variations are usually predictable and most municipal designers will follow conservative design approaches.

The Idle step occurs between the Draw and the Fill steps, during which treated effluent is removed and influent wastewater is added. The length of the Idle step varies depending on the influent flowrate and the operating strategy. Equalization is achieved during this step if variable idle times are used. Mixing to condition the biomass and sludge wasting can also be performed during the Idle step, depending on the operating strategy.

Influent wastewater is added to the reactor during the Fill step. The following three variations are used for the Fill step and any or all of them may be used depending on the operating strategy: static fill, mixed fill, and aerated fill. During static fill, influent wastewater is added to the biomass already present in the SBR. Static fill is characterized by no mixing or aeration, meaning that there will be a high substrate (food) concentration when mixing begins. A high food to microorganisms (F:M) ratio creates an environment favorable to floc forming organisms versus filamentous organisms, which provides good settling characteristics for the sludge. Additionally, static fill conditions favor organisms that produce internal storage products during high substrate conditions, a requirement for biological phosphorus removal. Static fill may be compared to using "selector" compartments in a conventional activated sludge system to control the F:M ratio.

Mixed fill is classified by mixing influent organics with the biomass, which initiates biological reactions. During mixed fill, bacteria biologically degrade the organics and use residual oxygen or alternative electron acceptors, such as nitrate-nitrogen. In this environment, denitrification may occur under these anoxic conditions. Denitrification is the biological conversion of nitrate-nitrogen to nitrogen gas. An anoxic condition is defined as an environment in which oxygen is not present and nitrate-nitrogen is used by the microorganisms as the electron acceptor. In a conventional biological nutrient removal (BNR) activated sludge system, mixed fill is comparable to the anoxic zone which is used for denitrification. Anaerobic conditions can also be achieved during the mixed fill phase. After the microorganisms use the nitrate-nitrogen, sulfate becomes the electron acceptor. Anaerobic conditions are characterized by the lack of oxygen and sulfate as the electron acceptor.

Aerated Fill is classified by aerating the contents of the reactor to begin the aerobic reactions completed in the React step. Aerated Fill can reduce the aeration time required in the React step.

The biological reactions are completed in the React step, in which mixed react and aerated react modes are available. During aerated react, the aerobic reactions initialized during aerated fill are completed and nitrification can be achieved. Nitrification is the conversion of ammonia-nitrogen to nitrite-nitrogen and ultimately to nitrate-nitrogen. If the mixed react mode is selected, anoxic conditions can be attained to achieve denitrification. Anaerobic conditions can also be achieved in the mixed react mode for phosphorus removal.

Settle is typically provided under quiescent conditions in the SBR. In some cases, gentle mixing during the initial stages of settling may result in a clearer effluent and a more concentrated settled sludge. In an SBR, there are no influent or effluent currents to interfere with the settling process as in a conventional activated sludge system.

The Draw step uses a decanter to remove the treated effluent, which is the primary distinguishing factor between different SBR manufacturers. In general, there are floating decanters and fixed

decanters. Floating decanters offer several advantages over fixed decanters as described in the Tank and Equipment Description Section.

Construction

Construction of SBR systems can typically require a smaller footprint than conventional activated sludge systems because the SBR often eliminates the need for primary clarifiers. The SBR never requires secondary clarifiers. The size of the SBR tanks themselves will be site specific, however the SBR system is advantageous if space is limited at the proposed site. A few case studies are presented in Table 2 to provide general sizing estimates at different flowrates. Sizing of these systems is site specific and these case studies do not reflect every system at that size.

TABLE 2 CASE STUDIES FOR SEVERAL SBR INSTALLATIONS

Flow	Reactors			Blowers	
(MGD)	No.	Size (feet)	Volume (MG)	No.	Size (HP)
0.012	1	18 x 12	0.021	1	15
0.10	2	24 x 24	0.069	3	7.5
1.2	2	80 x 80	0.908	3	125
1.0	2	58 x 58	0.479	3	40
1.4	2	69 x 69	0.678	3	60
1.46	2	78 x 78	0.910	4	40
2.0	2	82 x 82	0.958	3	75
4.25	4	104 x 80	1.556	5	200
5.2	4	87 x 87	1.359	5	125

Note: These case studies and sizing estimates were provided by Aqua-Aerobic Systems, Inc. and are site specific to individual treatment systems.

The actual construction of the SBR tank and equipment may be comparable or simpler than a conventional activated sludge system. For Biological Nutrient Removal (BNR) plants, an SBR eliminates the need for return activated sludge (RAS) pumps and pipes. It may also eliminate the need for internal Mixed Liquor Suspended Solid (MLSS) recirculation, if this is being used in a conventional BNR system to return nitrate-nitrogen.

The control system of an SBR operation is more complex than a conventional activated sludge system and includes automatic switches, automatic valves, and instrumentation. These controls are very sophisticated in larger systems. The SBR manufacturers indicate that most SBR installations in the United States are used for smaller wastewater systems of less than two million gallons per day (MGD) and some references recommend SBRs only for small communities where land is limited. This is not always the case, however, as the largest SBR in the world is currently a 10 MGD system in the United Arab Emirates.

Tank and Equipment Description

The SBR system consists of a tank, aeration and mixing equipment, a decanter, and a control system. The central features of the SBR system include the control unit and the automatic switches and valves that sequence and time the different operations. SBR manufacturers should be consulted for recommendations on tanks and equipment. It is typical to use a complete SBR system recommended and supplied by a single SBR manufacturer. It is possible, however, for an engineer to design an SBR system, as all required tanks, equipment, and controls are available through different manufacturers. This is not typical of SBR installation because of the level of sophistication of the instrumentation and controls associated with these systems.

The SBR tank is typically constructed with steel or concrete. For industrial applications, steel tanks coated for corrosion control are most common while concrete tanks are the most common for municipal treatment of domestic wastewater. For mixing and aeration, jet aeration systems are typical as they allow mixing either with or without aeration, but other aeration and mixing systems are also used. Positive displacement blowers are typically used for SBR design to handle wastewater level variations in the reactor.

As previously mentioned, the decanter is the primary piece of equipment that distinguishes different SBR manufacturers. Types of decanters include floating and fixed. Floating decanters offer the advantage of maintaining the inlet orifice slightly

below the water surface to minimize the removal of solids in the effluent removed during the DRAW step. Floating decanters also offer the operating flexibility to vary fill-and-draw volumes. Fixed decanters are built into the side of the basin and can be used if the Settle step is extended. Extending the Settle step minimizes the chance that solids in the wastewater will float over the fixed decanter. In some cases, fixed decanters are less expensive and can be designed to allow the operator to lower or raise the level of the decanter. Fixed decanters do not offer the operating flexibility of the floating decanters.

Health and Safety

Safety should be the primary concern in every design and system operation. A properly designed and operated system will minimize potential health and safety concerns. Manuals such as the Manual of Practice (MOP) No. 8, Design of Municipal Wastewater Treatment Plants, and MOP No. 11, Operation of Municipal Wastewater Treatment Plants should be consulted to minimize these risks. Other appropriate industrial wastewater treatment manuals, federal regulations, and state regulations should also be consulted for the design and operation of wastewater treatment systems.

PERFORMANCE

The performance of SBRs is typically comparable to conventional activated sludge systems and depends on system design and site specific criteria. Depending on their mode of operation, SBRs can achieve good BOD and nutrient removal. For SBRs, the BOD removal efficiency is generally 85 to 95 percent.

SBR manufacturers will typically provide a process guarantee to produce an effluent of less than:

- 10 mg/L BOD
- 10 mg/L TSS
- 5 - 8 mg/L TN
- 1 - 2 mg/L TP

OPERATION AND MAINTENANCE

The SBR typically eliminates the need for separate primary and secondary clarifiers in most municipal systems, which reduces operations and maintenance requirements. In addition, RAS pumps are not required. In conventional biological nutrient removal systems, anoxic basins, anoxic zone mixers, toxic basins, toxic basin aeration equipment, and internal MLSS nitrate-nitrogen recirculation pumps may be necessary. With the SBR, this can be accomplished in one reactor using aeration/mixing equipment, which will minimize operation and maintenance requirements otherwise be needed for clarifiers and pumps.

Since the heart of the SBR system is the controls, automatic valves, and automatic switches, these systems may require more maintenance than a conventional activated sludge system. An increased level of sophistication usually equates to more items that can fail or require maintenance. The level of sophistication may be very advanced in larger SBR wastewater treatment plants requiring a higher level of maintenance on the automatic valves and switches.

Significant operating flexibility is associated with SBR systems. An SBR can be set up to simulate any conventional activated sludge process, including BNR systems. For example, holding times in the Aerated React mode of an SBR can be varied to achieve simulation of a contact stabilization system with a typical hydraulic retention time (HRT) of 3.5 to 7 hours or, on the other end of the spectrum, an extended aeration treatment system with a typical HRT of 18 to 36 hours. For a BNR plant, the aerated react mode (oxic conditions) and the mixed react modes (anoxic conditions) can be alternated to achieve nitrification and denitrification. The mixed fill mode and mixed react mode can be used to achieve denitrification using anoxic conditions. In addition, these modes can ultimately be used to achieve an anaerobic condition where phosphorus removal can occur. Conventional activated sludge systems typically require additional tank volume to achieve such flexibility. SBRs operate in time rather than in space and the number of cycles per day can be varied to control desired effluent limits, offering additional flexibility with an SBR.

COSTS

This section includes some general guidelines as well as some general cost estimates for planning purposes. It should be remembered that capital and construction cost estimates are site-specific.

Budget level cost estimates presented in Table 3 are based on projects that occurred from 1995 to 1998. Budget level costs include such as the blowers, diffusers, electrically operated valves, mixers, sludge pumps, decanters, and the control panel. All costs have been updated to March 1998 costs, using an ENR construction cost index of 5875 from the March 1998 Engineering News Record, rounded off to the nearest thousand dollars.

TABLE 3 SBR EQUIPMENT COSTS BASED ON DIFFERENT PROJECTS

Design Flowrate (MGD)	Budget Level Equipment Costs ($)
0.012	94,000
0.015	137,000
1.0	339,000
1.4	405,000
1.46	405,000
2.0	564,000
4.25	1,170,000

Source: Aqua Aerobics Manufacturer Information, 1998.

In Table 4, provided a range of equipment costs for different design flowrates is provided.

TABLE 4 BUDGET LEVEL EQUIPMENT COSTS BASED ON DIFFERENT FLOW RATES

Design Flowrate (MGD)	Budget Level Equipment Costs ($)
1	150,000 - 350,000
5	459,000 - 730,000
10	1,089,000 - 1,370,000
15	2,200,000
20	2,100,000 - 3,000,000

Note: Budget level cost estimates provided by Babcock King - Wilkinson, L.P., August 1998.

Again the equipment cost items provided do not include the cost for the tanks, sitework, excavation/backfill, installation, contractor's overhead and profit, or legal, administrative, contingency, and engineering services. These items must be included to calculate the overall construction costs of an SBR system. Costs for other treatment processes, such as screening, equalization, filtration, disinfection, or aerobic digestion, may be included if required.

The ranges of construction costs for a complete, installed SBR wastewater treatment system are presented in Table 5. The variances in the estimates are due to the type of sludge handling facilities and the differences in newly constructed plants versus systems that use existing plant facilities. As such, in some cases these estimates include other processes required in an SBR wastewater treatment plant.

TABLE 5 INSTALLED COST PER GALLON OF WASTEWATER TREATED

Design Flowrate (MGD)	Budget Level Equipment Cost ($/gallon)
0.5 - 1.0	1.96 - 5.00
1.1 - 1.5	1.83 - 2.69
1.5 - 2.0	1.65 - 3.29

Note: Installed cost estimates obtained from Aqua-Aerobics Systems, Inc., August 1998.

There is typically an economy of scale associated with construction costs for wastewater treatment,

meaning that larger treatment plants can usually be constructed at a lower cost per gallon than smaller systems. The use of common wall construction for larger treatment systems, which can be used for square or rectangular SBR reactors, results in this economy of scale.

Operations and Maintenance (O&M) costs associated with an SBR system may be similar to a conventional activated sludge system. Typical cost items associated with wastewater treatment systems include labor, overhead, supplies, maintenance, operating administration, utilities, chemicals, safety and training, laboratory testing, and solids handling. Labor and maintenance requirements may be reduced in SBRs because clarifiers, clarification equipment, and RAS pumps may not be necessary. On the other hand, the maintenance requirements for the automatic valves and switches that control the sequencing may be more intensive than for a conventional activated sludge system. O&M costs are site specific and may range from $800 to $2,000 dollars per million gallons treated.

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United States Environmental Protection Agency

Wastewater Management Fact Sheet

Membrane Bioreactors

INTRODUCTION

The technologies most commonly used for performing secondary treatment of municipal wastewater rely on microorganisms suspended in the wastewater to treat it. Although these technologies work well in many situations, they have several drawbacks, including the difficulty of growing the right types of microorganisms and the physical requirement of a large site. The use of microfiltration membrane bioreactors (MBRs), a technology that has become increasingly used in the past 10 years, overcomes many of the limitations of conventional systems. These systems have the advantage of combining a suspended growth biological reactor with solids removal via filtration. The membranes can be designed for and operated in small spaces and with high removal efficiency of contaminants such as nitrogen, phosphorus, bacteria, biochemical oxygen demand, and total suspended solids. The membrane filtration system in effect can replace the secondary clarifier and sand filters in a typical activated sludge treatment system. Membrane filtration allows a higher biomass concentration to be maintained, thereby allowing smaller bioreactors to be used.

APPLICABILITY

For new installations, the use of MBR systems allows for higher wastewater flow or improved treatment performance in a smaller space than a conventional design, i.e., a facility using secondary clarifiers and sand filters. Historically, membranes have been used for smaller-flow systems due to the high capital cost of the equipment and high operation and maintenance (O&M) costs. Today however, they are receiving increased use in larger systems. MBR systems are also well suited for some industrial and commercial applications. The high-quality effluent produced by MBRs makes them particularly applicable to reuse applications and for surface water discharge applications requiring extensive nutrient (nitrogen and phosphorus) removal.

ADVANTAGES AND DISADVANTAGES

The advantages of MBR systems over conventional biological systems include better effluent quality, smaller space requirements, and ease of automation. Specifically, MBRs operate at higher volumetric loading rates which result in lower hydraulic retention times. The low retention times mean that less space is required compared to a conventional system. MBRs have often been operated with longer solids residence times (SRTs), which results in lower sludge production; but this is not a requirement, and more conventional SRTs have been used (Crawford et al. 2000). The effluent from MBRs contains low concentrations of bacteria, total suspended solids (TSS), biochemical oxygen demand (BOD), and phosphorus. This facilitates high-level disinfection. Effluents are readily discharged to surface streams or can be sold for reuse, such as irrigtion.

The primary disadvantage of MBR systems is the typically higher capital and operating costs than conventional systems for the same throughput. O&M costs include membrane cleaning and fouling control, and eventual membrane replacement. Energy costs are also higher because of the need for air scouring to control bacterial growth on the membranes. In addition, the waste sludge from such a system might have a low settling rate, resulting in the need for chemicals to produce biosolids acceptable for disposal (Hermanowicz et al. 2006). Fleischer et al. 2005 have demonstrated that waste sludges from MBRs can be processed using standard technologies used for activated sludge processes.

Membrane Filtration

Membrane filtration involves the flow of water-containing pollutants across a membrane. Water permeates through the membrane into a separate channel for recovery (Figure 1). Because of the cross-flow movement of water and the waste constituents, materials left behind do not accumulate at the membrane surface but are carried out of the system for later recovery or disposal. The water passing through the membrane is called the *permeate*, while the water with the more-concentrated materials is called the *concentrate* or *retentate*.

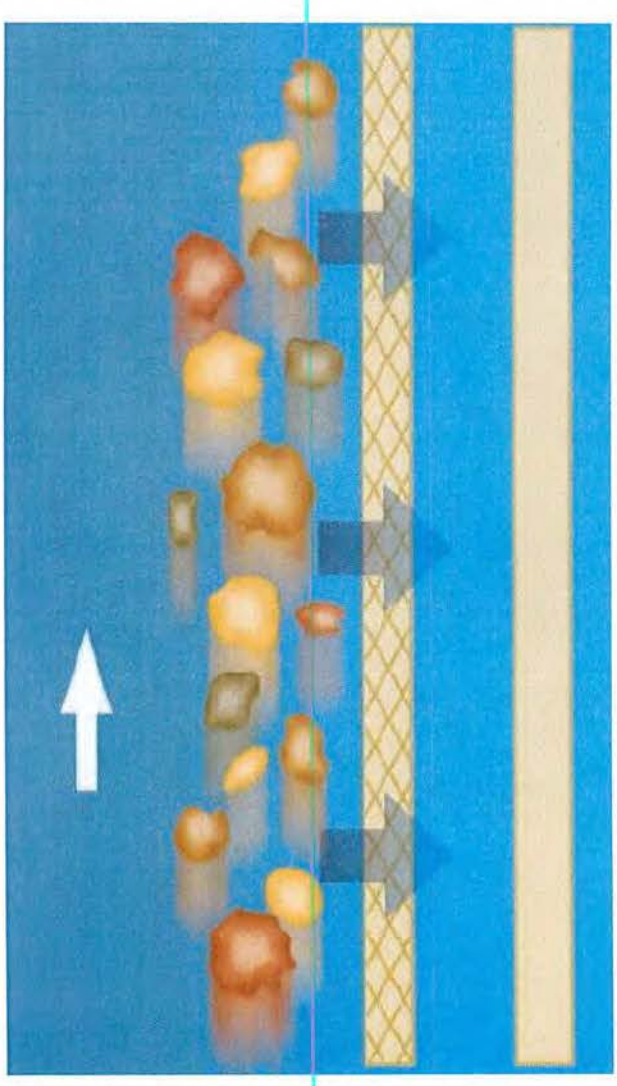

Figure 1. Membrane filtration process (Image from Siemens/U.S. Filter)

Membranes are constructed of cellulose or other polymer material, with a maximum pore size set during the manufacturing process. The requirement is that the membranes prevent passage of particles the size of microorganisms, or about 1 micron (0.001 millimeters), so that they remain in the system. This means that MBR systems are good for removing solid material, but the removal of dissolved wastewater components must be facilitated by using additional treatment steps.

Membranes can be configured in a number of ways. For MBR applications, the two configurations most often used are hollow fibers grouped in bundles, as shown in Figure 2, or as flat plates. The hollow fiber bundles are connected by manifolds in units that are designed for easy changing and servicing.

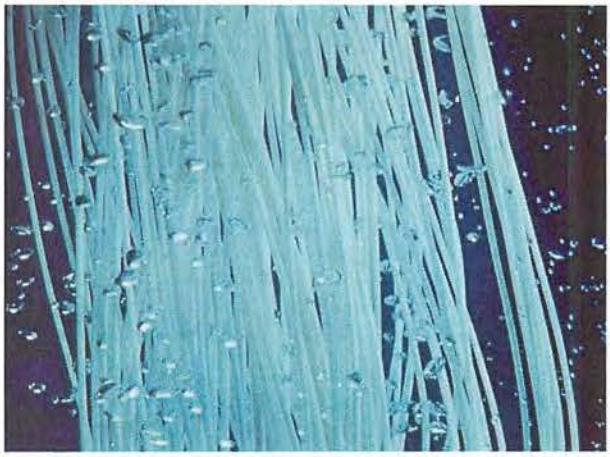

Figure 2. Hollow-fiber membranes (Image from GE/Zenon)

Design Considerations

Designers of MBR systems require only basic information about the wastewater characteristics, (e.g., influent characteristics, effluent requirements, flow data) to design an MBR system. Depending on effluent requirements, certain supplementary options can be included with the MBR system. For example, chemical addition (at various places in the treatment chain, including: before the primary settling tank; before the secondary settling tank [clarifier]; and before the MBR or final filters) for phosphorus removal can be included in an MBR system if needed to achieve low phosphorus concentrations in the effluent.

MBR systems historically have been used for small-scale treatment applications when portions of the treatment system were shut down and the

wastewater routed around (or bypassed) during maintenance periods.

However, MBR systems are now often used in full-treatment applications. In these instances, it is recommended that the installation include one additional membrane tank/unit beyond what the design would nominally call for. This "N plus 1" concept is a blend between conventional activated sludge and membrane process design. It is especially important to consider both operations and maintenance requirements when selecting the number of units for MBRs. The inclusion of an extra unit gives operators flexibility and ensures that sufficient operating capacity will be available (Wallis-Lage et al. 2006). For example, bioreactor sizing is often limited by oxygen transfer, rather than the volume required to achieve the required SRT—a factor that significantly affects bioreactor numbers and sizing (Crawford et al. 2000).

Although MBR systems provide operational flexibility with respect to flow rates, as well as the ability to readily add or subtract units as conditions dictate, that flexibility has limits. Membranes typically require that the water surface be maintained above a minimum elevation so that the membranes remain wet during operation. Throughput limitations are dictated by the physical properties of the membrane, and the result is that peak design flows should be no more than 1.5 to 2 times the average design flow. If peak flows exceed that limit, either additional membranes are needed simply to process the peak flow, or equalization should be included in the overall design. The equalization is done by including a separate basin (external equalization) or by maintaining water in the aeration and membrane tanks at depths higher than those required and then removing that water to accommodate higher flows when necessary (internal equalization).

Design Features

Pretreatment

To reduce the chances of membrane damage, wastewater should undergo a high level of debris removal prior to the MBR. Primary treatment is often provided in larger installations, although not in most small to medium sized installations, and is not a requirement. In addition, all MBR systems require 1- to 3-mm-cutoff fine screens immediately before the membranes, depending on the MBR manufacturer. These screens require frequent cleaning. Alternatives for reducing the amount of material reaching the screens include using two stages of screening and locating the screens after primary settling.

Membrane Location

MBR systems are configured with the mem-

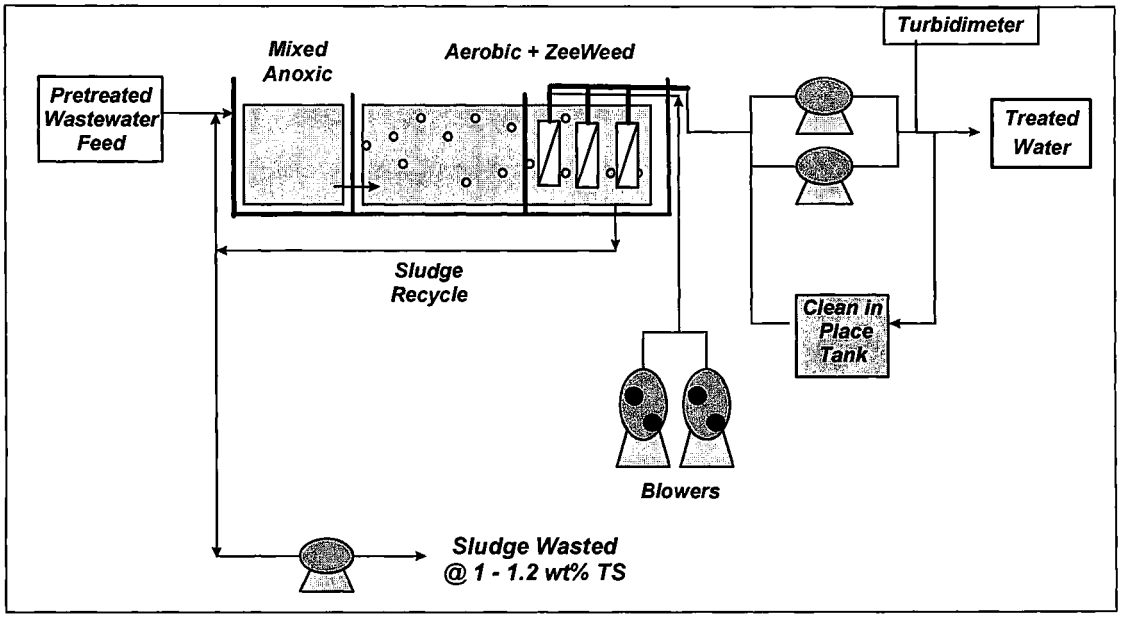

Figure 3. Immersed membrane system configuration (Image from GE/Zenon)

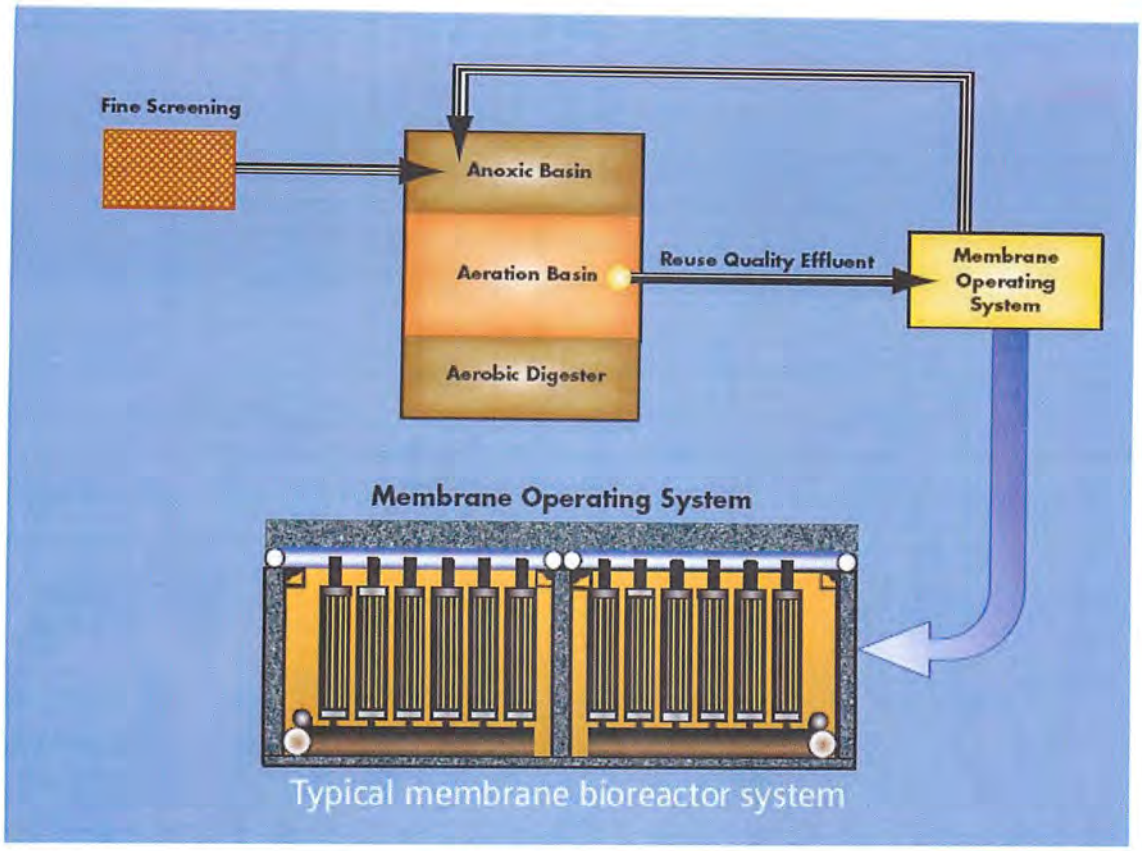

Figure 4. External membrane system configuration (Image from Siemens/U.S. Filter)

branes actually immersed in the biological reactor or, as an alternative, in a separate vessel through which mixed liquor from the biological reactor is circulated. The former configuration is shown in Figure 3; the latter, in Figure 4.

Membrane Configuration

MBR manufacturers employ membranes in two basic configurations: hollow fiber bundles and plate membranes. Siemens/U.S.Filter's Memjet and Memcor systems, GE/Zenon's ZeeWeed and ZenoGem systems, and GE/Ionics' system use hollow-fiber, tubular membranes configured in bundles. A number of bundles are connected by manifolds into units that can be readily changed for maintenance or replacement. The other configuration, such as those provided by Kubota/Enviroquip, employ membranes in a flat-plate configuration, again with manifolds to allow a number of membranes to be connected in readily changed units. Screening requirements for both systems differ: hollow-fiber membranes typically require 1- to 2-mm screening, while plate membranes require 2- to 3-mm screening (Wallis-Lage et al. 2006).

System Operation

All MBR systems require some degree of pumping to force the water flowing through the membrane. While other membrane systems use a pressurized system to push the water through the membranes, the major systems used in MBRs draw a vacuum through the membranes so that the water outside is at ambient pressure. The advantage of the vacuum is that it is gentler to the membranes; the advantage of the pressure is that throughput can be controlled. All systems also include techniques for continually cleaning the system to maintain membrane life and keep the system operational for as long as possible. All the principal membrane systems used in MBRs use an air scour technique to reduce buildup of material on the membranes. This is done by blowing air around the membranes out of the manifolds. The GE/Zenon systems use air scour, as well as a back-pulsing technique, in which permeate is occasionally pumped back

into the membranes to keep the pores cleared out. Back-pulsing is typically done on a timer, with the time of pulsing accounting for 1 to 5 percent of the total operating time.

Downstream Treatment

The permeate from an MBR has low levels of suspended solids, meaning the levels of bacteria, BOD, nitrogen, and phosphorus are also low. Disinfection is easy and might not be required, depending on permit requirements..

The solids retained by the membrane are recycled to the biological reactor and build up in the system. As in conventional biological systems, periodic sludge wasting eliminates sludge buildup and controls the SRT within the MBR system. The waste sludge from MBRs goes through standard solids-handling technologies for thickening, dewatering, and ultimate disposal. Hermanowicz et al. (2006) reported a decreased ability to settle in waste MBR sludges due to increased amounts of colloidal-size particles and filamentous bacteria. Chemical addition increased the ability of the sludges to settle. As more MBR facilities are built and operated, a more definitive understanding of the characteristics of the resulting biosolids will be achieved. However, experience to date indicates that conventional biosolids processing unit operations are also applicable to the waste sludge from MBRs.

Membrane Care

The key to the cost-effectiveness of an MBR system is membrane life. If membrane life is curtailed such that frequent replacement is required, costs will significantly increase. Membrane life can be increased in the following ways:

- Good screening of larger solids before the membranes to protect the membranes from physical damage.

- Throughput rates that are not excessive, i.e., that do not push the system to the limits of the design. Such rates reduce the amount of material that is forced into the membrane and thereby reduce the amount that has to be removed by cleaners or that will cause eventual membrane deterioration.

- Regular use of mild cleaners. Cleaning solutions most often used with MBRs include regular bleach (sodium) and citric acid. The cleaning should be in accord with manufacturer-recommended maintenance protocols.

Membrane Guarantees

The length of the guarantee provided by the membrane system provider is also important in determining the cost-effectiveness of the system. For municipal wastewater treatment, longer guarantees might be more readily available compared to those available for industrial systems. Zenon offers a 10-year guarantee; others range from 3 to 5 years. Some guarantees include cost prorating if replacement is needed after a certain service time. Guarantees are typically negotiated during the purchasing process. Some manufacturers' guarantees are tied directly to screen size: longer membrane warranties are granted when smaller screens are used (Wallis-Lage et al. 2006). Appropriate membrane life guarantees can be secured using appropriate membrane procurement strategies (Crawford et al. 2002).

System Performance

Siemens/U.S. Filter Systems

Siemens/U.S.Filter offers MBR systems under the Memcor and Memjet brands. Data provided by U.S. Filter for its Calls Creek (Georgia) facility are summarized below. The system, as Calls Creek retrofitted it, is shown in Figure 5. In essence, the membrane filters were used to replace secondary clarifiers downstream of an Orbal oxidation ditch. The system includes a fine screen (2-mm cutoff) for inert solids removal just before the membranes.

The facility has an average flow of 0.35 million gallons per day (mgd) and a design flow of 0.67 mgd. The system has 2 modules, each containing 400 units, and each unit consists of a cassette with manifold-connected membranes. As shown in Table 1, removal of BOD, TSS, and ammonia-nitrogen is excellent; BOD and TSS in the effluent are around the detection limit. Phosphorus is also removed well in the system, and the effluent

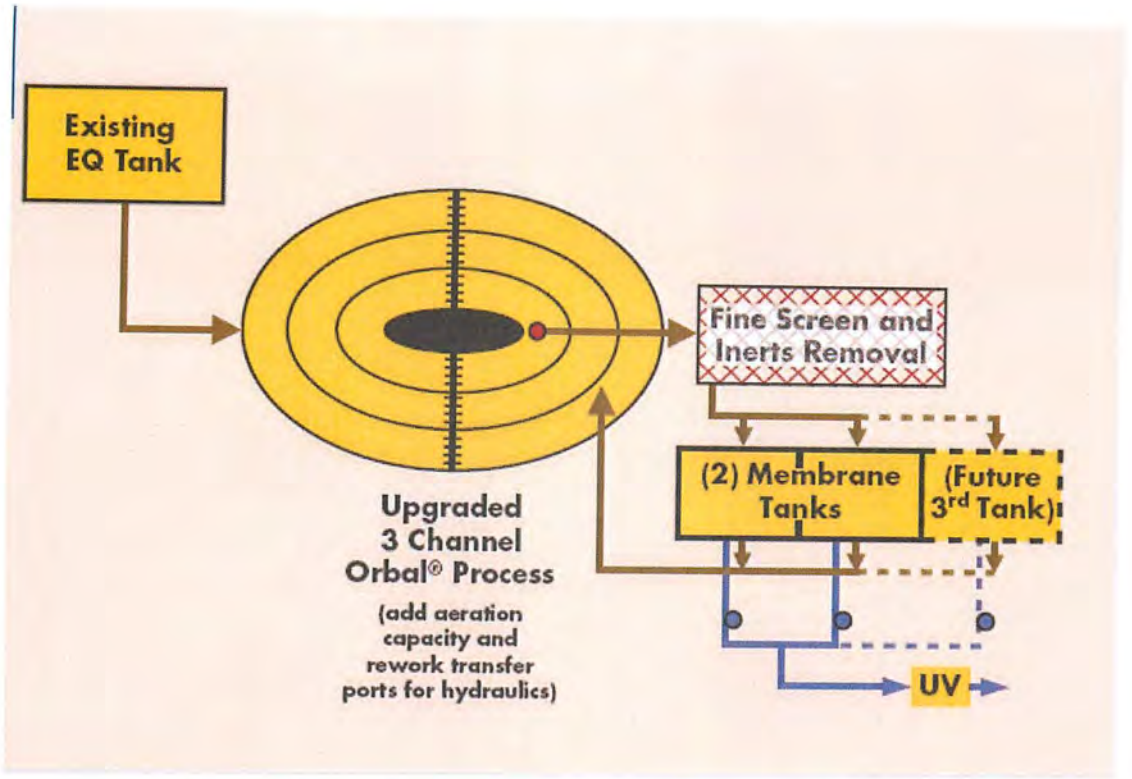

Figure 5. Calls Creek flow diagram (courtesy of Siemens/U.S. Filter)

Table 1.
Calls Creek results 2005

Parameter	Influent	Effluent		
	Average	Average	Max Month	Min Month
Flow (mgd)	0.35	--	0.44	0.26
BOD (mg/L)	145	1	1	1
TSS (mg/L)	248	1	1	1
Ammonia-N (mg/L)	14.8	0.21	0.72	0.10
P (mg/L)	0.88	0.28	0.55	0.12
Fecal coliforms (#/100 mL)	--	14.2	20	0
Turbidity (NTU)	--	0.30	1.31	0.01

has very low turbidity. The effluent has consistently met discharge limits.

Zenon Systems

General Electric/Zenon provides systems under the ZenoGem and ZeeWeed brands. The ZeeWeed brand refers to the membrane, while ZenoGem is the process that uses ZeeWeed.

Performance data for two installed systems are shown below.

Cauley Creek, Georgia. The Cauley Creek facility in Fulton County, Georgia, is a 5-mgd wastewater reclamation plant. The system includes biological phosphorus removal, mixed liquor surface wasting, and sludge thickening using a ZeeWeed system to minimize the required volume of the aerobic digester, according to information provided by GE. Ultraviolet disinfection is employed to meet regulatory limits. Table 2 shows that the removal for all parame-

Table 2.
Cauley Creek, Georgia, system performance

Parameter	Influent	Effluent		
	Average	Average	Max Month	Min Month
Flow (mgd)	4.27	--	4.66	3.72
BOD (mg/L)	182	2.0	2.0	2.0
COD (mg/L)	398	12	22	5
TSS (mg/L)	174	3.2	5	3
TKN (mg/L)	33.0	1.9	2.9	1.4
Ammonia-N (mg/L)	24.8	0.21	0.29	0.10
TP (mg/L)	5.0	0.1	0.13	0.06
Fecal coliforms (#/100 mL)	--	2	2	2
NO3-N (mg/L)	--	2.8		

ters is over 90 percent. The effluent meets all permit limits, and is reused for irrigation and lawn watering.

Traverse City, Michigan. The Traverse City Wastewater Treatment Plant (WWTP) went through an upgrade to increase plant capacity and produce a higher-quality effluent, all within the facility's existing plant footprint (Crawford et al. 2005). With the ZeeWeed system, the facility was able to achieve those goals. As of 2006, the plant is the largest-capacity MBR facility in North America. It has a design average annual flow of 7.1 mgd, maximum monthly flow of 8.5 mgd, and peak hourly flow of 17 mgd. The membrane system consists of a 450,000-gallon tank with eight compartments of equal size. Secondary sludge is distributed evenly to the compartments. Blowers for air scouring, as well as permeate and back-pulse pumps, are housed in a nearby building.

Table 3 presents a summary of plant results over a 12-month period. The facility provides excellent removal of BOD, TSS, ammonia-nitrogen, and phosphorus. Figure 6 shows the influent, effluent, and flow data for the year.

Operating data for the Traverse City WWTP were obtained for the same period. The mixed liquor suspended solids over the period January to August averaged 6,400 mg/L, while the mixed liquor volatile suspended solids averaged 4,400 mg/L. The energy use for the air-scouring blowers averaged 1,800 kW-hr/million gallons (MG) treated.

Costs

Capital Costs

Capital costs for MBR systems historically have tended to be higher than those for conventional systems with comparable throughput because of the initial costs of the membranes. In certain situations, however, including retrofits, MBR systems can have lower or competitive capital costs compared with alternatives because MBRs have lower land requirements and use smaller tanks, which can reduce the costs for concrete. U.S. Filter/Siemen's Memcor package plants have installed costs of $7–$20/gallon treated.

Fleischer et al. (2005) reported on a cost comparison of technologies for a 12-MGD design in Loudoun County, Virginia. Because of a chemical oxygen demand limit, activated carbon adsorption was included with the MBR system. It was found that the capital cost for MBR plus granular activated carbon at $12/gallon treated was on the same order of magnitude as alternative processes, including multiple-point alum addition, high lime treatment, and post-secondary membrane filtration.

Operating Costs

Operating costs for MBR systems are typically higher than those for comparable conventional systems. This is because of the higher energy

Table 3.
Summary of Traverse City, Michigan, Performance Results

Parameter	Influent	Effluent		
	Average	Average	Max Month	Min Month
Flow (mgd)	4.3	--	5.1	3.6
BOD (mg/L)	280	< 2	< 2	< 2
TSS (mg/L)	248	< 1	< 1	< 1
Ammonia-N (mg/L)	27.9	< 0.08	< 0.23	< 0.03
TP (mg/L)	6.9	0.7	0.95	0.41
Temperature (deg C)	17.2	--	23.5	11.5

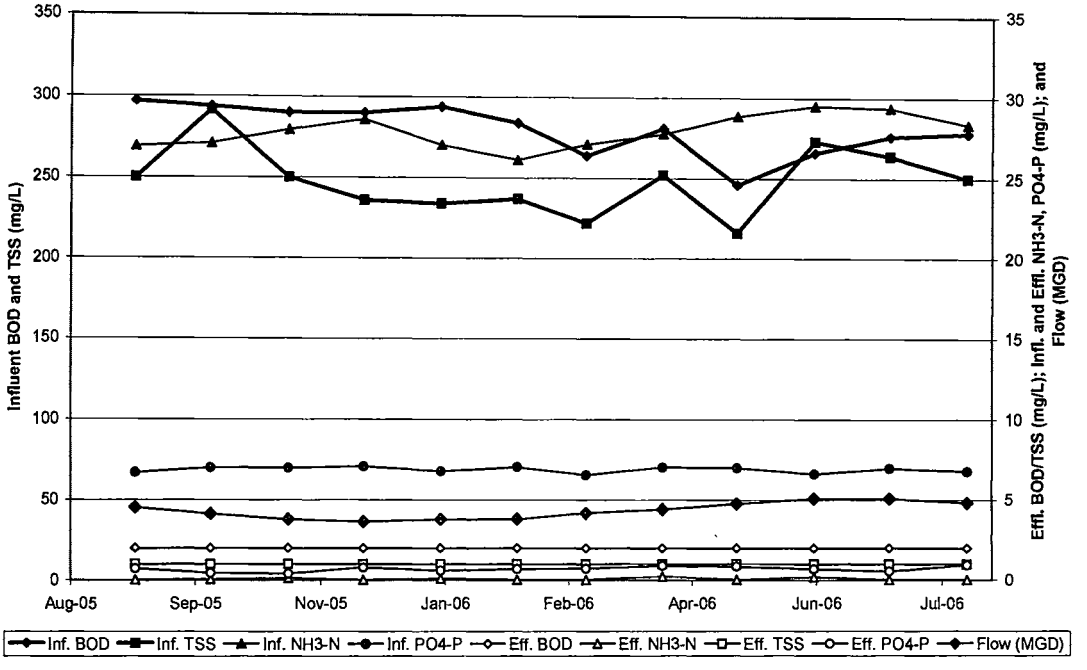

Figure 6. Performance of the Traverse City plant

costs if air scouring is used to reduce membrane fouling. The amount of air needed for the scouring has been reported to be twice that needed to maintain aeration in a conventional activated sludge system (Scott Blair, personal communication, 2006). These higher operating costs are often partially offset by the lower costs for sludge disposal associated with running at longer sludge residence times and with membrane thickening/dewatering of wasted sludge.

Fleischer et al. (2005) compared operating costs. They estimated the operating costs of an MBR system including activated carbon adsorption at $1.77 per 1,000 gallons treated. These costs were of the same order of magnitude as those of alternative processes, and they compared favorably to those of processes that are chemical-intensive, such as lime treatment.

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EPA
United States
Environmental Protection
Agency
September 2007

Attachment 4

DEQ Email

From:	ANDERSEN Keith
To:	Jim Hossley
Cc:	NOMURA Ranei; Rodger Craddock; Jennifer Wirsing
Subject:	RE: Questions from City of Coos Bay
Date:	Friday, April 22, 2016 12:37:09 PM
Attachments:	Coos Bay QA 4-22-16 final.docx

Jim:

Attached are DEQ's answers to the questions posed below. We look forward to the conversation with the Council at Tuesday's work session.

Keith Andersen
Western Region Administrator
Oregon Department of Environmental Quality
165 E. 7th Street
Eugene, OR 97401
541.687.7355 (direct)
503.983.2378 (mobile)

From: Jim Hossley [mailto:JHossley@coosbay.org]
Sent: Thursday, April 21, 2016 1:33 PM
To: ANDERSEN Keith <ANDERSEN.Keith@deq.state.or.us>
Cc: NOMURA Ranei <NOMURA.Ranei@deq.state.or.us>; Rodger Craddock <rcraddock@coosbay.org>; Jennifer Wirsing <jwirsing@coosbay.org>
Subject: RE: Questions from City of Coos Bay

Hi Keith/Ranei:

City of Coos Bay staff is sending a packet of information to the City Council late tomorrow afternoon(Friday the 21st) in advance of the Council's work session on Tuesday the 26th. If that timing does not work for you all, that is ok, I'll just let Council know that answers to our questions to DEQ will be forth coming. The questions highlighted below can be answered by our consultants, but we welcome any insight you would wish to add.

Thanks for your continued assistance.

Jim Hossley
Public Works Director
City of Coos Bay
500 Central Avenue
Coos Bay, OR 97420
(541) 269-8918

From: ANDERSEN Keith [mailto:ANDERSEN.Keith@deq.state.or.us]
Sent: Friday, April 15, 2016 11:16 AM

To: Jim Hossley <JHossley@coosbay.org>; NOMURA Ranei <NOMURA.Ranei@deq.state.or.us>
Cc: Rodger Craddock <rcraddock@coosbay.org>; Jennifer Wirsing <jwirsing@coosbay.org>
Subject: RE: Questions from City of Coos Bay

Jim:

We will work on providing a response as soon as possible to any of the questions we can answer readily. Of note, your own consultants probably have the expertise to answer some of these also.

Ranei: As we discussed.

Keith Andersen
Western Region Administrator
Oregon Department of Environmental Quality
165 E. 7th Street
Eugene, OR 97401
541.687.7355 (direct)
503.983.2378 (mobile)

From: Jim Hossley [mailto:JHossley@coosbay.org]
Sent: Friday, April 15, 2016 11:13 AM
To: ANDERSEN Keith <ANDERSEN.Keith@deq.state.or.us>
Cc: Rodger Craddock <rcraddock@coosbay.org>; Jennifer Wirsing <jwirsing@coosbay.org>; Jim Hossley <JHossley@coosbay.org>
Subject: Questions from City of Coos Bay

Hi Keith:

Here are some questions the Coos Bay City Council has for DEQ based on DEQ staff's knowledge and expertise. Rodger asked that I send this to you. We would be thankful for your answers to any of the questions posed below.

Regarding the approved SBR for WWTP2:
Will the SBR be capable of meeting current Water Quality standards?
Will the proposed approved WWTP2 SBR & UV system meet WQ standards of the future, i.e. for the next 20 years?
Is the SBR "Upgradeable" to MBR?
Is there validity to claim that EPA is on cusp of issuing more stringent water quality standards?

MBR:
Are construction and operation/maintenance cost for an MBR typically more, similar, or less than those cost for an SBR?
DEQ staff attended VA where MBR was discussed as option, does DEQ staff still concur with SBR alternative chosen?
We understand MBR produces higher quality effluent than SBR, with that, why is DEQ not requiring

Coos Bay to install tertiary treatment?
Typically, what is % removal of viruses for an MBR?
Is virus removal rate with MBR/UV combo significantly better than or is it similar to an SBR/UV system?
What is the feasibility of an MBR plant when there with big variations in seasonal influent flows like Coos Bay?
If Coos Bay was to use MBR technology, would Coos Bay need a dual system like Ashland has and Sutherlin is proposing?
How does the performance of an MBR compare with that of an SBR vs dissolved metals and pharmaceuticals?

Infiltrating Effluent:
If regional WWTP effluent is to be infiltrated into the dunes sands of the North Spit, what is permitting process / timeline with DEQ? What other state or federal agencies would be involved?
Is effluent groundwater recharge done anywhere in Oregon?
Does DEQ have concerns with recharge of a drinking water aquifer with tertiary treated effluent?

Failure to meet MAO or NPDES Permit:
What is the likelihood of WWTP2 MAO penalties being enforced and/or additional penalties beyond those in the MAO?
Can the existing WWTP 2 meet the City's 2003 NPDES permit?
When will DEQ issue a new NPDES permit replacing the 2003 permit?
Will the existing WWTP2 will be able to meet the proposed limits in the new NPDES permit?
What is a possible course of action (COA) by DEQ for City's failure to meet NPDES permit limits?
Likely COA by DEQ for City's failure to meet NPDES permit limits?

SRF Funding:
Is SRF loan still available if Council approves loan agreement?
Should Council change design and/or location will SRF loan funding be available, and if so what rate?

If Coos Bay City Council Seeks new WWTP2 site and/or technology alternative:
What is DEQ likely COA?
Will DEQ support regional WWTP?
What is the likely permitting time?
Is use of private WW facility by municipality to treat influent permissible?
What is DEQ's view of local government depending upon private utility to treat it's influent?

Thanks,

Jim Hossley
Public Works Director
City of Coos Bay
500 Central Avenue

Coos Bay, OR 97420
(541) 269-8918

DEQ Response to City of Coos Bay Questions
4/22/2016

1. **Regarding the approved SBR for WWTP2:**
   a. **Will the SBR be capable of meeting current Water Quality standards?**
   Yes.

   b. **Will the proposed approved WWTP2 SBR & UV system meet WQ standards of the future, i.e. for the next 20 years?**
   The proposed wastewater treatment plant is designed to meet all current and known future water quality standards. However, the Clean Water Act requires DEQ to review the water quality standards at least once every three years. During the review, DEQ revises standards to incorporate the latest scientific information and to make any other revisions the state determines are needed. DEQ cannot predict what information will become available over the next 20 years. This is true for both freshwater and salt water discharges. Should DEQ promulgate water quality standards that require modifications to the treatment plant and/or new treatment processes, DEQ will work with the City to establish a reasonable compliance schedule.

   c. **Is the SBR "Upgradeable" to MBR?**
   Yes.

   d. **Is there validity to claim that EPA is on cusp of issuing more stringent water quality standards?**
   EPA recently proposed for public comment copper and cadmium criteria that, if finalized, would apply in Oregon. DEQ is simultaneously preparing a state rule to address copper with the objective of mooting out the need for EPA to publish its rule. DEQ is also in the midst of rulemaking to clarify state bacteria standard. This is not an effort to make the bacteria criteria more stringent, rather the rulemaking identifies the location of recreational and shellfish uses to clarify which bacteria criteria apply.

   Whether the proposed copper criteria would be more or less stringent than what previously applied varies around the state because the criteria vary with water chemistry. EPA's recently proposed cadmium criteria are slightly more stringent than what had applied previously. EPA must also propose criteria for aluminum in 2017 and it is too early to predict the relative stringency of those criteria.

   Nationally, EPA has efforts underway to develop criteria for viruses and selenium. However, it is too early in EPA's process to predict concentrations and these criteria would not become effective in Oregon until the state initiates its own rulemaking to include them in state water quality standards.

2. **MBR:**
   a. **Are construction and operation/maintenance cost for an MBR typically more, similar, or less than those cost for an SBR?**
   More.

   b. **DEQ staff attended VA where MBR was discussed as option, does DEQ staff still concur with SBR alternative chosen?**

Yes.

c. **We understand MBR produces higher quality effluent than SBR, with that, why is DEQ not requiring Coos Bay to install tertiary treatment?**
The SBR produces effluent in compliance with state standards and meets DEQ rules. DEQ has no authority to require the City to go beyond what is required by state rule.

d. **Typically, what is % removal of viruses for an MBR?**
Viral removal by the membrane itself will depend on the pore size of the membrane and the size of the virus. The types of membranes typically used in MBRs have pore sizes that range from 10 to 0.1 microns. Viruses range from 0.005 microns to 0.3 microns. Also, membranes are subject to breakage and tears which would allow both bacteria and viruses to pass though. Accordingly, DEQ requires the MBR effluent to be disinfected, which is the same requirement as for a SBR.

e. **Is virus removal rate with MBR/UV combo significantly better than or is it similar to an SBR/UV system?**
It will depend on the design and capacity of both the SBR and the UV system.

f. **What is the feasibility of an MBR plant when there with big variations in seasonal influent flows like Coos Bay?**
MBR alternatives were included in the 2009 (West Yost) and 2012 (Civil West) facilities plans. Both plans determined that MBR technology was not practical for Coos Bay. Civil West states: "...While the MBR system can provide unparalleled effluent quality, the costs of providing capacity and redundancies in these systems simply make them impractical for this project." DEQ agrees with Civil West's assessment.

g. **If Coos Bay was to use MBR technology, would Coos Bay need a dual system like Ashland has and Sutherlin is proposing?**
Any treatment system Coos Bay chooses must meet DEQ's requirements for capacity and redundancy. These are available in DEQ's guidance documents.

Note: Ashland does not have a MBR and Sutherlin is not proposing a MBR. Ashland has a tertiary membrane filtration system. Sutherlin is proposing a SBR with a tertiary disc filter.

h. **How does the performance of an MBR compare with that of an SBR vs. dissolved metals and pharmaceuticals?**
Research indicates that activated sludge systems with longer residence times have greater removal efficiencies for dissolved metals and pharmaceuticals. In general, SBRs operate with longer residence times. Accordingly, in general, a SBR will have better removal efficiencies for dissolved metals and pharmaceuticals.

3. **Infiltrating Effluent:**
   a. **If regional WWTP effluent is to be infiltrated into the dunes sands of the North Spit, what is permitting process / timeline with DEQ? What other state or federal agencies would be involved?**
   Prior to application, DEQ would expect land use compatibility issues to be resolved and groundwater studies be conducted by the applicant. Given the location of the North Spit and need for funding through SRF, DEQ expects that the state and federal agencies involved would

be similar to what the City is currently experiencing with the upgrade to plant #2. In addition, we expect that tribal nations would be interested in any project on the North Spit. Once the application is complete and submitted to DEQ, it could take anywhere from six months or more to get the permit to public notice. It is difficult to determine whether or when the permit could be issued until the public participation process concludes. This of course does not account for any other federal or state approval/permitting processes that may be required.

b. **Is effluent groundwater recharge done anywhere in Oregon?**
Injection of municipal effluent into underground sources of drinking water is prohibited by OAR 340-044-0015. However, infiltration basin systems may be permitted if it can be shown that beneficial uses will remain protected and treated wastewater will not be directly injected into groundwater. Wedderburn and Camp Rilea are examples of infiltration systems in the coastal area of DEQ's Western Region.

c. **Does DEQ have concerns with recharge of a drinking water aquifer with tertiary treated effluent?**
Infiltration of any treated wastewater into the ground poses the potential to contaminate groundwater. DEQ reviews each project for potential impacts on a case-by-case basis.

4. **Failure to meet MAO or NPDES Permit:**
   a. **What is the likelihood of WWTP2 MAO penalties being enforced and/or additional penalties beyond those in the MAO?**
   DEQ intends to enforce the provisions of the MAO and assess stipulated penalties if the City does not meet the schedule set forth in the MAO.

   b. **Can the existing WWTP 2 meet the City's 2003 NPDES permit?**
   No.

   c. **When will DEQ issue a new NPDES permit replacing the 2003 permit?**
   DEQ put the NPDES permit renewal for WWTP #2 on hold to allow the city to repair its outfall and collect additional mixing zone data. Since the City has completed this work, the renewal process is scheduled to begin again in late 2016.

   d. **Will the existing WWTP2 will be able to meet the proposed limits in the new NPDES permit?**
   No.

   e. **What is a possible course of action (COA) by DEQ for City's failure to meet NPDES permit limits?**
   For plant #2, the MAO allows the City to operate with "interim" limits. Failure to meet the interim limits results in stipulated penalties specified in the MAO. For violations not covered by the MAO or violations at plant #1, DEQ would address violations according to DEQ enforcement rules and guidelines.

   f. **Likely COA by DEQ for City's failure to meet NPDES permit limits?**
   See answer in (e) above.

5. **SRF Funding:**
   a. **Is SRF loan still available if Council approves loan agreement?**

Yes, the current SRF loan is still available through FY2017.

b. **Should Council change design and/or location will SRF loan funding be available, and if so what rate?**
If the project should change design and/or location, the city would likely need to re-apply for SRF funding. Based on the nature of the changes, federal cross cutting authorities may also need to be updated. For example, changing location would require an update to the federal cross-cutting authorities, while a change to design might not. Given the SRF funds currently available in the program, it is likely SRF funding would be available. Rates change every quarter, so the rate for a future loan would be dependent on the rate when the loan is signed. If the loan is paired with a Sponsorship Option as it is now, the loan could be as low as 1%.

6. **If Coos Bay City Council Seeks new WWTP2 site and/or technology alternative:**
   a. **What is DEQ likely COA?**
   DEQ requires corrective actions to be completed "as soon as possible." Seeking a new site and/or technology alternatives would unacceptably delay the project and DEQ would reject the City's request for additional time. Should the City fail to comply with the time schedule in the MAO, DEQ will assess the penalties stipulated in the MAO.

   b. **Will DEQ support regional WWTP?**
   Not at this time for the reasons in 6.a. above. However, DEQ may support a regional WWTP in the future.

   c. **What is the likely permitting time?**
   It is difficult to determine the permitting time for any project without details. Prior to application, DEQ would expect land use compatibility issues to be resolved and groundwater and/or mixing zone studies to be conducted by the applicant. Once the application is complete and submitted to DEQ, it could take six months or more to get the permit to public notice. Due to permit complexity, a National Pollutant Discharge Elimination System permit for discharges to surface water typically takes longer than Water Pollution Control Facilities permit. It is difficult to determine whether or when the permit could be issued until the public participation process concludes. This of course does not account for any other federal or state approval/permitting processes that may be required.

   d. **Is use of private WW facility by municipality to treat influent permissible?**
   DEQ needs more detail on how this would be accomplished to research this concept further. Please be aware that private facilities are not able to access the same funding sources as public entities.

   e. **What is DEQ's view of local government depending upon private utility to treat its influent?**
   DEQ will need to conduct additional research on this subject. To our knowledge, this model does not exist in Oregon. As a result, we do have concerns about the applicability of various NPDES permitting requirements because federal regulations have provisions for publicly owned treatment works that may not apply to private utilities. We are also concerned that access to different funding programs may also be affected with a move to a private utility.

We do, however, have many examples of private companies operating publically owned treatment plants successfully. For example, Coos Bay's wastewater treatment plants are operated and maintained by a private company.

Attachment 5

Summary of Considerations for Implementing Artificial Groundwater Recharge Using Treated Wastewater (Recycled Water) in Oregon And OAR 340-044-0015

GSI Water Solutions, Inc.

Memorandum

To: Jim Hossley – Public Works Director, City of Coos Bay

From: Jason Melady, RG, CWRE – Senior Hydrogeologist, GSI Water Solutions, Inc.
Dave Livesay, RG – Principal Hydrogeologist, GSI Water Solutions, Inc.

Date: April 21, 2016

Re: **Summary of Considerations for Implementing Artificial Groundwater Recharge Using Treated Wastewater (Recycled Water) in Oregon**

Introduction

This memorandum provides a summary of the basic permitting and technical considerations for using recycled wastewater to recharge groundwater in Oregon. We understand the City of Coos Bay (City) is in the early stages of assessing the potential of developing a regional wastewater treatment plant (WWTP) using membrane bioreactor (MBR) technology to produce high-quality effluent that would be used to recharge the shallow dunal aquifer in the vicinity of the North Spit sand dunes. Based on our recent discussion, the treated effluent discharge rates from the WWTP may range from 3 million gallons per day (mgd) during low use periods to 30 mgd during peak discharge periods, when the stormwater component of WWTP influent is high, particularly during the rainy season.

Project Permitting

The proposed project will require permits and licensing from the Oregon Department of Environmental Quality (DEQ) and Oregon Water Resources Department (OWRD). Additionally, the proximity of the project to the Oregon Dunes National Recreational Area (ODNRA) and an existing drinking water wellfield maintained by the Coos Bay North Bend Water Board (Water Board) likely will require several state and federal permits related to land use and environmental impacts. The following sections summarize the potential spectrum of permitting processes that would be typical for this type of project. Specific permitting requirements for the proposed project can be refined as basic parameters for the project are further defined.

OWRD Permitting

OWRD is the lead state agency for authorizing and administering artificial groundwater recharge projects. OWRD evaluates and issues authorizations for projects based on consultation and approval from DEQ and Oregon Health Authority's Drinking Water Program (OHA-DWP) for project elements that fall under the regulatory authority of those agencies. OHA-DWP will be a part of the review process and likely will weigh in with regard to protection of the dunal aquifer for drinking water purposes and will be

particularly attuned to the proximity of the recharge project relative to the Water Board's drinking water wellfield (which is not currently operated). OWRD administers a two-step process for permitting artificial groundwater recharge projects: (1) OWRD initially issues a "limited license" for a period of 5 years to assess the viability of the project; OWRD may renew the limited license, as necessary, to fully evaluate project feasibility at full buildout, and (2) the project owner can apply to OWRD for a permit for long-term authorization of the project after feasibility has been confirmed through testing under a limited license. OWRD defines two separate artificial groundwater recharge rule structures and authorizations, depending on the type of recharge proposed. Aquifer storage and recovery (ASR) refers to rules associated with artificial recharge through a well, and artificial groundwater recharge (AR) refers to rules associated with artificial recharge through surface infiltration, but also can include recharge through a well. The following list summarizes requirements for OWRD limited license permitting for either ASR or AR using recycled or reclaimed water:

- Source water for recharge requires authorization for use by either a water right permit, certificate, or reclaimed water registration issued by OWRD.
- Recharge water quality must meet drinking water standards (ASR rules require recharge water quality to be less than half of the drinking water standards for most constituents) and cannot degrade groundwater quality. OWRD will defer to DEQ and OHA-DWP for approval of recharge water quality compliance.
- An ASR or AR limited license application will require a registered geologist and/or professional engineer to submit information describing geologic and hydrogeologic conditions and a preliminary confirmation of project feasibility based on (1) anticipated recharge rates and volumes and hydrogeologic characteristics of the target aquifer for recharge, (2) a water quality compatibility analysis of the proposed recharge source water and native groundwater, and (3) a detailed description and design drawings of project infrastructure. Land use approval by the agencies with jurisdiction over the site of the project also generally will be required as part of the limited license application.
- Annual reporting of project monitoring data and analysis will be required by OWRD under a limited license and long-term permit.

DEQ Permitting

DEQ administers rules and permitting associated with use of treated wastewater, or recycled water, for several purposes, including artificial groundwater recharge. Current requirements for use of recycled water for artificial groundwater recharge include, but may not limited to, the following:

- Recycled water must be treated to "Class A" standards as defined by DEQ rules (Oregon Administrative Rule 340-055), which generally require the highest levels of oxidation, filtration, and disinfection treatment standards for treated wastewater.
- Recycled water must meet federal and state drinking water standards and the quality must be such that it does not degrade the quality of groundwater in the aquifer receiving the artificially recharged water.
- Recycled water, such as from the proposed WWTP, can only be recharged using surface infiltration or through a well completed in the shallow subsurface above the groundwater table (vadose zone injection). Direct injection of recycled water into groundwater is specifically prohibited by DEQ rules.
- Based on discussions with DEQ's staff, the selected wastewater treatment method likely will require (1) evaluation by DEQ to verify effluent water quality and (2) redundancy elements to

ensure adequate treatment before artificial groundwater recharge in the event of the failure or ineffectiveness of primary elements.

- An underground injection control (UIC) permit may be required depending on the selected method of artificial groundwater recharge.
- An approved recycled water use plan will be required. This plan will include a groundwater monitoring plan, a description of hydrogeologic characteristics to assess groundwater time of travel from the recharge area to areas of groundwater use and discharge, and a determination of whether recharge will be to a drinking water protection area.

Other Permitting

The construction and operation of an advanced WWTP and artificial groundwater recharge system would require a number of permits, many of which cannot be definitively identified at this point. However, because the location of the project may be within or in close proximity to the ODNRA and a drinking water wellfield maintained by the Water Board, the associated environmental issues related to permitting should be anticipated to be significant. Other permitting may include compliance with the following federal, state, and local programs, in addition to the state requirements described above:

- Special Use Permit (U.S. Forest Service)
- National Environmental Policy Act (NEPA) review (Endangered Species Act and public use value along temporary or permanent disturbance areas)
- Clean Water Act
- State and/or county land use modification
- 404d Joint Permit (Oregon Department of State Lands/U.S. Army Corps of Engineers jurisdictional wetlands)
- Indian Trust, Confederated Tribes of Coos, Lower Umpqua, and Siuslaw Indians (subterranean disturbance areas)
- Coastal Zone Compliance
- Solid Waste (land application)

Groundwater Recharge Technical Considerations

Implementation of an artificial groundwater recharge project requires evaluation of several hydrogeologic characteristics primarily related to the (1) ability of the target aquifer to accept and store the proposed recharge rates and volumes without causing flooding, (2) potential impacts from an increase in groundwater discharge from the aquifer, (3) potential for degradation of groundwater quality, (4) potential for injury to existing groundwater users, and (5) operational and maintenance parameters. There have been decades of studies on the groundwater and surface water resources in the vicinity of the proposed project area and much is known about the area's hydrology. The dunal aquifer is bounded to the west by the Pacific Ocean, to the south by Coos Bay, and to the east by the North Slough and sedimentary bedrock. The aquifer is composed of dune and marine sands, which act as a single hydrologic unit. The aquifer extends from near the ground surface to a depth of approximately 150 to 200 feet. Groundwater is naturally recharged almost exclusively by precipitation falling on the dunes; annual precipitation in this area is approximately 65 inches per year.

The majority of groundwater in the dunal aquifer discharges offshore to the surrounding saltwater bodies. There is an ecologically important interaction between groundwater and surface water on the dunes and wildlife habitat in the surrounding areas. In low-lying areas, known as deflation plains, the groundwater table intersects the land surface and forms shallow freshwater lakes and wetlands on the dunal surface. The depth to the groundwater surface in many locations suitable for siting recharge facilities is relatively close to the ground surface, commonly within 10 feet of ground surface. Groundwater levels also generally rise to levels closer to ground surface during high precipitation periods or during the winter. Consequently, a key element to evaluating the feasibility of the proposed project will be to identify and assess whether there are locations that have the necessary combination of the following attributes: (1) high vertical permeabilities, (2) sufficient "space" within the dunal aquifer to accommodate the recharge water during the wet season, and (3) suitable location, size, and other physical attributes for the recharge facilities. The presence of sufficient "space" within the dunal aquifer for significant artificial groundwater recharge and storage is perhaps the greatest uncertainty, particularly during elevated periods of precipitation when dunal groundwater levels are already high and recycled water discharge rates are anticipated to be at their highest. This appears to be a significant project feasibility element that needs to be carefully assessed if the project moves forward.

In addition to basic hydrogeologic feasibility considerations, the Water Board maintains a wellfield (authorized by several OWRD-issued groundwater permits) within the ODNRA. Because the wells are located on federal land, the wellfield is maintained and operated under a Special Use Permit with the U.S. Forest Service, the agency that administers the ODNRA. The wellfield consists of 21 water supply wells that historically provided up to 5 mgd of groundwater from the shallow dunal aquifer for industrial operations on the North Spit. Currently, the wells are used on a minimal basis (less than 1 mgd) to provide water to maintain an ocean outfall, and the Water Board maintains a treatment facility to use up to 1 mgd of groundwater for potable uses as an emergency backup supply. Long-term water supply planning envisions increased use of this wellfield as a source of drinking water for the Water Board. The feasibility and potential risks of discharging recycled wastewater into the dunal aquifer within the vicinity of the drinking water wellhead protection area for the Water Board's wellfield most certainly will require detailed evaluation, and consultation and coordination with the Water Board if the project moves forward.

ATTACHMENT 5A

DEPARTMENT OF ENVIRONMENTAL QUALITY

DIVISION 44
CONSTRUCTION AND USE OF WASTE DISPOSAL WELLS OR OTHER UNDERGROUND INJECTION ACTIVITIES (UNDERGROUND INJECTION CONTROL)

340-044-0005
Definitions
As used in these regulations unless the context requires otherwise:
(1) "Absorption Facility" means a system receiving the flow from septic tanks or other treatment units to distribute wastewater for oxidation and absorption by the soil within the zone of aeration.
(2) "Aquifer" means an underground zone holding water that is capable of yielding a significant amount of water to a well or spring.
(3) "Aquifer Storage and Recovery" means the storage of water from a separate source that meets drinking water standards in a suitable aquifer for later recovery and not having as one of its primary purposes the restoration of the aquifer.
(4) "Authorized Representatives" means the staff of the Department or of the local unit of government performing duties for and under agreement with the Department as authorized by the Director to act for the Department.
(5) "Best Management Practices (BMPs)" for storm water means schedules of activities, prohibitions of practices, maintenance procedures or other management practices to prevent or reduce the pollution of waters of the state. BMPs for storm water may include operational and structural source controls that minimize and prevent contaminants from entering storm water as well as treatment BMPs that remove contaminants contained in storm water runoff before disposal or discharge.
(6) "Cesspool" means a receptacle that receives sewage, allows separation of solids and liquids, retains the solids and allows liquids to seep into the surrounding soil through perforations in the lining or an open bottom.
(7) "Commercial" means a type of business activity that may distribute goods or provide services, but does not involve the manufacturing, processing or production of goods.
(8) "Confinement Barrier" means a naturally occurring zone in subsurface soil or bedrock that prevents the movement of liquids and contaminants into the underlying groundwater aquifer and which may act as a confining unit to an underlying groundwater aquifer.
(9) "Construction" includes installation, alteration, repair or extension.
(10) "Contaminant" means any chemical, ion, radionuclide, synthetic organic compound, microorganism, waste or other substance that does not occur naturally in groundwater or that occurs naturally but at a lower concentration.
(11) "Contamination" means introduction of a contaminant.
(12) "Department" means the Department of Environmental Quality.
(13) "Director" means the Director of the Department of Environmental Quality or the Director's authorized designee.
(14) "Drywell" means a well, other than a subsurface fluid distribution system, completed so that its bottom and sides are typically dry except when receiving fluids.
(15) "Fluid" means any material or substance that flows or moves whether in a semisolid, liquid, sludge, gas or any other form or state.
(16) "Governmental Unit" means the state or federal government or any agency thereof.
(17) "Groundwater Point Source" means any confined or discrete source of pollution where contaminants can either enter into, or be conveyed by the movement of water, to public waters.
(18) "Hazardous Substance" means:
(a) Hazardous waste.
(b) Any substance defined as a hazardous substance pursuant to section 101(14) of the federal Comprehensive Environmental Response, Compensation and Liability Act.

(c) Oil or petroleum products.
(d) Any substance designated by the Environmental Quality Commission under ORS 465.400.
(19) "Hazardous Waste" means a waste as defined in ORS 466.005 or 40 CFR 261.3.
(20) "Improved Sinkhole" means a naturally occurring depression, rock fracture, or other natural crevice, found in volcanic or other types of bedrock formations, that has been modified for the purpose of directing and emplacing fluids into the subsurface.
(21) "Industrial Activities" for the purpose of storm water injection control means, but is not limited to, manufacturing, processing and material handling activities and those areas of an industrial facility associated with such activities. Material handling activities include the storage, loading and unloading, transport or conveyance of any raw material, intermediate product, final product or waste product, and specifically includes hazardous substances, toxic materials and petroleum products.
(22) "Industrial Waste" means any liquid, gaseous, radioactive or solid waste substance or a combination thereof resulting from any process of industry, manufacturing, trade or business, or from the development or recovery of any natural resources.
(23) "Injection" or "Underground Injection" means the emplacement or discharge of fluids into the subsurface.
(24) "Injection System" or "Underground Injection System" means a well, improved sinkhole, sewage drain hole, subsurface fluid distribution system or other system or groundwater point source used for the subsurface emplacement or discharge of fluids.
(25) "Low-Temperature Geothermal Fluid" means any groundwater used for its thermal characteristics that is encountered in a well with a bottom hole temperature of less than 250 degrees Fahrenheit.
(26) "Mine Backfill" means mine tailings, sand or other solids with fluids used to fill mined-out portions of subsurface mines.
(27) "Municipal Sanitary Sewer Service" means a sanitary waste collection, transmission or treatment facility owned and operated by a municipality.
(28) "Municipality" means any county, city, special service district, or other governmental entity.
(29) "North American Industry Classification System" or "NAICS" means the system used for classifying businesses and reporting industry statistics adopted in 1997 for United States federal agency implementation that replaces the Standard Industrial Code (SIC) system.
(30) "On-Site Sewage Disposal System" means a sewage disposal system such as a standard subsurface, alternative or experimental system as defined in OAR 340-071 that is installed on land of the owner of the system or on other land on which the owner of the system has the legal right to install the system.
(31) "Owner or Operator" means any person who alone, or jointly, or severally with others:
(a) Owned, leased, operated, controlled or exercised significant control over the operation of a facility;
(b) Has legal title to any lot, dwelling, or dwelling unit;
(c) Has care, charge, or control of any real property as agent, executor, executrix, administrator, administratix, trustee, lessee or guardian of the estate of the holder of legal title; or
(d) Is the contract purchaser of real property.
(32) "Permit" means a written authorization from the Director or the Director's authorized designees to discharge wastes or construct, install, modify or operate a disposal system. A Water Pollution Control Facilities (WPCF) permit is one type of permit.
(33) "Person" means the United States and agencies thereof, any state, any individual, public or private corporation, political subdivision, governmental agency, municipality, industry, copartnership, association, firm, trust, estate or any other legal entity whatsoever.
(34) "Pollution" means alteration of the physical, chemical or biological properties of any waters of the state, including changes in temperature, taste, color, turbidity, silt or odor of the waters, or such discharge of any liquid, gaseous, solid, radioactive or other substance into any waters of the state, which will or tends to, either by itself or in connection with any other substance, create a public nuisance or which will or tends to render such waters harmful, detrimental or injurious to public health, safety or welfare, or to domestic, commercial, industrial, agricultural, recreational or other legitimate beneficial uses or to livestock, wildlife, fish or other aquatic life or the habitat thereof.
(35) "Radioactive Waste" means waste as defined in ORS 469.300 or that contains radioactive material in concentrations that exceed those listed in 10 CFR Part 20, Appendix B, Table II, Column 2.
(36) "Sanitary Waste" means liquid or solid wastes originating solely from humans and human activities, such as wastes collected from toilets, showers, wash basins, sinks used for cleaning domestic areas,

sinks used for food preparation, clothes washing operations and sinks or washing machines where food and beverage serving dishes, glasses and utensils are cleaned. Sources of these wastes may include, but are not limited to, single or multiple residences, hotels and motels, restaurants, bunkhouses, schools, ranger stations, crew quarters, guard stations, campgrounds, picnic grounds, day-use recreation areas, other commercial facilities and industrial facilities provided the waste is not mixed with industrial waste. The combination of industrial waste and sewage is not considered sanitary waste.
(37) "Seepage Pit" means a type of absorption facility that is a covered pit with an open-jointed lining through which septic tank effluent may seep or leach into surrounding soil.
(38) "Septic System" means a system used to emplace sanitary waste below the surface and is typically comprised of a septic tank and subsurface fluid distribution or disposal system.
(39) "Sewage" means the water-carried human or animal waste from residences, buildings, industrial establishments or other places, together with such groundwater infiltration, surface water or industrial waste as may be present.
(40) "Sewage Drain Hole" or "Sewage Drill Hole" means a drilled, hammered or blasted borehole or natural lava crack or fissure used for sewage or sanitary waste disposal, and that may include a septic tank ahead of the disposal well.
(41) "Storm Water" means water from precipitation or snow melt that collects on or runs off outdoor surfaces such as buildings, roads, paved surfaces and unpaved land surfaces.
(42) "Subsurface Fluid Distribution System" means an assemblage of perforated pipes, drain tiles or other mechanisms intended to distribute fluids below the surface of the ground.
(43) "Surface Infiltration" means fluid movement from the ground surface into the underlying soil material without the use of a subsurface fluid distribution system or injection system.
(44) "Time-of-Travel" means the amount of time it takes groundwater to flow within an aquifer to a given well.
(45) "Toxic Material" means any material that will cause or can reasonably be expected to cause a hazard to aquatic, human or animal life.
(46) "Underground Source of Drinking Water" means an aquifer or groundwater source that supplies or potentially could supply drinking water for human consumption.
(47) "Vehicle Trips" means a one-direction vehicle movement either entering or exiting a facility.
(48) "Waste Disposal Well" means a well used to dispose of wastes.
(49) "Wastes" means sewage, industrial wastes, agricultural wastes, and all other liquid, gaseous, solid, radioactive or other substances which will or may cause pollution or tend to cause pollution of any waters of the state.
(50) "Waters of the State" or "Public Waters" means lakes, bays, ponds, impounding reservoirs, springs, wells, rivers, streams, creeks, estuaries, marshes, inlets, canals, the Pacific Ocean within the territorial limits of the State of Oregon and all other bodies of surface or underground waters, natural or artificial, inland or coastal, fresh or salt, public or private (except those private waters which do not combine or effect a junction with natural surface or underground waters), which are wholly or partially within or bordering the state or within its jurisdiction.
(51) "Well" means a bored, drilled, driven or dug hole whose depth is greater than its largest surface dimension, an improved sinkhole, a sewage drain hole, or a subsurface fluid distribution system.
(52) "WPCF Permit" means a Water Pollution Control Facilities permit as defined in OAR 340-045 to construct and operate a disposal system with no discharge to navigable waters.
[Publications: Publications referenced in this rule are available from the agency.]
Stat. Auth.: ORS 454.625, ORS 468.020, ORS 468B.020 & ORS 468B.165
Stats. Implemented: ORS 454.605 & ORS 468.005
Hist.: SA 41, f. 5-15-69; DEQ 35-1979, f. & ef. 12-19-79; DEQ 15-1983, f. & ef. 8-26-83; DEQ 8-2001, f. 7-13-01, cert. ef. 9-20-01

340-044-0010

Policy, Purpose and Effective Date

(1) These rules set forth requirements for the State of Oregon Underground Injection Control (UIC) program adopted in conformance with Part C of the federal Safe Drinking Water Act (SDWA) in effect on the date of this rule adoption. It is the policy of the Environmental Quality Commission that the injection of wastes to the subsurface shall be limited and controlled in a manner that protects existing groundwater quality for current or potential beneficial uses including use as an underground source of drinking water.

(2) The injection of untreated or inadequately treated sewage or wastes to waste disposal wells and particularly to waste disposal wells in the lava terrain of Central Oregon constitutes a threat of serious, detrimental and irreversible pollution of valuable groundwater resources and a threat to public health. The policy of the Environmental Quality Commission is to restrict, regulate or prohibit the further construction and use of waste disposal wells in Oregon and to phase out completely the use of waste disposal wells as a means of disposing of untreated or inadequately treated sewage or wastes as rapidly as possible in an orderly and planned manner.
(3) These rules as adopted, amended and repealed by the Environmental Quality Commission on June 22, 2001 are effective on September 20, 2001. The rules previously in effect are effective and enforceable until September 20, 2001.
Stat. Auth.: ORS 454.625, ORS 468.020, ORS 468B.020 & ORS 468B.165
Stats. Implemented: ORS 454.607, ORS 468B.015, ORS 468B.080 & ORS 468B.160
Hist.: SA 41, f. 5-15-69; DEQ 35-1979, f. & ef. 12-19-79; DEQ 8-2001, f. 7-13-01, cert. ef. 9-20-01

340-044-0011

Classification of Underground Injection Systems

Injection systems are classified as follows:
(1) Class I. Injection systems that inject hazardous waste, radioactive waste or other fluids *beneath* the lowermost formation containing an underground source of drinking water. This includes the disposal of fluids containing hazardous waste or radioactive waste into wells, drill holes, sinkholes and cesspools regardless of their capacity or flow rate.
(2) Class II. Injection systems that inject fluids:
(a) Produced by natural gas storage operations, or conventional oil or natural gas production;
(b) Used to enhance recovery of oil or natural gas; or
(c) For storage of hydrocarbons that are liquid at standard temperature and pressure.
(3) Class III. Injection systems that inject fluids for extraction of minerals or other natural resources including sulfur, uranium, metals, salts or potash by methods such as solution mining, in-situ production or stopes leaching.
(4) Class IV. Injection systems that inject hazardous waste or radioactive waste into or above a formation containing an underground source of drinking water. This includes the disposal of fluids containing hazardous waste or radioactive waste into septic systems, drill holes and cesspools regardless of their capacity or flow rate.
(5) Class V. Injection systems not included in Classes I, II, III or IV that inject fluids other than hazardous waste or radioactive waste into the subsurface. Types of Class V injection systems include, but are not limited to, the following:
(a) Sanitary waste injection systems that inject sanitary waste fluids into subsurface fluid distribution or injection systems such as septic systems, drainfields, disposal trenches, seepage pits, cesspools, or sewage drain holes or drill holes.
(b) Industrial/commercial injection systems that inject waste fluids from industrial or commercial business activities. Typical North American Industry Classification System (NAICS) industrial sectors that may produce waste fluids include manufacturing, agriculture, mining and transportation. Injection systems that combine or mix any amount of industrial or commercial wastewater or animal waste with storm water or sanitary waste are considered industrial/commercial injection systems.
(c) Fluid return injection systems that re-inject spent geothermal fluids into the source aquifer following extraction of heat energy or electric power generation, spent brines after extraction of salts, or non-contact heat pump and air conditioning return fluids. Irrigation return flows are not considered fluid return flows.
(d) Storm water injection systems that inject only storm water runoff from residential, commercial or industrial facilities or roadways.
(e) Groundwater management injection systems that inject fluids to manage groundwater quality, groundwater levels, groundwater flow, or groundwater quantity. Injection systems may be used for aquifer recharge, aquifer storage and recovery, subsidence control, saltwater intrusion control, aquifer remediation, aquifer characterization, water well maintenance, groundwater table management, landslide stabilization or special experimental purposes. In general, fluids being injected have water quality equivalent to the background groundwater, or have only localized effects around the well bore when used in aquifer remediation or water well maintenance, or are beneficial to the aquifer remediation.

(c) Class III injection systems injecting fluids for mineral or natural resource extraction.
(d) Class IV injection systems, except for wells reinjecting treated groundwater into the same formation from which it was drawn as part of a removal or remedial action if the injection has prior approval from the Environmental Protection Agency (EPA) or the Director under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or the Resource Conservation and Recovery Act (RCRA).
(2) No person shall cause or allow the following types of Class V injection systems injecting:
(a) Fluids into residential cesspools, or non-residential cesspools designed to serve 20 or more people per day or with a design flow of 2,500 gallons or more per day after April 5, 2005. Construction of new cesspools of any capacity is prohibited by OAR 340-071.
(b) Fluids from industrial or commercial processes that use hazardous substances or toxic materials including petroleum products. The Director may grant exceptions to this prohibition and issue a permit if:
(A) No other reasonable alternative to injection is available;
(B) Treatment of wastewater will remove hazardous substances and toxic materials to background groundwater quality levels prior to injection of wastewater; and
(C) Reliable and adequate treatment can be demonstrated with effluent monitoring and sampling prior to each batch injection of wastewater, and with groundwater monitoring for immediate detection of releases of inadequately treated wastewater.
(c) Fluids from industrial or commercial operation areas where hazardous substances or toxic materials including petroleum products are stored, used or handled, except as allowed in OAR 340-044-0018(3).
(d) Fluids directly from floor pits or floor drains at industrial or commercial facilities, including injection into subsurface fluid distribution systems.
(e) Motor vehicle waste from vehicle repair or maintenance activities.
(f) Industrial or municipal wastewater directly into an underground source of drinking water.
(g) Agricultural drainage.
(3) No person shall cause or allow Class V injection systems injecting sanitary waste, sewage, or industrial or commercial waste into sewage drain holes or sewage drill holes, except as allowed under OAR 340-044-0015(3)(b), 340-044-0017, or 340-044-0018(3).
(a) New sewage drain holes or sewage drill holes are prohibited.
(b) After January 1, 1983, use of existing sewage drain holes or sewage drill holes is prohibited unless municipal sanitary sewer service is not available to the property. Except for single family residences, use of an existing sewage drain hole must be authorized by a permit.
(A) Sanitary sewer service shall be deemed available to a property when:
(i) A sanitary sewer is extended to within 300 feet from the property boundary for a single family dwelling or other establishment with a maximum design flow of not more than 450 gallons per day, or 200 feet multiplied by the number of dwellings or dwelling equivalents for other establishments or greater flows, and
(ii) A sanitary sewer system is not under a connection permit moratorium and the system owner is willing or obligated to provide sewer service.
(B) Within 90 days after sanitary sewer service is available to a property, the owner of that property shall make connection to the sewer and shall abandon and decommission the sewage drain hole in accordance with OAR 340-044-0040. On a case-by-case basis, the Director may waive the requirement to connect to sewer if the Director determines that connection to the sewer is impracticable or unreasonably burdensome.
(c) No person shall modify any structure or change or expand any use of a structure or property that utilizes a sewage drain hole.
(4) After the effective date of these rules, no person shall construct, place in operation or operate any allowable injection system without first obtaining a permit from the Director, unless the injection system is authorized by rule under OAR 340-044-0018.
Stat. Auth.: ORS 454.625, ORS 468.020, ORS 468B.020 & ORS 468B.165
Stats. Implemented: ORS 454.215, ORS 454.615, ORS 454.645, ORS 454.655, ORS 454.675, ORS 468B.025, ORS 468B.050, ORS 468B.080 & ORS 468B.160
Hist.: SA 41, f. 5-15-69; DEQ 35-1979, f. & ef. 12-19-79; DEQ 22-1981, f. & ef. 9-2-81; DEQ 15-1983, f. & ef. 8-26-83; DEQ 8-2001, f. 7-13-01, cert. ef. 9-20-01

Attachment 6

Letters of Support

Attachment 7

MAO

BEFORE THE ENVIRONMENTAL QUALITY COMMISSION

OF THE STATE OF OREGON

IN THE MATTER OF:	)	MUTUAL AGREEMENT AND ORDER
CITY OF COOS BAY, Wastewater Facility No. 2,	)	NO. WQ WQ/M-WR-03-022
Permittee	)	COOS COUNTY

WHEREAS:

1. On August 21, 2003, the Department of Environmental Quality (Department or DEQ) issued National Pollutant Discharge Elimination System (NPDES) Waste Discharge Permit Number 100771 (Permit) to the City of Coos Bay (Permittee). The Permit authorizes the Permittee to construct, install, modify or operate wastewater treatment control and disposal facilities (facilities) and discharge adequately treated wastewaters into Coos Bay, waters of the state, in conformance with the requirements, limitations and conditions set forth in the Permit. The Permit expires on December 31, 2007.

2. Condition 1 of Schedule A of the Permit does not allow Permittee to exceed the waste discharge limitations for fecal coliform, total residual chlorine and ammonia at Outfall 001 after the Permit issuance date. The fecal coliform limitations are a monthly median of 14 organisms per 100 mL with not more than 10 percent of the samples exceeding 43 organisms per 100 mL. The total residual chlorine limitations are 0.02 mg/L monthly average and 0.05 mg/L daily maximum. The ammonia limitations are 20 mg/L monthly average and 30 mg/L daily maximum.

3. DEQ and the Permittee recognize that until new or modified facilities are constructed and put into full operation, Permittee will likely violate the fecal coliform, total residual chlorine and ammonia effluent limitations at times.

4. (a) Permittee presently is capable of treating its effluent so as to meet effluent limitations, measured as specified in the Permit, of 200 organisms per 100 mL as a monthly

geometric mean and 400 organisms per 100 mL as a weekly geometric mean for fecal coliform, 1.0 mg/L monthly average for total residual chlorine and 40 mg/L monthly average and 60 mg/L daily maximum for ammonia.

(b) After completion of the Phase I improvements, the Permittee will be capable of treating its effluent so as to meet effluent limitations, measured as specified in the Permit, of not more than 10 percent of the samples exceeding 43 fecal coliform organisms per 100 mL, 0.25 mg/L monthly average and 0.50 mg/L daily maximum for total residual chlorine and 40 mg/L monthly average and 60 mg/L daily maximum for ammonia. During the start up period in Paragraph 7.B(7), the Permittee shall operate the facilities as effectively as practicable but shall not be required to meet any specific pollutant limitation.

5. The Department and Permittee recognize that the Environmental Quality Commission has the power to impose a civil penalty and to issue an abatement order for violations of conditions of the Permit. Therefore, pursuant to ORS 183.415(5), the Department and Permittee wish to limit and resolve the future violations referred to in Paragraph 3 in advance by this Mutual Agreement and Order (MAO).

6. This MAO is not intended to settle any violation of any interim effluent limitations set forth in Paragraph 4 above. Furthermore, this MAO is not intended to limit, in any way, the Department's right to proceed against Permittee in any forum for any past or future violations not expressly settled herein.

NOW THEREFORE, it is stipulated and agreed that:

7. The Environmental Quality Commission shall issue a final order:

A. Requiring Permittee to comply with the following schedule for Phase I improvements:

(1) By no later than thirty (30) days after issuance of this MAO, the Permittee shall submit to the Department a plan for notifying the public of the potential discharge of bacteria levels exceeding the shellfish standard. The plan shall include procedures

to be followed by the Permittee that may include, but not be limited to, media notifications, posting of warning signs and other public notification steps. Upon approval of the Department, the Permittee shall implement the plan.

(2) By no later than fifteen (15) months after issuance of this MAO, the Permittee shall design, construct and initiate operation of interim dechlorination facilities. It is recognized that the facilities will be low cost and temporary in nature but must be designed to reduce the bacteria and chlorine levels in the effluent to comply with the post -Phase I interim limits in Paragraph 4(b). To the extent possible, the facilities may be used permanently as part of the Phase II improvements.

B. Requiring Permittee to comply with the following schedule for Phase II improvements:

(1) By no later than eighteen months after issuance of this MAO, the Permittee shall submit a draft Facilities Plan to the Department that evaluates alternatives for complying with all water quality standards and ensures that the Permittee can continuously comply with all effluent limitations included in Permittee's Permit.

(2) By no later than ninety (90) days of receiving Department comments, the Permittee shall submit a final approvable Facilities Plan for providing wastewater control facilities as needed to assure that the Permittee can continuously comply with all water quality standards and effluent limitations included in Permittee's Permit. If the Facilities Plan recommends new facilities that will result in a new or modified NPDES Permit, the Facilities Plan submittal shall include an application for a new or modified NPDES Permit.

(3) By no later than nine (9) months after Department approval of the Facilities Plan, the Permittee shall submit draft engineering plans and specifications for the necessary wastewater control facilities to the Department.

(4) By no later than sixty (60) days after of receiving Department comments, the Permittee shall submit a final approvable engineering plans and specifications

for the necessary wastewater control facilities to the Department.

(5) By no later than four (4) months after Department approval of the engineering plans and specifications, Permittee shall award a contract for the construction of the necessary wastewater control facilities.

(6) By no later than two (2) years after award a contract, the Permittee shall complete construction of the approved wastewater control facilities and initiate operations.

(7) By no later than sixty (60) days after the completion of construction, the Permittee shall attain operation level of the wastewater treatment facilities and comply with all water quality standards and all effluent limitations in Permittee's permit.

C. Requiring Permittee to meet the interim effluent limitations set forth in Paragraph 4(a) above from the date this MAO is executed until completion of the corrective actions required by the schedule in Paragraph 7.A. Requiring Permittee to meet the interim effluent limitations set forth in Paragraph 4(b) from the completion of the corrective actions required by Paragraph 7.A. until completion of the corrective actions required by Paragraph 7.B., except, during the start up period in Paragraph 7.B(7), the Permittee is not required to meet the interim limitations in Paragraph 4(b) so long as Permittee operates the facilities as effectively as practicable.

D. Requiring Permittee, upon receipt of a written Penalty Demand Notice from the Department, to pay the following civil penalties:

(1) $250 for each day of each violation of the compliance schedule set forth in Paragraphs 7A and 7.B.

(2) $100 for each violation of each daily average waste discharge limitation set forth in Paragraph 4.

(3) $500 for each violation of each monthly average waste discharge limitation set forth in Paragraph 4.

8. If any event occurs that is beyond Permittee's reasonable control and that causes or may cause a delay or deviation in performance of the requirements of this MAO, Permittee shall immediately notify the Department verbally of the cause of delay or deviation and its anticipated duration, the measures that have been or will be taken to prevent or minimize the delay or deviation, and the timetable by which Permittee proposes to carry out such measures. Permittee shall confirm in writing this information within five (5) working days of the onset of the event. It is Permittee's responsibility in the written notification to demonstrate to the Department's satisfaction that the delay or deviation has been or will be caused by circumstances beyond the control and despite due diligence of Permittee. If Permittee so demonstrates, the Department shall extend times of performance of related activities under this MAO as appropriate. Circumstances or events beyond Permittee's control include, but are not limited to, acts of nature, unforeseen strikes, work stoppages, fires, explosion, riot, sabotage, or war. Increased cost of performance or consultant's failure to provide timely reports may not be considered circumstances beyond Permittee's control.

9. Regarding the schedule set forth in Paragraphs 7A and 7B above, Permittee acknowledges that Permittee is responsible for complying with that schedule regardless of the availability of any federal or state grant monies.

10. The terms of this MAO may be amended by the mutual agreement of the Department and Permittee.

11. The Department may amend the compliance schedule and conditions in this MAO upon finding that such modification is necessary because of changed circumstances or to protect public health and the environment. The Department shall provide Permittee a minimum of thirty (30) days written notice prior to issuing an Amended Order modifying any compliance schedules or conditions. If Permittee contests the Amended Order, the applicable procedures for conduct of contested cases in such matters shall apply.

12. This MAO shall be binding on the parties and their respective successors, agents;

and assigns. The undersigned representative of each party certifies that he or she is fully authorized to execute and bind such party to this MAO. No change in ownership or corporate or partnership status relating to the facility shall in any way alter Permittee's obligations under this MAO, unless otherwise approved in writing by DEQ.

13. All reports, notices and other communications required under or relating to this MAO should be directed to Ruben Kretzschmar, DEQ Coos Bay Regional Office, 340 N. Front Street, Coos Bay, Oregon 97420, phone number (541) 269-2721, extension 23. The contact person for Permittee shall be the City Manager, 500 Central Ave., Coos Bay, OR 97420, phone number 541-269-8912.

14. Permittee acknowledges that it has actual notice of the contents and requirements of the MAO and that failure to fulfill any of the requirements hereof would constitute a violation of this MAO and subject Permittee to payment of civil penalties pursuant to Paragraph 7D above.

15. Any stipulated civil penalty imposed pursuant to Paragraph 7D shall be due upon written demand. Stipulated civil penalties shall be paid by check or money order made payable to the "Oregon State Treasurer" and sent to: Business Office, Department of Environmental Quality, 811 S.W. Sixth Avenue, Portland, Oregon 97204. Within 21 days of receipt of a "Demand for Payment of Stipulated Civil Penalty" Notice from the Department, Permittee may request a hearing to contest the Demand Notice. At any such hearing, the issue shall be limited to Permittee's compliance or non-compliance with this MAO. The amount of each stipulated civil penalty for each violation and/or day of violation is established in advance by this MAO and shall not be a contestable issue.

16. Providing Permittee has paid in full all stipulated civil penalties pursuant to Paragraph 15 above, this MAO shall terminate 60 days after Permittee demonstrates full compliance with the requirements of the schedule set forth in Paragraphs 7A and 7B above.

PERMITTEE

08/20/03
Date

City Manager, City of Coos Bay

DEPARTMENT OF ENVIRONMENTAL QUALITY

8/21/03
Date

Kerri L. Nelson, Western Region Administrator

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FINAL ORDER

IT IS SO ORDERED:

ENVIRONMENTAL QUALITY COMMISSION

8/21/03
Date

Kerri L. Nelson, Western Region Administrator
Department of Environmental Quality
Pursuant to OAR 340-11-136(1)

Attachment 8

The Dyer Partnership MBR Information

THE DYER PARTNERSHIP
ENGINEERS & PLANNERS, INC.

1330 TEAKWOOD AVENUE
Coos Bay, Oregon 97420
Ph: (541) 269-0732
Fx: (541) 269-2044
www.dyerpart.com

MEMORANDUM

DATE April 22, 2016

TO Jim Hossley
City of Coos Bay
500 Central Avenue
Coos Bay, OR 97420

COPY TO Jennifer Wirsing

FROM Steve Major, PE SM
Principle Engineer

PROJECT NAME MBR Performance

PROJECT NO. 187.00

Per your request I have researched the typical performance for a membrane bioreactor (MBR) treatment facility. OVIVO Corporation, one of the leaders of MBR technology, assisted with providing information for a number of the questions. Their technical information pertains to flat plate and flat sheet systems. Hollow fiber systems will have slightly different values but are very similar.

The following information lists the original question along with our response.

1. Are construction and operation/maintenance cost for an MBR typically more, similar, or less than those cost for an SBR?

   Costs are higher for a MBR versus SBR facility due to the fact membranes cost more than SBR equipment and there are more valves, pumps and instrumentation for the MBR facility. We did an analysis between the two systems when we authored the city of Sutherlin Wastewater Facility Plan Amendment in November 2013. The facility was similar in size to Plant 2. The MBR alternative included a MBR to treat dry weather flows and a SBR to treat wet weather flows. The size of the SBR was reduced since both the MBR and SBR systems would operate during higher flow periods. Construction costs for the SBR and MBR/SBR options were $5,491,000 and $7,461,000, respectively. Twenty year present worth life cycle costs, which included O&M and salvage value were $6,940,000 versus $10,819,000.

2. Typically, what is % removal of viruses for an MBR?

   You can achieve a six log removal value (LRV) for bacteria and four LRV for viruses. Two LRV is 99% removal and five LRV is 99.999% removal.

3. Is virus removal rate with MBR/UV combo significantly better than or is it similar to an SBR/UV system?

   Virus removal rates are better with the MBR/UV combination since the MBR uses a physical process, filtering, versus a gravity settling process for the SBR. With the settling process there are more solids in the finished product which the viruses can attach to.

4. What is the feasibility of an MBR plant when there are big variations in seasonal influent flows like Coos Bay?

   Large variation in flows is one of the reasons we do not see MBR plants in western Oregon. Plant 2 has a design value of 2.09 million gallons per day (mgd) for maximum weak weather flow and 6.31 mgd for peak day. Eighty five percent of the flow is at 2.7 mgd or less. Therefore, membranes with a capacity of 4.22 mgd are only being utilized fifteen percent of the time. There is a high cost for providing the required capacity of membranes and keeping the membranes ready to go for only being used approximately fifteen percent of the time.

5. If Coos Bay was to use MBR technology, would Coos Bay need a dual system like Ashland has and Sutherlin is proposing?

   Not sure what facilities Ashland utilizes but we are designing a four basin flow through SBR for Sutherlin. When we evaluated the MBR-SBR option, we included the SBR for treatment of wet weather flows to keep the costs down. The cost for a full MBR facility would have been several times more.

6. How does the performance of an MBR compare with that of an SBR vs dissolved metals and pharmaceuticals?

   MBRs provide for a greater removal rate except for zinc. Not sure why SBRs are more efficient for this metal. MBRs also provide a higher level of removal for pharmaceuticals. This is mainly due to the lack of solids in the MBR effluent as compared to an average solids concentration of 5 to 10 mg/l in the SBR effluent.

I will send electronic copies of three documents that expands on the information provided above. These documents are titled: Metals Removal in Conventional Wastewater Treatment Process and Membrane Bioreactor Process, Final Report – Pilot Testing the Enviroquip (OVIVO) Flat Plate Membrane Bioreactor and Poly-chlorinated dibenzo-*p*-dioxins, dibenzo-furans and dioxin-like poly-chlorinated bipheyls occurrence and removal in conventional and membrane activated sludge processes.

Another point that should be made is that effluent requirements, historically, have become more stringent when NPDES permits are renewed. The flow through SBR is well suited to address future regulatory requirements. The SBR can be converted to an MBR within the proposed tank structure. We designed the conversion at the Spirit Mountain Casino wastewater treatment facility. Membranes were installed within the existing structures which saved money and increased flow capacity.

If you have any questions with the above comments please give me a call.

Final Report

Pilot Testing the Enviroquip Flat Plate Membrane Bioreactor

April, 2004

King County
Technology Assessment and Resource Recovery
Department of Natural Resources and Parks

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Microscopic observations of activated sludge are presented in Figure 2. On February 25, 2003, the floc size was small to moderate. The flocs were dispersed and filamentous organisms were observed. Some free bacteria and small particles were present.

The March 14, 2003 sample contained less free bacteria and small particles than the the Feb 25, 03 sample. Not many free bacteria and only a few floc fragments. Nocardia were observed. No protozoa.

The April 2, 2003 sample contained small flocs (20-30 um), many free bacteria and many floc fragments. A few filament and some Nocardia were present. No protozoa.

The floc size on April 2, 03 appeared to be most dispersed. This concurs with the longer SRT and lower filterability than the other two samples.

5.1.4 Microbiology, metals, organics and endocrine disrupting chemicals

Microbial removal

The MBR shows excellent removal of the microbial population. The total coliform in the effluent was mostly non-detected, as shown in Table 8. Of 39 samples analyzed, total coliform was detected in only 3 samples. Influent and effluent heterotrophic plates counts show 3-4 log removal.

Table 8 Total Coliform and Heterotrophic Plate Counts

	Heterotrophic Plate Count (83 data points)		Total Coliform (39 data points)	
	CFU/100mL		CFU/100mL	
	Influent	Effluent	Influent	Effluent
Average	7.68E+08	1.22E+05	1.02E+08	nd
Max	8.60E+09	1.71E+06	2.00E+09	5
Min	7.60E+06	1.57E+02	2.20E+06	Nd
90^{th} percentile	1.06E+09	3.42E+05	1.16E+08	Nd

Metals and organic compounds

Once per month, the influent and effluent was analyzed for metals and organic compounds on EPA's priority pollutant list. The results are presented in Table 9 and Table 10. Most of the metals were partially removed in the system. The removal ranged from no removal (Magnesium) to 90% (Lead). The removal of some compounds was not quantifiable since the concentration in the effluent was below detection limits. Monthly data on the MBR influent and effluent metal concentration is included in appendix D.

Most of the organic compounds on the priority pollutant list were not detected in the effluent and/or the influent. Some were detected in the influent but not in the effluent. Therefore, removal efficiency was not calculated.

Table 9 Metals

Parameters	Detection limits			Average (7 samples)		
	MDL	RDL	Units	Influent	Effluent	Removal
	- Wet Weight Basis					(%)
M=MT EPA 200.7 (06-02-004-002)						
Aluminum, Total, ICP	0.1	0.5	mg/L	1.58	<MDL	
Calcium, Total, ICP	0.05	0.25	mg/L	19.96	17.90	9.49
Magnesium, Total, ICP	0.03	0.15	mg/L	11.75	13.26	-13.16
M=MT EPA 200.8 (06-03-004&004A-001)						
Antimony, Total, ICP-MS	0.0005	0.0025	mg/L	0.001	0.001	14.02
Arsenic, Total, ICP-MS	0.0005	0.0025	mg/L	0.002	0.002	24.55
Barium, Total, ICP-MS	0.0002	0.001	mg/L	0.027	0.004	77.58
Beryllium, Total, ICP-MS	0.0002	0.001	mg/L	<MDL	<MDL	
Cadmium, Total, ICP-MS	0.0001	0.0005	mg/L	0.0004	<MDL	
Chromium, Total, ICP-MS	0.0004	0.002	mg/L	0.0036	0.0005	78.11
Cobalt, Total, ICP-MS	0.0002	0.001	mg/L	0.0005	0.0003	33.69
Copper, Total, ICP-MS	0.0004	0.002	mg/L	0.0502	0.0054	81.63
Lead, Total, ICP-MS	0.0002	0.001	mg/L	0.0076	0.0006	89.22
Manganese, Total, ICP-MS	0.0002	0.001	mg/L	0.0955	0.0678	
Molybdenum, Total, ICP-MS	0.0005	0.0025	mg/L	0.0063	0.0052	15.34
Nickel, Total, ICP-MS	0.0003	0.0015	mg/L	0.0046	0.0030	25.83
Selenium, Total, ICP-MS	0.0015	0.0075	mg/L	<MDL	<MDL	
Silver, Total, ICP-MS	0.0002	0.001	mg/L	0.0016	<MDL	
Thallium, Total, ICP-MS	0.0002	0.001	mg/L	<MDL	<MDL	
Vanadium, Total, ICP-MS	0.0003	0.0015	mg/L	0.0027	0.0021	19.80
Zinc, Total, ICP-MS	0.0005	0.0025	mg/L	0.1003	0.0466	46.74
M=MT EPA 245.2 (06-01-004-003)				<MDL	<MDL	
Mercury, Total, CVAA	5E-05	0.0002	mg/L	0.0032	<MDL	

Appendix D Monthly Metal Data

Parameters	MDL	RDL	Units	Sep 23, 02			Aug 26, 02			Oct 28, 02			Nov 25, 02		
				Influent	Effluent	Removal	Influent	Effluent	Removal	Influent	Effluent	Removal	Influent	Effluent	Removal
	- Wet Weight Basis					%			%			%			%
M=MT EPA 200.7 (06-02-004-002)															
Aluminum, Total, ICP	0.1	0.5	mg/L	1.64	<MDL	>93.9	4.9	<MDL	>98	1.05	<MDL	>90.5	0.786	<MDL	>87.3
Calcium, Total, ICP	0.05	0.25	mg/L	20.2	20.4	-1.0	25	17.9	28.4	19	18.6	2.1	17.8	16.3	8.4
Magnesium, Total, ICP	0.03	0.15	mg/L	9.67	12	-24.1	12	13	-8.3	10.1	13.5	-33.7	11.3	13.7	-21.2
M=MT EPA 200.8 (06-03-004&004A-001)															
Antimony, Total, ICP-MS	0.0005	0.0025	mg/L	<0.0005	0.0012		0.00092	0.00086	6.5	<MDL	<MDL		<MDL	<MDL	
Arsenic, Total, ICP-MS	0.0005	0.0025	mg/L	0.00298	0.002	32.9	0.00362	0.00282	22.1	0.0019	0.0014	26.3	0.0019	0.0014	26.3
Barium, Total, ICP-MS	0.0002	0.001	mg/L	0.0314	0.00165	94.7	0.07	0.00594	91.5	0.0152	0.00383	74.8	0.0147	0.00346	76.5
Beryllium, Total, ICP-MS	0.0002	0.001	mg/L	<MDL	<MDL		<MDL	<MDL		<MDL	<MDL		<MDL	<MDL	
Cadmium, Total, ICP-MS	0.0001	0.0005	mg/L	0.00044	<MDL	>77.3	0.00073	<MDL	>86.3	0.00025	<MDL	>60	0.00023	<MDL	>56.5
Chromium, Total, ICP-MS	0.0004	0.002	mg/L	0.00324	<MDL	>87.7	0.0109	0.00053	95.1	0.0018	0.00046	74.4	0.0015	0.00043	71.3
Cobalt, Total, ICP-MS	0.0002	0.001	mg/L	0.00048	0.00036	25.0	0.00108	0.00029	73.1	0.00033	0.00025	24.2	0.00027	0.00024	11.1
Copper, Total, ICP-MS	0.0004	0.002	mg/L	0.0658	0.00436	93.4	0.145	0.00203	98.6	0.0283	0.0016	94.3	0.0282	0.0163	42.2
Lead, Total, ICP-MS	0.0002	0.001	mg/L	0.00955	0.00034	96.4	0.0204	0.00181	91.1	0.00386	0.00051	86.8	0.00318	0.00077	75.8
Manganese, Total, ICP-MS	0.0002	0.001	mg/L												
Molybdenum, Total, ICP-MS	0.0005	0.0025	mg/L	0.0116	0.00945	18.5	0.0111	0.00858	22.7	0.00427	0.00403	5.6	0.00685	0.00498	27.3
Nickel, Total, ICP-MS	0.0003	0.0015	mg/L	0.00456	0.00353	22.6	0.0111	0.00576	48.1	0.00294	0.00325	-10.5	0.00233	0.00157	32.6
Selenium, Total, ICP-MS	0.0015	0.0075	mg/L	<MDL	<MDL		<MDL	<MDL		<MDL	<MDL		<MDL	<MDL	
Silver, Total, ICP-MS	0.0002	0.001	mg/L	0.00293	<MDL	>93.2	0.00215	<MDL	>90.7	0.00172	<MDL	>88.4	0.00127	<MDL	>84.3
Thallium, Total, ICP-MS	0.0002	0.001	mg/L	<MDL	<MDL		<MDL	<MDL		<MDL	<MDL		<MDL	<MDL	
Vanadium, Total, ICP-MS	0.0003	0.0015	mg/L	0.00263	0.00408	-55.1	0.00539	0.00341	36.7	0.0016	0.0011	31.3	0.00157	0.0012	23.6
Zinc, Total, ICP-MS	0.0005	0.0025	mg/L	0.112	0.0201	82.1	0.285	0.127	55.4	0.0623	0.0406	34.8	0.0635	0.0504	20.6
M=MT EPA 245.2 (06-01-004-003)															
Mercury, Total, CVAA	0.00005	0.00015	mg/L	0.00019	<MDL	>73	0.0004	<MDL	>87.5	<MDL	<MDL		0.0151	<MDL	>98.7

				Dec 30, 02			Jan 27, 03			Feb 24, 03		
Parameters	**MDL**	**RDL**	**Units**	**Influent**	**Effluent**	**Removal**	**Influent**	**Effluent**	**Removal**	**Influent**	**Effluent**	**Removal**
	- Wet Weight Basis					%			%			%
M=MT EPA 200.7 (06-02-004-002)												
Aluminum, Total, ICP	0.1	0.5	mg/L	1.21	<MDL		1	<MDL		0.47	<MDL	
Calcium, Total, ICP	0.05	0.25	mg/L	18.4	17.4	5.4	20.6	17.4	15.5	18.7	17.3	7.5
Magnesium, Total, ICP	0.03	0.15	mg/L	15.4	18.3	-18.8	10.8	9.12	15.6	13	13.2	-1.5
M=MT EPA 200.8 (06-03-004&004A-001)												
Antimony, Total, ICP-MS	0.0005	0.0025	mg/L	0.00057	<MDL		0.00079	0.00062	21.5	<MDL	<MDL	
Arsenic, Total, ICP-MS	0.0005	0.0025	mg/L	0.00271	0.0018	33.6	0.0022	0.0018	18.2	0.0016	0.0014	12.5
Barium, Total, ICP-MS	0.0002	0.001	mg/L	0.0228	0.00388	83.0	0.0234	0.00679	71.0	0.00979	0.00474	51.6
Beryllium, Total, ICP-MS	0.0002	0.001	mg/L	<MDL	<MDL		<MDL	<MDL		<MDL	<MDL	
Cadmium, Total, ICP-MS	0.0001	0.0005	mg/L	<MDL	<MDL	>56.5	0.00016	<MDL		<MDL	<MDL	
Chromium, Total, ICP-MS	0.0004	0.002	mg/L	0.00345	0.00049	85.8	0.00285	0.00049	82.8	0.0012	0.00049	59.2
Cobalt, Total, ICP-MS	0.0002	0.001	mg/L	0.00062	0.00027	56.5	0.00061	0.00033	45.9	0.00032	0.00032	0.0
Copper, Total, ICP-MS	0.0004	0.002	mg/L	0.0425	0.00296	93.0	0.021	0.00291	86.1	0.0206	0.00747	63.7
Lead, Total, ICP-MS	0.0002	0.001	mg/L	0.00741	0.00021	97.2	0.00698	0.0002	97.1	0.00166	0.00033	80.1
Manganese, Total, ICP-MS	0.0002	0.001	mg/L	0.0955	0.0678	29.0	<MDL	<MDL				
Molybdenum, Total, ICP-MS	0.0005	0.0025	mg/L	0.0042	0.00377	10.2	0.00291	0.0025	14.1	0.00325	0.00296	8.9
Nickel, Total, ICP-MS	0.0003	0.0015	mg/L	0.00449	0.00196	56.3	0.00409	0.00217	46.9	0.00243	0.0028	-15.2
Selenium, Total, ICP-MS	0.0015	0.0075	mg/L	<MDL	<MDL		<MDL	<MDL		<MDL	<MDL	
Silver, Total, ICP-MS	0.0002	0.001	mg/L	0.00167	<MDL	>84.3	0.00055	<MDL	>84.3	0.00062	<MDL	
Thallium, Total, ICP-MS	0.0002	0.001	mg/L	<MDL	<MDL		<MDL	<MDL		<MDL	<MDL	
Vanadium, Total, ICP-MS	0.0003	0.0015	mg/L	0.0031	0.0013	58.1	0.0031	0.00197	36.5	0.00169	0.00156	7.7
Zinc, Total, ICP-MS	0.0005	0.0025	mg/L	0.0809	0.029	64.2	0.0597	0.0246	58.8	0.039	0.0346	11.3
M=MT EPA 245.2 (06-01-004-003)												
Mercury, Total, CVAA	0.00005	0.00015	mg/L	5.1E-05	<MDL		7.1E-05	<MDL		<MDL	<MDL	

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Poly-chlorinated dibenzo-*p*-dioxins, dibenzo-furans and dioxin-like poly-chlorinated biphenyls occurrence and removal in conventional and membrane activated sludge processes

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ABSTRACT

The paper presents the results of a study focused on the occurrence and removal of dioxins and furans (PCDD/F) and poly-chlorinated biphenyls (PCB) in both conventional and membrane wastewater treatment processes. It was found that the conventionally activated sludge process could perform a good removal of PCDDs/Fs and PCBs, but the relatively low solid retention time applied and the presence of suspended solids in the effluent limited the removal capability of the system. On the other hand, the membrane bioreactor was capable of perfectly removing PCDDs/Fs and PCBs giving an effluent characterised by concentrations under the limit of detection for most of the tested compounds. This efficiency was the result of both the solids removal from the effluent (permeate) and the application of prolonged solid retention times which enabled the bioconversion of those compounds as demonstrated by the mass balances. A mathematical model was developed to predict the final fate of a given molecule according to the operational conditions applied in the wastewater treatment process.

1. Introduction

The concern for the health related problems determined by organic chemicals in the environment has grown due to the medical reports on endocrine-related disease in humans, including declining male fertility, and to adverse effects observed in wildlife (Birkett and Lester, 2003). Therefore, the effective treatment of wastewaters to remove thousands of industrial compounds present at very low concentrations to preserve fresh water reservoirs is one of the key environmental issue facing humanity (Schwarzenbach et al., 2006).

In the infinite series of synthetic organic compounds two classes have attracted the interest of scientists for their potential toxicity: poly-chlorinated biphenyls (PCBs) and dioxin/furans (PCDDs/Fs). In spite of their different origin and chemical characteristics, a number of PCBs and PCDDs/Fs have common characteristics, in particular the dioxin-like PCBs, which are co-planar and have a geometric configuration like 2,3,7,8-TCDD.

PCB is a family of 209 congeners, all exhibiting varying degrees of toxicity (estrogenic activity) depending on the number and position of chlorine atoms. These compounds have been used extensively during last century in several industrial applications because of their high stability and electrical resistance, in particular, in dielectric fluids in transformers and capacitors, plasticizers, hydraulic lubricants, paint and adhesive, therefore they can be found in industrial effluents but also in the environment in general (Morris and Lester, 1994). The global production of PCBs was supposed to be some 1326 million tons between 1930 and the mid 1990s when their use was banned (Lohmann et al., 2007). Because of their chemical–physical characteristics, these compounds are ubiquitous in the environment and have the potential for bioaccumulation and biomagnification.

Poly-chlorinated dibenzodioxines (PCDDs or dioxins) and poly-chlorinated dibenziofurans (PCDFs or furans), are two groups of planar tri-cyclic compounds which may contain between 1 and 8 atoms of chlorine: dioxins have 75 possible positional isomers and furans have 135 positional isomers, however, when considering "dioxins" only seven PCDDs and ten PCDFs are considered in toxicological studies (Birkett and Lester, 2003).

These compounds are not produced commercially but are formed as by-products of various industrial and combustion processes: waste incineration, fuel, coal and wood combustion, paper and pulp industry, cement and glass industry (Lohmann et al., 2007; Birkett and Lester, 2003; Dyke and Amendola, 2007).

In order to reduce the presence of these compounds in water bodies and reduce their magnification along the food chain, it is necessary to control PCBs and PCDs/Fs emissions from wastewater

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treatment works and reduce their emissions toward a virtual "zero discharge".

Several studies showed that wastewater treatment processes can remove organic pollutants like PCDD/F and PCBs with a high extent, up to 95% and more for some compounds (e.g., Morris and Lester, 1994; Katsoyiannis and Samara, 2004, 2005), but this is unfortunately insufficient to preserve environment from decay. As a consequence, very high efficiencies are generally requested to accomplish with effluent standards and advanced technologies are needed to obtain a virtually total removal of organic priority pollutants from the treated water. To obtain this target the membrane biological reactor (MBR) processes are claimed as one of the best available techniques because of their capability of retaining suspended solids and allowing for a flexible operation of the biological process. This then allows for the possibility to adopt high solid retention times (SRT) which can advantage the biotransformation of partially persistent organic substances associated to the solids phase (Auriol et al., 2006; Clara et al., 2004, 2005; Cecchi et al., 2003; Fatone et al., 2005).

According to the given scenario, this paper presents the results of a pilot scale study concerning the treatment of real mixed urban and industrial wastewaters by means of a conventional (CASP) and a membrane (MBR) activated sludge process for the removal of PCBs and dioxins/furans. In the paper, the mass balances of the target compounds are also given in order to define the final fate of these molecules and a predictive empirical model was derived.

2. Methods

2.1. The pilot scale bioreactor and the experimental design

The experimentation was carried out in two pilot-scale bioreactors operating in parallel and treating real wastewater originated from an urban and industrial area of North-east Italy. The bioreactors used in the experimentation were 1.4 m^3 tanks provided of air blowers for aeration and mixers for sludge mixing. They operated a denitrification–nitrification (D–N) process: one reactor operated as a conventional activated sludge process (CASP) and the other as a membrane bioreactor (MBR).

The membrane module used in this experimentation was an ultrafiltration submerged hollow-fiber membrane ZeeWeed®-500 by GE-Zenon (see Innocenti et al., 2002, for details). The working cycle of the filtration module was due to a filtration cycle of 300 s of permeation and 30 s backwashing, and the whole system was automatically controlled by a Program Line Control (Logo Siemens).

The experimental design considered the parallel comparison of the CASP and MBR systems: the activated sludge concentrations were 4 g/L for the CASP system and 9 and 16 g/L respectively for the two MBR experimental runs. Table 1 reports the main operational conditions applied to the bioreactor.

Table 1
Operational conditions of the bioreactor related to sludge production for the different experimental periods.

Parameter	0	1	2
Flow (m^3/d)	2.4	2.4	2.4
Hydraulic Retention Time (HRT), h	14	14	14
$MLSS_{reactor}$ (g/l)*	3.7	9.2	16.6
$MLVSS_{reactor}$ (g/l)	3	5.8	8.6
MLVSS/MLSS (%)	75	63	53
F/M (kg COD/kg MLVSS d)	0.1	0.07	0.06
Y_{obs} (kg MLVSS/kg $COD_{removed}$)	0.5	0.08	0.01
Solid retention time (SRT) * (d)	12	~200	>600

* Process in the MBR was operated fixing the MLSS concentration while SRT was self-determined by the system.

2.2. Analytical methods

The pilot plant was monitored on the basis of 24-h averaged and refrigerated samples for both influent wastewater and treated effluent (or permeate). Grab samples were taken for the definition of the waste activated sludge (WAS) characteristics. Physical parameters, temperature, pH, dissolved oxygen (DO) and oxidation–reduction potential (ORP), were measured on-line. The main chemical–physical characteristics and presence of conventional pollutants were determined according to the Standard Methods (2005).

Poly-chlorinated biphenyls (PCB) and dioxins and furans (PCDD/F) were determined by high resolution gas chromatography (HRGC) and mass spectrometry (HRMS) analyses carried out on a HP 6890 Plus gas-chromatograph coupled to a Micromass Autospec Ultima mass spectrometer, operating in SIR-EI mode at 35 eV and with a resolution of 10,000 (5% valley). PCDD/Fs and PCBs sample injections were performed in the splitless mode on a 60-m DB5 ms column (J&W 0.25 mm ID, 0.25 μm film) and, for PCDD/Fs only, on a 60-m Rtx 200 (Restek 0.25 mm ID, 0.25 μm film) for verification. Quantitative determination was performed by isotope dilution methods, using relative response factors previously obtained from five standard solution injections (US EPA Method 1613B/94; US EPA Method 1668/99, POP003 rev.2). Recoveries always ranged between 50% and 110%. Reproducibility was 15% or better for lower values. Laboratory blanks, repeated twice a week, were lower than 9% with respect to the minimum concentration found. Overall uncertainty (cover factor $K = 2.45$) in analysis of PCDD/Fs and PCBs, calculated at detection limit, was less than 20% for each congener.

All solvents (*n*-hexane, di-chloro-methane, acetone, toluene, ethylacetate) were Picograde reagent grade (Pomochem GmbH, Wesel, Germany). Native and $^{13}C_{12}$-labelled PCDD/Fs, PCB and HCB standards were purchased from Cambridge Isotope Laboratories (Woburn, MA, USA). Samples were first spiked with a series of 15 $^{13}C_{12}$-labelled 2,3,7,8 PCDD/Fs and 12 $^{13}C_{12}$-labelled PCB, and $^{13}C_6$-HCB substituted isomers as internal standards, and then extracted. Water samples were extracted in a separatory funnel with di-chloro-methane (4–50 ml). Sludge samples were extracted by ASE 200 (DIONEX, Sunnyvale, CA) in 50 ml of toluene at 135 °C, 2000 psi, 7 min heat-up and 2 cycles of 10 min static time. Extracts were transferred to hexane before clean-up treatment. The extracts were first spiked with 37 Cl_4-labelled 2,3,7,8 PCDD and 3 $^{13}C_{12}$-labelled PCB, and then cleaned with sulphuric acid (98%) and potassium hydroxide (20%) in a 100-ml separatory funnel. Clean-up was performed by an automatic system (Power Prep. Fluid Management System, Inc.) with 3 pre-packed disposable columns containing multilayer silica, alumina and carbon. As a result, LOQ was 10 pg/L for the single PCB congeners and 0.5–3 pg/L for the single PCDD/F congeners.

3. Results and discussion

The typical characteristics of the raw wastewater treated in the pilot-scale reactors are shown in Table 2: this was a typical mixed wastewater (civil and industrial 50% each), where the industrial component was mainly due to petrochemical and organic chemistry industry. The wastewater had a relatively low total suspended solids (TSS) content and an average chemical oxygen demand (COD) of about 300 mg/L, of which 37% was soluble (SCOD) and 13% readily biodegradable (RBCOD). Total nitrogen (determined according to the Kjeldahl method, TKN) was about 45 mgN/L (half of it ammonium) and the COD/TKN was 7 (on average). The total phosphorus (TP) was 4 mgP/L, of which 25% was soluble. The variability of the concentrations along the experimentation was relatively low: typically <50% of the average values.

Table 2
Characteristics of the treated wastewater (concentrations in mg/l).

Parameter	Average	Minimum	Maximum
TSS	226	22	548
COD	295	93	725
SCOD	110	15	221
RBCOD	38	5	189
TKN	42.2	12.4	121.0
NH_4–N	22.8	5.2	52.4
NO_3–N	1.2	<0.1	3.4
Total P	4.0	0.5	10.4
P–PO_4	1.2	0.1	4.1

3.1. Occurrence of PCDDs/Fs and PCBs in the influent wastewater

Typical concentrations of PCDD/Fs and PCBs found in the wastewater are reported in Tables 3 and 4, respectively. The dioxins and furans (Table 3) were generally detectable in most of the samples (see last column in Table 3): only 2,3,7,8-TCDD, the most toxic compound, was found at levels <0.5 pg/L in 60% of the samples. Penta- and hexa-chlorinated dioxins were typically found in 70% of the samples (except 1,2,3,6,7,8-HxCDD which was always detected) with average concentrations in the range between 2 and 4 pg/L while highly chlorinated dioxins were most abundant: 1,2,3,4,6,7,8-HpCDD reached average levels of 44.7 pg/L (92.8 pg/L as a maximum) and OCDD reached concentrations as high as 475 pg/L and averaged 275 pg/L. In general, average and median concentrations were very close and sometime coincident for all the studied dioxins indicating a relatively low variability in the presence of these compounds in the wastewater.

As for furans, these were typically found at concentrations above the limit of detection (LOD): 1,2,3,4,6,7,8-HpCDF and OCDF, the most abundant congeners, were present at average concentrations of 154.2 and 677.4 pg/L, with corresponding maximum levels of 863 and 3981 pg/L, respectively. Other furans were found at levels averaging between 7 and 34 pg/L. The congeners 1,2,3,4,7,8,9-HpCDF and 1,2,3,4,7,8-HxCDF had maximum concentrations that in some cases exceeded 100 pg/L but their average levels were comparable to those of other congeners.

The concentrations reported for furans were greater than those for dioxins and also had higher variability; in this case average and median concentrations were very different: in particular, median concentrations were from 3 to 10 times lower compared to average concentrations.

These results are consistent with those of previous studies were hepta- and octa-chlorinated dioxins were found as dominant congeners in wastewaters (e.g., Dyke and Amendola, 2007; Eljarrat and Barcelo, 2003).

Table 4 reports the results for the dioxin-like PCBs and congeners 170 and 180, which are not considered dioxin-like but are often present at considerable concentrations in the environment (Birkett and Lester, 2003). All these compounds were generally found in the wastewater samples (except PCB-169) and showed average concentrations 1000 times greater than those of the PCDDs/Fs. Only congeners 81, 123, 126 and 169 were found at least once at levels lower than the detection limit of 0.01 ngl/L while all the other congeners were always present at concentrations greater than 0.01 ng/L. In general, congeners 170 and 180 were the most abundant reaching average levels of 22.2 and 44.4 ng/L, respectively. On the other hand, when considering dioxin-like PCBs (congeners 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, 189) only congener 118 had a relatively high concentration (13.5 ng/L) but the median values lowered to 4.4 ng/L. In general, median concentrations were considerably lower than the averages and only in some cases (see congeners 123, 126 and 157) average and median values were comparable.

The global presence of PCBs was also evaluated in terms of Aroclor 1254 and 1260: the average concentration was 587 ng/L, with a maximum concentration of 2715 ng/L, while the median concentration reduced to 120 ng/L. Therefore, PCBs other than those specifically studied, were also abundant in the wastewater.

The comparison of these results with literature data is not very easy, as different authors considered different PCB congeners in their studies; moreover, reported range of concentrations are very broad. For example, Durell and Lizotte (1998), monitored 26 WWTPs in New Jersey and New York State, looking for 71 individual PCBs presence and variations in influent flowrate. They found that the concentrations for the individual PCBs in wastewater ranged from "not detectable" to 100 ng/L, but were mostly less than 5 ngl/L. Congeners 52, 70, 95, 101, 105, 110, 118, 138, 149 and 153 were typically the ones detected at the highest concentrations. Pham and Proulx (1997) considered the PCB presence in the waste-

Table 3
Dioxins and furans in raw wastewater (samples = 10).

		Average	Median	Minimum	Maximum	Samples > LOD
Chloro-dibenzo-p-dioxin						
2,3,7,8-TCDD	pg/L	nc	0.6	<0.5	0.6	4
1,2,3,7,8-PeCDD	pg/L	1.5	1.2	<0.5	3.1	7
1,2,3,4,7,8-HxCDD	pg/L	2.6	1.8	<1.0	5.7	7
1,2,3,6,7,8-HxCDD	pg/L	3.4	2.8	1.0	6.9	10
1,2,3,7,8,9-HxCDD	pg/L	3.0	3.0	<1.0	4.8	7
1,2,3,4,6,7,8-HpCDD	pg/L	44.7	46.1	3.0	92.8	10
OCDD	pg/L	275.4	271.2	101.5	475.3	10
Chloro-dibenzo-p-furans						
2,3,7,8-TeCDF	pg/L	7.0	4.5	1.7	19.0	9
1,2,3,7,8-PeCDF	pg/L	9.1	2.1	0.7	42.9	9
2,3,4,7,8-PeCDF	pg/L	10.0	3.7	1.0	38.0	9
1,2,3,4,7,8-HxCDF	pg/L	33.8	5.1	2.3	177.6	9
1,2,3,6,7,8-HxCDF	pg/L	16.1	2.9	1.3	83.3	9
2,3,4,6,7,8-HxCDF	pg/L	12.0	3.3	1.3	55.0	9
1,2,3,7,8,9-HxCDF	pg/L	12.1	1.6	1.0	44.2	9
1,2,3,4,6,7,8-HpCDF	pg/L	154.2	38.4	11.9	863.5	10
1,2,3,4,7,8,9-HpCDF	pg/L	26.0	3.8	1.6	159.2	10
OCDF	pg/L	677.4	116.1	78.5	3981.8	10

TCDD, tetra-chloro-dibenzo-dioxines, PeCDD, penta-chloro-dibenzo-dioxines, HxCDD, hexa-chloro-dibenzo-dioxines, HpCDD, hepta-chloro-dibenzo-dioxines, OCDD, octo-chloro-dibenzo-dioxines, TeCDF, tetra-chloro-dibenzo-furans, PeCDF, penta-chloro-dibenzo-furans, HxCDF, hexa-chloro-dibenzo-furans, HpCDF, hepta-chloro-dibenzo-furans, OCDF, octo-chloro-dibenzo-furans.

Table 4
Dioxin-like PCBs and PCB congeners 170 and 180 in raw wastewater (samples = 10).

	Congener IUPAC N		Average	Median	Minimum	Maximum	Samples > LOD
3,4,4′,5-Tetrachlorobiphenyl	81	ng/L	0.1	0.03	<0.01	0.3	7
3,3′,4,4′-Tetrachlorobiphenyl	77	ng/L	1.3	0.3	0.1	7.3	10
2′,3,4,4′,5-Pentachlorobiphenyl	123	ng/L	0.4	0.3	<0.01	1.1	9
2,3′,4,4′,5-Pentachlorobiphenyl	118	ng/L	13.5	4.4	1.7	41.5	10
2,3,4,4′,5-Pentachlorobiphenyl	114	ng/L	0.4	0.1	0.04	1.7	10
2,3,3′,4,4′-Pentachlorobiphenyl	105	ng/L	5.1	1.2	0.5	22.9	10
3,3′,4,4′,5-Pentachlorobiphenyl	126	ng/L	0.1	0.04	<0.01	0.2	8
2,3′,4,4′,5,5′-Hexachlorobiphenyl	167	ng/L	1.1	0.3	0.2	4.2	10
2,3,3′,4,4′,5-Hexachlorobiphenyl	156	ng/L	2.8	1.1	0.4	10.6	10
2,3,3′,4,4′,5′-Hexachlorobiphenyl	157	ng/L	0.3	0.1	0.1	0.8	10
3,3′,4,4′,5,5′-Hexachlorobiphenyl	169	ng/L	0.01	0.01	<0.01	0.01	5
2,3,3′,4,4′,5,5′-Heptachlorobiphenyl	189	ng/L	0.5	0.2	0.1	2.3	10
2,2′,3,4,4′,5,5′-Heptachlorobiphenyl	180	ng/L	44.4	8.4	5.0	239.2	10
2,2′,3,3′,4,4′,5-Heptachlorobiphenyl	170	ng/L	22.2	4.1	1.9	120.4	10
Aroclor 1254 + 1260		ng/L	587	120.3	64	2715	10

water and effluents of the Montreal metropolitan area: the average concentration for the 13 PCB (congeners 77, 101, 105, 118, 126, 128, 138, 149, 153, 156, 169, 170, 180, 183 and 194) was some 4.6 ± 1.8 ng/L while total PCBs (209 congeners) showed an average concentration of some 17–18 ng/L. Congeners 138 and 180 were the most abundant: 1.1 and 0.8 ng/L. Congeners 101, 118, 128, 138, 153, 170 and 180 were found in at least 80% of the samples.

3.2. Data correlations

In order to better understand the behaviour of the studied compounds and their interactions in wastewaters, a correlation matrix was calculated (not shown). As for dioxins and furans it was found that these compounds were highly correlated the ones with the others, with correlation coefficients typically >0.75 and very often >0.9. Only OCDD, the most abundant dioxin, showed a relatively low correlation with other dioxins and furans (always <0.7) except for the correlation with 1,2,3,4,6,7,8-HpCDD ($r = 0.94$), the second in the rank of the most abundant dioxins. This suggested a common origin for these two compounds. On the other hand, OCDD was the only dioxin clearly related to the presence of suspended solids in the wastewater (correlation of 0.99). OCDF, the most abundant compound of the family of dioxins/furans in wastewater, showed some correlation (r in the range 0.6–0.7) with dioxins 1,2,3,6,7,8-HxCDD, 1,2,3,4,6,7,8-HpCDD and OCDD and very strong ($r > 0.95$) with all the other furans considered in this study.

Considering the dioxin-like PCBs these showed negative correlations with dioxin/furans because of their different origin. On the other hand, good correlations were found among the different PCB congeners, generally showing correlation coefficients >0.75. Only some congeners showed low correlations: in particular, it was clear that tetra-chlorinated and high chlorinated (hexa- and hepta-) PCBs showed good correlations the ones with the others, while two penta-chlorinated PCBs showed low correlations with other PCBs: PCB-114 gave correlations always <0.5, while PCB-77, showed negative correlations with all the other PCBs.

A clear correlation with suspended solids in the wastewater was not evident, therefore their presence seemed not strictly related to run-off events and should probably related to the industrial component of the treated wastewater.

3.3. Effluent characteristics

The bioreactors (both in the submerged membrane bioreactor and conventional activated sludge process configurations) worked properly along all the experimentation (see Table 1 for operational conditions) allowing for satisfactory removal of total solids, COD, nitrogen and phosphorous. The main difference between the two systems was the capability of removing suspended solids (sludge flocs): the CASP system showed an average concentration of 10 mg/L suspended solids while the MBR systems were able to perfectly remove the suspended solids producing a virtually solids free permeate. This fact determined a good improvement in terms of COD removal: effluent COD passed from about 100 mg/L in the CASP system to some 30–40 mg/L in the MBR system. As for nitrogen, nitrification was complete in the two configurations and denitrification was always efficient (80% nitrogen removal) because of the good COD/TKN ratio in the influent and the presence of a considerable fraction of soluble and readily biodegradable COD. Phosphorus was removed effectively (removal >60%) without any chemical addition.

PCDDs/Fs and PCBs, were effectively removed by the MBR and CASP systems with minimum removal efficiencies of ca. 60% and many removal efficiencies >90%. Table 5 reports the typical effluent concentrations and removal efficiencies for PCDDs/Fs. The MBR system removed high levels of both these classes of compounds: all the investigated congeners were found in the effluent at concentrations below the limit of detections of 0.5 pg/L for tetra- and penta-chlorinated compounds, 1.0 pg/L for Hx and HpCDD/Fs and 3.0 pg/L for OCDD/F. The removal rates were therefore very high and generally >90%. Clearly, the best removal performances were observed for the compounds that were present at the highest concentrations in the influent wastewater, in fact, HpCDDs/Fs and OCDD/F showed removal rates greater than 99%.

In the CASP system some high-chlorinated compounds (1,2,3,4,6,7,8-HpCDD and OCDD among the dioxins and 1,2,3,4,6,7,8-HpCDF and OCDF among the furans) that had the highest concentrations in the influent, were also found at higher levels than other compounds in the effluent. OCDD and OCDF, in particular, had average effluent concentrations of 9.2 and 10.3 pg/L, respectively. Therefore, even though more than 95% of these compounds were removed, both were still present in the effluent of the CASP system because of their association with suspended solids present at 10 mg/L on average in the effluent. Those compounds, in fact, showed the highest concentrations in the activated sludge (see Fig. 1).

Also the PCBs were removed with very high rates: the studied congeners were present in the effluent of the MBR system at concentrations typically lower than the limit of detection of <0.01 ng/L (see Table 6). Only the congeners 118 and 156 were detected at the same level of the limit of detection in the effluent of the MBR operating at a MLSS concentration of 9 g/L while when operating at a biomass concentration of 16 g/L, the congener 118 had an average concentration of 0.03 ng/L, the congener 156 remained at 0.01 ng/L

Table 5
Concentrations found in the effluent of the pilot-scale reactors (6 samples for any steady state condition).

		MBR 1 (MLSS 9 g/L)	Removal (%)	MBR 2 (MLSS 16 g/L)	Removal (%)	CASP (MLSS 4 g/L)	Removal (%)
Chloro-dibenzo-p-dioxin							
2,3,7,8-TCDD	pg/L	<0.5	nc	<0.5	nc	<0.5	nc
1,2,3,7,8-PeCDD	pg/L	<0.5	>67.2	<0.5	>67.2	<0.5	>67.2
1,2,3,4,7,8-HxCDD	pg/L	<1.0	>61.2	<1.0	>61.2	<1.0	>61.2
1,2,3,6,7,8-HxCDD	pg/L	<1.0	>70.7	<1.0	>70.7	<1.0	>70.7
1,2,3,7,8,9 – HxCDD	pg/L	<1.0	>66.7	<1.0	>66.7	<1.0	>66.7
1,2,3,4,6,7,8 – HpCDD	pg/L	<1.0	>97.4	<1.0	>97.4	1.6 ± 0.3	95.9
OCDD	pg/L	<3.0	>98.9	<3.0	>98.9	9.2 ± 4.6	96.7
Chloro-dibenzo-p-furans							
2,3,7,8-TeCDF	pg/L	<0.5	>92.8	<0.5	>92.8	<0.5	>92.8
1,2,3,7,8-PeCDF	pg/L	<0.5	>94.5	<0.5	>94.5	<0.5	>94.5
2,3,4,7,8-PeCDF	pg/L	<0.5	>95.0	<0.5	>95.0	<0.5	>95.0
1,2,3,4,7,8-HxCDF	pg/L	<1.0	>97.0	<1.0	>97.0	<1.0	>97.0
1,2,3,6,7,8-HxCDF	pg/L	<1.0	>93.8	<1.0	>93.8	<1.0	>93.8
2,3,4,6,7,8-HxCDF	pg/L	<1.0	>91.6	<1.0	>91.6	<1.0	>91.6
1,2,3,7,8,9-HxCDF	pg/L	<1.0	>91.7	<1.0	>91.7	<1.0	>91.7
1,2,3,4,6,7,8-HpCDF	pg/L	<1.0	>99.4	<1.0	>99.4	1.7 ± 0.7	98.9
1,2,3,4,7,8,9-HpCDF	pg/L	<1.0	>96.2	<1.0	>96.2	<1.0	>96.2
OCDF	pg/L	<3.0	>99.6	<3.0	>99.6	10.3 ± 12.0	98.5

TCDD, tetra-chloro-dibenzo-dioxines, PeCDD, penta-chloro-dibenzo-dioxines, HxCDD, hexa-chloro-dibenzo-dioxines, HpCDD, hepta-chloro-dibenzo-dioxines, OCDD, octo-chloro-dibenzo-dioxines, TeCDF, tetra-chloro-dibenzo-furans, PeCDF, penta-chloro-dibenzo-furans, HxCDF, hexa-chloro-dibenzo-furans, HpCDF, hepta-chloro-dibenzo-furans, OCDF, octo-chloro-dibenzo-furans.

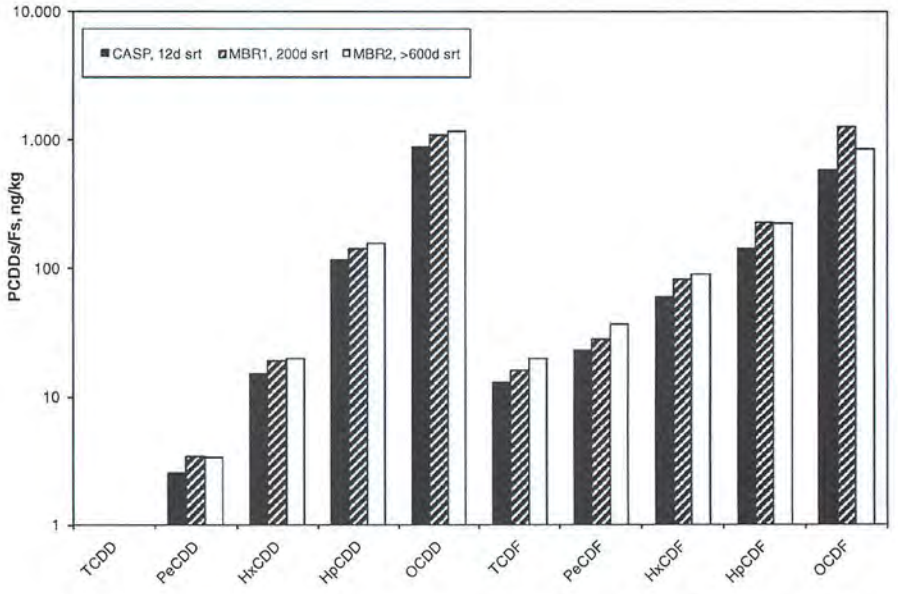

Fig. 1. PCDD/Fs concentrations in sludge for the CASP and the MBR systems as function of the applied SRT.

and the congeners 170 and 180 were found in the effluent at concentrations of 0.02 and 0.04 ng/L, respectively. Also the Aroclor mix, which was found at levels lower than the detection limit of 0.5 ng/L when operating at 9 g/L MLSS, was then detected at concentrations of some 0.7 ng/L when working with a concentration of the biomass in the bioreactor of 16 g/L. This was probably due to the fact that the concentration of PCBs in the activated sludge was near to the saturation level (see Fig. 2), and therefore, according to the typical octanol/water partition coefficient, K_{ow}, concentration levels similar to 0.01 ng/L could be expected in the water phase.

In general, the removal rates were always very high and typically >85% for all the investigated congeners, with levels >99% for most of the congeners studied.

On the other hand, when considering the effluent of the CASP system, most of the PCB congeners were found in the effluent at concentrations above the limit of detection and congeners 105, 118, 170 and 180 had concentrations greater than 0.1 ng/L. Aroclor 1254 and 1260 averaged about 10 ng/L. The presence of almost the PCB congeners in the effluent was related to the presence of sludge flocs in the effluent: in fact, considering the typical concentration these molecules in sludge (see Fig. 2) and an average concentration of 10 mg/L as suspended solids in the effluent it is then possible calculated the expected concentrations for the PCB congeners in the effluent. These values are very similar to those reported in Table 6.

In general, however, also for the CASP system, the removal efficiency remained important and typically greater than 85%.

The effective removal of these compounds in biological treatment systems was widely reported in literature: Morris and Lester (1994), Durell and Lizotte (1998) and Pham and Proulx (1997) all reported the effective removal of PCBs in conventional activated sludge processes.

Table 6
PCBs in the effluent and relative removals in MBR and CASP (6 samples for any steady state condition).

	Congener IUPAC N		MBR 1 (MLSS 9 g/L)	Removal (%)	MBR 2 (MLSS 16 g/L)	Removal (%)	CASP MLSS (4 g/L)	Removal (%)
3,4,4′,5-Tetrachlorobiphenyl	81	ng/L	<0.01	>89.2	<0.01	>89.2	<0.01	>89.2
3,3′,4,4′-Tetrachlorobiphenyl	77	ng/L	<0.01	>99.3	<0.01	>99.3	0.03 ± 0.03	97.8
2′,3,4,4′,5-Pentachlorobiphenyl	123	ng/L	<0.01	>97.2	<0.01	>97.2	0.01 ± 0.01	95.8
2,3′,4,4′,5-Pentachlorobiphenyl	118	ng/L	0.01 ± 0.01	99.9	0.03 ± 0.01	99.9	0.30 ± 0.2	97.6
2,3,4,4′,5-Pentachlorobiphenyl	114	ng/L	<0.01	>97.3	<0.01	>97.3	<0.01	>97.3
2,3,3′,4,4′-Pentachlorobiphenyl	105	ng/L	<0.01	>99.8	<0.01	>99.8	0.12 ± 0.09	97.6
3,3′,4,4′,5-Pentachlorobiphenyl	126	ng/L	<0.01	>85.3	<0.01	>85.3	<0.01	>85.3
2,3′,4,4′,5,5′-Hexachlorobiphenyl	167	ng/L	<0.01	>99.1	<0.01	>99.1	0.02 ± 0.01	97.6
2,3,3′,4,4′,5-Hexachlorobiphenyl	156	ng/L	0.01 ± 0.01	99.6	0.01 ± 0.01	99.6	0.08 ± 0.04	97.0
2,3,3′,4,4′,5′-Hexachlorobiphenyl	157	ng/L	<0.01	>96.7	<0.01	>96.7	0.01 ± 0.01	96.7
3,3′,4,4′,5,5′-Hexachlorobiphenyl	169	ng/L	<0.01	nc	<0.01	nc	<0.01	nc
2,3,3′,4,4′,5,5′-Heptachlorobiphenyl	189	ng/L	<0.01	>97.9	<0.01	>97.9	0.01 ± 0.01	97.1
2,2′,3,4,4′,5,5′-Heptachlorobiphenyl	180	ng/L	<0.01	>99.9	0.04 ± 0.01	>99.9	0.88 ± 0.64	98.0
2,2′,3,3′,4,4′,5-Heptachlorobiphenyl	170	ng/L	<0.01	>99.9	0.02 ± 0.01	>99.9	0.48 ± 0.34	97.8
Aroclor 1254 + 1260		ng/L	<0.5	>99.9	0.7 ± 0.3	>99.9	10.78 ± 5.73	98.2

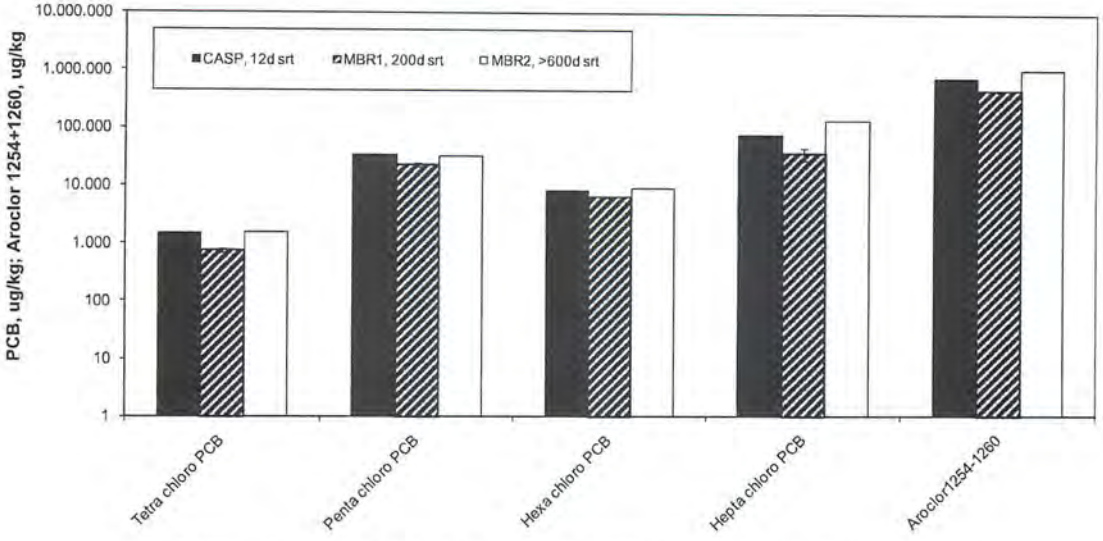

Fig. 2. PCBs concentrations in sludge for the CASP and the MBR systems as function of the applied SRT.

The better performances experienced by the MBR were clearly related to the capability of this system to perfectly retain the suspended solids in the effluent thus originating a virtually "solid free" stream. Moreover, the higher concentration of biomass typical of MBR systems improved the bio-sorption capability of the system (Aksu, 2005) while the high solid retention time (SRT) selects particular bacterial strains capable of bio-converting, at least partially, these molecules (Clara et al., 2005; Joss et al., 2005; Cirja et al., 2008).

3.4. Sludge characteristics

Figs. 1 and 2 show the typical concentrations of PCDD/Fs and PCBs in the activated sludge, respectively. According to their typical chemical–physical characteristics (a low solubility in water and a high value of the octanol/water partition coefficient), dioxins, furans and dioxin-like PCBs were expected to extensively accumulate in sludge. Results confirmed this supposition.

As for PCDD/Fs, it was found that the compounds that had the highest concentrations in the influent wastewater were then the most abundant in the waste activated sludge: in particular, OCDD and OCDF had concentrations of about 1000 ng/kg in the sludge of the MBR system while in the sludge of the CASP system OCDD and OCDF were found at concentrations of 875 and 581 ng/kg, respectively. This suggests that increasing the SRT of the system (passing from the CASP to the MBR) these molecules tend to accumulate (at least partially) because of their reduced bio-availability or biodegradability. Therefore, as expected, the SRT of the system played a fundamental role in the magnitude of accumulation (see below mass balances). Also hepta-chlorinated dioxins and furans were quite abundant in sludge: the congeners 1,2,3,4,6,7,8-HpCDD and 1,2,3,4,6,7,8-HpCDF had concentrations of 100 and 200 ng/kg in the sludge of the CASP and MBR systems, respectively. All the other PCDD/Fs were found at concentration levels below 50 ng/kg except for TCDD: this molecule, which had concentrations close to the limit of detection in the raw wastewater, was then found at levels below 1 ng/kg in the waste activated sludge. In general, the higher the number of chlorine atoms, the higher the concentrations in sludge: in fact, it is clear, considering the profiles in Fig. 1, that the congeners with a higher number of chlorine atoms, that is a higher log K_{ow} value, accumulated in sludge and had the highest concentrations. Moreover, it was found that the wasted sludge produced by the MBR systems, where high SRTs were applied, clearly presented the highest concentrations of PCDD/Fs. However, it is important to emphasise that, despite the dramatic increase of the SRT in the MBR system (up to more than 500 days), the concentra-

tions of these molecules in the activated sludge were still comparable to those found in the CASP system suggesting that, although accumulation occurred, important bioconversion phenomena reduced the presence of those compounds.

The concentration levels for PCBs in sludge are shown in Fig. 2: similarly to what observed for the wastewater samples, these molecules were clearly more abundant than PCDD/Fs. Also in this case, however, the molecules with a higher number of chlorine atoms were the most abundant in sludge: in fact, PCB congeners with 5–7 chlorine atoms had concentrations clearly higher than tetra-chlorinated PCBs. In particular, while tetra-chlorinated congeners had concentrations of about 1000 μg/kg in the waste activated sludge of both the CASP and MBR systems, penta-chlorinated, hexa-chlorinated and hepta-chlorinated congeners had concentrations in the range between 23,000 and 34,000 μg/kg, 6000 and 8000 μg/kg and 76,000 and 134,000 μg/kg, respectively.

Differently from the case of PCDD/Fs, the SRT did not play a dominant role in the presence of PCBs in sludge: the concentrations of the different PCBs were in fact very similar in the activated sludge of the three systems (CASP, MBR1 and MBR2).

The results of this study are consistent with those reported in literature: for example, Eljarrat and Barcelo (2003) and Fuentes et al. (2007) both reported OCDD and 1,2,3,4,6,7,8-HpCDD among the dioxins and OCDF and 1,2,3,4,6,7,8-HpCDF among the furans, as the dominant compounds in waste activated sludge of Spanish wastewater treatment plants. Although the concentrations found in waste activated sludge of this study may appear high, it should be emphasised that these concentrations may reduce considerably in the sludge to be finally disposed of. In fact, these molecules are reported to be prone to further degradation during excess sludge stabilisation both in aerobic and anaerobic conditions (Katsoyiannis and Samara, 2004; Disse et al., 1995).

3.5. Mass balances and fate of selected PCDD/Fs and PCBs

According to the results reported above, it turns out clear that PCDDs/Fs and PCBs were removed with high rates in both the CASP and MBR systems. It is well known that an organic molecule entering an activated sludge process undergoes to different fate processes: advection, adsorption onto sludge (thus discharge via excess sludge withdrawn), volatilisation and bioconversion (e.g., Byrns, 2001).

In order to clarify the fate of PCDD/Fs and PCBs in the systems studied in this research, the mass balance was calculated for each compound. This was determined according to the concentrations of these molecules in the influent wastewater (Tables 3 and 4), effluent/permeate (Tables 5 and 6) and waste activated sludge (Figs. 1 and 2). Since most of the tested compounds showed concentrations in the effluent below the limit of detection, the mass of pollutant exiting the MBR or CASP systems was calculated considering the effluent concentration equal to the limit of detection (LOD) for a given compound. Because of this assumption, most of the removal rates calculated are to be considered conservative.

According to the chemical–physical characteristics of the molecules considered in this study, adsorption onto sludge is a particularly important phenomenon governing the final fate of a given congener. In fact, PCDD/Fs and PCBs generally show a low solubility in water, typically in the range 10^{-5}–10^{-3} mg per litre, thus high value of the octanol/water partition coefficient with log K_{ow} values in the range 6–12 for dioxins and furans with a number of chlorine atoms from 4 to 8 and in the range 5–8 for the PCB congeners considered in this study. Moreover, the Henry's law constant, H_c, has values in the range 10^{-6}–10^{-5} atm m^3/mol for dioxins and 10^{-4}–10^{-3} atm m^3 mol^{-1} for PCBs. According to several authors (e.g., Rogers, 1996) low values of the Henry's law constant, H_c, and increased partitioning to the organic carbon content reduce volatilisation. So, molecules characterised by $H_c < 10^{-4}$ and $H_c/K_{ow} > 10^{-9}$ unlikely volatilise. According to this classification, it is therefore expected that PCDD/Fs did not volatilise while some PCB congeners could at least partially volatilise.

On the other hand, when considering compounds with these characteristics, and using systems where large SRT are applied (i.e., MBR), bioconversion can play an important role in terms of removal rates. In fact, the importance of biotransformation increases with SRT and the log K_{ow} value therefore long SRTs are required for the bioconversion of very hydrophobic compounds (Byrns, 2001; Birkett and Lester, 2003; Clara et al., 2005). In this study, an indirect proof of bioconversion of chlorinated compounds like PCDD/Fs and PCBs comes from the typical concentrations of chlorine found in the influent and effluent of both the CASP and MBR systems: in fact, the average concentrations for chlorine (as Cl^-) in the raw wastewater were in the range 95–195 mg/L (avg. 152 mg/L) while the average concentrations increased to some 180 mg/L and to 195 mg/L in the CASP and MBR effluent, respectively. Clearly, PCDD/Fs and PCBs were only a minimal part of the organo-chlorinated compounds in the wastewater and their removal could not justify such an increase of concentration in the effluent, however this evidence is of particular significance to support the existence of a bioconversion process.

PCDD/Fs were removed very effectively, in most cases with rates typically greater than 90% (see Table 5). With reference to the MBR system, working both at 9 or 16 g/L, the concentrations of dioxins and furans in the permeate were constantly below the detection limit while in the CASP system 1,2,3,4,6,7,8-HpCDD, OCDD, 1,2,3,4,6,7,8-HpCDF and OCDF were normally found (see Table 5). Because of their chemical–physical characteristics these molecules tend to accumulate onto sludge (Fig. 1): here, they can be bioconverted/degraded or discharged with wasted sludge. Taking into account the PCDD/Fs concentrations in sludge (Fig. 1) and the operational conditions applied to the MBR and CASP systems (Table 1) it can be calculated that less than 10% of the influent loads (except for OCDD, 11%) for MBR 1 and less than 4% of the influent loads for MBR 2 were discharged with wasted sludge. On the other hand, when considering the CASP system, large quantities of dioxins and furans were eliminated through excess sludge withdrawn. In particular, 57% of OCDD and about 45% of 1,2,3,6,7,8-HxCDD and 1,2,3,4,6,7,8-HpCDD were discharged with waste activated sludge. Moreover, about 30% 1,2,3,7,8-PeCDD, 1,2,3,7,8,9-HxCDD, 2,3,7,8-TeCDF, 2,3,4,7,8-PeCDF and 2,3,4,6,7,8-HxCDF were in the excess sludge. For all the other congeners less than 20% of the influent load was found in the waste activated sludge. Since air stripping is a very unlike removal process for these molecules (see discussion above), bioconversion/degradation was the most significant removal mechanism for these compounds in the MBR system and still very important in the CASP system. In particular, according to the mass balances calculated, bioconversion accounted for more than 90% removal in MBR1 and MBR2, while it accounted for the removal of some 40–50% of dioxins and 60–80% of furans in the CASP system. According to these data the SRT applied to the system played a key role in the removal mechanisms: the higher the applied SRT the higher the bioconversion (Clara et al., 2005). Clearly, the increased SRT determined an improvement of some 10–30% in bio-removal rates passing from the CASP to the MBR system. Fig. 3 shows in detail some experimental evidences: it turns out clear from the profiles that hexa-chlorinated dioxins and furans were less prone to bioconversion compared to hepta- and octa-chlorinated congeners and that, in general, furans were more easily bioconverted than the dioxin homologues. Moreover, the SRT increase determined a net improvement of the bioconversion rates.

Bioconversion of PCDD/Fs is widely report in literature: Field and Sierra-Alvarez (2008) reported that several strains of *Pseudo-*

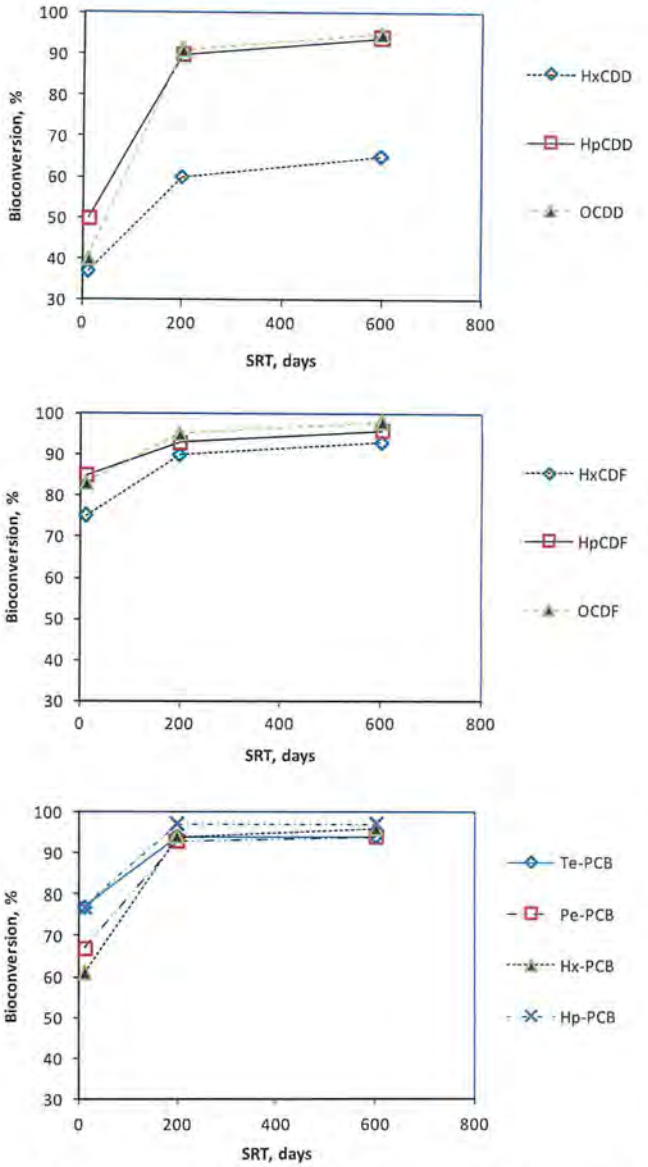

Fig. 3. Bioconversion of PCDDs, PCDFs and PCBs in relation to the applied SRT.

monas and *Sphingomonas* were capable of degrading these molecules both in aerobic and anaerobic conditions. Although PCDD/s are generally co-metabolised together with other readily biodegradable organic compounds, some examples of growth on the chlorinated compounds as sole carbon source were also reported in literature (Kim et al., 2002; Kao et al., 2001; Ishiguro et al., 2000).

With reference to PCBs fate, it turned out clearly from the study that these molecules were removed with high rates. As for the definition of the final fate of these molecules the behaviour in the CASP and MBR system should be distinguished.

In the CASP system, 20–30% up to 40% of the molecules were discharged with waste activated sludge: in particular, some 20% of congeners 77, 114, 123, 170, 180 and 189, 30% of congeners 105, 118, 126, 156 and 167 and 40% of congener 157 were removed through this way, respectively. Since PCBs loads in the effluent were generally 2–3% of the influent load (except for PCB congeners 81, 126 and 169), some 56–79% of the influent loads were actually removed. As for the removal mechanisms, it is important to highlight that less chlorinated PCBs are potentially susceptible to air stripping (Cousins et al., 1997), while the higher log K_{ow} values for penta-, hexa- and hepta-chlorinated compounds suggested bioconversion as the dominant removal mechanism. The fraction of the different PCB congeners lost due to volatilisation was calculated. The mass of a given compound lost through volatilisation from an activated sludge process can be estimated by the equation

$$M_{\text{volatilise}} = \frac{\text{AFR} \cdot H_c \cdot C_{\text{sol}}}{R \cdot T}$$

where, H_c is the Henry's law constant for a given PCB congener (atm·L/mol), AFR is the air flow rate (L/d), C_{sol} is the PCB bulk concentration (ng/L), R is the universal gas constant (0.083 atm L/mol K) and T is the absolute temperature (K). The H_c values at 20 °C were taken from Bamford et al. (2000).

By applying this equation, it turned out that some PCB congeners underwent to a partial removal through volatilisation: this mechanism accounted for some 15% for congeners 81, 126 and 189, 7–9% for congeners 156 and 157 while it accounted for less than 5% for all the other PCBs. Therefore, volatilisation can be accounted as an important removal mechanism only for PCB congeners 81, 126 and 189 in CASP systems.

With specific reference to the MBR system, PCBs in the effluent were virtually absent while PCBs discharged with wasted sludge were just 1–3% of the total influent load. Volatilisation could participate only partially because of the concentrations in the bulk typically similar to the limit of detection. Therefore, bioconversion/degradation accounted for some 90–99% of the global removal rate. Fig. 3 emphasises how penta- and hexa-chlorinated PCB were less prone to bioconversion than other PCBs and how increasing the SRT resulted in a clear improvement of bioconversion rates. Several authors reported the bioconversion/degradation of these molecules in wastewater treatment processes: Morris and Lester (1994), Pieper (2005), van Haelst et al. (1995) and Di Gioia et al. (2006) among the others.

According to the results obtained it was then evident that PCDDs/Fs and PCBs were removed effectively both in the CASP and MBR systems but in the CASP system some 10% of the molecules were still present in the effluent because of the presence of suspended solids (sludge flocs) in the effluent while, on the other hand, the MBR system produced an effluent in which the concentrations of PCDDs/Fs and PCBs were below the limit of detection.

3.6. Process modeling

Several models have been proposed in these years concerning the fate of organic pollutants in wastewater treatment processes (e.g., Byrns, 2001 and Clark et al., 1995, among the others).

The equation describing the fate of an organic pollutant in a continuous stirred reactor, neglecting stripping, which in this case is not particularly significant except for few PCBs, is the following:

$$V \cdot \frac{dC}{dt} = Q_{\text{in}} \cdot C_{\text{ww}} - Q_{\text{in}} \cdot C_{\text{eff}} \cdot (1 + SS \cdot K_{\text{pb}}) - Q_{\text{was}} \cdot X_{\text{was}} \cdot K_{\text{pb}} \cdot C_{\text{eff}} - K_{\text{bio}} \cdot X \cdot V \cdot C_{\text{eff}} \quad (1)$$

where,

Q_{in}, wastewater and effluent (or permeate) flowrate, m^3/d.
C_{ww}, influent pollutant concentration, g/m^3.
C_{eff}, pollutant concentration in the soluble phase in the bioreactor, g/m^3.
SS, effluent suspended solids, kg/m^3.
K_{pb}, pollutant partition coefficient, m^3/kg.
Q_{was}, waste activated sludge flowrate, m^3/d.
X_{was}, waste activated sludge concentration, kg/m^3.
K_{bio}, biodegradation rate of the organic pollutant, $m^3/kg\ d$.

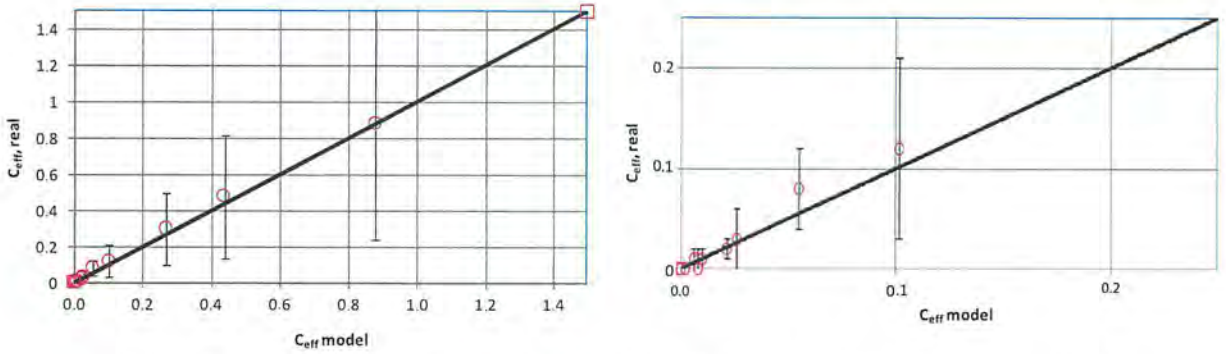

Fig. 4. Modelled versus experimental effluent data for PCBs in the CASP system (on the right particular of the range 0–2 ng/L).

V, volume of the bioreactor, m^3.
X, activated sludge concentration, kg/m^3.

This was basically derived for a CASP system, while when considering a MBR the term for suspended solids, SS, in the permeate can be considered null and the effluent micropollutant will be present only in its soluble form, C_{eff}.

In general, at steady state, the equation will become

$$Q_{in} \cdot C_{ww} - Q_{in} \cdot C_{eff}(1 + SS \cdot K_{pb}) - Q_{was} \cdot X_{was} \cdot K_{pb} \cdot C_{eff} - K_{bio} \cdot X \cdot V \cdot C_{eff} = 0 \quad (2)$$

and it is then possible to predict the effluent concentration through the equation

$$C_{eff} = \frac{Q_{in} \cdot C_{ww}}{Q_{in} \cdot (1 + SS \cdot K_{pb}) + Q_{was} \cdot X_{was} \cdot K_{pb} + K_{bio} \cdot X \cdot V} \quad (3)$$

The value for K_{pb}, which represents the distribution coefficient of the pollutant, is directly related to the partition coefficient between octanol and water, K_{ow}, of a given compound and to the fraction of organic carbon in the adsorbent, F_{oc}, through the relation $K_{pb} = 6.3 \times 10^{-7} \cdot F_{oc} \cdot K_{ow}$, with $F_{oc} = 0.531$ for activated sludge (in Byrns, 2001). The values for this parameter are in the range 4–6 m^3/kg for dioxins and furans and 3–4 m^3/kg for PCBs.

Obviously, for organic compounds, biodegradation can occur both in the liquid or solid phase: these two mechanisms can be described through the equation:

$$K_{bio} = K_1 \cdot HRT \cdot \left(1 - \frac{K_{pb}MLSS}{1 + K_{pb}MLSS}\right) + K_2 \cdot SRT \cdot \left(\frac{K_{pb}MLSS}{1 + K_{pb}MLSS}\right) \quad (4)$$

As a first assumption, because of the strong affinity of the investigated compounds for the organic phase and the difference in the time scale between HRT and SRT, especially in the MBR systems, the degradation in the soluble phase was neglected and it was assumed that the degradation completely occurred in the sludge phase, and was thus strictly dependent on the SRT of the system. The biodegradation rate was assumed in the range 1–3 m^3/kgd for PCDDs/Fs (Field and Sierra-Alvarez, 2008) and 2–4 m^3/kgd for PCBs (in Birkett and Lester, 2003). In both cases, the higher the number of chlorine of the compound, the lower the degradation rate.

This model was applied to predict the effluent concentrations of the compounds investigated: results for PCBs in the CASP system, which were the only compounds actually found in the effluent, are shown in Fig. 4. These were well predicted by the model: plotting the experimental versus the theoretical values it turns out easy to notice that the plotted values tend to stay on the same line.

As for PCDDs/Fs the results of the model gave values under the limit of detection, which is consistent with the experimental results for both the CASP and MBR system.

4. Conclusions

In this research the removal capability and fate of PCDD/Fs and dioxin-like PCBs in a pilot scale bioreactor operated as both a conventional activated sludge process and a membrane bioreactor were investigated. It was found that the conventional activated sludge process could perform a good removal of PCDDs/Fs and PCBs but the solid retention time adopted (typically less than 20 days) and the presence of suspended solids in the effluent (some 10 mg/l) limited the removal rates of the system if compared to the membrane bioreactor.

Acknowledgements

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Metals Removal in Conventional Wastewater Treatment Process and Membrane Bioreactor Process

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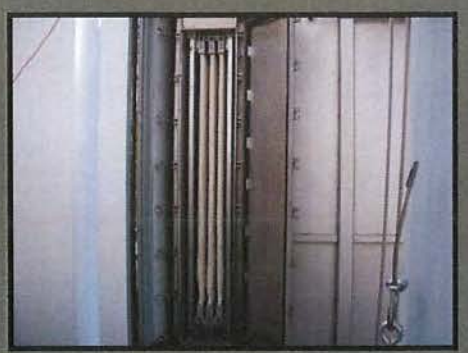
Wastewater Treatment Division

Presentation Objectives

- Present metal removal efficiency data from MBR pilot plants.
- Compare metal removal efficiency between MBR pilots and conventional treatment.
- Discuss the effect of process configuration and operating conditions on the metal removal efficiency.

Pilot Plants Operated

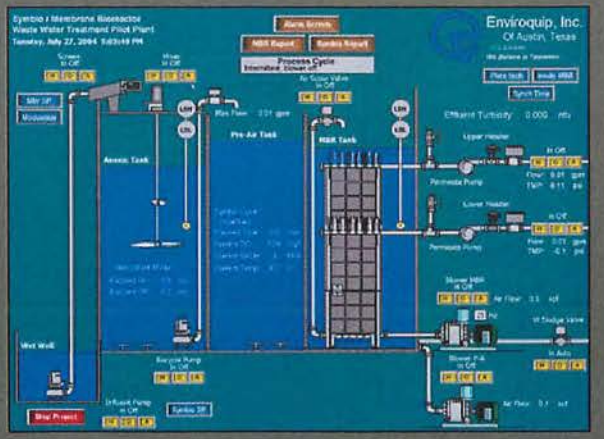
- Enviroquip/Kubota
  - Plate membranes
  - West Point Treatment Plant
- Zenon
  - Hollow fiber membranes
  - South Treatment Plant

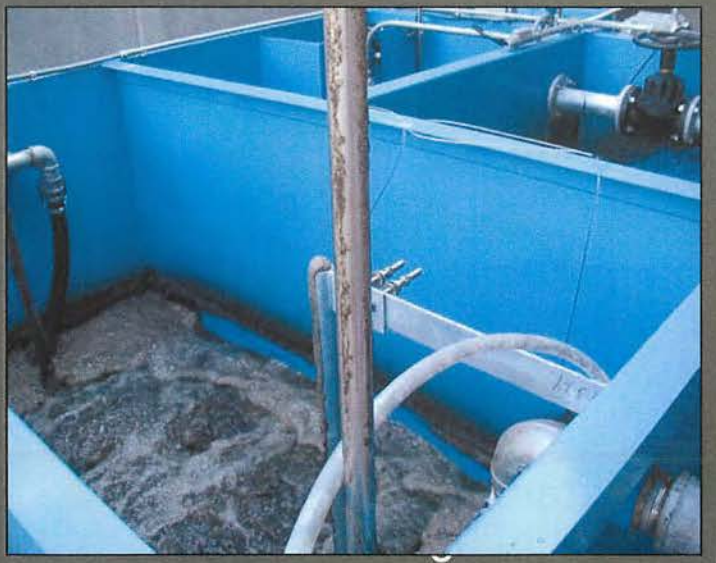


Pilot Plants Information

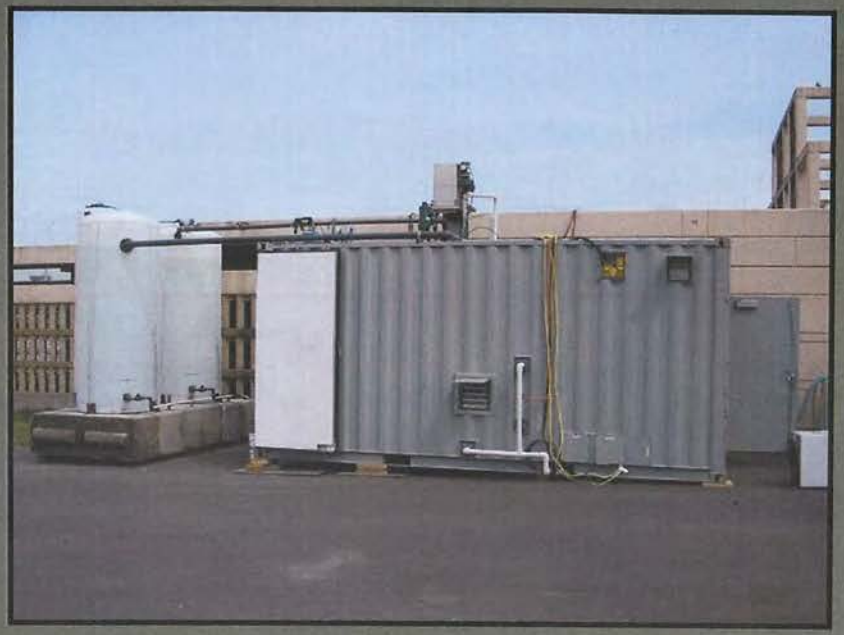
	Enviroquip	Zenon
Feed Source	Raw Sewage	Raw Sewage
Process Volume (gal)	9,000	3,240
Flow (gpm)	36,700	8,000
Flux (gfd)	14-32	8-18
MLSS (mg/L)	2,900-12,300	6,000-11,000
SRT (days)	13-53	10-12
Pore size (micron)	0.40/0.10	0.10/0.04

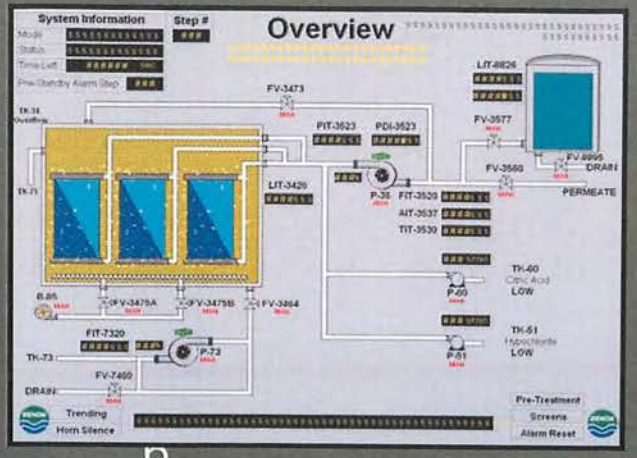
Enviroquip/MBR pilot





Zenon Pilot




System Information
Step #
Overview
LIT-8826
FV-3473
FV-3577
PIT-3523
PDI-3523
FV-8895
DRAIN
FV-3560
PERMEATE
LIT-3426
P-35
FIT-3529
AIT-3537
TIT-3530
TK-40
Citric Acid
LOW
P-60
FV-3479A
FV-3479B
FV-3464
FIT-7320
P-73
TK-73
FV-7460
DRAIN
TK-51
Hypochlorite
LOW
P-51
Pre-Treatment
Screens
Alarm Reset
Trending
Horn Silence

Conventional Treatment Plants

	WTP	STP
Process	Pri. Clarifiers HPO Secondary Sec. Clarifiers	Pri. Clarifiers CAS Secondary Sec. Clarifiers
Flow (MGD)	70-110	65 - 95
MLSS (mg/L)	1,800-2,500	2,000-2,500
SRT (days)	2-4	3-5

Conventional Treatment Plants

West Point Treatment Plant (WPTP)
Seattle, WA

South Treatment Plant (STP)
Renton, WA

Operational Comparison (MBR vs. CAS)

- Clarification Method
  - ✓Physical barrier versus gravity settling
- Biological Process
  - ✓Importance of good biological process control
- Adverse Impacts
  - ✓Loss of treatment capacity versus solid carryover
- Process Monitoring
  - ✓MBR parameters (flux, TMP, and permeability)

Metal Sampling During MBR Operation

- 24-hr composite
  - Pilot influent
  - Pilot effluent
  - Treatment plant effluent
- Grab (WTP Study only)
  - Mixed liquor
- Frequency - Bi-weekly
- Analytical Methods - ICP, ICP-MS, CVAA

List of Metals Analyzed

- Aluminum
- Antimony
- Arsenic
- Barium
- Beryllium *
- Cadmium
- Calcium
- Chromium
- Cobalt
- Copper
- Lead
- Magnesium
- Mercury
- Molybdenum
- Nickel
- Selenium *
- Silver
- Thallium *
- Vanadium
- Zinc

*concentrations below MDL (0.2-2 µg/L) in the influent

Influent Metal Concentrations

Metal (µg/L)	WTP	STP	239-plant survey *
Chromium	13	6	145
Copper	124	81	151
Lead	60	6	103
Nickel	17	5	140
Zinc	390	142	354

* Petrasek et al, 1983

WTP and Enviroquip MBR

	MBR			WTP	
	Inf (µg/L)	Eff (µg/L)	%	Eff (µg/L)	%
Aluminum, Total, ICP	< 3847.0	< 100.0	> 92.0	120.0	89.6
Antimony, Total *	1.32	0.67	35.41	0.82	33.37
Arsenic, Total *	3.29	1.36	40.27	1.69	29.76
Barium, Total *	80.51	4.78	85.31	6.20	80.92
Chromium, Total *	13.29	0.61	87.07	0.88	80.48
Cobalt, Total, ICP-MS	2.28	0.36	69.97	0.40	53.04
Copper, Total *	124.06	3.54	93.91	9.74	84.25
Lead, Total *	60.22	0.30	96.67	0.78	92.22
Molybdenum, Total *	10.84	8.33	20.36	8.45	18.24
Nickel, Total *	16.66	2.89	53.01	3.53	46.47
Silver, Total *	< 4.10	0.21	93.66	0.58	84.24
Vanadium, Total *	9.97	1.46	57.44	1.37	62.50
Zinc, Total *	390.39	89.84	28.75	34.83	73.37

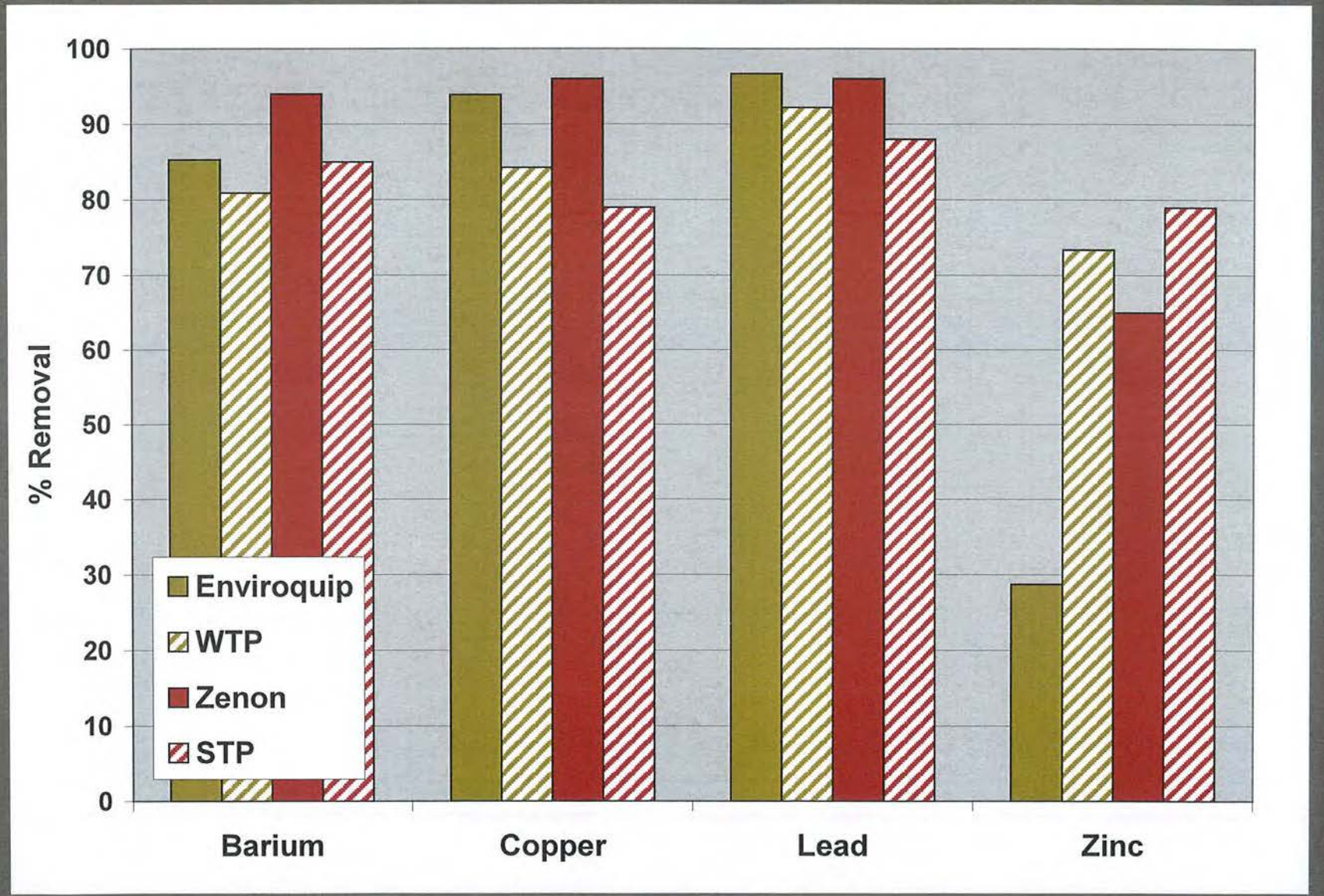
Note: 13 samples collected

STP and Zenon MBR

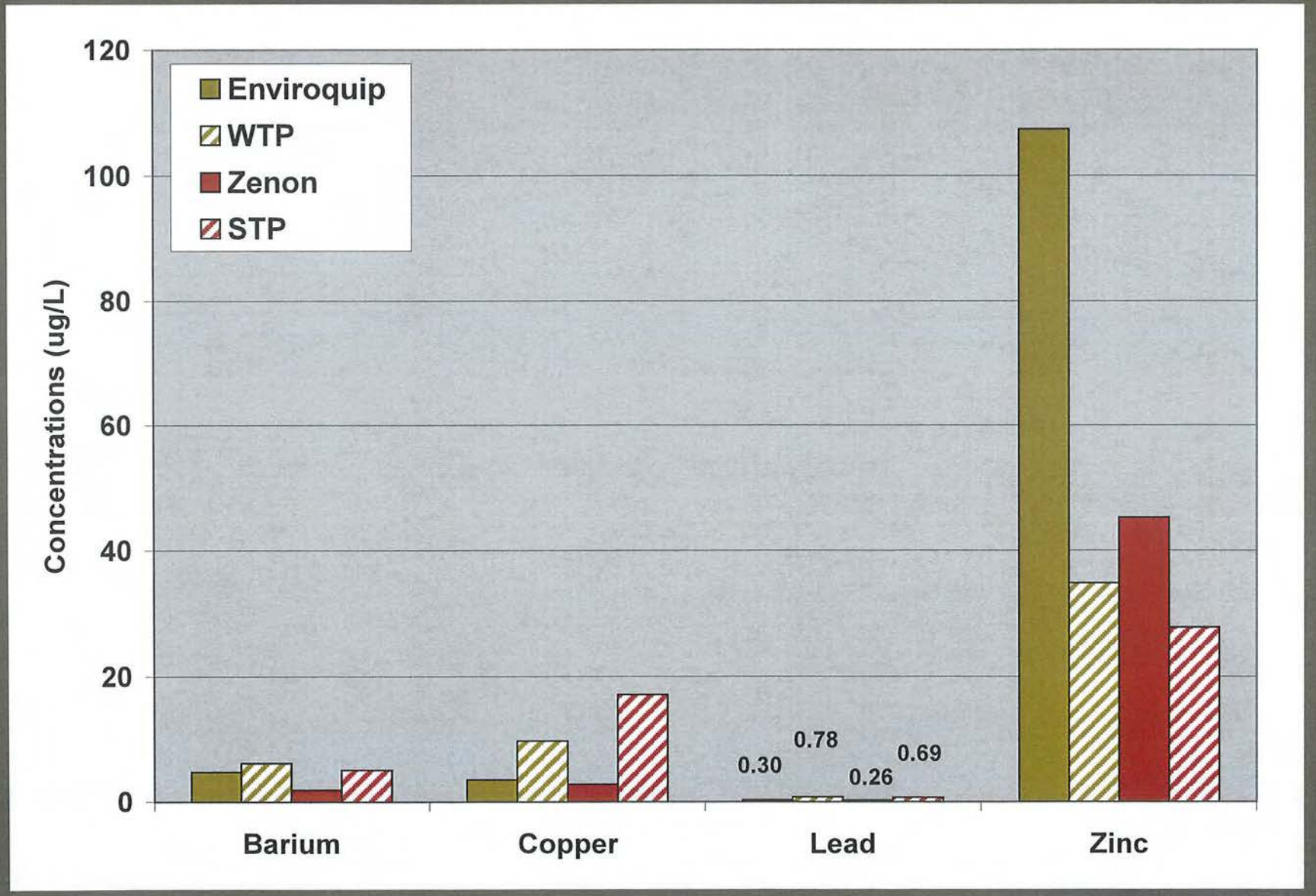
	MBR			STP		
	Inf (µg/L)	Eff (µg/L)	%	Inf (µg/L)	Eff (µg/L)	%
Aluminum, Total, ICP	1309	< 100	> 92	1310	148	> 89
Antimony, Total *	0.63	< 0.42	> 32	1	0.4	41
Arsenic, Total *	2.06	1.04	44	2.06	142	34
Barium, Total *	30.29	1.88	94	31.19	5.07	85
Chromium, Total *	5.77	0.46	90	6.24	1.08	85
Cobalt, Total, ICP-MS	0.81	0.34	57	0.85	0.42	51
Copper, Total *	74.4	2.8	96	81.1	17.11	79
Lead, Total *	5.96	0.26	96	5.84	0.69	88
Mercury, Total, CVAA	0.197	< 0.005	> 96	0.162	0.012	90
Molybdenum, Total *	9.26	7.5	19	10.19	7.87	19
Nickel, Total *	5.3	2.21	60	5.61	2.67	53
Silver, Total *	1.59	< 0.05	> 97	1.76	0.41	76
Vanadium, Total *	2.78	1.24	55	2.86	0.97	66
Zinc, Total *	132.24	45.23	65	141.7	27.8	79

Note: 9 samples collected

Comparing Removal Efficiencies

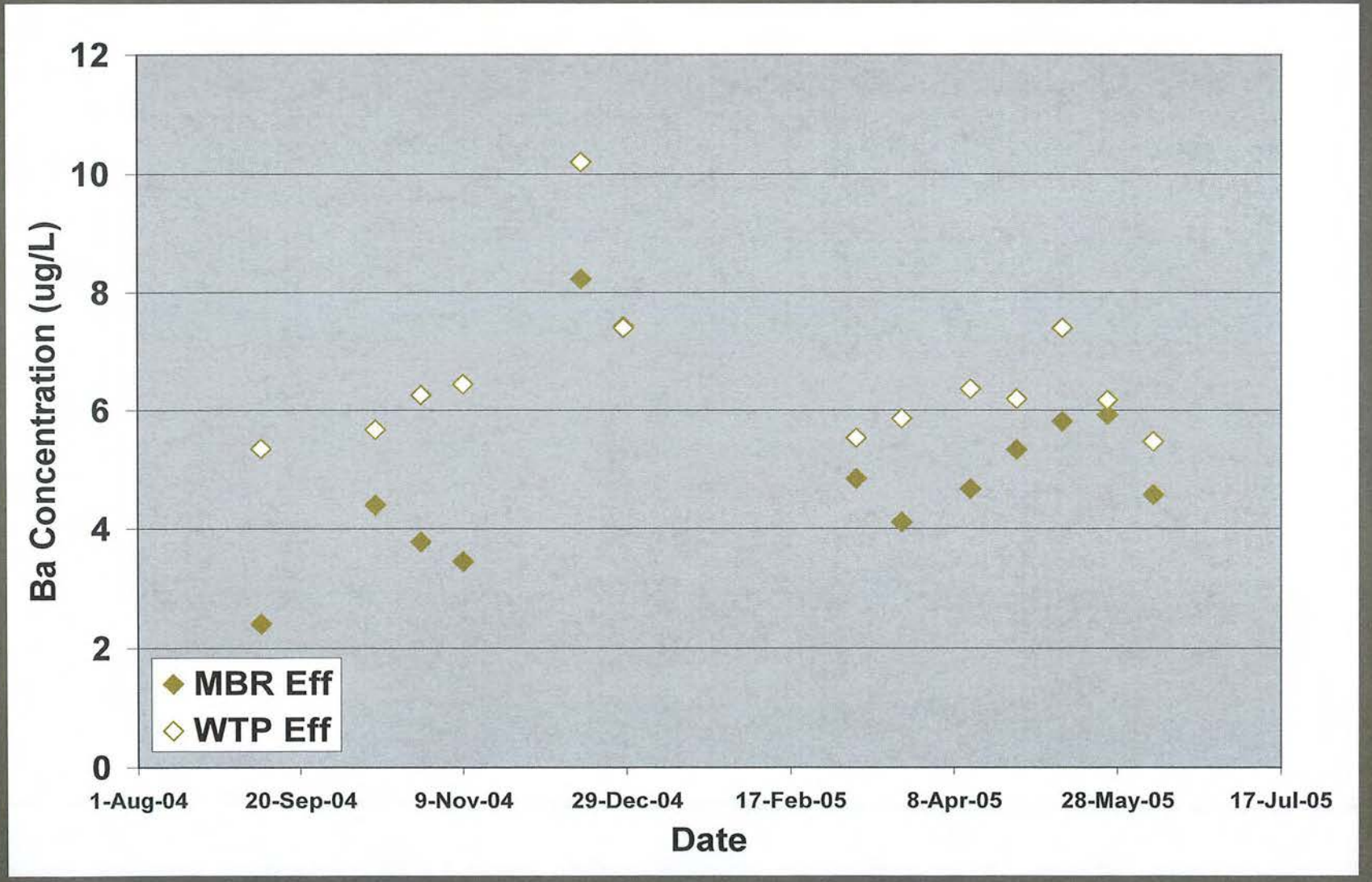


Comparing Effluent Concentrations



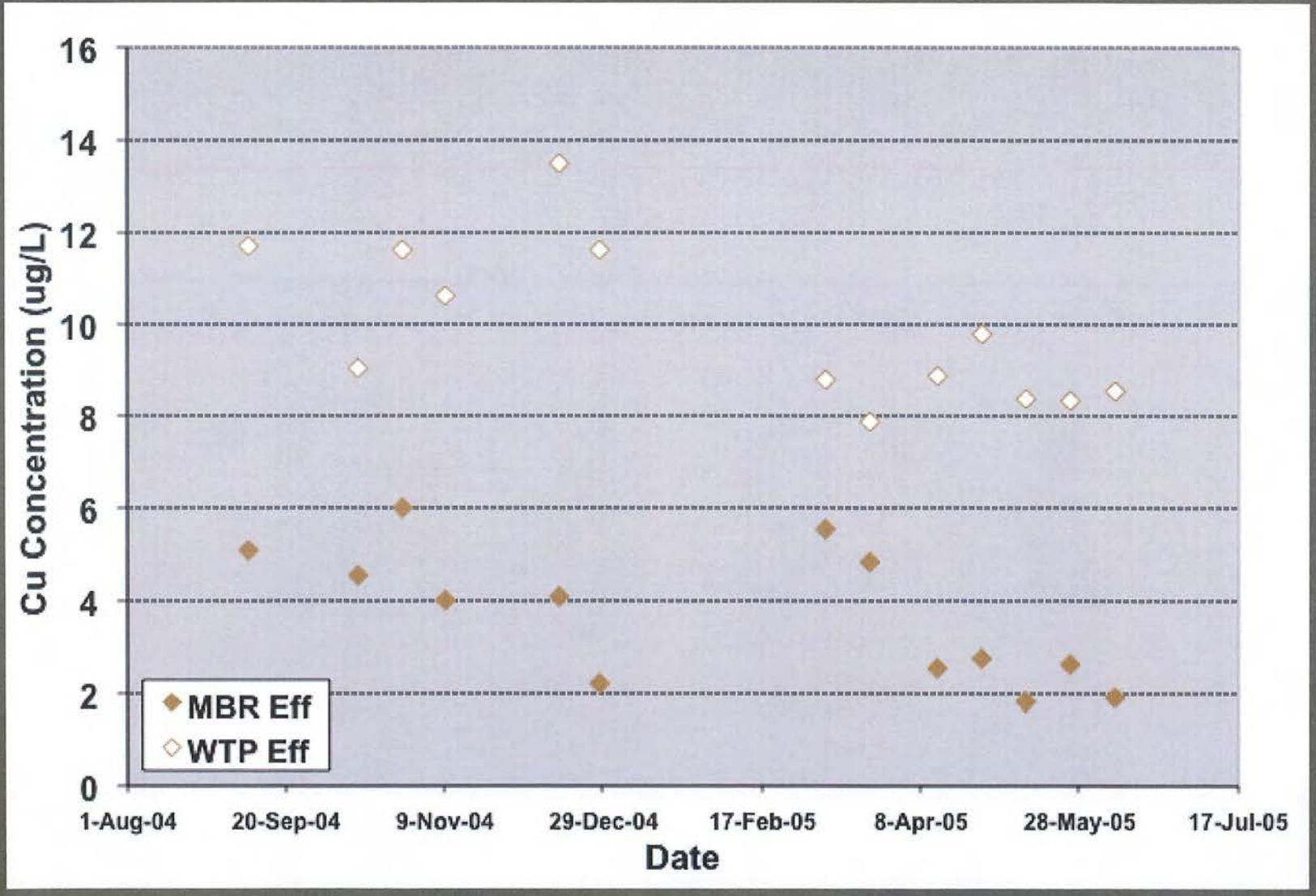
Barium Effluent Concentration

Enviroquip vs WTP



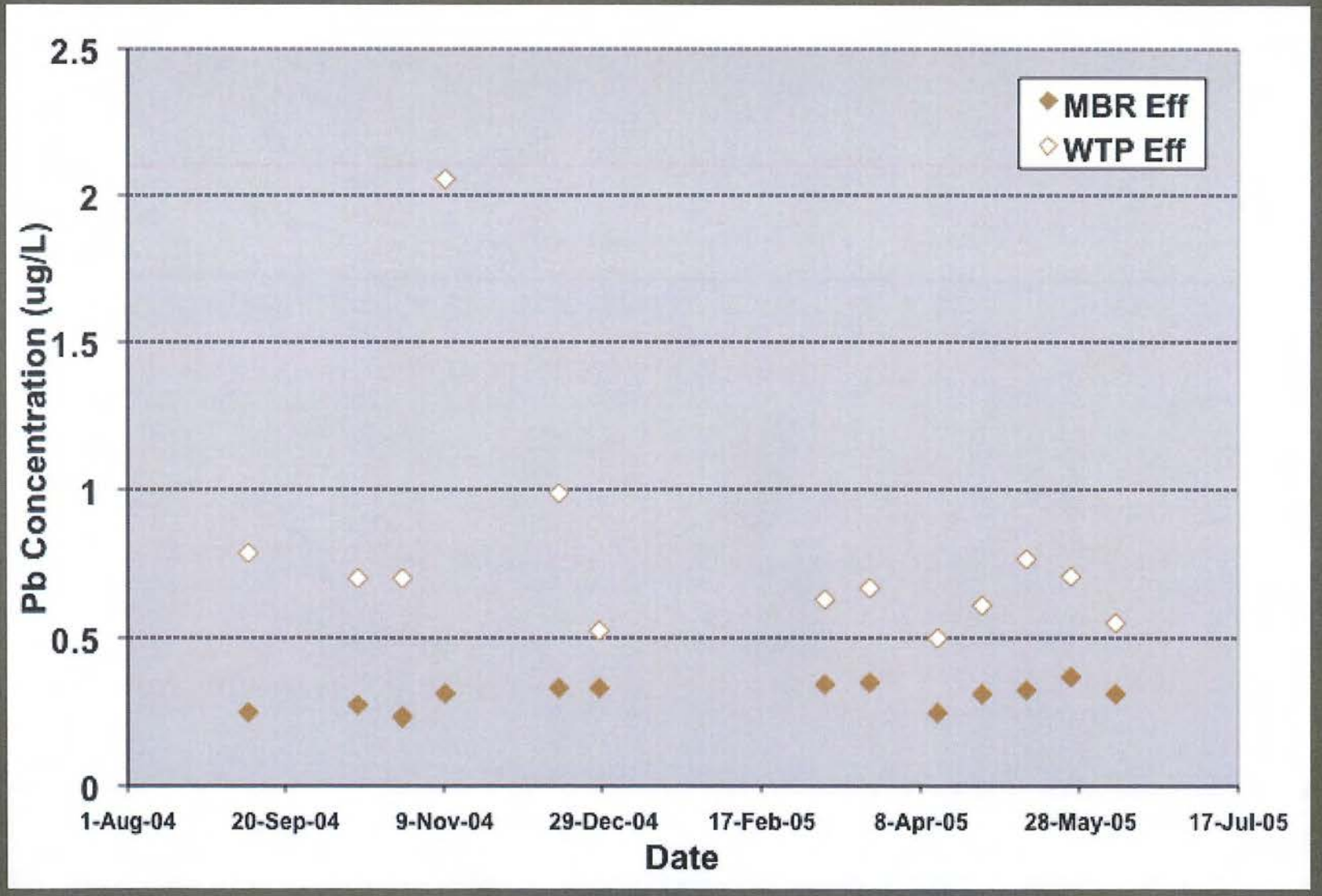
Copper Effluent Concentration

Enviroquip vs WTP



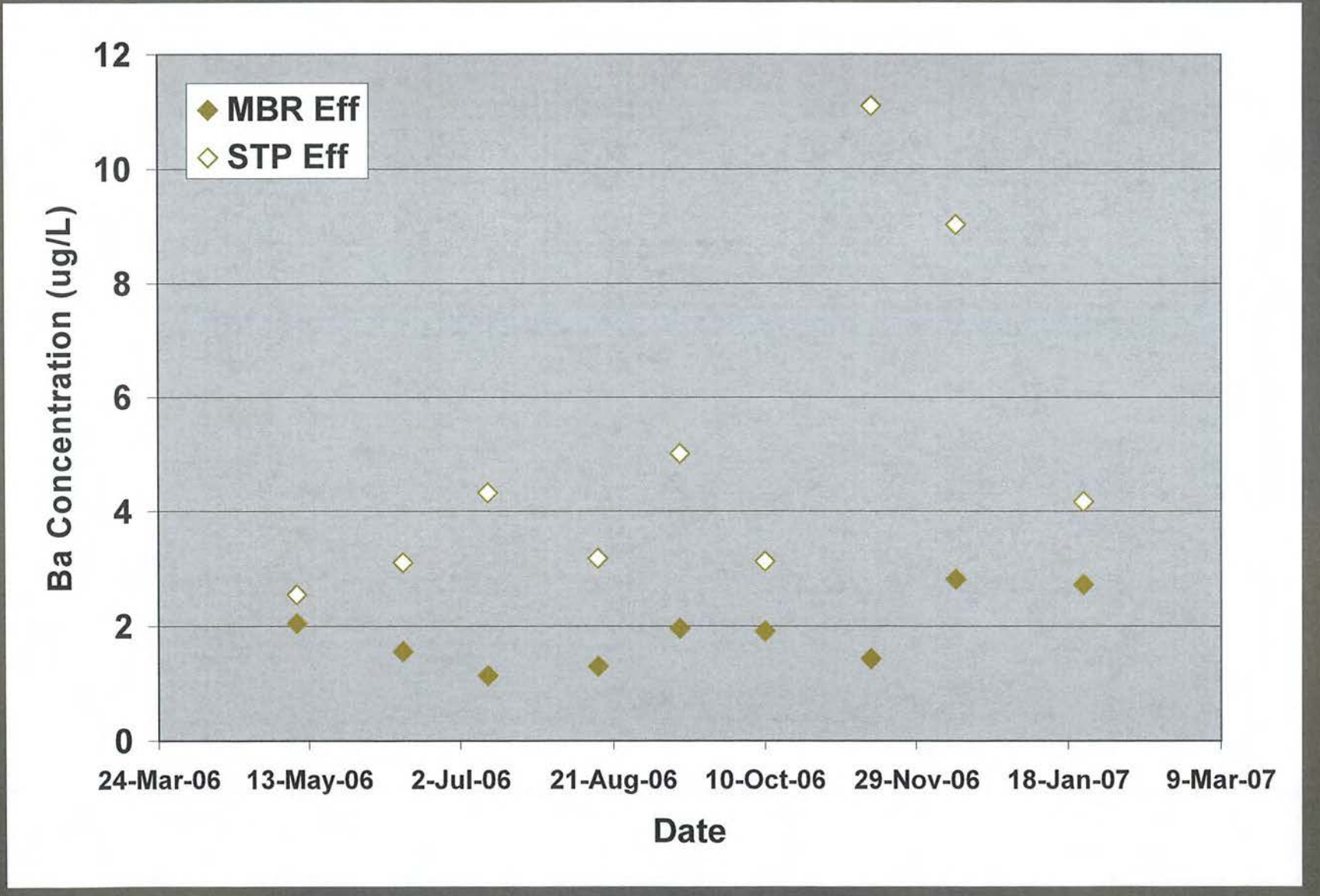
Lead Effluent Concentration

Enviroquip vs WTP



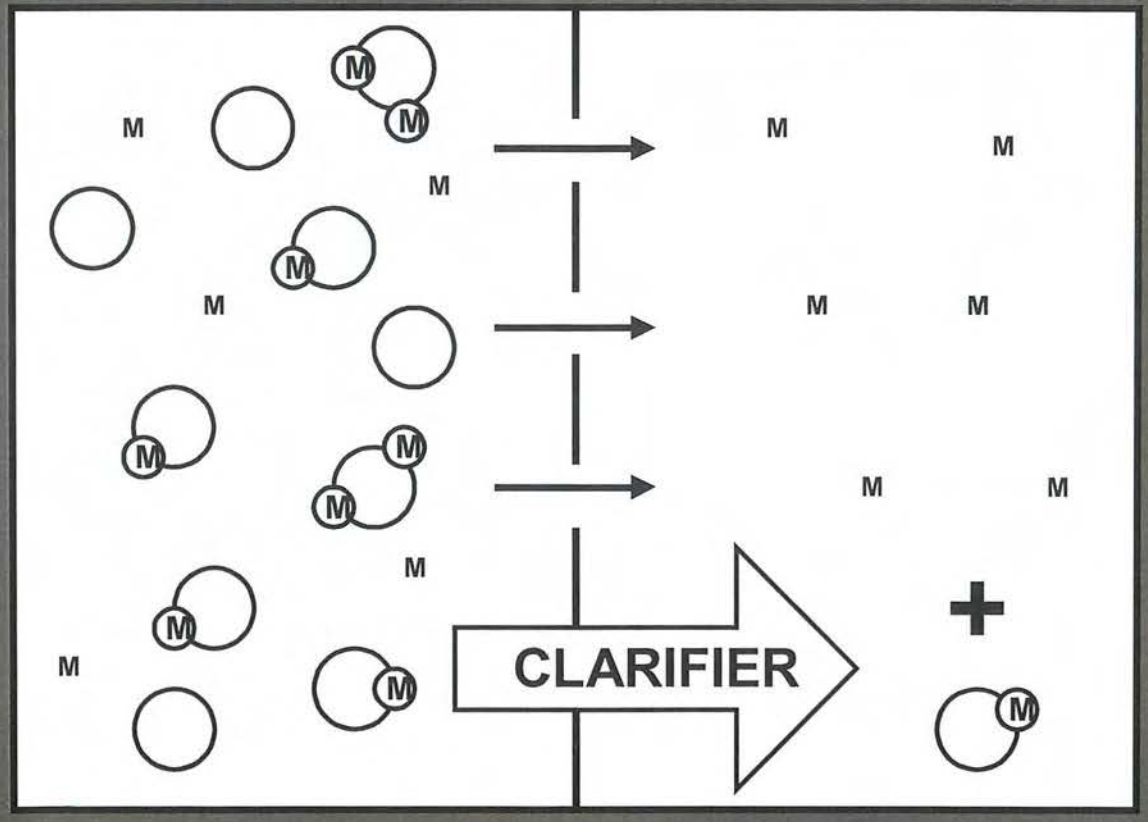
Barium Effluent Concentrations

Zenon vs STP



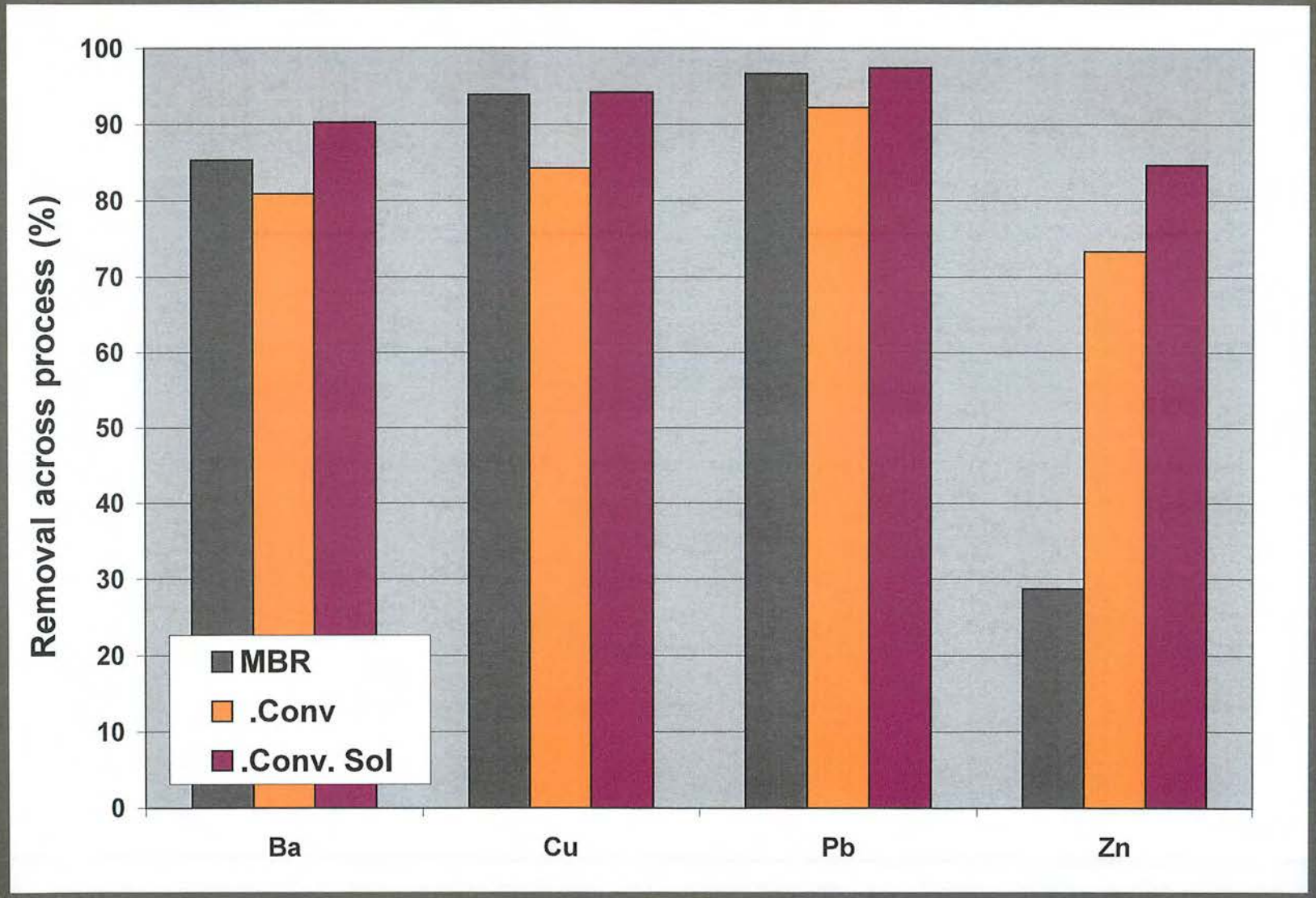
Metals Removal – Solids Separation

HYPOTHESIS: Membrane filtration provides enhanced metals removal.



TESTING: Compare filtered (0.45 µm) and unfiltered CAS effluent to identify the effect of filtration.

Comparing MBR and Conventional



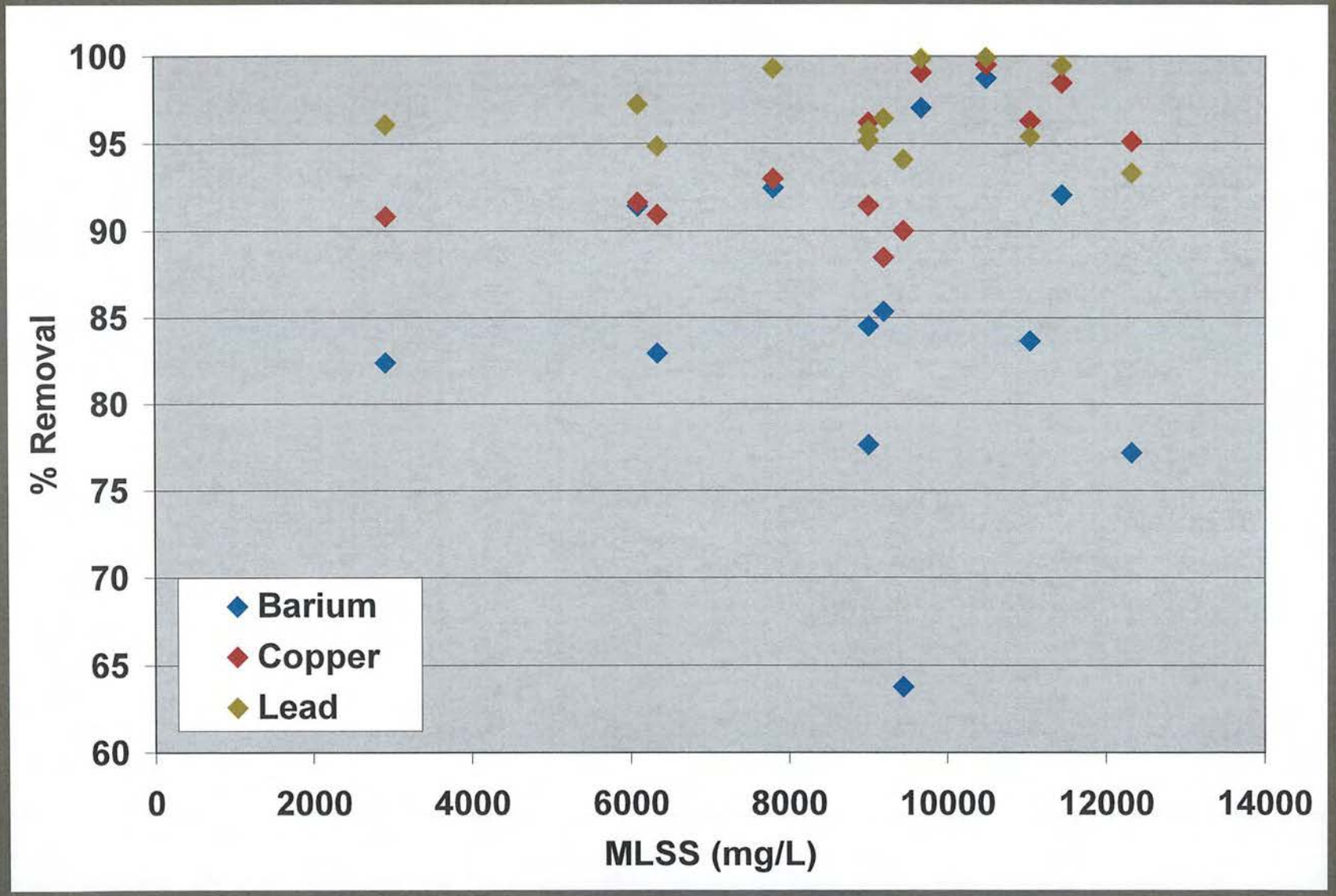
Enviroquip MBR and WTP data from Sep 04- Jun 05

Metals Removal - Effect of Biological Process Operating Conditions

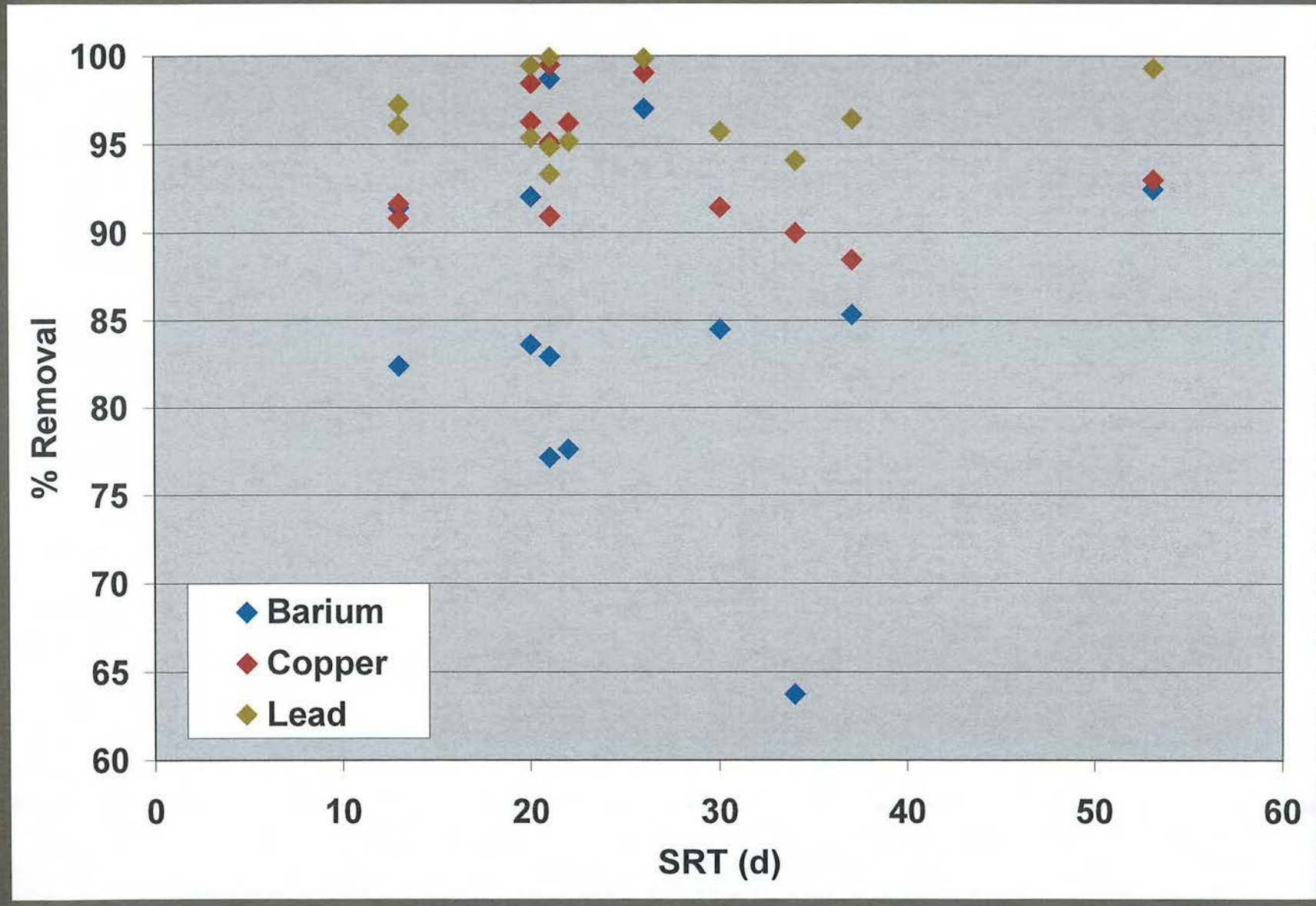
Hypothesis: Higher MLSS concentration and longer SRT will enhance metals removal.

Testing: Evaluate metals removal as a function of MLSS and SRT.

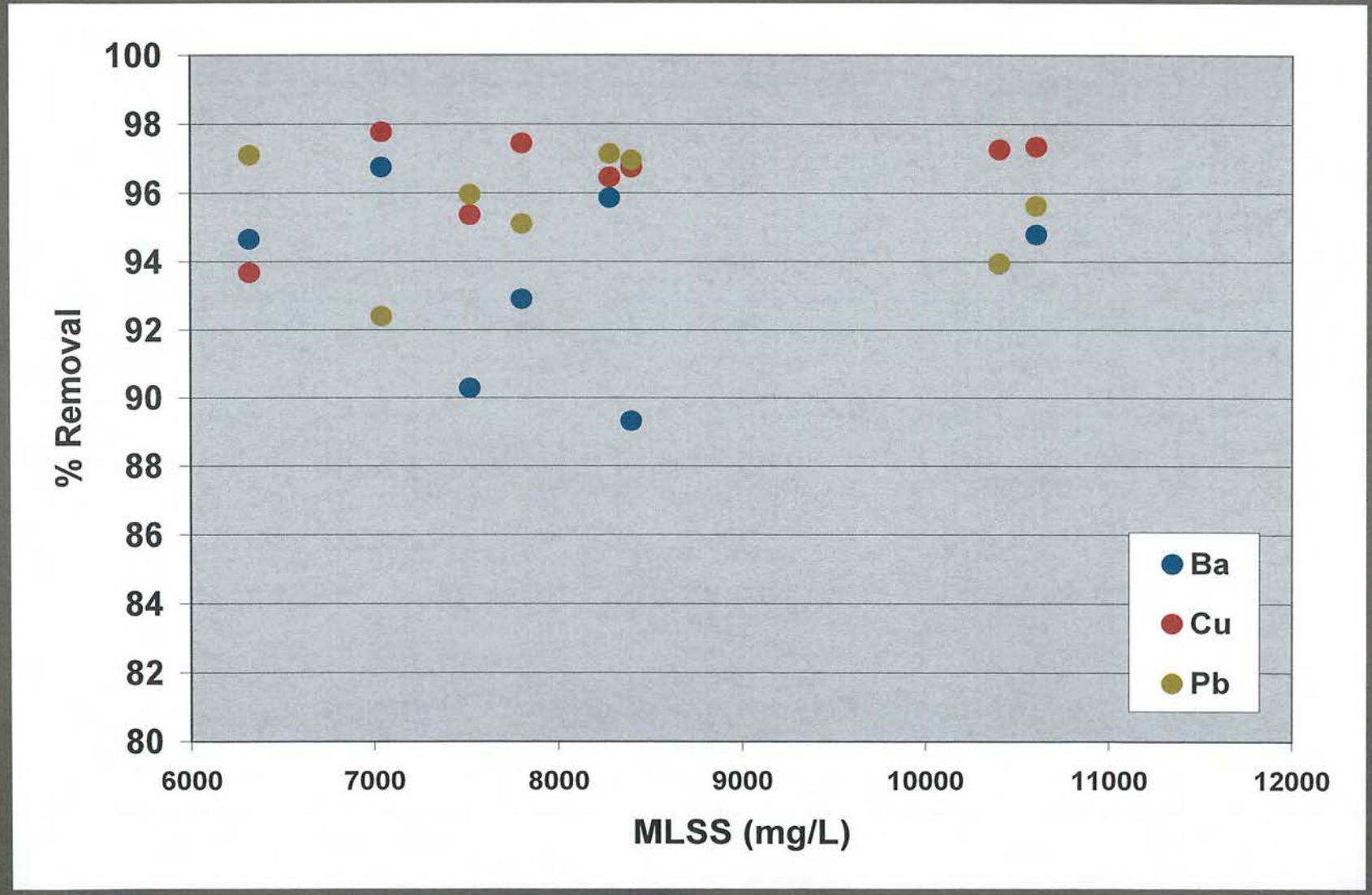
Enviroquip Metal Removal vs. MLSS



Enviroquip Metal Removal vs SRT



Zenon Metal Removal vs. MLSS



Summary

- MBR pilots had better metal removal efficiency compared to conventional activated sludge/clarifier.
- Membrane filtration is a contributing factor in the increased metal removal efficiency.
- No clear correlation existed between biological operating conditions (SRT or MLSS) and metals removal.

Acknowledgements

- Enviroquip/Kubota and GE-Zenon for providing pilot equipment.
- King County treatment plant staff for maintenance and operations support.
- King County treatment plants process laboratory and Environmental Laboratory for analytical support.

Metals Removal in Conventional Wastewater Treatment Process and Membrane Bioreactor Process

QUESTIONS

King County Department of Natural Resources and Parks
Wastewater Treatment Division

King County