Quarterly Report

for

Reducing Eutrophic Conditions of the Salton Sea

(The First of Four)

Prepared for the
State Water Resources Control Board

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Introduction

The Salton Sea is California's largest inland water body and home to more species of birds than any other place in California. Over 390 species of birds, including the endangered brown pelican and Yuma clapper rail, have been identified at the Sonny Bono Salton Sea National Wildlife Refuge. Eutrophication of the Salton Sea has sufficiently impacted its beneficial uses (including recreation, fishing, and wildlife resources) that TMDLs for pollutants causing this impairment may soon be implemented. Some of the specific effects of eutrophication include high algal biomass, high fish productivity, low clarity, frequent very low dissolved oxygen concentrations, massive fish kills, and noxious odors. External loading of nutrients, particularly phosphorus (P), is responsible for the eutrophication of the Salton Sea. Because internal phosphorus loading in the Salton Sea is low and external phosphorus loading to the Sea is high, reduction of tributary phosphorus loading to the Salton Sea may reduce eutrophication.

The first goal of the project is to determine the efficacy of removing phosphorus from water that eventually discharges into the Salton Sea. Because the Salton Sea is phosphorus limited, removing phosphorus and sediment from agricultural drainage water (ADW) should reduce the overall amount of phosphorus entering the Sea via local rivers and thereby decrease eutrophication. Although phosphorus and suspended solids removal is commonly practiced in municipal wastewater treatment, the high sediment concentrations and salinity of the ADW will require testing and possible modification to the typical procedures used in municipal wastewater treatment.

All of the tributaries to the Salton Sea contain low concentrations of selenium. There is some concern about the potential for selenium bioaccumulation at the various stages of treatment. With this in mind, our second project goal is to monitor selenium levels at each stage of the CEP and flocculation treatment processes. Currently, most scientists believe that selenium is sequestered in the Salton Sea due to the high salinity and is not likely to cause the types of serious environmental impacts that have occurred at Kesterson Reservoir and other sensitive sites. However, if future plans to reduce salinity in the Sea are enacted, there may be a need to consider treating the tributaries for selenium in addition to phosphorus. During these studies, we will monitor selenium at each step of the process and note any bioaccumulation that may occur. If these monitoring efforts indicate that a potential problem exists, we will seek additional support from outside agencies to investigate techniques for selenium control. There have been several promising studies that indicate that managed high-rate algal ponds, very similar to those used in the CEP process, may be able to concentrate low levels of selenium and allow them to be removed in a cost-effective manner.

Project Tasks

The cumulative percent completion to date for each task and its subtasks is noted next to each task's title herein. Also, Table 1 is a modified project work schedule that summarizes this information.

Table 1. Modified project work schedule with cumulative percentages of tasks completed to date.

	Year/Quarter/Month																	
	2003			2004												2005		
	4th			1st			2nd			3rd			4th			1st		
Project Task	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
1. Modifying existing pilot-scale P-removal systems:		100%																
2. Conduct laboratory-scale studies of P-removal		60%																
3. Conduct bench-scale CFS studies of P-removal																		
4. Conduct ditch-scale studies for P-removal:																		
5. Conduct CEP flocculant/ polymer treatment evaluations																		
6. Monitor biological Se-uptake and evaluate CEP for Se-removal		21%																
7. Quarterly, draft and final reports:		10%																

Task 1. Modifying existing P removal systems (24% complete)

1.1 Bench-scale unit

A bench-scale coagulation, flocculation, sedimentation (CFS) unit will be used to evaluate the behavior of chemical flocculants and polymers in a simulated full-scale conventional water treatment system (see Photo 1).

Photo 1. Dr. Matsumoto's coagulation, flocculation, sedimentation (CFS) unit

Located in Mark Matsumoto's laboratory at UCR, the CFS system consists of an integrated chemical mixing chamber, three-stage flocculator, and inclined-plate sedimentation tank apparatus. The system allows one to monitor the effects of a specific water treatment over a 10 hour period. Treatments are to be performed on 300 gallon water samples trucked in from the CEP and Salton Sea tributaries. Polymer and chemical flocculant injection systems have been assembled and are being optimized in preparation for use as soon as the ideal treatments have been determined in the lab-scale vial tests (see task 2.).

1.2 Simulated drainage ditches

A small-scale earthen drainage ditch supplied with Whitewater River (WWR) water has been excavated to test the ability of alum and various polymers to remove phosphorus and sediment (see Photo 2a and 2b).

Photo 2a and 2b. The newly excavated simulation drainage ditch. a) The weir-boarded drop structure and potential mixing tanks for flocculant treatments. b) A view of the outflow structure.

a) 

b) 

Flow in the 200 ft. long ditch is approximately 60 gal/min though it can slow or stop due to silting-up of the intake structure and pumps located next to the WWR. A larger river water intake structure will soon be installed to remedy this problem. A second ditch will possibly be dug parallel to the first in February 2004 once experience in optimizing the first has been gained.

<u>1.3 Optimization of Selenium Uptake by Algae in the CEP</u>

Although the CEP was designed for phosphorus removal, selenium could also be removed by bioaccumulation and "bioflocculation" of the captive algae and fish populations, and thus improve the effluent water quality. Starting in July 2004, we will make modifications of the water velocity and the circulation rate through the algal settling zone in the CEP to optimize selenium removal.

Task 2. Conduct laboratory-scale studies of P-removal (60% complete)

Introduction

In Dr. Chris Amrhein's laboratory at UC Riverside, we are screening chemical flocculants and polymers for their capacities to remove total and soluble phosphorus (P_T and P_S, respectively) from samples of river water from the Coachella and Imperial Valleys (The Whitewater, New, and Alamo Rivers) and the CEP Algae Zone water. Tests are being conducted in glass scintillation vials and jar testers.

Methods

Water Collection

Bulk water samples were collected from the New River and CEP Algae Zone (see table 1 for sample dates). Samples were transported back to UC Riverside and refrigerated. Samples were brought to room temperature, well mixed and then sub-sampled for water turbidity and phosphorus analysis in order to document seasonal fluctuations in ambient P and suspended solids.

Baseline values of turbidity were determined with a HF Scientific, Inc. Micro 100 Turbidimeter (Fort Myers, FL). Phosphorus analysis were done using a modified ascorbic acid-molybdate blue method on an Astoria-Pacific Int. Alpkem RFA 300 Autoanalyzer (Clackamas, OR).

Table 2. Dates and baseline conditions of water used in treatment studies.

Date Sampled	Source	Turbidity (NTU)	Soluble Phosphate Concentration (mg P L^{-1})
3/4/03	CEP Algae Zone	47.1	N/A
10/13/03	CEP Algae Zone	N/A	0.49
10/27/03	CEP Algae Zone	53.0	0.49
6/23/02	New River	149.6	0.76
10/8/02	New River	157.4	1.19
11/14/02	New River	19.1	1.50
2/14/03	New River	25.2	1.84
10/13/03	White Water River	N/A	1.30
10/27/03	White Water River	13.4	1.60

N/A = parameter not analyzed

Vial Tests

For each test listed in Table 2, solutions of polymer and trivalent metal salts (alum or ferric chloride) were gravimetrically added to a 25 mL clear glass vial. The vial was then filled to 25 mL with test water and placed on an Eberbach Corp. shaker (Ann Arbor, MI) on low for 3 minutes. After a 10 minutes settling time, the turbidity was measured. A 7 mL sample was pipetted from the top 1/3 of the vial and collected in a glass test tube with 1 drop of concentrated

H_2SO_4 added to preserve the sample for P analysis. The solution was syringe filtered < 0.45μm pore size (Fisherbrand Membrane) then run on the Alpkem to determine P_S.

A persulfate digestion method is being evaluated (Greenberg et.al., 1992) to test the amount of P_T. The difference between P_T and P_S will be designated as the organic phosphorus available from suspended algae.

Table 3. Preliminary lab-scale vial tests completed

Polymer Treatment					Metal Salt Treatment		
Polymer		Charge		Molecular Wt.	None	Alum	FeCl3
GE-Betz	AE1115	Low	-	Low		NR	
GE-Betz	AE1123	Low	-	High		NR	
GE-Betz	AE1128P	Low	-	Med		NR	
GE-Betz	AE1132	High	-	Med		NR	
GE-Betz	AE1138	Med	-	High		NR	
GE-Betz	AE1701	Low	-	High		NR	
GE-Betz	AE1702	Low	-	High		NR	
GE-Betz	AP1100	Low	-	Med		AZ, WWR	
GE-Betz	AP1120	Med	-	Med		AZ, WWR	
GE-Betz	AP1142	Low	-	Med		AZ, WWR	
Celanese	T-4246		-			AZ	
Celanese	2J		-			AZ	
Celanese	21J		-			AZ	
Celanese	40J		-				
GE-Betz	CE1154	Med	+	Low	NR		
GE-Betz	CE1159	High	+	Med	NR		
GE-Betz	CE1161	Low	+	Low	NR		
GE-Betz	CE2680	Low	+	Low	NR	NR	NR
GE-Betz	CE2681	Low	+	Med	NR		
GE-Betz	CE2688	High	+	Med	NR		
GE-Betz	CP1155	Med	+	Low		AZ, WWR	
GE-Betz	CP1160	Low	+	Low		AZ, WWR	
Celanese	T-4141		+			AZ, WWR	AZ
Celanese	CP-14		+			AZ, WWR	AZ
Celanese	Percol 763		+			AZ	AZ
GE-Betz	IC1172				NR		
GE-Betz	IC1187				NR		
GE-Betz	P763					NR	

AZ = CEP algae zone water
NR = New River water
WWR = Whitewater River water

The polymers initially used in these tests were made by Celanese Corp. Though these polymers were used in various other polymers studies found in the literature (e.g.; Saleh and Letey, 1988), the Celanese Corp. no longer produces them. Because of this, we have made GE-Betz Corp. our new polymer supplier. Because of a non-disclosure agreement that we have signed with GE-Betz, we cannot list the precise charge density or molecular weight in Table 3. Instead, we have made approximate relative classifications of Low, Med(ium), and High positive or negative relative charge density and Low, Med, or High molecular weight (MW). It should be noted that these classifications are on a relative scale that allows comparison of GE-Betz polymers to one another but not to other polymer makers.

Jar Tests

Two liter jar tests are being conducted concurrently to the vial tests on the most promising treatments. Their larger volumes are hoped to allow floccules to settle deeper before sub-sampling for P analysis. A Phipps & Bird PB-700 Jartester (Richmond, VA) system was used. Each treatment was mixed for 30 min., allowed to settle for 60 min, and then sub-sampled near the surface for turbidity measurement.

Table 4. Preliminary lab-scale jar tests completed

Polymer Treatment		Mineral Treatment	
		Alum	FeCl3
GE-Betz	AE1702	NR	
Celanese	2J	NR, AZ	AZ
Celanese	21J	NR	
Celanese	40J	NR	
GE-Betz	CE2680	NR	NR
	Alum		AZ
	FeCl3	AZ	

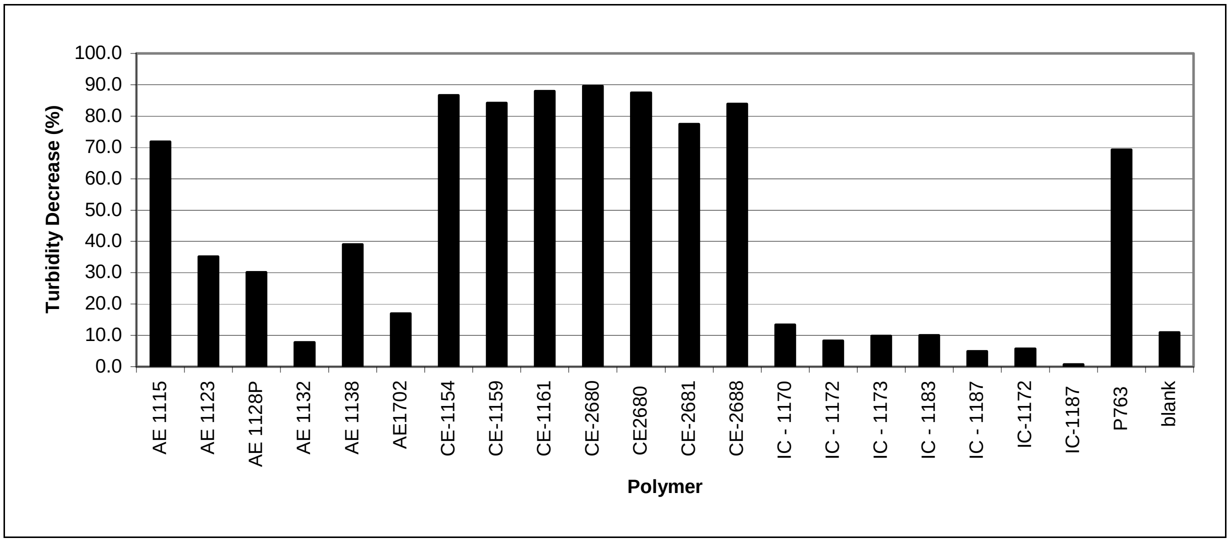
NR = New River water
AZ = CEP algae zone water

Results and Discussion

Vial Tests

The polymers alone had mixed effects on the turbidity of New River water when examined for the first five minutes after treatment addition (see Figure 1). At 4ppm of inorganic coagulant, IC1187 performed the worst reducing turbidity by less then 1%. The anionic emulsion (AE) series

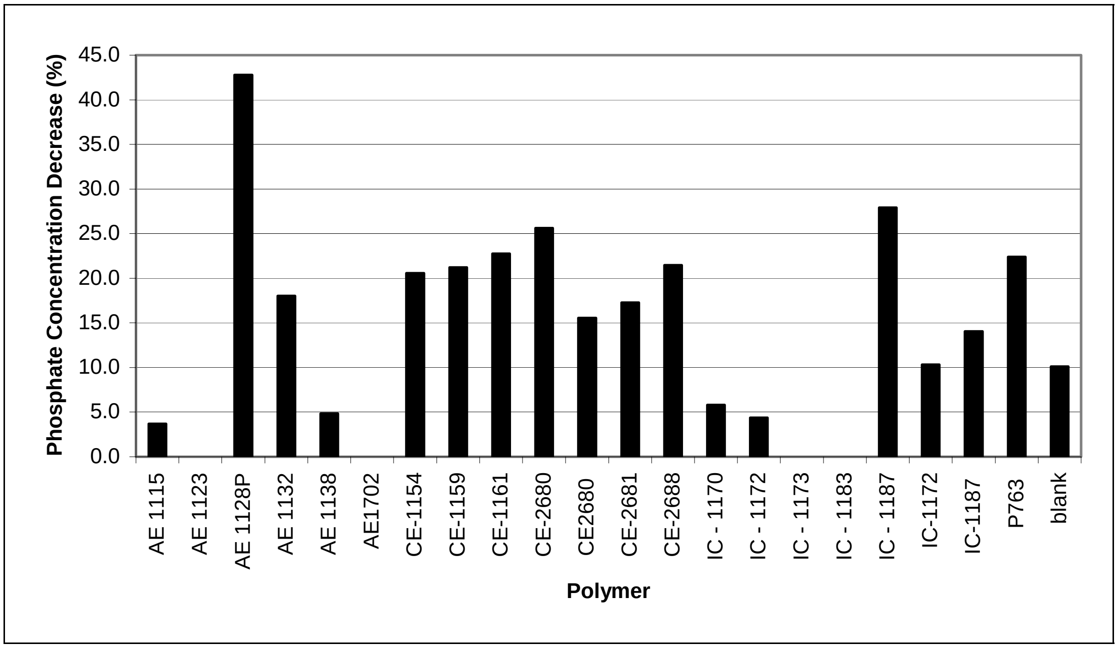
Figure 1. Turbidity decrease of New River water in vial tests due to polymer additions (4ppm). All measurements made 5 minutes after treatment addition.



resulted in a moderate decrease in turbidity (8-72%). Of these, AE1115 had the largest decrease in water turbidity. The cationic emulsion (CE) series all produced large decreases in turbidity averaging 75% more than the blank.

Though many polymer treatments were effective in decreasing turbidity, none were as effective in reducing phosphate concentrations (see Figure 2). The range of turbidity decreases was 0-43%. Considering that the blank decreased 10% just from the natural settling of suspended particles, it is understandable that the treatments listed as 0% actually inhibited PO_4 settling. In the case of AE 1702, the PO_4 concentration was actually raised 10% although further tests would be needed to verify this finding.

Figure 2. Phosphate concentration decreases in New River water in vial tests due to polymer additions (4ppm). All measurements made 5 minutes after treatment addition.



At concentrations of 4 ppm, AE 1128P performed the best reducing the soluble reactive phosphorous concentrations 43%. For most of the polymers, the majority of the flocculation and settling took place within the first 2-3 minutes of still conditions (as seen in Figure 3).

In an effort to increase the phosphate removal, the most promising polymer species were combined with alum and ferric chloride. The combination of polymer and mineral typically improved the removal of suspended solids (see Figure 4) and PO_4 (see Figure 5 and Figure 7). Turbidity was further reduced approximately 60% by adding 4ppm alum concurrently with 4ppm CE2680. Alum alone did very little to reduce the turbidity even at concentrations of 8ppm (Figure 6). Higher concentrations of alum were observed to have less impacts on reducing turbidity as can be seen in Fig. 4. At 8ppm alum, the average turbidity at 5 minutes was ~60 NTU compared to the ~12 to 40 NTU seen for the combinations using lower alum doses. By combining equal parts alum and CE 2680 (4ppm) phosphate concentrations were reduced to about 0.2 ppm compared to the 1 ppm for CE2680 alone. Similar reductions were observed with the addition of Fe (Figure 7).

Figure 3. Average turbidity measurements of New River water samples subjected to CE polymer treatments in vial tests.

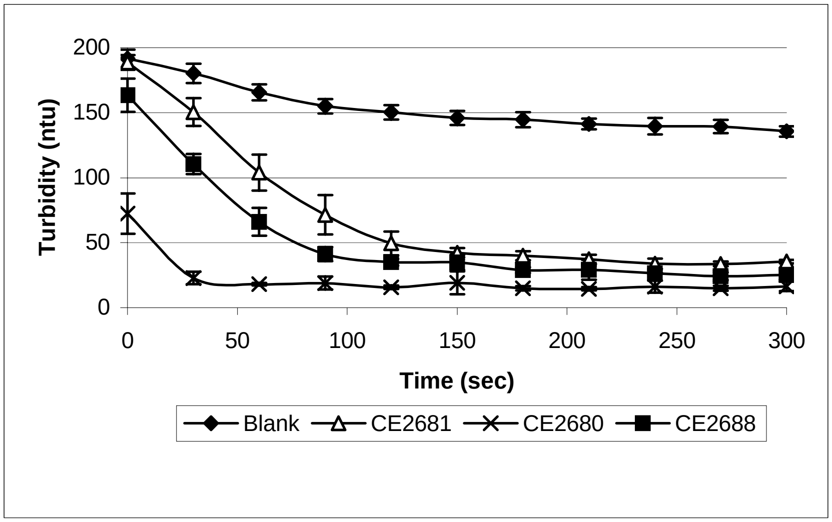


Figure 4. Turbidity measurements of water samples with 4ppm of polymer 21J and varying amounts of alum in vial tests.

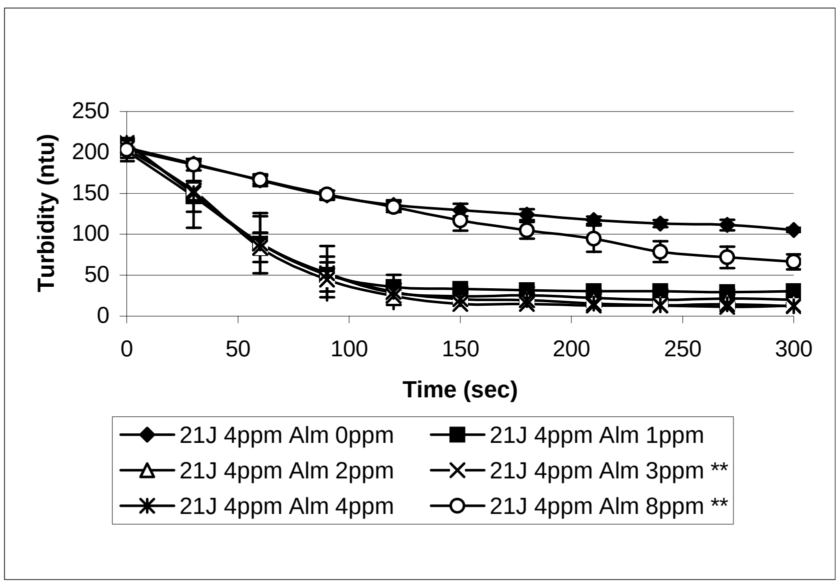


Figure 5. Phosphate measurements of New River water samples with 4ppm of polymer CE2680 and varying amounts of alum in vial tests.

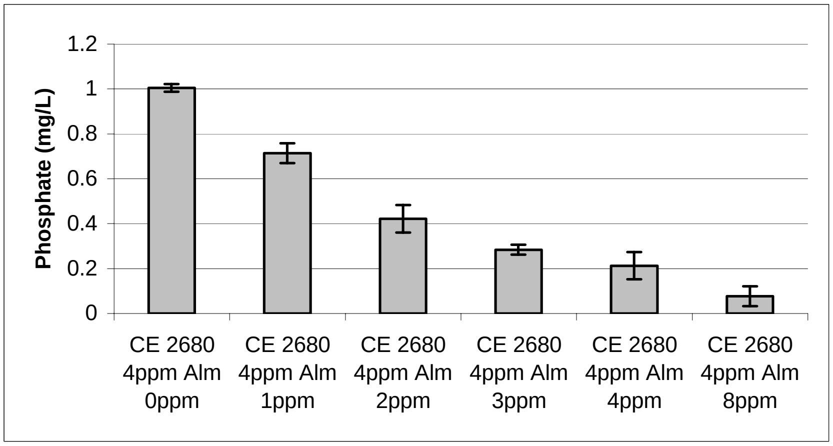


Figure 6. Changes in New River water turbidity with time for varying amounts of alum in vial tests.

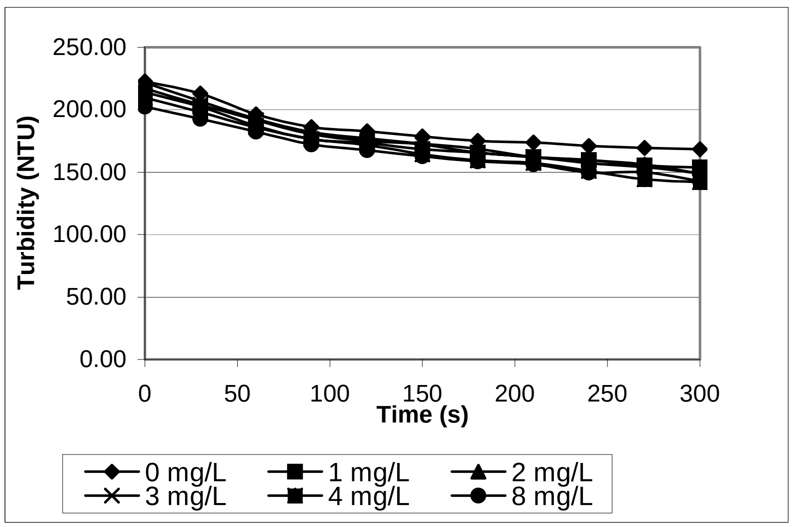
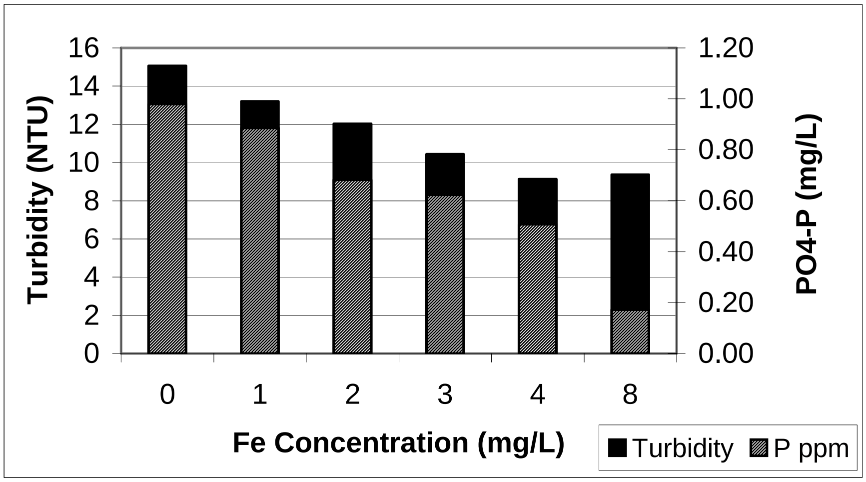
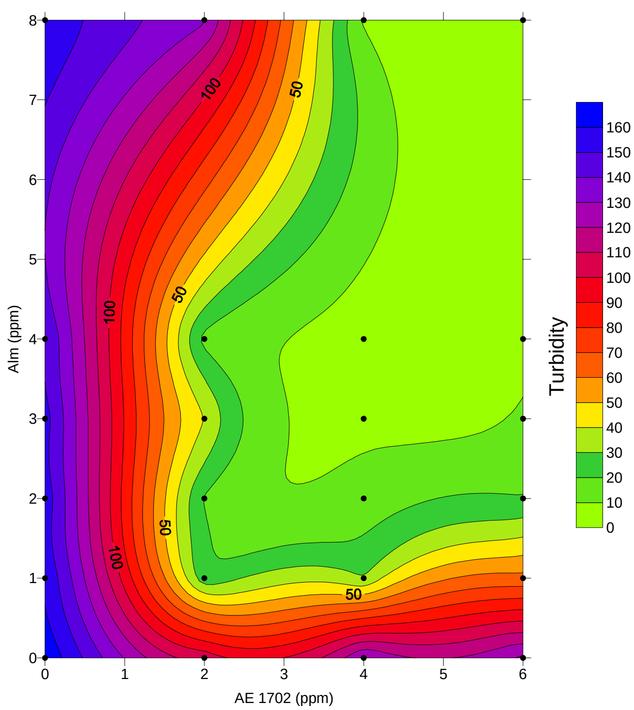


Figure 7. Turbidity and phosphorus concentrations of water samples 5 minutes after additions of 4ppm CE2680 and varying amounts of Fe.



We experimented with colored map-plots that allow interpolation of the precise concentrations of polymer and trivalent cation needed to achieve a desired numerical target for turbidity or phosphate concentration. For example, visual comparisons of Figures 8a, 8b, 9a, and reveal that, given equal concentrations of polymer, AE 1702 requires more alum to produce the same effects as CE 2680.

Figure 8a and 8b. Turbidity (a) and PO_4-P concentrations of New River water subjected to varying treatments of AE 1702



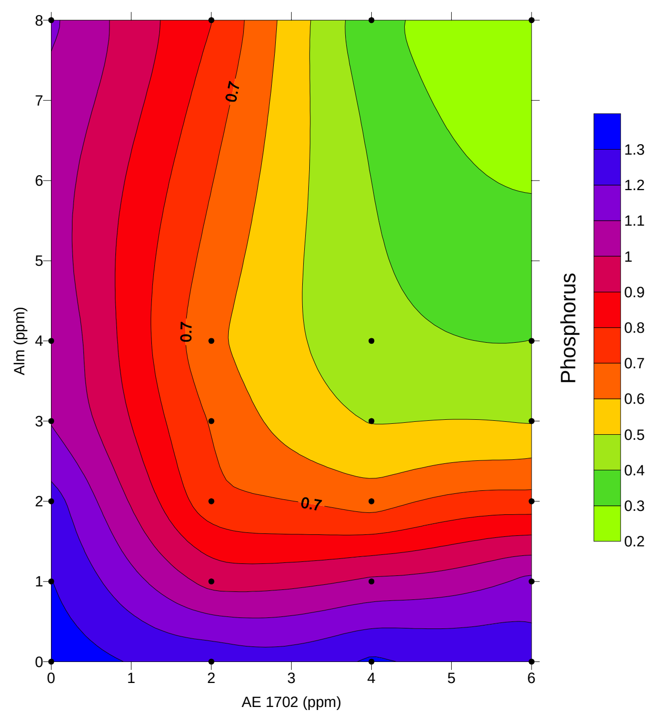
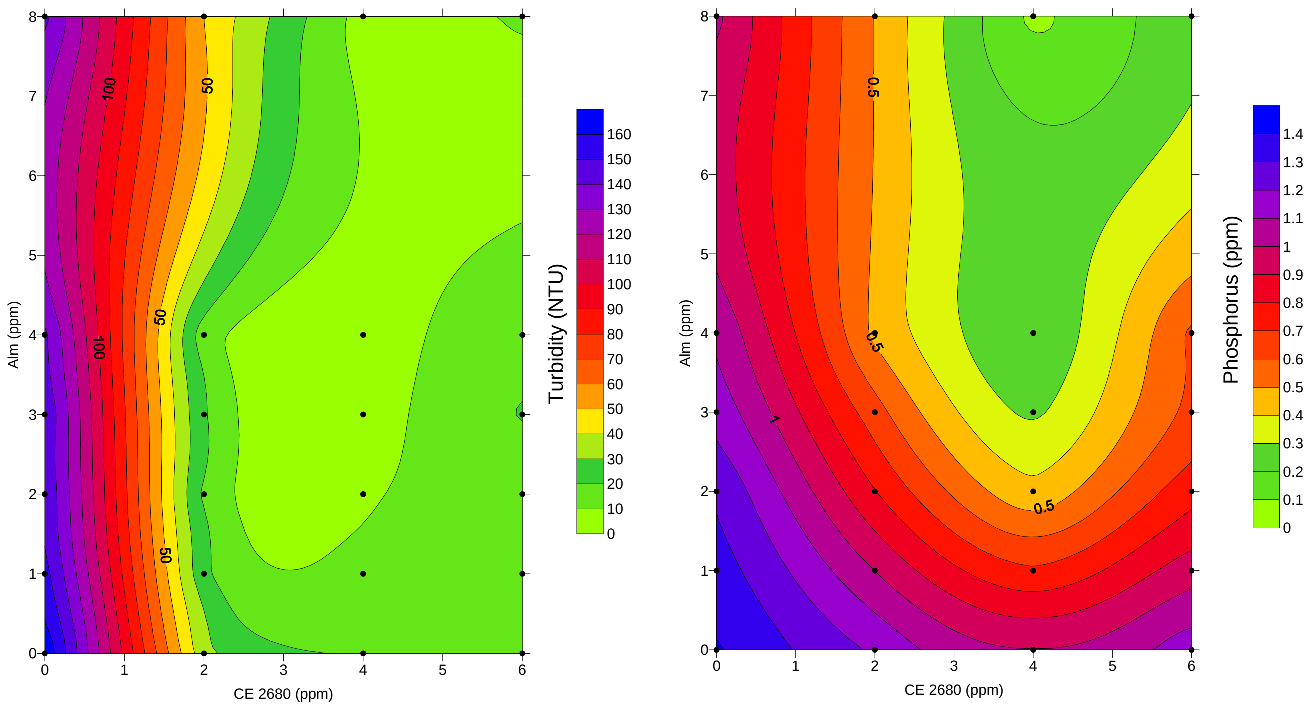


Figure 9a and 9b. Turbidity (a) and PO_4-P concentrations of New River water subjected to varying treatments of alum and CE2680.



Jar Tests

Until just recently, we have had difficulties with collecting the large volumes of sample water needed to conduct sufficient jar tests treatments to create map-plots comprable to those generated from vial tests. Figure 10 appears to reinforce the vial-test results from alum and 21J treatments which show the increased efficacy of alum with increasing anionic polymer concentrations. Comparing the vial test and jar test results is difficult given that the maximum concentrations in the jar tests are four times smaller than those of the vial tests. Though the turbidity decreases in Figure 8a for alum and AE 1702 treatments appear consistent to their vial tests, PO_4^{3-} seems to increase with polymer addition. A similar affect was seen in Figure 4. for the 4 ppm alum and 8 ppm 21J vial test treatment.

The effects of varying alum and ferric chloride concentrations on CEP algae zone water turbidity in the absence of polymer are seen in Figure 12. This shows ferric chloride decreasing turbidity more effectively than alum. However, neither trivalent cation was capable of effectively removing residual PO4 not consumed by the algae without polymer present (data not shown).

Figure 10. Turbidity of New River water subjected to varying treatments of alum and 21J.

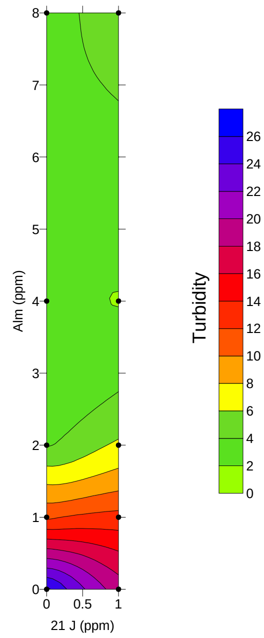


Figure 11. Turbidity (a) and PO_4-P concentrations of New River water subjected to varying treatments of alum and AE1702.

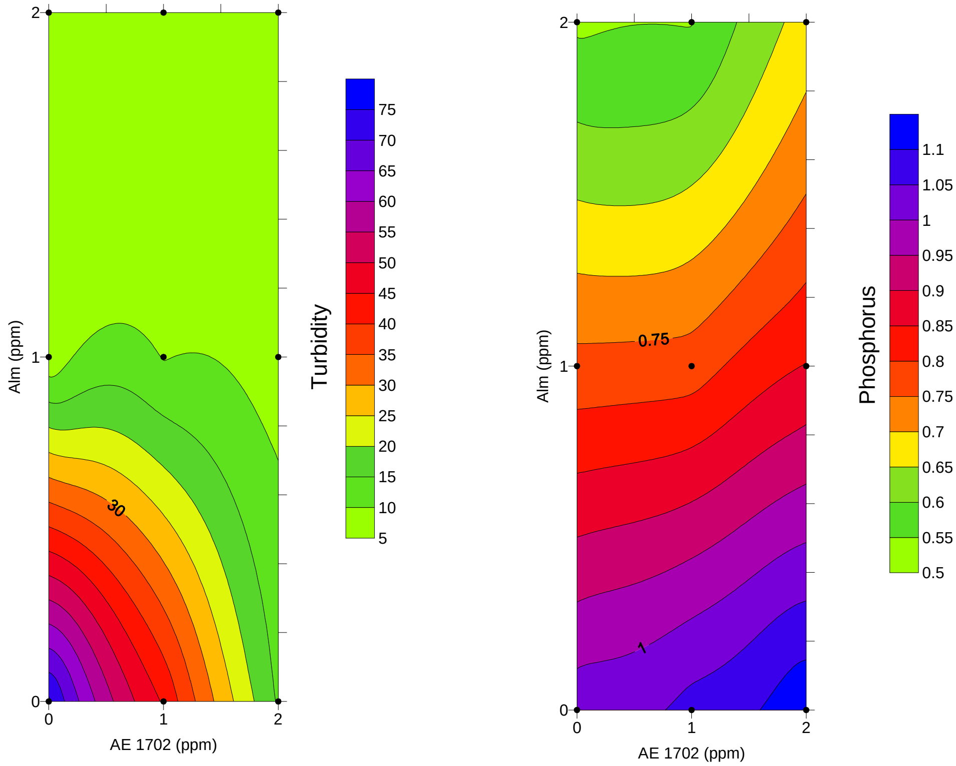
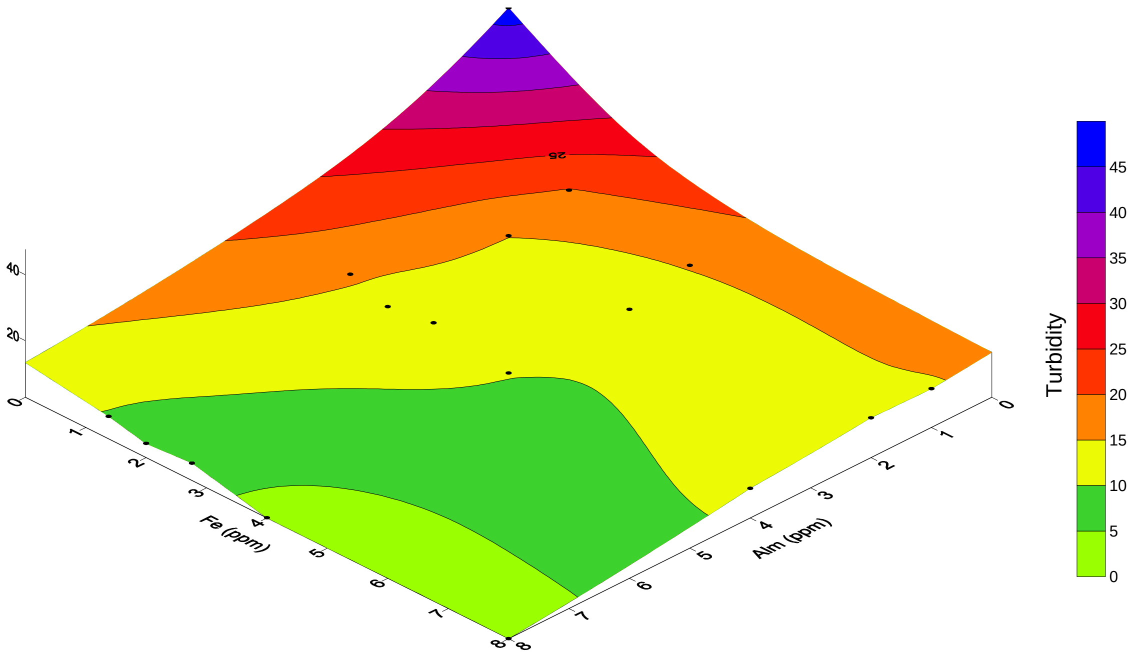


Figure 12. Feric chloride vs. alum turbidity map for CEP algae zone water jar test.



Preliminary Conclusions

In vial and jar tests, the most effective AE and CE polymers decreased New River water turbidity 72% and 90%, respectively, but only reduced PO_4 concs. by 43% at best. By mixing equal parts CE 2680 and trivalent cation (4 ppm), a 90% P conc. decrease was achieved. However, the apparent advantages of cationic polymers seen in these tests must be considered alongside their potential toxicity to aquatic organisms if used carelessly. By promoting the use of anionic polymers over cationic polymers, environmental incidents that could lead to the passage of undue restrictions on all polymers can be avoided.

In preparation for flocculant trials in the CEP, our current vial tests and jar tests are with CEP Algae Zone and Whitewater River water. For these tests, we are using anionic and cationic powdered (AP and CP) polymers since they can be stored without the weekly mixing required of AE and CE polymers. We have achieved good algal flocculation and PO_4 deceases from alum and AP additions to CEP Algae Zone water. Though all of the tests completed prior to December 18, 2003 are listed in Table 2, the most recent data generated still requires evaluation and will be included in the next quarterly report.

This task will continue into January, 2004 due to difficulties in locating polymer suppliers and the unexpectedly large number of samples needed to reliably screen each treatment applied to each type of water. The results from this task will narrow down the possible combinations of flocculants to be utilized in the next tasks.

Task 3. Conduct meso-scale tank studies of P-removal (0% complete)

Based on the results of the lab-scale studies described in task 2, bench-scale trials of phosphorus removal and sediment flocculation will be conducted in the CFS unit mentioned in task 1.1 starting in January, 2004. Agricultural drainage water will be either pumped directly from the Whitewater River or trucked from the New and Alamo Rivers, stored in the poly-tanks, and subjected to the chemical flocculation treatments determined in task 2 to be most effective. The UC Riverside staff will oversee the testing operation and apparatus, record background data, and collect water samples (pre-, during, and post-treatment) during treatment runs. The water samples will then be analyzed in Dr. Amrhein's laboratory at UC Riverside.

Task 4. Conduct ditch-scale studies for P-removal (0% complete)

This task involves pilot-scale evaluations of the Whitewater River implementing the best possible sediment and phosphorus removal techniques determined by the laboratory and bench-scale testing studies described in Tasks 2 and 3. One or two 200 ft. simulated earthen agricultural drainage ditches will be utilized in these studies.

4.1 Flocculant/polymer work plan for in-ditch treatment

In January, 2004, we will create a work plan based on the lab-scale and bench-scale studies in tasks 2 and 3 for pilot-scale, in-ditch trials. Based on the available data, the work plan will be designed to permit comparison of the most promising flocculant/polymer combinations.

4.2 Conduct in-ditch treatment trials

Starting in February, 2004, we will conduct pilot-scale trials of phosphorus and sediment removal in the simulation channels. Untreated water will be added to the channels until an equilibrium state is reached. Untreated water samples will be collected and treatment (as determined in Subtask 4.1) commenced. Periodic time samples will be collected as the treatment proceeds. Treatment will then be halted and samples periodically collected until channel returns to the pretreatment state. Four seasonal sets of trials will be completed to determine the effects of seasonal variations in sediment and phosphorus load, water temperature and chemistry. Researchers from UC Riverside will oversee these trials and also will collect water samples that will be analyzed in Dr. Amrhein's laboratory.

Task 5. Conduct CEP treatment trials (0% complete)

During the winter months, algae production is higher than the rate of consumption by the caged tilapia fish. In order to make up for this lack of algae "packaging" as fish waste, trials using chemical flocculants and polymers to remove phosphorus and, potentially, selenium will be performed during winter months. Treatments will be injected via a chemical mixing chamber submerged in the water-polishing zone of the CEP. Sampling will mimic that of the ditch-scale trials and last for two to three days.

Task 6. Monitor biological Se-uptake and evaluate CEP for Se-removal (21% complete)

Introduction

Any water treatment technology which concentrates nutrients for ultimate removal from the system can potentially bioaccumulate toxic compounds that could effect the usefulness of the concentrate. There is some concern that selenium, which is present in low levels in the Salton Sea tributaries, could become concentrated in the food chain. We have begun to monitor the levels of selenium in these rivers and the degree to which the levels may be reduced in the the CEP system.

Methods

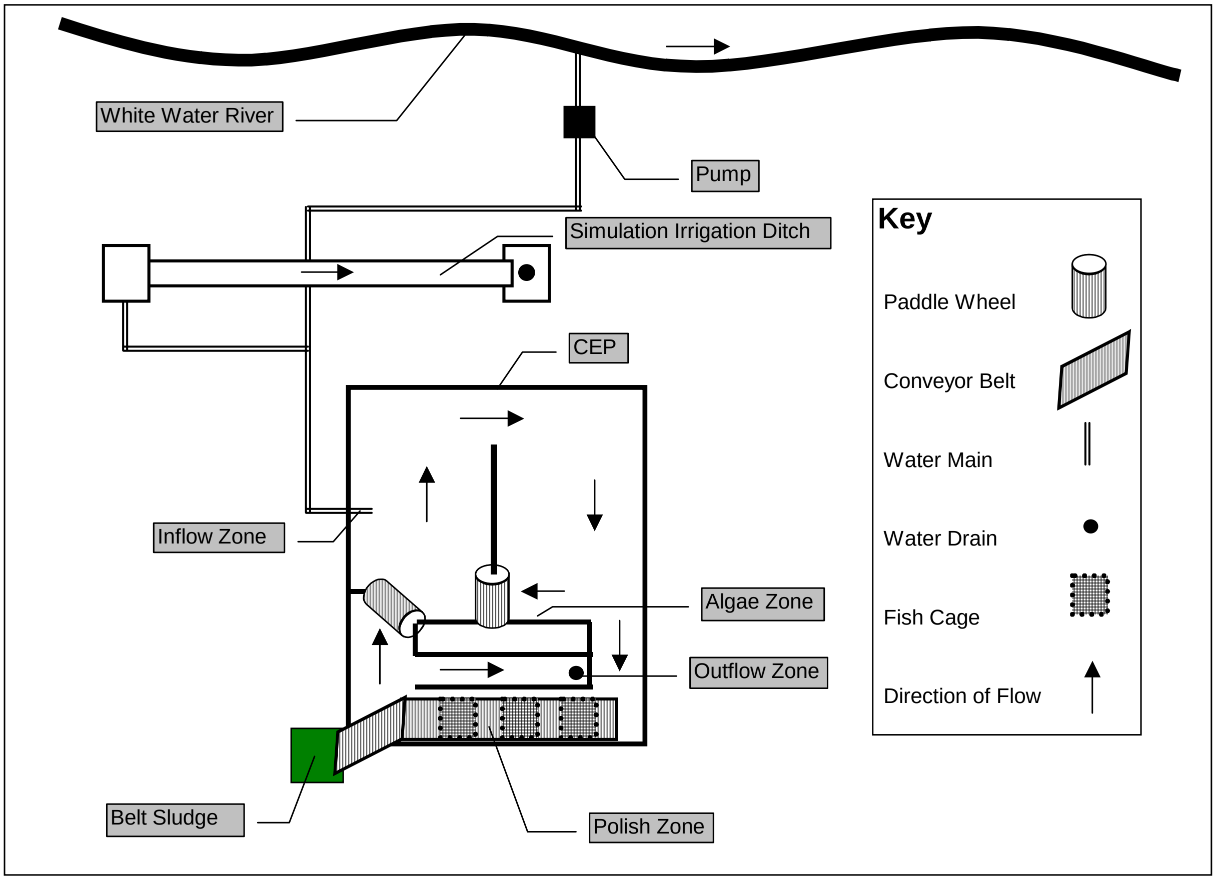
Sample Collection

Bulk water samples were collected from the Alamo, New, and White Water Rivers and the CEP Inflow, Algae, Polished, and Outflow Zones, (see Figures 14 and 15 for sample points).

Table 5. River water sampling sites

Site	Location
Alamo River	Eddins Rd. (Route S30) bridge
New River	Gentry Rd. (Route S30) bridge
Whitewater River	Kent SeaTech Fish Farm, CEP Inflow Zone

Figure 15. WhiteWater River, CEP and sampling points used at Kent SeaTech's Coachella Valley fish farm (not drawn to scale).



Random samples of tilapia fish were scooped from the CEP fish cages with a net and immediately Ziplock® bagged and transported on ice to an in-lab freezer. Fish waste and algae freshly removed by the CEP conveyor belt (Belt Sludge) was scooped directly from the exit trough, Ziplock® bagged, and put on ice, and stored in a refrigerator.

Sample Preparation

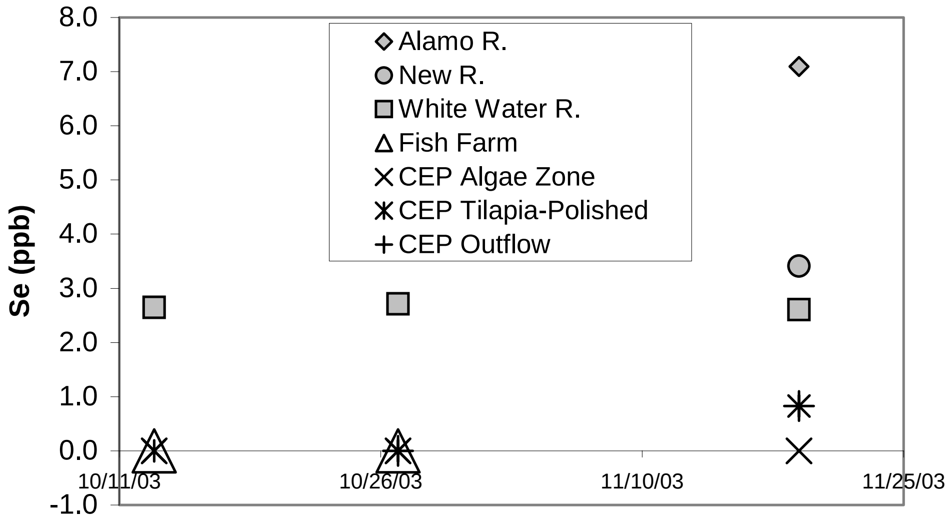
Bulk water samples were transported back to UC Riverside and refrigerated. Samples were brought to room temperature, well mixed, sub-sampled, and syringe filtered <0.45 µm (Fisherbrand Membrane). In 10 ml plastic mailing tubes, 0.5 ml of sample water and 0.3 ml of 0.2 M potassium persulfate were combided and heated for 20 min. to digest organic Se (Zhang et al. 1999). Once acidified to 0.6 M with HCl, they were run on a Varian Hydride Generation Atomic Adsorption (AA) Spectrometer (Australia) for total selenium concentrations.

Fish were thawed prior to processing. Whole body samples were prepared by hand chopping whole fish with a kitchen knife then further homogenizing them with a Pampered Chef spring-loaded chopper. All other fish had skinless filets, livers, and gonads dissected out. Equivalent dry weights were determined by oven drying sample aliquots at 100 C for 24 hrs. Half-gram equivalent dry weight aliquots of whole-body, filet, and composite liver and gonad samples were microwave digested with 2 ml nanopure water, 9 ml conc. HNO3, and 3 ml conc. HCl after Milward and Kluckner, 1989 and EPA Method 3050. Digests were diluted and analyzed on the AA.

Results and Discussion

During the sampling period, all three rivers were above the California Central Valley Grassland Marshes monthly average TMDL of 2 ppb Se (see Figure 13). Fish Farm water was the treated return flow from Kent SeaTech's commercial hybrid striped bass operation. Since it originates as groundwater, it is understandable that its Se concs. are near zero. As a result, since the CEP inflow water was Fish Farm water until 10/28/03, CEP water Se was near zero as well.

Figure 13. River and CEP water selenium concentrations



However, even with low water Se concentrations, fish with longer residence times in the CEP accumulated greater concentrations of tissue Se (see Figure 14). The lack of a sufficiently large, representative sample of fish gonads and livers along with difficulties during digestion rendered those data suspect and were not included here.

Figure 14. CEP fish and belt sludge dry weight selenium. The key lists Sample Matrix, CEP Residence Time, and (Replicates).

As stated in task 1.3, we will also will determine whether modifications in the water velocity and circulation rate through the algal settling zone of CEP can be used to enhance the amount of Se that can be concentrated and removed in the algal biomass starting in July, 2004.

Task 7. Quarterly, Draft and Final Reports (10% complete)

7.1 Quarterly Reports

We will ensure that the contract requirements are met through completion of quarterly status reports submitted to the Contract Manager by the 10^{th} of the month following the end of the calendar quarter and through regular communication with the Contract Manager. The progress reports shall describe activities undertaken and accomplishments of each task during the quarter, milestones achieved, and any problems encountered in the performance of the work under this contract. The description of activities and accomplishments of each task during the quarter shall be in sufficient detail to provide a basis for payment of invoices and shall be translated into percent of task work completed for the purpose of calculating invoice amounts.

7.2 Draft Report

Starting in October, 2004, a draft report will be prepared that includes a list of products of the tasks listed above. The report shall include the following narrative sections: 1) A brief introduction section including a statement of purpose, the scope of the project, and a description of the approach and techniques used during the project. 2) A list of task products previously submitted as outlined in the Schedule of Completion. 3) Any additional information that is deemed appropriate by the Project Director.

7.3 Draft submission

In January, 2005, copies of the draft report will be submitted to the Contract Manager for review and comment.

7.4 Corrections and final draft submission

In February and March of 2005, a final report will be prepared that addresses, to the extent feasible, comments made by the Contract Manager on the draft report. We will submit one reproducible master and two copies of the final project report to the Contract Manager for review and acceptance.

References

Greenberg A.E., L.S. Clesceri, and A.D. Eaton, eds. 1992 *Standard methods for the examination of water and wastewater*. 18th Edition. American Public Health Association.

Milward C.G. and Kluckner P.D. 1989. Microwave digestion technique for the extraction of minerals from environmental marine sediments for analysis by inductively coupled plasma atomic emission spectrometry and atomic absorption spectrometry. *Journal of Analytical Atomic Spectroscopy* 4: 709-713.

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