Final Report

for

Reducing Eutrophic Conditions of the Salton Sea

Prepared for the
California Regional Water Quality Control Board, Colorado River Basin Region

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GENERAL 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 relatively low and external phosphorus loading to the Sea is high, reduction of tributary phosphorus loading to the Salton Sea may reduce eutrophication.

The 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.

The following is a brief history of how this project evolved. The original ideas for this project came from a proposal written by James Setmire (formerly with the USGS) which suggested that aluminum sulfate (alum) could be used to remove P from the rivers flowing into the Salton Sea. In the original proposal, it was suggested that tank car-loads of alum be continuously applied to the New and Alamo Rivers in order to precipitate and settle out phosphorus. Due to the expense of these large scale alum applications, the project was not funded. However, the proposal was adjusted in July, 2002 to focus on the Imperial Valley's agricultural drains and to include the use of polyacrylamide (PAM), a class of non-toxic polymers that have proven effective for sediment and nutrient removal from agricultural surface discharge water (tailwater) in Idaho's Snake River Valley. Specifically, the revised project was to investigate controlling the suspension of sediment and nutrients during drain cleaning operations that are continuously implemented throughout the Imperial Valley by the Imperial Drainage District (IID). However, for undisclosed reasons, IID board members were reluctant to allow PAM and alum research to proceed in IID drains and the project's scope of work had to be revised. Work finally started in October, 2003. Therefore, the following report represents the project as it was conducted under a revised scope of work.

Overall, two general methods for sediment and phosphorus removal from ADW were investigated. One method involved the use of chemical flocculants (PAM and alum). Another method investigated was the Controlled Eutrophication Process, a flow-through system in which single-celled algae are cultivated in order to sequester ADW nutrients. The algae are then removed from the water by fish. Thje fish effectively “package” the nutrients in their waste, which settles out of the water column and can be collected. These methods were investigated in lab and field settings.

EXECUTIVE SUMMARY

Work conducted for this project was guided by the thirteen tasks outlined in the Revised Scope of Work.

Task 1 involved the project’s management and administration. Deliverables for this and other the tasks are listed in Table 1.

Task 2 covered the environmental permitting needs of the project. However, since this project’s goal was to improve water quality, it qualified for a categorical exemption of all NEPA/CEQA permits.

Task 3 resulted in the quality assurance protocol plan (QAPP) that governs sample and data collection. The QAPP established a set of guidelines for sampling, sample handling, analysis, and data processing that ensured quality data production throughout the project.

Task 4 required that a project assessment and evaluation plan (PAEP) be written. This document provides a general description of the baseline water quality of the Salton Sea and its tributaries (the Alamo, New and Whitewater Rivers), the manner in which the water treatment activities would be implemented, and their effectiveness in preventing or reducing pollution. It also attempted to assess the economic benefits resulting from these water treatment activities.

Task 5 involved modifying existing pilot scale phosphorus (P) removal systems in preparation for research experiments. This included calibrating the mixing energy of a bench-scale jar test system, adding an algae sludge removal belt to the CEP, and constructing a simulation drain water ditch such that it could receive inflows of Whitewater River water.

In Task 6, we conducted laboratory experiments on phosphorus adsorption and de-sorption. Erosion of agricultural soils is believed to be a significant contributor to phosphorus loading to the Salton Sea. However, little is known about how P adsorbs or desorbs from soils in waters of varying salinities as they are washed from fields, into agricultural drains, and eventually into the Salton Sea. To investigate this, we tested Imperial Valley soils for P adsorption/desorption under varying salinities and PAM concentrations. These studies showed that both feshwater and saltwater promote the release of soil P into solution. However, soil P

release is greater and more rapid in saltwater. In solutions with ionic strength that matches Salton Sea water, equilibrium solution-P concentrations were 132% to 143% of those observed in freshwater. Imperial Valley soils with 0.2 to 0.6 mg/g adsorbed P yielded 0.05 to 1.3 mg/L equilibrium freshwater solution-P concentrations. Additions of anionic PAM had no effect on equilibrium solution-P concentrations, neither in fresh nor in saltwater.

In Task 7, bench-scale jar tests evaluated various alum and PAM treatments for sediment, particulate P (P_P) and soluble P (P_S) removals. These tests indicated that PAM promotes sediment floc formation even at the high mixing energies that one finds in the Alamo, New, and Whitewater Rivers. However, PAM alone did not remove P_S. Alum was required to remove the soluble P, however, the alum floc did not settle at the high mixing energies. Alum (4 mg/L Al) plus nonionic PAM (2 mg/L) proved the most effective treatment for flocculating soluble P and suspended solids from the tributary waters. Based on these lab studies, settling basins or systems with lower flow rates may be required for optimum settling of the flocculated solids and precipitated phosphorus.

In Task 8, we treated Whitewater River water with alum and PAM in a simulation wastewater ditch. Alum was the only chemical evaluated that significantly reduced P_S. The greatest P_S removals were achieved by increasing the alum floc density by adding an equal part of PAM. At best, a 50% reduction of Whitewater River water P_T was achieved with 2 mg L^{-1} alum-Al and 1 mg L^{-1} anionic PAM. Although 4 to 8 mg L^{-1} alum-Al drove P_S concentrations to nil, P_T removals remained $\leq$50% since floc removal was poor. Improved alum floc formation settling may have occured if the alum were applied upstream of the PAM. Engineered systems for light Al-P floc removal (like settling basins, skimmers, filters, or dissolved air injectors) merit further investigation.

Also for Task 8, we conducted continuous PAM applications to agricultural irrigation water inflows as a means to reduce sediment and P loading to the Salton Sea. We demonstrated that anionic PAM applied to irrigation water can effectively reduce the sediment and particulate-bound phosphorus leaving Imperial Valley agricultural fields. Continuous additions of 1 mg L^{-1} PAM to irrigation inflows could reduce drain water total suspended solids (TSS) by 71-91% and P_P by 44-52% for bare, tilled fields. The beneficial effects of PAM could be greatly enhanced by simple management practices: modifications to the slope, and slope profiles of field tails, coupled with improved drain ditch and drain box construction could greatly improve drain water quality. PAM did not control excess P_S fertilizer loss in tailwater. A soil P-management program is needed in the Imperial Valley to help growers decide when, where, and which form of P fertilizer to apply. This would surely curtail agricultural P loading to the Salton Sea and be a major step toward relieving its eutrophic condition.

Task 10 investigated the capacity for the CEP system to bioaccumulate and remove selenium (Se) from inflowing agricultural drainage water. For this task, we compared levels of Se in the Salton Sea's tributary rivers and in the CEP. All three rivers were above the Central Valley's 2 ppb Se TMDL when sampled. However, the CEP reduced Whitewater river water Se to levels within the limits of this TMDL. Therefore, it is probable that Se actually is removed by bioflocculation and settling and/or volatilization from the CEP. Analysis of tilapia fish and belt sludge from the CEP indicates that Se accumulates at all trophic levels of the CEP system. These results indicate that the CEP could be a useful tool for Se removal from ADW.

For Task 11, we investigated the contribution of the rivers' suspended sediments to biologically available phosphorus (BAP) in the Salton Sea and, potentially, a CEP. Suspended sediments were collected from the three tributaries and subjected to various extractions in the lab. Based on these extractions, we found that reductions in the rivers' suspended solids loads to the Salton Sea will have a limited impact on reducing eutrophic conditions. Two-thirds of the P entering the sea is already in the soluble, most bio-available form (P_S). Of the total particulate-bound P (P_P), 52-70% is not biologically available. This suggests that reducing the rivers' suspended solids load to meet the 200 mg/L TMDL will only reduce BAP loading to the Salton Sea by 13 to 20%.

In Task 12, we developed preliminary projections for annual costs of some of the major components discussed in this report. The primary cost considered during this analysis was the annual expense involved in the purchase of flocculants. The calculations were based on the premise that in order to have a significant impact on the sediment and phosphorus entering the Salton Sea, it will be necessary to treat the input flows from the three principal tributaries of the Sea: the Alamo River, the New River, and the Whitewater River. Based on jar tests, the total alum and PAM costs to treat the total flow in all three rivers would be approximately $44 million per year. The simulation ditch studies with alum and PAM suggest that the highest level (97%) of P_S removal from Whitewater River water would require approximately $5.2 million per year for flocculants alone. The on-field PAM treatment in the Imperial and Coachella Valleys would cost $11 to $18.4 million per year and result in highly significant sediment load reductions. The controlled eutrophication process (CEP) has been shown to remove approximately 75% of the nutrients from Whitewater River water. Although the estimated capital cost for CEP construction on the Whitewater River would be roughly $100 million, CEP operating costs would be $17 million per year, a much lower figure compared to the other technologies evaluated. Note that these estimates do not include the costs of engineering (settling basins) and solids removal.

I. PROJECT TASKS

Table 1 is a list of task products submitted during the course of this project. Many of these products can be found in the Attachments section of this report in order of their Task Numbers. For experimental work, these attachments include scientific journal manuscripts that have been or will be submitted for publication. These documents contain more detailed materials and methods, results, discussion, and references sections than are provided in the brief summaries of this report.

Table 1. Schedule of deliverables.

Task	Product	Approximate Date
1.0	**Project Management and Administration**	
1.2	Quarterly reports	December 19, 2003 and quarterly thereafter
1.5	Contract Summary Form	September 9, 2003
1.6	Subcontractor documentation and activities	Ongoing
1.7	Expenditure/Invoice projections	August 31, 2003 and every six months
1.8	Project survey form	May 31, 2005
2.0	**CEQA/NEPA Documentation, and Permits**	
2.1	CEQA/NEPA Documentation	July 1, 2003
2.2	Permits	July 1, 2003
3.0	**Quality Assurance Project Plan**	
3.1	Draft QAPP	June 1, 2003
3.2	Final QAPP	December 1, 2003
4.0	**Project Assessment and Evaluation Plan**	
4.1	Project Assessment and Evaluation Plan	October 1, 2003
5.0	**Modify existing pilot-scale P removal systems**	
5.1	Description, photos of completed modifications	July 10, 2004
6.0	**Lab-scale studies of flocculant removal of P**	
6.1	Analytical results on untreated water	March 10, 2005
6.2	Flocculant usage reports	March 10, 2005
6.3	Analytical results on treated water	March 10, 2005
7.0	**Bench-scale studies of flocculant removal of P**	
7.1	Analytical results on untreated water	July 10, 2004
7.2	Flocculant usage reports	July 10, 2004
7.3	Analytical results on treated water	July 10, 2004
8.0	**Studies of P removal in simulated ditches**	
8.1	Analytical results on untreated water	April 10, 2004
8.2	Report on optimal flocculant application techniques	July 10, 2004
8.3	Flocculant usage reports	July 10, 2004
8.4	Analytical results on treated water	July 10, 2004
9.0	**Pilot-scale studies of P removal using CEP**	
9.1	Report on optimal methods for P removal	July 29, 2005
9.2	Report on flocculants needed to enhance removal	July 29, 2005
9.3	Report on algal productivity variations	July 29, 2005
9.4	Report on algal species variations	July 29, 2005

9.5	Report on carbon requirements of CEP	July 29, 2005
9.6	Report on algal belt efficiency	July 29, 2005
9.7	Report on algal uptake and conversion	July 29, 2005
9.8	Report on algal digestion	July 29, 2005
10.0	**Monitor and enhance Se uptake in CEP system**	
10.1	Report on Se forms in untreated water	July 10, 2004
10.2	Report on Se forms in algal sludge	July 10, 2004
10.3	Report on Se forms in algavorous fish	July 10, 2004
10.4	Report on Se forms in treated water	July 10, 2004
11.0	**Determine effects of TSS on CEP efficiency**	
11.1	Report on TSS in Salton Sea tributaries	July 29, 2005
11.2	Results of lab-scale algal productivity trials	July 29, 2005
11.3	Results of bench-scale algal productivity trials	July 29, 2005
12.0	**Prepare cost projections**	
12.1	Projections of flocculating ditch method costs	March 10, 2005
12.2	Projections of CEP method costs	March 10, 2005
12.3	Projections of costs of combined approach	March 10, 2005
13.0	**Draft and Final report**	
13.1	Draft report	April 10, 2005
13.2	Final report	July 29, 2005

Task 1. Project Management and Administration

Deliverables for this task were supplied to the Project Representative throughout. These included Quarterly Reports, the Contract Summary Form, Subcontractor Documentation and Activities, Expenditure/Invoice Projections, the Project Survey Form, and the Contract Summary form. Copies of these forms appear in the Attachments section of this report.

Task 2. CEQA/NEPA Documentation and Permits

Deliverables for this task were supplied during the initiation of the project. The Preliminary Exemption Assessment and Categorical Exemption forms can be found in the Attachments section.

Task 3. Quality Assurance Project Plan

The deliverable for this task, the QAPP, was supplied during the initiation of the project and can be found in the Attachments section. The QAPP document outlined the field and laboratory procedures to be followed in order to ensure that the data produced were scientifically sound.

Task 4. Project Assessment and Evaluation Plan

The deliverable for this task, the PAEP, was supplied during the initiation of the project and can be seen in the Attachments section.

Task 5. Modifying existing P removal systems

The following summarizes the work done to modify experimental systems for this project (a full description and photos of completed modifications appears in the Attachments section).

We decided to do bench-scale testing with 2 L jar test systems (Photo 1). These systems are widely used in the waste water industry for testing water treatment methods and offer a more standardized comparison of the results. Preparations for the tests included determinations of the optimum paddle speeds to promote coagulation, flocculation, and floc settling with alum and PAM. Initial work indicated that 25 to 50 RPM paddle speeds (mixing energy, G = 18 to 45 s^{-1}) were optimal for testing the efficacy of the alum + PAM for flocculation and settling.

Photo 1. Phipps and Bird PB-700 jar test system.

A simulation agriculture drainage ditch was constructed at the east end of the CEP units (Photo 2). Earth was moved and leveled with a bulldozer, backhoe, and excavator for a length of 188 feet. A plastic liner 6 mm thick and 20 feet wide was placed on the bottom of the ditch. Earth was then leveled on top of the plastic and compacted. The filled and lined ditch was then re-excavated with a backhoe equipped with a jig to form the 1:1 sloped sidewalls. The bottom of the ditch was laser-leveled with zero slope. The resulting simulation ditch is 2 feet deep, 2 feet wide with side slopes of 1:1. A V-notch weir was set in place in the incoming monk box to permit accurate flow measurements. Three 100 gallon tanks were set up at the head end of the simulation agriculture drain ditch, to be used in mixing and preparing the chemical flocculants for testing. An adjustable 1/20 hp mixing motor and peristaltic pump were set up to mix and deliver the chemical mixtures to the head of the ditch.

Photo 2. Simulation ditch construction.

Although the CEP was designed for phosphorus removal, selenium (Se) could also be removed by bioaccumulation and “bioflocculation” of the captive algae and fish populations, and thus improve the effluent water quality. A new conveyor belt for removing Se-rich solids was installed in preparation for this work (Photo 3). In order to test the bioflocculation effects of captive fish populations on Se-rich algae, three steel mesh pens containing tilapia were lowered into the flocculation zone of the CEP. Pumps and piping were installed to deliver Whitewater River water to the CEP. Last, the paddle speeds in the main CEP algae growth tank were monitored for consistency over time.

Photo 3. CEP algae zone and outflow water; tilapia; sludge belt before and after modifications.

Task 6. Lab-scale studies of flocculant removal of P

Erosion of agricultural soils is believed to be a significant contributor to phosphorus (P) loading to the Salton Sea. However, we were unsure of how P adsorbs or desorbs from soils in waters of varying salinities as they are washed from fields, into agricultural drains, and eventually into the Salton Sea. We were also unsure of the efficacy of polyacrylamide (PAM) for suspended solids and P removal in these extremes of salinity.

As a preliminary investigation, we conducted laboratory studies on soil P adsorption/desorption with varying salinities and PAM flocculant usage. Theses studies, combined with the findings presented for Task 7, provided points of reference for the larger scale treatment trials described in Tasks 8 through 11.

A series of experiments were used to determine equilibrium solution P concentrations as a function of soils' adsorbed-P concentration. The soils used were collected from alfalfa and vegetable fields of the Imperial Valley. The soils were extracted for water soluble P and digested for total P content. Following the extraction/digestion, P concentrations were determined using the colorimetric molydate/ascorbic acid method. Soil total-P content was found to range from 0.24 to 0.31 mg-P/g soil for the soils tested.

Using the soluble-P extract data, concentration and time series experiments were designed and conducted. The data were used to develop a set of relationships for solution-P vs. soil adsorbed-P. These experiments showed that both feshwater and saltwater promote the release of soil P into solution. However, soil P release was greater and more rapid in saltwater. In solutions with ionic strength that matches Salton Sea water, equilibrium solution-P concentrations were 132% to 143% of those observed in freshwater. Conversely, saltwater prevented adsorption of solution-P by soil. Adsorption/desorption isotherms suggest that soils with 0.2 to 0.6 mg/g adsorbed P yield 0.05 to 1.3 mg/L equilibrium solution-P concentrations. Thus removing suspended soil particles from the drain and river waters will help remove biologically-available P. Additional studies (reported below) quantified the contribution of particulate-bound P to the biologically available pool of phosphorus.

Anionic PAM had no effect on equilibrium solution-P concentrations, neither in freshwater nor in saltwater.

Task 7. Bench-Scale studies of flocculant removal of P

Bench-scale jar tests were used to determine the optimum polyacrylamide (PAM) type for turbidity removal in agricultural drainage water (ADW). Bulk water samples were collected from the three tributaries to the Salton Sea: the Whitewater, New, and Alamo Rivers. All laboratory scale jar tests were performed in a 2L jar apparatus (Phipps & Bird PB-700, Richmond, VA). The main method used included a gradient reduction of paddle speed from 300 to 0 RPM (settling), followed by an increase in paddle speed from 0 to 300 RPM (resuspension), where each speed was held constant for five minutes. Samples were collected at 300, 200, 100, 50, 25, 15, 10, 5, and 0 RPM. The jars were filled with river water to the 2 L mark (14.5 cm water depth), and an initial sample was collected using a pipette at a depth of approximately 3.5 cm while the water was mixed at 300 RPM. The change in turbidity or phosphorus concentration in each jar was compared to the initial sample of that particular jar. Alum-Al and/or PAM were then added to the jars and the gradient reduction in paddle speed began. Anionic, neutral, and cationic PAMs were used in these experiments.

We concluded from these jar tests that all PAM types can promote sediment floc formation even at the high mixing energies found in the Alamo, New, and Whitewater Rivers. However, alum required slower speeds for settling to occur, indicating that alum was less effective than PAM as a flocculant for suspended sediment.

Of the total P in the tributaries, 47-100% is soluble P. Alum was the only flocculant tested that could precipitate this soluble P as Al-P floc. However, this Al-P floc did not settle at moderate mixing energies. To solve this, we had hoped that a combination of alum and PAM would promote both the flocculation and settling of soluble P while removing suspended sediment. However, In the presence of alum, the anionic PAM became ineffective for sediment flocculation. The only PAM type that was not hindered by the alum was the nonionic PAM (AP1142). Alum (4 mg/L alum-Al) plus nonionic PAM (2 mg/L) proved the most effective at flocculating soluble P and the suspended solids from the river waters. The floc formed with this treatment was dense enough to settle and resisted re-suspension back into the water column of the jar tester. It should be noted that settling of the alum-PAM floc only occurred in these jar tests at mixing energies that were at the low end for those found in the rivers. This leads us to believe that the mixing energies of the rivers may be too high to allow for any significant settling of PAM + alum floc. Therefore, a settling basin or a system with lower flow rates than typically found in the rivers may be required for optimum settling of the flocculated solids and phosphorus. PAM alone was highly effective in removing suspended solids at higher mixing energies, but did not remove the biologically available P_S.

Task 8. Studies of P removal in simulated ditches

This task involved implementing some of the sediment and phosphorus removal techniques developed in the laboratory-scale studies discussed in Tasks 6. A 188 ft. simulated agricultural drainage ditch was used for these trials as seen in Task 5.

8.1 Flocculant/polymer work plan for in-ditch treatment

Lab- and bench-scale studies described in Tasks 6 and 7 indicated that combinations of alum and anionic polymer had minimal effects on P_T concentrations. We then hoped that by adding anionic polymers to the ditch, perhaps downstream of the alum input, we could more successfully settle out alum floc. While equal parts alum and cationic PAM gave extremely effective removals in jar tests, the cationic PAM presents an ecotoxic risk and was disregarded.

Therefore, we set out to conduct alum and PAM ditch trials to examine changes in P_T, P_S, and turbidity at controlled ditch flow rates by a) adding 1 to 10 ppm Al alone, b) adding 1 to 4 ppm of various PAM formulations alone, and c) adding combinations of 1 to 4 ppm of both Al and anionic PAM.

8.2 Conduct in-ditch treatment trials

Following the lab and bench-scale studies, we tested the chemical flocculants in a simulation drainage ditch constructed at Kent SeaTech's Coachella Valley facility. The ditch was plumbed to receive inflows from the Whitewater River (WR). We had originally planned to build two ditches side-by-side in order to conduct control and treatment runs simultaneously. However, after preliminary tests, one ditch was considered best. By performing the control runs before the treatment runs in the same ditch, followed by a control run at the end, baseline conditions could be checked for stability and reproducibility was assured.

We performed treatment trials with aluminum sulfate (alum) and four commercial polyacrylamide (PAM) formulations (Photo 4). These trials were used to screen the flocculants for their capacity to remove total phosphorus (P_T), dissolved phosphorus (P_S), and turbidity from Whitewater river water.

Photo 4. Injection tubes dripping PAM and alum solutions into the inflow monk box and a view from the drain monk box.

Compared to the average turbidities of the New and Alamo Rivers (~200 NTU), the Whitewater River has very little suspended sediment (Table 2). Though P_T in all three Salton Sea tributary rivers is comparable, the P_S fractions vary. Phosphorus in the Whitewater river. is 90% P_S while the New and Alamo Rivers contain only 40-50% P_S. Removing this high P_S content was a major focus in our ditch treatments of WR water.

Table 2. Mean outflow conditions of Whitewater River water during Control treatments.

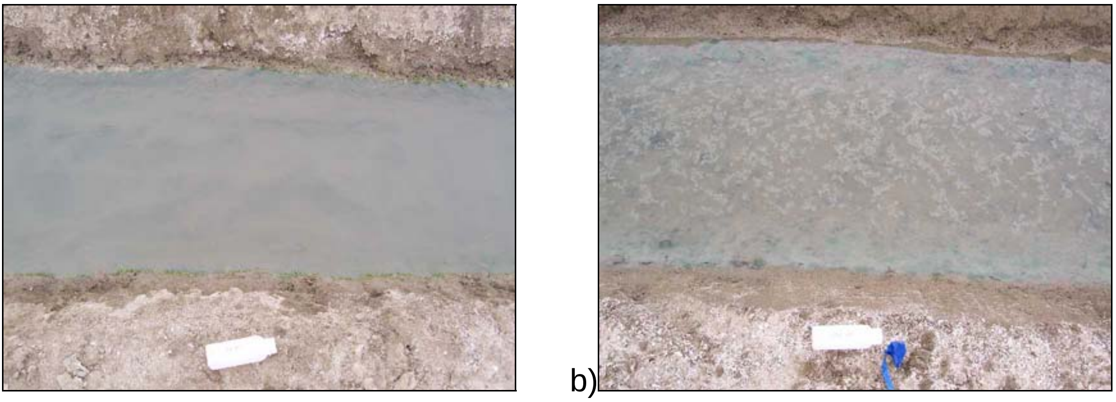
EC $\mu S\ cm^{-1}$	T °C	pH	Ditch Flow gal min^{-1}	Turbidity NTU	Total P mg L^{-1}	Soluble P mg L^{-1}
			Mean (standard deviation)			
2043 (206)	21 (3)	7.1 (1)	88 (9)	29.7 (10)	1.51 (0.3)	1.41 (0.3)

Averages for all controls (with no chemical addtions) at the ditch outflow (125-188 ft.)

We found that PAM had little effect on P_T since WR water is naturally low in the solid P fraction (P_P) and high in the soluble P fraction (P_S). Conversely, alum treatments increased the P_P fraction by producing copious amounts of buoyant Al-P floc (Photo 5). Settling this floc, however, proved difficult.

Though PAM had little effect to remove P_S on its own, we hypothesized that it could increase the density of Al-P floc enough to make it settle out. Since an Al/PAM combination produced the maximum turbidity removal, we hoped that the same treatments would settle out Al floc and drive down P_T. But we found that this was not the case: at best, a 50% reduction of WR P_T could be achieved with 2 mg L^{-1} alum-Al and 1 mg L^{-1} anionic PAM. Though adding large amounts of alum (4-8 mg L^{-1} alum-Al) drove P_S concentrations to nil, P_T concentrations were never decreased by more than 50% since the amount of Al-P floc settled was erratic.

Photo 5. Floc formation at a) 25 ft. and b) 175 ft. with 7 mg Al/L and 55 gpm of Whitewater River water.



a)

b)

Alum was the only chemical evaluated that significantly reduced P_S concentrations. Removal of P_T, P_S, and turbidity occurred in all alum trials, however, the greatest P_S removals were achieved when alum floc density was increased by simultaneously adding an equal part of PAM.

Future work for in-drain water treatment may include adding alum upstream of where PAM is added. Alum floc formation and subsequent settling may have worked better in our ditch if alum were applied first and PAM second at two separate zones of turbulent flow. However, since the weir was our only point of turbulent flow in the ditch, we were not able to test this idea. More robust tests of PAM and alum's efficacy over distance and with a range of turbulent flows would be best done in real drains. Engineered systems for low density Al-P floc removal (like settling basins, skimmers, filters, or dissolved air injectors) should also be investigated.

Interest in chemically treating ADW may grow with the recent passage of sediment TMDLs and with nutrient TMDLs in preparation for the Sea's tributaries. Though in-drain chemical treatments may offer a partial solution, grower implementation of on-field BMPs to control runoff sediment and P may be the more economical way to improve ADW quality.

In the end, any management solutions adopted to control eutrophication in the Salton Sea should focus on P_S load reductions. Continued eutrophication of the Sea will be the direct consequence of not reducing P_S, the most bioavailable P-fraction

Controlling sediment and phosphorus in agricultural tailwater with PAM

During the course of the project, we were given the unexpected but valuable opportunity to work directly with Imperial County growers to test the efficacy of PAM for removing sediment and P from agricultural surface discharge water (tailwater). The Imperial County Farm Bureau (ICFB) located growers willing to volunteer agricultural field sites located throughout the Imperial Valley. Given free PAM treatments and an assurance of confidentiality, growers allowed us to conduct the treatments as controlled experiments to evaluate the effects of PAM amended irrigation water on turbidity, total suspended solids (TSS), P_P and P_S.

In each case, "Control" (0 mg L^{-1} PAM) samples were taken from near the middle of a group of three to five border-controlled lanes irrigated with un-amended irrigation water. Surface water grab samples where collected in transects from 1) the inflow above the PAM applicator, 2) field head, 3) mid field, 4) field tail, 5) drain box locations noted in Figure 1. When the irrigation was completed for a set of lanes, the water was switched over to the next set of lanes for PAM treatment, and water samples taken as with the Control treatment.

In this study, we demonstrated that anionic PAM applied to irrigation water can effectively reduce the sediment and particulate-bound phosphorus in Imperial Valley tailwater. There, continuous additions of 1 mg L^{-1} PAM to irrigation inflows could reduce drain water TSS by 71-91% and P_P by 44-52% for bare, tilled fields. This could reduce the frequency of drain cleaning as less suspended solids would collect in the drains. PAM concentrations leaving the field in the drain water were below detection limits when PAM was added at 1 mg L^{-1} to the irrigation water.

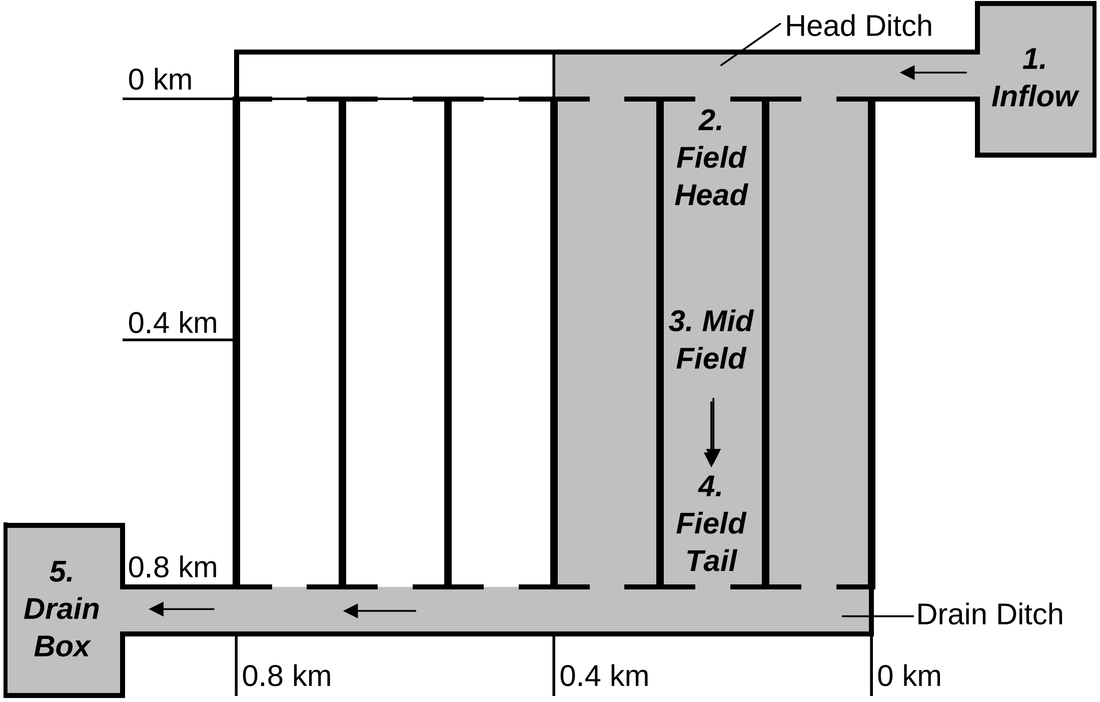
PAM application rates $\geq$ 5 mg L^{-1} to irrigation water resulted in >2 mg L^{-1} residual PAM in the drainage water. Thus, higher concentrations of PAM are not recommended and the 1 mg L^{-1} addition was highly effective.

The beneficial effects of PAM in irrigation water could be greatly enhanced if water velocities were reduced at the tail-ends of agricultural fields. Modifications to the slope and slope profiles of field tails coupled with improved drain ditch and drain box construction could greatly improve drain water quality.

Phosphorus is one of the few constituents in Imperial Valley soils that has increased over the last 50 years due to fertilizer application. In recent years, water-run fertilizer has become a common practice, especially for alfalfa production. The release of tailwater during liquid soluble P fertilizer applications surely represents a major portion of the P_S load to the Salton Sea. Based on our observation of a 173 ha field being fertilized with water-run liquid soluble P fertilizer, 65 kg of fertilizer (worth ~$100) left the field as tailwater and was discharged directly into the Salton Sea.

It may be possible for growers to reduce their P_P and sediment loads with their own BMPs and PAM applications. However, a soil P-management program is needed to help growers decide when, where, and which form of P fertilizer to apply. Such a P management program would curtail agricultural P_S loading to the Salton Sea and be a major step toward relieving its eutrophic condition.

a) No PAM Treament



b) PAM Treament

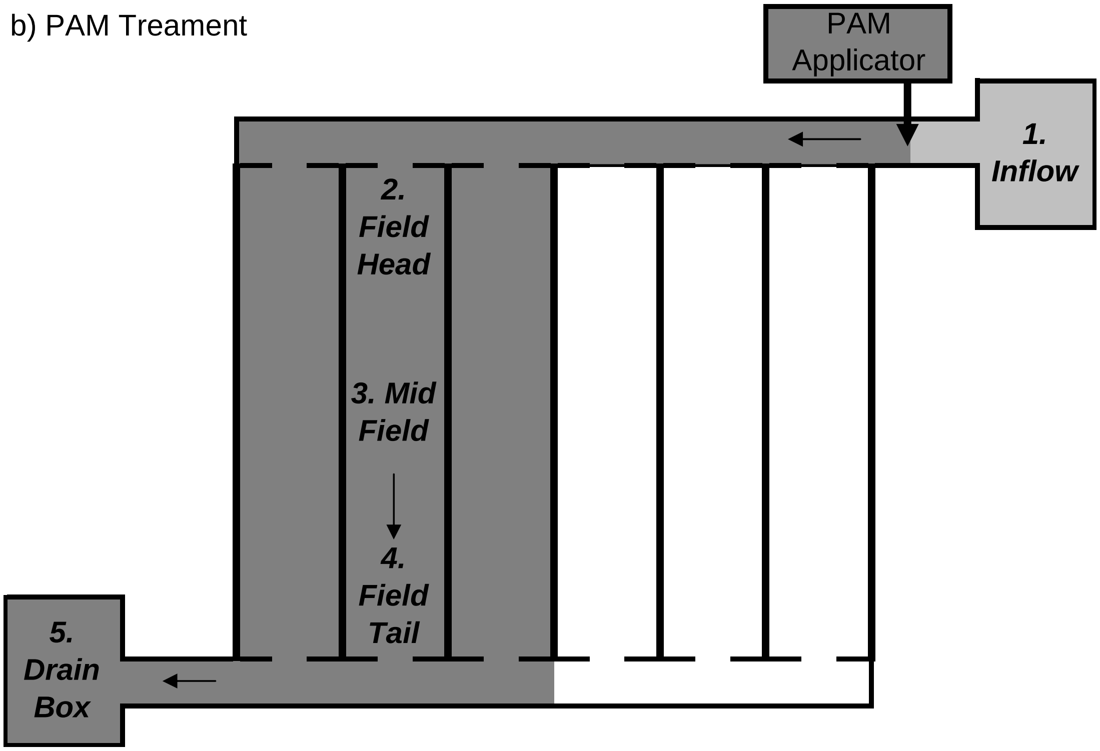


Figure 1. Schematic of field sampling locations for a) No PAM and b) PAM Treated sets of border-controlled lanes. Distances are approximate.

Task 9. Conduct CEP treatment trials

Subtask 9.1 and 9.3 Reports on optimal methods of P removal and algal productivity variations

The CEP units were supplied with 85 to 100 gallons minute^{-1} acre^{-1} of water from the Whitewater River. Incoming phosphorus concentrations ranged from 1.2 to 2.7 mg/L total phosphorus. Algal uptake rates are temperature dependent, resulting in significantly lower phosphorus uptake rates during the winter compared to summer. We found that winter nutrient fixation rates can be as little as 25% of the summer time rates. When 100% of the algae were removed by filtration the phosphorus concentration remaining in the water ranged from 0.36 mg/L to 1.0 mg/L.

Subtask 9.2 Report on flocculants needed to enhance removal

Additions of chemical flocculants like iron sulfate and alum were hoped to aid with the removal of phosphorus, potentially as a final polishing step, or for winter time P removal to make up for lower wintertime CEP performance. However, these chemicals did not remove a sufficient amount of P during periods of low productivity (due to low temperature). In the large 0.7 acre unit, to obtain a residual soluble phosphorus concentration of 0.05 mg/ L, it was found that 10 mg Fe as $FeCl_3$ per L of CEP water was required, while 100 mg alum-Al per L of CEP water was required. The total phosphorus remaining in the water column was dependent on the ability to remove the chemical flocs. We feel that the only chemical additions needed throughout this process may be as a final polishing step, after biological (Nile Perch) removal of the algal biomass, thus reducing the amount required to perhaps 1%.

Subtask 9.4 Report on algal species variations

We have operated CEP systems for several years near the Salton Sea and have monitored the single-celled algae species that develop as the systems become established. There are predictable seasonal changes that occur in the algal populations, with the summer first dominated by blue-green algae and then switching to green algae. During the fall and spring, a population of diatoms will often develop and then the system will revert again to primarily green algae. Diatoms tend to dominate during rapid temperature fluctuations (fall, spring). The system tends to be dominated by green algae species as long as there is a filter feeding fish present. Blue-green algae appear to dominate if there is no filter feeding fish present.

During this pilot-scale effort, we sampled and identified the algal populations. We also developed estimates of the algal standing crop, based on Secchi disk transparency measurements and suspended solids concentrations. For the 4 months of observations, two species dominated the water column. For the stable cold water, 9-12 ^{o}C (AM temperature), *Scenedesmu*s was the dominant species. During the transitional warming period a Centric diatom dominated. After stabilization at 16 – 18 ^{o}C (AM temperature), the *Scenedesmus* dominated once again. Photo 6 shows a few of the algae that have been observed in the CEP over the past 3 years.

Photo 6. A variety of species have been identified in the CEP process over the years.

Subtask 9.5 Report on carbon requirement of the CEP

For optimal productivity, the CEP requires that carbon be supplied at the rate that the algae fix nutrients. A portion of that carbon may be supplied by the filter feeding fish in the form of CO_2. However, an additional source of carbon might come from the use of anaerobic fermenters to produce biogas which when combusted produce electricity and carbon dioxide. This carbon dioxide could be captured and recycled back to the CEP units to maximize algal production and thus phosphorus uptake. Our collaborating researchers at Clemson University found that biogas (methane and CO_2)

production could be increased when the C/N ratio was adjusted slightly and thus supply 100% of the required carbon for the CEP. These findings are very promising for the future of the CEP. In the full scale application of the CEP technology, the use of both fish and anaerobic fermenters as carbon dioxide sources could greatly decrease the amount of supplemental CO_2 needed for maximum algae production. More research on fermentation systems will be needed to determine the scalability of these systems for large scale implementation.

Subtask 9.6 Report on algal belt efficiency

An algal harvest belt system was designed and installed at Clemson University's CEP units during the first phase of CEP work. The belt harvester operates on the principal of sedimentation of algal biomass, gravity thickening of the algal sludge, and continuous removal via the slow (3 inches/minute) cleated belt action that lifts the settled algae from the water at a critical angle of 11 degrees. The belt harvester has been shown to be capable of delivering a concentrated algal paste that consists of 10-15% algal cells on a dry weight basis. Algal paste density did not increase with the used of metal salts as flocculant aids.

Subtask 9.7 and 9.8 Reports on algal uptake, conversion, and digestion.

Researchers at Clemson University found increased gas production rates as the C/N ratio was increased to about 20:1. Carbon was added to the digesters in the form of waste cellulose (paper). The methane production rate increased from 400-600 mL per L to 1000-1200 mL per L. Such a significant increase in methane production makes anaerobic fermentation a very realistic possibility to generate revenue for the CEP process. In addition, with the waste paper, enough carbon (in the form of CO_2) is generated to supply 100% of the algal needs.

Task 10. Monitor biological Se-uptake and evaluate CEP for Se-removal

Any water treatment technology which concentrates nutrients for ultimate removal from the system can potentially bioaccumulate toxic compounds as well. There is some concern that selenium (Se), which is present in low concentrations in the Salton Sea tributaries, could become concentrated in the food chain. For this task, we sought to compare levels of selenium and other analytes in these rivers and the degree to which they may be reduced by the CEP system.

Bulk water samples were collected from the Alamo, New, and Whitewater Rivers and the CEP Algae Zone (see Table 3 and Figure 2).

Table 3. River and CEP 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
CEP Algae Zone	Kent SeaTech Fish Farm, CEP Algae Zone

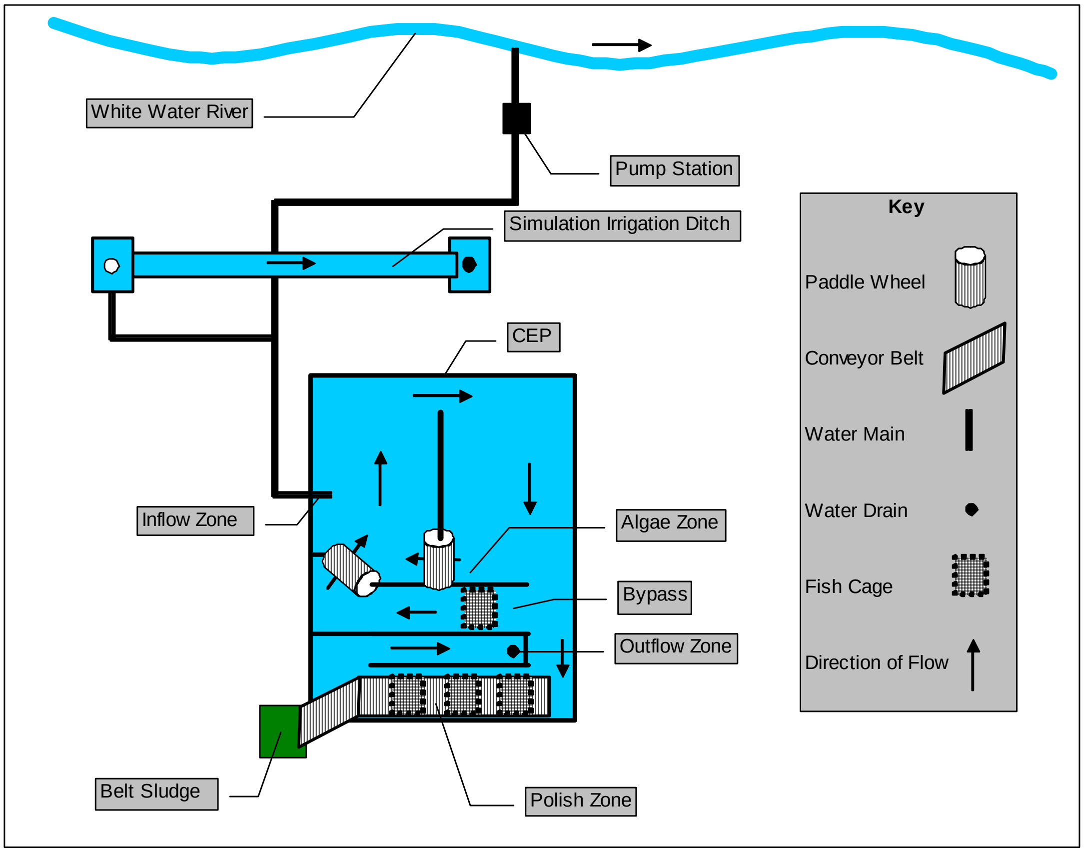


Figure 2. WhiteWater River, CEP and sampling points used at Kent SeaTech's Coachella Valley fish farm (not drawn to scale).

Water samples were appropriately preserved and analyzed for total selenium, arsenic, iron, turbidity, ammonia, nitrate, phosphorus, alkalinity, pH, total suspended solids (TSS), and electrical conductivity (EC) (Table 4).

Table 4. Fall/Winter '03/'04 conditions in the Salton Sea's tributary rivers.

	Ammonia-N	Nitrate-N	Dissolved Reactive Phosphorus-P	Total Phosphorus-P	Al	Fe	TSS
	(mg/L)						
Alamo R.	1.2	6.6	0.7	1.0	1.293	4	190
New R.	10.9	2.6	2.4	2.6	0.903	13	200
Whitewater R.	2.0	20.9	1.5	1.9	0.250	NA	10
CEP-Treated Whitewater R.	1.8	9.3	0.3	0.6	0.323	NA	56

	As	Se	Alkalinity to pH 4.4	pH	EC	Turbidity	Temp.
	(ug/L)		(mgCaCO3/L)		(uS/cm)	(NTU)	(deg. C)
Alamo R.	4.3	6.3	267	7.4	3404	145	NA
New R.	4.5	3.1	379	7.3	7030	83	NA
Whitewater R.	1.9	2.5	215	7.4	2111	77	17
CEP-Treated Whitewater R.	4.5	1.5	222	7.3	1793	31	NA

Samples were taken between 10/13/03 and 2/3/04. Ammonia-N, Nitrate-N, and DRP values are averages from samples of filtered water (n=1 for Alamo R. and New R., n=3 for Whitewater R). TSS, Turbidity, EC, pH, and Temperature were measured on raw water.

Random samples of tilapia were netted from the CEP fish cages for whole-body Se analysis. Fish waste and algae freshly removed by the CEP conveyor belt (Belt Sludge) was sampled directly from the exit trough and analyzed for Se.

Results and Discussion

All three of the Salton Sea's tributary rivers were above the California Central Valley Grassland Marshes monthly average TMDL of 2 ppb Se. Although the Se concentration in the WR water is only slightly above the 2 ppb limit, the CEP's Se concentration remained below that of the inflow and within the limits of this TMDL. Therefore, it is probable that Se was removed by bioflocculation and settling, and/or volatilization, from the CEP. Additional work on CEP Se removal is recommended with water containing higher Se concentrations.

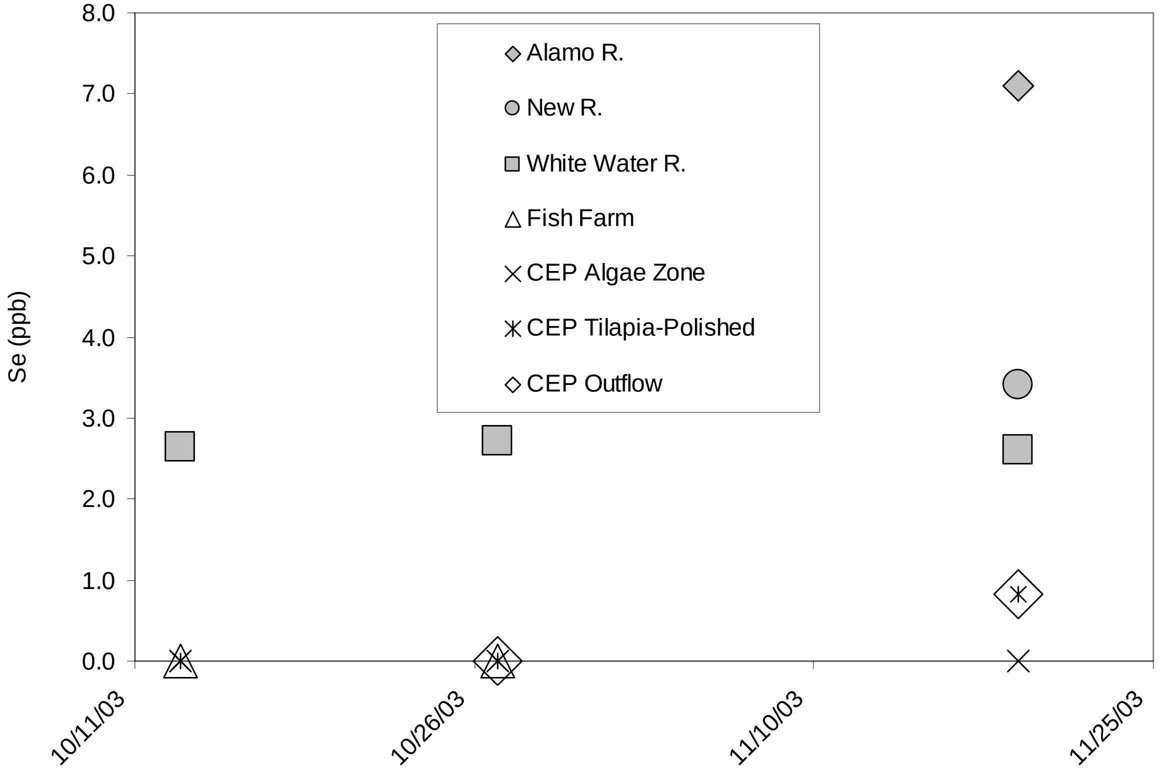


Figure 3. River and CEP water selenium concentrations

Even with low water Se concentrations the caged fish in the CEP accumulated greater concentrations of tissue Se with longer residence times (see Figure 4). These data indicate that Se can and does accumulate at all trophic levels of the CEP system, and the CEP could be a useful tool for Se removal from agricultural waste water flows.

A daily intake of between 50 to 200 micrograms of selenium is considered "safe and adequate" by the USFDA. It recommends 0.055 mg d^{-1} for women, 0.070 for men, and between 0.010 and 0.045 mg d^{-1} for infants and children up to age 14. Based on these selenium guidelines and a 75% moisture content of the tilapia filets, we conclude that moderate consumption of CEP tilapia fish should not pose a human health risk. Concentrations of Se exceeding 6 mg/kg (dry weight) are considered an ecological risk. No fish from the CEP had Se concentrations this high, although the inflow water was very low in Se. Higher Se concentrations in the inflow could lead to elevated fish tissue Se concentrations.

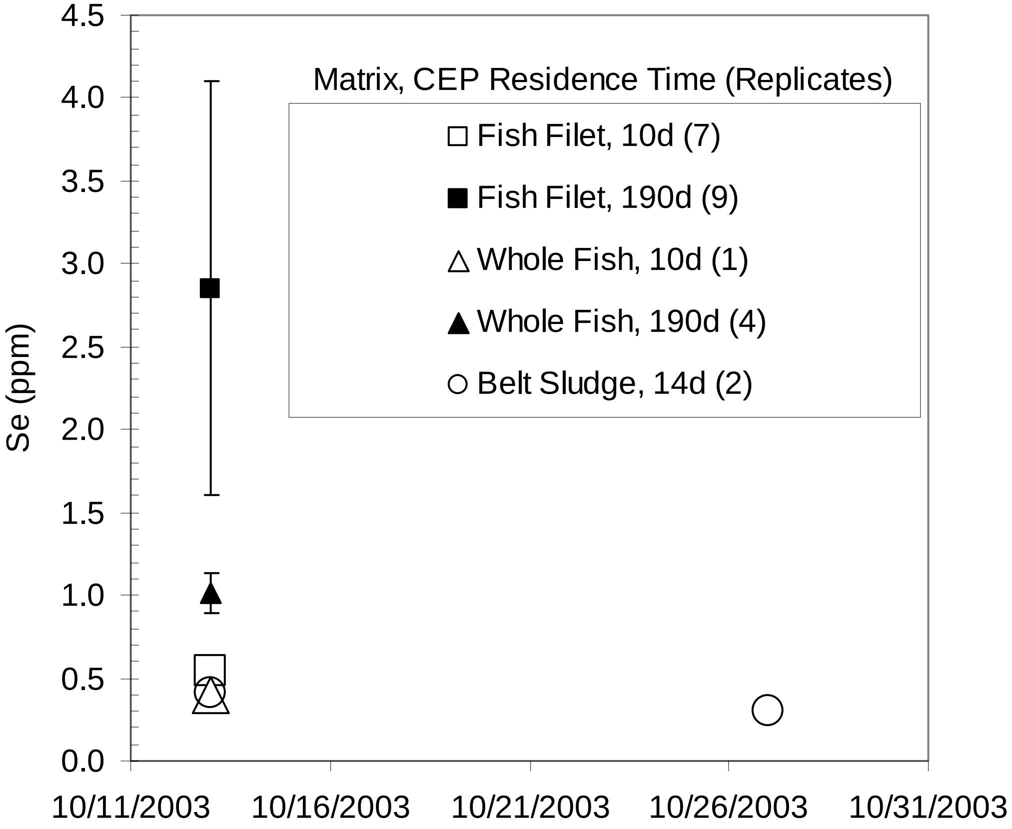


Figure 4. CEP fish and belt sludge dry weight selenium. The key lists Sample Matrix, CEP Residence Time, and (Replicates). Error bars indicate one standard error.

Task 11. Determine the effects of turbidity in a CEP

In this study, total suspended solids (TSS) in the Salton Sea's three tributaries were analyzed. We quantified the fraction of total particulate P (TPP) that can become bioavailable to evaluate the potential benefit of suspended solids reduction on the eutrophic status of the Sea. Extractions were completed to include both bioavailable particulate P (BPP) that is available under oxic (well aerated) conditions and iron-related P that can become available under anoxic (low oxygen) conditions. Low oxygen conditions can occur in the sediment layer of the CEP, rivers, and Salton Sea. Under these conditions, the Fe(III)-oxides dissolve and release adsorbed phosphorus.

Bulk river water samples for the three tributaries were collected on 4/13/05 and brought back to the lab for analysis. The river water samples were centrifuged and the suspended solids collected and stored moist at 6 ˚C for <24 hours prior to the following analysis. Bioavailable particulate P (BPP) was analyzed using the Olsen Method where 0.5 M $NaHCO_3$ (pH 8.5) was used as the extraction solution. The Salton Sea water was also used as an extractant to mimic the environmental conditions that might be expected for sediments entering the sea. Extraction of suspended river sediments for total particulate P (TPP), iron oxide-associated P (PFeO), inorganic particulate P (P_I), organic particulate P (P_O), and organic matter (OM) were determined by cited literature methods. Saturation index (SI) values were calculated using the speciation model Visual MINTEQ and river water values collected 3/30/2004 (Holdren, 2004, personal communication), and iron concentrations from Holdren & Montaño (2002)

We concluded that P release from the suspended solids in the Whitewater, New, and Alamo Rivers could potentially influence the eutrophic conditions in the Salton Sea. P released in the Salton Sea water under oxic conditions was lower than the amount solubilized by the classic Olsen method. This is attributed to the high bicarbonate concentration of the Olsen extractant compared to Salton Sea water. Under anoxic conditions where Fe(III)-oxide would be dissolving, P release was higher in New and Alamo River water since these sediments were higher in iron oxides than the Whitewater river sediments. Organic particulate phosphorus (P_O) ranged from 1.5 to 12% of TPP and can contribute to eutrophication when the organic matter decomposes. Most of the TPP (52-70%) was mineral-related P and considered non-biologically available. The New and Alamo River suspended solids were high in calcium, but the Whitewater River solids appeared to be dominated by an iron-phosphate mineral hypothesized to be vivianite.

Reduction of suspended solids loads to the Salton Sea will have a limited impact on reducing eutrophic conditions. Two thirds of the total P entering the sea is in a soluble, biologically-available form. Though particulate P comprises the other third of the total P load, only 30-48% of this fraction is biologically-available. Reducing the suspended solids load by 42% to meet the target of 200 mg/L will reduce biologically-available P by 13 to 20%, thus having a limited impact on reducing P loading to the sea.

Task 12. Prepare cost projections

In this task, we developed preliminary projections of the annual costs of some of the major components discussed in this report. The primary cost considered during this analysis was the annual expense involved in the purchase of flocculants. The calculations were based on the premise that in order to have a significant impact on the sediment and phosphorus entering the Salton Sea, it will be necessary to treat the input flows from the three principal tributaries of the Sea: the Alamo River, the New River, and the Whitewater River. Estimates were based on an alum cost of \$4.00-\$5.60 per kg of active ingredient and, for PAM, \$6.60-\$11.00 per kg of active ingredient. These estimates do not include an engineered solution to trap the chemical sediment floc and remove it from the rivers.

The following predictions for full-scale treatment of all three rivers with flocculants are based on the Jar Tests in Task 7 that produced the highest sediment and P removals. High sediment removals are achievable with PAM applications alone, but nutrient removal would be substantially less. Using alum would greatly aid with soluble P removal. Alum costs for treating the total flow in all three rivers would run approximately \$26 million per year. PAM costs would be approximately \$18 million per year. Thus, the total flocculant cost to treat all three rivers would be approximately \$44 million per year. Using chemical flocculants to settle suspended solids could result in 1,125 metric tonnes of solid waste per day from all three rivers. Removing this sludge may be as expensive as the chemicals.

The simulation ditch studies allowed us to try combinations of alum and anionic PAM concentrations to treat soluble P (P_S) in the Whitewater River water. Results showed that alum and PAM costs for maximum P_S removals from the Whitewater River (97% removal) would be approximately \$14,000 per day or \$5.2 million per year. These figures represent the upper limit of flocculant costs for “ideal” P_S removal rates.

Irrigation water application of PAM is a cost-effective tool to help reach the eventual TSS TMDL of 200 mg/L for the New and Alamo Rivers. Using Imperial County Farm Bureau suggested PAM application rates, the estimated on-field PAM treatment costs are \$11 to \$18.4 million per year for the entire agricultural area of both the Imperial and Coachella Valleys. Not all fields would require treated irrigation water to substantially reduce TSS loads.

The controlled eutrophication process (CEP) has been shown to be capable of removing approximately 75% of the nutrients present in the Whitewater River. Removal of both nitrogen and phosphorus occur in the CEP process as opposed to only phosphorus removal with chemical treatments. Although the estimated capital cost for CEP construction on the

Whitewater River would be roughly $100 million, CEP operating costs would be $17 million per year, a much lower figure compared to the other technologies evaluated.

Task 13. Quarterly, Draft and Final Reports

13.1 Quarterly Reports

We ensured that the contract requirements were met through completion of quarterly status reports submitted to the Contract Manager by the 10th of the month following the end of the calendar quarter and through regular communication with the Contract Manager. 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.

13.2 Draft Report

A draft final report was 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.

13.3 Draft submission

Copies of the draft report will be submitted to the Contract Manager for review and comment.

13.4 Corrections and final draft submission

This final report 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.

II. ATTACHMENTS

Attachments

Contents

TASK 1.2 CONTRACT SUMMARY

CONTRACT SUMMARY

Date filled out: September 9, 2003

A) Project Information **Please use complete phrases/ sentences. Fields will expand as necessary as you type.**

1. Project Title: Reducing Eutrophicants in Streams that Feed into the Salton Sea

2. Project Purpose – Problem / Goals ("why" the project): The overall goal of the project is to evaluate the efficacy of chemical flocculation and the Controlled Eutrophication Process (CEP) to remove phosphorous from tributaries that discharge into the Salton Sea and to determine whether positive synergies exist that make it prudent to utilize both these treatment strategies in tandem. Because internal phosphorous loading in the Salton Sea is low and external phosphorous loading to the Sea is high, reduction of tributary phosphorous loading to the Salton Sea may reduce eutrophication.

3. Project Abstract (brief description of project): Small-scale earthen drainage channels will be constructed to evaluate the ability of alum, ferric chloride, and various polymers, both separately and and in combination to directly remove phosphorus and sediment from agricultural drainage water (ADW) flowing through the channels. Concurrently, ongoing evaluations of the CEP process will be studied and water samples will be taken from the New River, Alamo River and Whitewater River to determine the amount of flocculant necessary to directly remove phosphorous.

5. Which SWRCB program is funding this project? *Please put an "X" by the one that applies.*

☒ *Prop 13* ☐ *EPA 319h grant*

B) Project Contact:

Name: Daniel Cain	**Job Title:** Senior Administrative Analyst
Organization: Salton Sea Authority	**Webpage Address:** Saltonsea.ca.gov

Address: 78-401 Highway 111, Suite T, La Quinta, CA 92253

Phone: (760) 564-4888

Fax number: (760) 564-5288

Email: dcain@saltonsea.ca.gov

C) Project Time Frame: Refers to the implementation period of project.

From: 09/24/03

To: 03/31/05

D) Participant Information: Name all agencies/groups involved with project. : U.S Bureau of Reclamation, University of California, Riverside, Kent Sea Tech, Clemson University, U.S. Geological Survey, Audubon Society, U.S Department of Fish & Game

E) Location:

1. **Size of Project** (include units):

2. **Counties** included in project: **Imperial County**

F) Biography of Group:

The Salton Sea Authority, in conjunction with the Bureau of Reclamation, is undertaking efforts to improve conditions at the Salton Sea. Restoration objectives include:

Maintaining the Sea as a repository of agricultural drainage from the Imperial and Coachella Valleys

Provide a safe, productive environment for resident and migratory birds

Restoring recreational uses

Maintaining a viable sport fishery

Providing opportunities for economic development

The Salton Sea Authority is a regional agency. The Authority was formed as a Joint Powers Agency by the Coachella Valley Water District, the Imperial Irrigation District, the County of Riverside and the County of Imperial. Additional information about the Sea and restoration efforts is provided at www.saltonsea.ca.gov.

G) Biography of Project:

The Salton Sea is California's largest lake and home

	to more species of birds than any other place in California. At one time, the Salton Sea state park hosted more annual visitors than Yosemite National Park. Eutrophication of the Salton Sea has severely impacted its beneficial uses, including recreation and fish and wildlife resources. Some of the effects of eutrophocation include high algal biomass, high fish productivity, low water clarity, frequent low dissolved oxygen concentrations, massive fish kills, and noxious odors.
H) Short-term Goals:	Reduce the amount of phosphorous and sediments discharging into the Salton Sea
I) Long-term Goals:	Reduce algal bio-mass, increase fish populations, improve water clarity, increase dissolved oxygen, and reduce odors

PAMELA PARKER, PROGRAM ANALYST
WATERSHED PROJECT SUPPORT SECTION
DIVISION OF WATER QUALITY
STATE WATER SOURCES CONTROL BOARD
1001 I STREET, 15th Floor
SACRAMENTO, CA 95814
parkp@dwq.swrcb.ca.gov

THANK YOU FOR YOUR TIME!! Mail completed form to address above and a copy to your contract Manager. You will be notified when your information is on-line

Task 1.8 Project Survey Form

NATURAL RESOURCE PROJECTS INVENTORY (NRPI) FORM 2000[1]

A Collaborative Effort between the Salton Sea Authority and the University of California, Riverside

Use the "tab" and arrow keys to move through the form. Skip Areas that Do Not Apply to Your Project

Date filled out: May 31, 2005

A) Project Information **Please use complete phrases/ sentences. Fields will expand as necessary as you type**
1. Project Title: Reducing Eutrophic Conditions of the Salton Sea- Project # 02-051-257-1
2. Project Purpose / Goals ("why" the project): The Salton Sea is California's largest inland water body and home to more species of birds than any other place in California. Eutrophication of the Salton Sea has severely impacted its beneficial uses, including recreation and fish and wildlife resources. External loading of nutrients, particular phosphorous, is responsible for the eutrophication of the Salton Sea. Since the Salton Sea is phosphorous limited, removing dissolved phosphorous and phosphorous-laden sediment from agricultural drainage water (ADW) should decrease eutrophication. The overall goal of the project is to determine the efficacy of several methods for phosphorous and sediment removal in both laboratory and field scale trials.
3. Project Abstract (brief description of project): The overall goal of the project is to evaluate the efficacy of chemical flocculation and the Controlled Eutrophication Process (CEP) to remove phosphorous from tributaries that discharge into the Salton Sea and to determine whether positive synergies may exist that make it prudent to utilize both of these treatment strategies. The ability of alum, ferric chloride, and various polymers, both separately and in combination were evaluated to determine their capabilities for removal of phosphorous and sediment from agricultural drain water.
5. Is this project part of an agency program? Put an "X" by all that apply: ☐ *NCCP* ☐ *HCP* ☐ *CRMP* ☐ *EPA 319h grant* ☐ *EPA 205j grant* ☐ *TMDL Program* ☐ *Larger watershed plan (name of plan):* X *Other (describe):*

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[1]

Prop 13	
B) Project Contact:	
Name: Dan Cain	**Job Title: Senior Administrative Analyst**
Organization: Salton Sea Authority	**Webpage Address: www.saltonsea.ca.gov**
Address: 78-401 Hwy 111, Suite T	
Phone: (760) 564-4888	**Fax number: (760) 564-5288**
Email: dcain@saltonsea.ca.gov	
Secondary Project Contact:	
Name: Chris Goodsen	**Job Title: Junior Specialist**
Organization: Univ of Cailifornia	**Webpage Address:**
Street Address: Office of Research Affairs, Riverside, CA 92521	
Phone:(951) 827-5108	**Email: cgoodson @ ucr.edu**
C) Data Contact: ***Data Contact same as Project Contact?*** *Y or X N*	
Name:	**Job Title:**
Organization:	**Webpage Address:**
Phone:	**Email:**

Is there data available? *Yes*

List Publicly Available Reports:

D. Project Time Frame:	
From: 07/01/2003	**To: 03/31/2005**

E) Participant and Funding Information: Name all agencies/groups involved with project; put an X by their role. If a Funder, note amount of Cash or Inkind contribution. Attach another sheet of paper if necessary.

Participant (include Volunteers)	Lead	Land-owner	Coop-erator	Funder	Cash Contrib	Inkind Contrib
Salton Sea Authority	X	☐				$
University of California, Riverside	☐	☐	X			$
Kent Sea Tech	☐	☐	X			$
Imperial County Farm Bureau	☐	☐	X			$

SWRCB	☐	☐		X	490,247	$
	☐	☐	☐	☐	$	$
	☐	☐	☐	☐	$	$
	☐	☐	☐	☐	$	$
	☐	☐	☐	☐	$	$

F) Location N/A

1. Size of Project (include units):

2. Counties included in project:

Riverside County and Imperial County

If **__over__ 5000 acres**, in addition to a point, attach a map of project. If **__under__ 5000 acres**, we onl need a center point.

3. Center Point: Lat/Long coordinates:

Lat Degrees: **33** Minutes: **43** Seconds: **318**

Long Degrees: **115** Minutes: **85** Seconds: **015**

(we will also accept decimal degrees - put all the numbers in the first latitude or longitude box)

__OR__

Township, Range and Section *(include Meridian)***:**

G) Project Focus

What types of resource issues does this project address? *(Please put an "X" by all resource areas that apply.)*

☐ Agriculture
☐ Erosion / Sedimen
☐ Grazing
☐ Stream Bank Prot
☐ Weed Control
☒ Water Quality*:
☐ Other: ____________

☐ Air Quality
☐ Fire Control
☐ Mining
☐ Urbanization
☐ Wetlands
☐ Water Quanti

☐ Biomass/ Fuels Contro
☐ Fisheries
☐ Recreation
☐ Urban Runoff
☐ Wildlife
☐ Ground Water or

☐ Dams
☐ Flood Contrl
☐ Riparian Enhanc
☐ Vegetation
☐ Surface Water

☐ Educ/Outreach
☐ Forestry
☐ Septic Systems

*For Water Quality Specify issue⇒

☒ Nutrients
☐ pH
☐ Salinity

☐ Pollutants
☐ Organics
☐ Heavy Mtls
☐ Pesticides

H) Habitat / Species **What habitats are in the project area?**

****Put an "E" by existing habitats and a "T" by those that are targeted as an end result**

__ 1. BEACH AND COASTAL DUNES	__14. GREAT BASIN SCRUBS	__28. CLOSED-CONE CONIFEROUS FORES
__ 2. INTERIOR DUNES	__15. CHAPARRALS	__29. LOWER MONTANE CONIFEROUS FOR
		__30. UPPER MONTANE CONIFEROUS FOR
__3. COASTAL AND INTERIOR SALT MARSH	__16. OAK WOODLANDS	__31. SUBALPINE CONIFEROUS FOREST
__4. BRACKISH AND FRESH WATER MARSH	__17. FOOTHILL PINE WOODLANDS	
__5. BOGS AND FENS	__18. PINYON AND JUNIPER WOODLANDS	__32. ALPINE COMMUNITIES
_E_6. STANDING WATER (LAKES, PONDS)	__19. SONORAN THORN WOODLANDS	
	__20. JOSHUA TREE WOODLANDS	__33. SOUTHERN CALIFORNIA ISLANDS
__7. COASTAL PRAIRIES		
__8. VALLEY AND FOOTHILL GRASSLANDS	__21. RIPARIAN FORESTS AND WOODLANDS	__34. AGRICULTURAL
__9. VERNAL POOLS	__22. RIPARIAN SCRUBS AND DESERT WASHES	__35. GRAZED PASTURE
__10. MEADOWS and SEEPS	__23. STREAM OR RIVER CHANNEL	__36. MINED LAND
__11. PLAYAS	(IN STREAM RESTORATION)	__37. URBAN/SUBURBAN
	__24. WETLAND (Type Unspecified)	__38. RUDERAL (WEED LOT)
__12. COASTAL SCRUBS	__25. BROADLEAF UPLAND FOREST	__39. NONE OF THE ABOVE (DESCRIBE) ⇓
__13. SONORAN DESERT SCRUBS	__26. NORTH COAST CONIFEROUS FOREST	
__14. MOJAVEAN DESERT SCRUBS	__27. MIXED EVERGREEN FOREST	

Does this project target the protection / conservation of specific species? Does this project try to Introduce or Eradicate a species as part of restoration or conservation efforts? Please Note Below.

Latin Name or	**Common Name**	Targeted for Protection	Introduced to Project Area	Seek to Eradicate from Area
		☐	☐	☐
		☐	☐	☐
		☐	☐	☐
		☐	☐	☐
		☐	☐	☐
		☐	☐	☐
		☐	☐	☐
		☐	☐	☐

I) Project Methods / Progress **(Table will expand as you type)**

Treatment Area Include Units (feet, miles)	General Habitat Type (ex: Weedlot, forest, river, wetland)	Treatment or Restoration Activity (ex: Woody debris, revegetation, fish screen)

Was fertilizer used? Y☐ or N☐ If yes, what type:

Was the site irrigated? Y☐ or N☐ Was irrigation ☐regularly scheduled or ☐supplemental/ needed

State frequency and method (drip, overhead sprinkler, hand, etc.):

What problems have you encountered with this project?

Was (or will) the project (be) monitored? ☐No

If yes, what is the monitoring schedule, i.e., how often per year and for how many years?

Has the project goal(s) listed in Section "A" been attained? ☒Yes ☐No ☐ Partially ☐ Too Soon to Tell

Are there performance standards (success criteria) for the project? ☐Yes ☒No

If yes, please describe:

Have the performance standards been attained? YES

J) Project Status, Funding & Needs

Current phases of project: *(Put an "X" by all applicable words)*

☐Scoping ☐Planning ☐Implementation ☐Monitoring ☐Writing Report ☒Completed

☐Other:

4. Indicate specific tasks in need of funding:

What are the project's current needs?
(Put an "X" by applicable terms)

☐Analysis
☐Legislation
☐Community Support
☐Modeling
☐Equipment
☐Monitoring
☐Funding
☐Public Outreach
☐Governmental Approval
☐Research
☐Habitat Management
☐Restoration
☐Inventory
☐Training
☐Legal Assistance
☐Volunteers
☐Other:

K) Project Data: Check those that apply.

EXAMPLES of Content Type (Write Answers in Boxes BELOW Examples)			
☐	☐	☐	☐
X☐**Water Quality**	X**Water Nutrients**	☐**Water Salinity**	☐**Water Pollution**
☐**Water - Heavy Meta**	☐**Water - Organics**	☐**Water - Pesticides**	☐**Water - pH**
☐	☐	☐	☐
☐	☐	☐	☐
☐	☐	☐	☐
☐	☐	☐	☐
☐**Other Data (Describe)**			

TASK 2.1 CEQA/NEPA DOCUMENTATION

PRELIMINARY EXEMPTION ASSESSMENT

(Certificate of Determination
When Attached to Notice of Exemption)

1. Name or description of project: Reduction of Eutrophicants in Streams that feed into the Salton Sea
2. Location: Kent Sea Tech, P.O. Box 757, Mecca, CA, 92254
3.
4. Entity or person undertaking project:

X A. Salton Sea Authority (Lead Agency)

X B. Other (Private)

(1) Name: University of California, Riverside

(2) Address: 1201 University Avenue, Suite I-208, University of California, Riverside, Riverside California 92521

5. Staff Determination:

The Authority Staff, having undertaken and completed a preliminary review of this project in accordance with the Authority's "Local Guidelines for Implementing the California Environmental Quality Act (CEQA)" has concluded that this project does not require further environmental assessment because:

a. ____ The proposed action does not constitute a project under CEQA.

b.____ The project is a Ministerial Project.

c.____ The project is an Emergency Project.

d.____ The project constitutes a feasibility or planning study.

e. X The project is categorically exempt.

Applicable Exemption Class: Class 6 (Section 15306)

f.____ The project is statutorily exempt.

Applicable Exemption: ______________________

g.____ The project is otherwise exempt on the following basis: ________

____

h.____ The project involves another public agency which constitutes the Lead Agency. Name of Lead Agency:__________________

Date:________________ ______________________
Staff

Notice of Exemption:

To: ☐ Office of Planning and Research
P.O. Box 3044, 1400 Tenth St., Rm. 222
Sacramento, CA 95812-3044

☒ County Clerk
County of Riverside
4080 Lemon Street, 1st Floor
Riverside, CA 92502-2204

From: (Public Agency) Salton Sea Authority
48-401 Highway 111, Suite T
LaQuinta, CA 92253

Project Title: **Reduction of Eutrophicants in Streams that feed into the Salton Sea**

Project Location - Specific: Project Physical Address: Kent Sea Tech, P.O. Box 757, Mecca, CA 92254

Project Location - City: Mecca **Project Location - County:** Imperial

Description of Project:

In the proposed project the overall goal is to determine the efficiency of removing phosphorous from water that eventually discharges into the Salton Sea. More specifically several methods of phosphorous and sediment removal will be tested in the laboratory as well as in the field. Because internal phosphoprus loading in the Salton Sea is low and external phosphourous loading to the Sea is high, reduction of tributary phosphouous loading to the Salton Sea may reduce eutrophication. ,

Name of Public Agency Approving Project: Salton Sea Authority

Name of Person or Agency Carrying Out Project: University of California, Riverside

Exempt Status: (*check one*)

☐ Ministerial (Sec. 21080(b)(1); 15268);
☐ Declared Emergency (Sec. 21080(b)(3); 15269(a));
☐ Emergency Project (Sec. 21080(b)(4); 15269(b)(c));
☒ Categorical Exemption. State type and section number: 15306 of the State CEQA Guidelines
☐ Statutory Exemptions: State code number: ____

Reasons why project is exempt:
The proposed project is exempt from CEQA under Section 15306, which states that : "Class 6 consists of basic data collection, research, experimental management, and resource evaluation activities which do not result in a serious or major disturbance to an environmental resource."

Lead Agency
Contact Person: Dan Cain Area Code/Telephone/Extension: (760) 564-4888

If filed by applicant:

1. Attach certified document of exemption finding.
2. Has a Notice of Exemption been filed by the public agency approving the project? ☒ Yes ☐ No

Signature: ____ Date: ____ Title: ____

☒ Signed by Lead Agency
☐ Signed by Applicant

Date received for filing at OPR: ____

TASK 3.2 QUALITY ASSURANCE PROJECT PLAN

Quality Assurance Project Plan

for

Reducing Eutrophic Conditions of the Salton Sea

Prepared for the
State Water Resources Control Board

Date: 11/24/03	
Contractor Name:	The Salton Sea Authority
Funding Program:	State Prop 13
Contract #:	02-051-257-1

Principal Investigators:
Prof. Chris Amrhein, Assoc. Prof. Michael Anderson, and Prof. Mark Matsumoto,
University of California Riverside

SECTION A: PROJECT MANAGEMENT

A1 Project Title and Approval Sheet

Reducing Eutrophic Conditions of the Salton Sea
University of California Riverside
Kent SeaTech Corporation
Salton Sea Authority

UC Riverside Principal Investigator: **Date**

Chris Amrhein ______________________________ ____________

Salton Sea Authority Project Officer: **Date**

Tom Kirk ______________________________ ____________

Contractor Quality Assurance Officer **Date**

Barry Gump ______________________________ ____________

Colorado River Basin Regional Board /
Contract Manager and QA Officer **Date**

Nadim Zeywar ______________________________ ____________

Salton Sea Authority Representative /
Project Director **Date**

Dan Cain ______________________________ ____________

CONTENTS

Distribution List

University of California, Riverside: Chris Amrhein, Jim Strong, Chris Goodson
State Water Resources Control Board: Nadim Zeywar
Salton Sea Authority: Dan Cain

List of Tables, Figures, and Appendices

A4 Project/Task Organization and Responsibilities

The Contractor Quality Assurance Officer is responsible for reviewing and approving this QAPP, ensuring that this QAPP is implemented and followed to meet the project objectives, and overseeing validation activities for field and lab data. Randomized sample serial numbers assigned by field samplers will remain undisclosed to laboratory workers to avoid bias.

The director and principal investigator of this project will be Dr. Chris Amrhein. Dr. Amrhein will supervise all field and laboratory investigations (figure 1). Chris Goodson, Junior Specialist, will have day-to-day responsibilities for the project and will coordinate field and laboratory efforts. Jim Strong, Staff Research Associate, will aid in field sampling and provide metal analysis. Two undergraduate students will assist in field sampling and laboratory analyses.

A5 Project Definition/Background

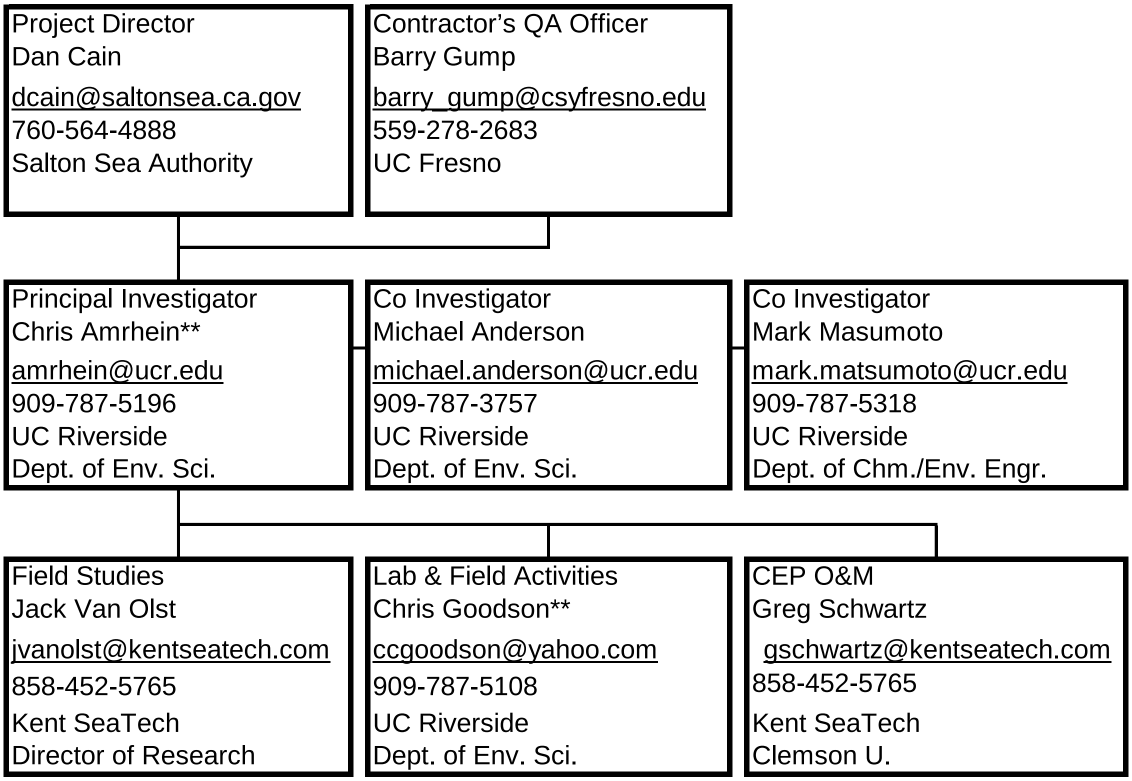
The Salton Sea is California's largest inland water body and home to more species of birds than any other place in California. Over 390 species of birds, including the endangered brown pelican and Yuma clapper rail, have been identified at the Sonny Bono Salton Sea National Wildlife Refuge. Eutrophication of the Salton Sea has severely impacted its beneficial uses, including recreation and fish and wildlife resources. Some of the 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.

Figure 1. Project Organization Chart

Project Organization Chart



* Approving Authority
** Individuals responsible for data validation and verification

A6 Project/ Task Descriptions

Methods for the chemical and biological removal of phosphorous and selenium from local river waters will be tested in various water treatment systems. Bench-scale studies will be done at UC Riverside and, at Kent SeaTech Corporation's Coachella Valley facility, pilot-scale treatment studies will be conducted in simulated wastewater ditches and controlled eutrophication process (CEP) systems.

Project Tasks

1. Modifying existing P removal systems

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. 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. A polymer / chemical flocculant injection system needs to be devised for the unit.

1.2 Simulated drainage ditches

Small-scale earthen drainage ditches supplied with ADW will be excavated to test the ability of alum and various polymers to remove phosphorous and sediment. Prior to each treatment trial, drainage flow and field conditions will be determined. For this, preliminary, non-treated samples will be collected for determination of soluble reactive phosphorous content, total phosphorous content, settleable solids and suspended solids. The treatment additive will then be metered out into the water and samples periodically taken producing time series of the analyses listed above. Once treatment has ceased, another set of samples will be collected. Given the seasonal variability of ADW, the trials will be replicated several times during the year to capture those differences. Solid collections/determinations will be made on site. Water samples for nutrient determinations will be collected and kept refrigerated until returned to the lab at UCR where they will be analyzed.

1.3 Optimization of Selenium Uptake by Algae in the CEP

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 (see section 5 for details). Selenium removal will be optimized by modifying the water velocity and the circulation rate through the algal settling zone in the CEP.

2. Conduct laboratory-scale studies of P-removal

Dr. Chris Amrhein's laboratory at UC Riverside will evaluate chemical flocculants and polymers for their capacities to remove phosphorus (P) from samples of river water from the Coachella and Imperial Valleys (The Whitewater, New, and Alamo Rivers) in scintillation vials. Prior to treatment, water turbidity will be measured and colorimetric determination of total phosphorus and soluble reactive phosphorus will be made using an Alpkem Autoanalyzer. This will document the ambient levels of phosphorus and suspended solids and determine to what extent levels vary as a function of season. Additionally, combinations of flocculants (including but not limited to alum, ferric chloride, and polyacrylamide) will be tested in glass scintillation vials to determine the concentrations and contact times required to achieve flocculation and settling of the phosphorus-laden sediments present in the water. The results from this task will narrow down the possible combinations of flocculants to be utilized in the next task.

3. Conduct meso-scale tank studies of P-removal

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. 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.

4. Conduct ditch-scale studies for P-removal

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. Two 200 ft. simulated earthen agricultural drainage ditches will be constructed at Kent Sea Tech and utilized in these studies.

4.1 Flocculant/polymer work plan for in-ditch treatment

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, a work plan will be prepared that will permit comparison of the most promising flocculant/polymer combinations.

4.2 Conduct in-ditch treatment trials

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.

5. Conduct CEP treatment trials

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.

6. Monitor biological Se-uptake and evaluate CEP for Se-removal

In any water treatment technology in which nutrients are concentrated for ultimate removal from the system, there is a potential for bioaccumulation of 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 will monitor the levels of selenium that are found in the Whitewater River and the degree to which the levels are reduced in the treated discharge from the CEP system. We will monitor selenium levels in the algal concentrate and the filter-feeding fish that will be the principal byproducts of the treatment process. We 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.

7. Quarterly, Draft and Final Reports

7.2 Quarterly Reports

We will ensure that the contract requirements are met through completion of quarterly status reports submitted to the Contract Manager by the 10th 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

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

Copies of the draft report will be submitted to the Contract Manager for review and comment.

7.4 Corrections and final draft submission

A final report will be prepared that addresses, to the extent feasible, comments made by the Contract Manager on the draft report. Submit one reproducible master and two copies of the final project report to the Contract Manager for review and acceptance.

Table 1. Project Work Schedule

	4th			1st			2nd			3rd			4th			1st		
	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:																		
1.1 Bench-scale CFS evaluations		▨	▨	▨	▨	▨	▨	▨										
1.2 Simulated irrigation ditch flocculant evaluations	▨	▨	▨	▨	▨	▨	▨	▨	▨									
1.3 Optimization of Selenium Uptake by Algae in the CEP										▨	▨	▨	▨	▨				
2. Conduct laboratory-scale studies of P-removal	▨	▨	▨	▨														
3. Conduct bench-scale CFS studies of P-removal					▨	▨	▨	▨	▨	▨	▨	▨						
4. Conduct ditch-scale studies for P-removal:																		
4.1 Flocculant/polymer work plan for in-ditch treatment				▨														
4.2 Conduct in-ditch treatment trials					▨	▨	▨	▨	▨									
5. Conduct CEP flocculant/ polymer treatment evaluations					▨	▨	▨	▨	▨									
6. Monitor biological Se-uptake and evaluate CEP for Se-removal	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨				
7. Quarterly, draft and final reports:																		
7.1 Quarterly reports			▨			▨			▨			▨						
7.2 Draft report													▨	▨	▨			
7.3 Draft submission																▨		
7.4 Corrections and final draft submission																	▨	▨

A7 Quality Objectives and Criteria for Measurement Data

Nutrient concentrations and other chemical and physical properties of water samples will be quantified using standard methods. Detection limits and operating ranges for the analytical techniques are provided in Table 2.

Analytical precision will be evaluated by analysis of replicate samples. Duplicates will be analyzed at a frequency of no less than one per 10 samples. Duplicate analyses of field splits will be used to assess the precision of analytical methods. Duplicate analysis of a sample on the same instrument will provide instrumental precision data. The relative percent difference (RPD) of duplicates will be calculated as follows:

$$RPD = (C_1-C_2)/((C_1+C_2)/2)*100$$

where C_1 and C_2 are concentrations of analyte in replicate samples 1 and 2. A control limit of 15% will be used for relative percent difference. Frequencies of replicate samples for various laboratory analyses are listed in Table 3.

Accuracy of analytical data will be evaluated by analyzing reference materials and spiked samples. Reference materials will be run with each batch of samples during laboratory analyses. Confidence intervals supplied with reference samples will be used as control limits at the 95% confidence level. The relative percent error (RPE) of standards will be calculated as follows:

$$RPE = (C_1-C_0)/C_0*100$$

where C_1 is the concentration analyzed in the sample and C_0 is the true concentration.

Spiked samples will be used to assess the recovery of various analytes. Spikes will contain analytes at the level present in the sample, or at the concentration of the mid-range calibration standard, whichever is higher. Spike recovery will be calculated as follows:

$$\% \text{ Recovery} = (A_s-A_o)/S*100$$

where A_s is the amount of analyte in the spiked sample, A_o is the amount of analyte in a non-spiked sample, and S is the amount of spike added. Control limits of 90 to 110% will be used for percent recovery. Frequencies of spike samples for various laboratory analyses are listed in Table 3.

Table 2. Method detection limits, normal operating ranges and calibration methods for various analytes.

Measurement	Method Detection Limit	Operating Range	Calibration Method
Alkalinity	10 mg/L	50-300 mg/L	Standards
Dissolved oxygen	0.01 mg/L	0-20 mg/L	External Calibration
Electrical Conductivity			External Calibration
pH			
Field	0.1	2-12	Buffers
Laboratory	0.01	0-14	Buffers
Phosphorous			
Soluble reactive	0.01 mg/L	0.01-4 mg/L	Standards
Total			
Selenium			
Total	.003 mg/L	.003-20 mg/L	Standards

Table 3. Frequency of replicates and spikes for various laboratory analyses.

Measurement	Frequency of replicates	Frequency of spikes
Dissolved oxygen	Single analysis	None
Electrical Conductivity	Single Analysis	None
pH		
Field	Single analysis	None
Laboratory	Single analysis	None
Phosphorous		
Total dissolved	One in ten duplicated	One in ten spiked
Soluble reactive	One in ten duplicated	One in ten spiked
Selenium		
Total	One in ten duplicated	One in ten spiked

A8 Special Training Requirements/Certification

The research team is well suited for the proposed research. Dr. Amrhein has considerable teaching and research experience related to the chemistry of waters, sediments and soils. Dr. Amrhein teaches graduate courses in soil chemistry and saline soils and waters and has conducted a number of studies on the chemistry of saline evaporation ponds. Recent published studies include work on mineral precipitation and solubility (e.g., Levy *et al.*, 1994; Amrhein *et al.*, 1993; Amrhein *et al.*, 1985) and the effects of redox on metal and trace element solubility (Duff *et al.*, 1999; Amrhein *et al.*, 1993). Dr. Amrhein will have primary responsibility for field sampling, budget calculations and oversee laboratory activities.

Chris Goodson, Junior Specialist, will provide the day-to-day oversight of the project. He holds a Master of Science degree in Soil and Water Sciences, specializing in biogeochemistry. His previous research experience includes field sample collection and analysis of plant tissue, soil and water for cations, anions, and trace metals - namely selenium. Throughout phosphorus and selenium analysis, Mr. Goodson will be responsible for quality assurance and related analytical problems.

Jim Strong, Staff Research Associate (SRA) IV, has an extensive experience in the analysis of environmental samples. He has been with Department of Environmental Sciences 27 years and is listed as coauthor on numerous scientific papers. Mr. Strong is the analyst in charge of the UCR Department of Environmental Sciences Optical Emission Spectrophotometer on which metal analysis will be completed.

Laboratory assistants will participate in field and laboratory sampling and analysis.

A9 Documentation and Records

During field trials all samples will be recorded in a sample collection record. Furthermore, details will be recorded in a field log. A chain of custody record form will be used to document the transfer of samples collected in the field to laboratory personnel. A field log and chain of custody record are included at the end of this chapter. Quality control sample records (for both field and lab operations) will be kept together in a binder in the lab. This includes but is not limited to data on blanks and duplicates. Included will be a log of any problems that are encountered that result in a deviation from standard procedures. Copies of the methods used for sample collection and analysis will be kept in binders on-site and in the lab. Please see section A6, task 6 for details on quarterly, draft, and final reports.

SECTION B: MEASUREMENT/DATA ACQUISITION

B1 Experimental Design

B1.1 Purpose/Background

There are essentially two components to the proposed experiments. One is to evaluate the effect of various chemical flocculant and polymer treatments on phosphorus removal from ADW. This will be accomplished by analyzing for total phosphorus in a variety of water samples taken from the systems described in section A6.

The other component is to evaluate selenium (Se) uptake by algae and fish from ADW in the CEP. For this, water and algae will be separated by filtering bulk water samples to 2 µm and analyzing each fraction separately for total Se concentrations. Fish samples from the CEP will undergo chemical digestion prior to analysis for total Se. On-site Kent personnel will provide weekly updates of background environmental data for the CEP.

B1.2 Scheduled Project Activities

Please refer back to Table 1 for a time frame of sampling and analytical activities. Please also see the Appendices B1.2 Project Sampling Plan for experimental treatments, timing, and numbers of samples to be taken.

B1.3 Rationale for the Design

Sampling locations for the phosphorus removal systems will be at influent and effluent pipes at appropriate times to determine their degree of nutrient removal. For Se uptake assessments, water/algae samples will be taken from the main algal zone quarterly in order to perceive seasonal variations in water concentrations and subsequent algal uptake. Tillapia will be sampled before and after a growth period in the CEP fish cages in order to determine weather they are bioaccumulating Se in the presence of a potentially high-Se foodsource.

B1.4 Design Assumptions

For all chemical flocculant and polymer evaluations, it is assumed that we can effectively mimic “real world” turbidity conditions by mixing in soils trucked from the watersheds of the rivers sampled. For the ditch scale experiments, it is assumed that there will be no downward migration of water if a bentonite seal is properly applied. However, should the seal fail, the accuracy of the chemical flocculant and polymer trials would be questionable.

For the Se uptake study, it is assumed that there are no “wild” fish outside of the fish cages in the CEP. However, if there were, an estimation of their biomass would be important to any mass balance calculations rendered.

B1.5 Procedures for Locating and Selecting Environmental Samples

The precise sampling locations in the various treatment systems will be kept constant once they are established. However, should the field workers deem it necessary to adjust the sampling locations, they should do so after consulting with the rest of the group. Water samples will be taken with poly propylene bottles attached to the end of a long aluminum pole. Large volume bulk water samples may be best taken using an electric pump and Tygon tubing setup. Fish samples will be netted from the tanks according to the instructions of Kent personnel.

B1.6 Classification of Measurements as Critical or Noncritical

Since the research conducted for this project is not meant to be defensible in a court of law nor be the basis for establishing new environmental regulations, all measurements produced should be considered as noncritical.

B1.7 Validation of Any Nonstandard Methods

Should any nonstandard sampling methods be employed, appropriate information will be provided in the final report to confirm the representativeness of the data generated. As a result, a more rigorous validation procedure may not be necessary.

B2 Sampling Methods Requirements

Basic field conditions (E.C, pH, D.O., temperature) of the agricultural drainage water will be determined using a hydrolab probe. Water samples for chemical and physical analysis will be collected by grab samples. The water samples will be divided into filtered (which will then be acidified with sulfuric acid to pH less than 2) and unfiltered subsets. The unfiltered water, which will be examined for turbidity and solid determinations, will be refrigerated until analyzed. Table 5 shows the type of container, sample volumes, preservation methods and holding time for the methods to be utilized.

Table 4. Methods to be used for analysis of water samples.

Measurement	EPA/Standard Method	Container	Preservative	Holding Time
Water Samples				
Alkalinity	310.2	P	Cool, 4C	14 days
Conductance	120.1/2510B	P	Cool, 4C	28 days
Dissolved oxygen	360.1/4500-O	N/A	Determine on site	N/A
PH	150.1/4500-H	P	Determine on site Cool, 4C	24 hours
Phosphorous				
Reactive	365.3/4500-P	P	Cool, 4C or H_2SO_4 to pH,2	28 days
Total	365.4/4500-P	P	Cool, 4C or H_2SO_4 to pH,2	28 days
Selenium (Se)	3015/207.3	P	Cool, 4C or H_2SO_4 to pH,2	28 days
Temperature	170.1/2550B	N/A	Determine on site	N/A
Algae and Fish				
Algal Se	3051/207.3	P	4C	28 days
Fish Se	3051/207.3	P	0C	28 days

B3 Sampling Handling and Custody Requirements

Each water, algae, and fish sample will be assigned a unique identification number. Individual sample identifications will consist of a number, the sampling date, time relative to treatment and site. Identification numbers for field-splits of samples will be appended with a letter “S”. Sample containers will be labeled prior to the time of collection. Labels will include the sample number, date, time and the field sampler’s initials. A Field Log will be completed during the collection of each water and sediment sample. Field Log entries will include the site number, date, time, trial identification, sample number, duplicate number, basic water measurements, weather/site conditions, field observations/comments and the signature of the sampler. A Chain-of-Custody form will be completed for each group of samples collected on the same day, and be used to transfer samples to laboratory personnel. Chain-of-Custody entries will include the project name, field samplers, sample numbers, sample types, number of containers, comments and signatures relinquishing the samples. Samples of the Field Log and Chain-of-Custody forms to be used for this study are included at end of this report.

Field documentation will be completed using indelible ink, with any corrections made by drawing a single line through the error and entering the correct value.

Water samples for nutrient and metal analysis will be filtered (if necessary) and acidified in the field and kept refrigerated until the return to the UC Riverside lab. All samples will begin to be processed within 24hrs.

B4 Analytical Methods Requirements

Standard methods will be used for all routine water, algae, and fish quality analyses. Methodologies used are taken from Methods of Chemical Analysis for Waters and Waste (EPA-600/4-79-020) published by EPA, Standard Methods for the Examination of Water and Wastewater 17th Edition, published by American Public Health Association, American Water Works Association, and Water Pollution Control Federation, and Methods of Soil Analysis 2nd Edition published by American Society of Agronomy and Soil Science Society of America. Applicable methods for sample analyses are listed in Table 4. Chemical standards will be used to calibrate instruments at the start of each run of samples. Blanks will be analyzed at a frequency of no less than one per 20 samples. Method detection limits, normal operating ranges and calibration methods for various analytes are given in Table 2.

B5 Quality Control Requirements

Care will be taken to ensure the collection of representative sediment and water samples. Equipment blanks will be used to aid in the identification of problems due to field contamination. Duplicate analyses of field splits will be used to assess the precision of analytical methods. Quality control in the laboratory will include analysis of reagent blanks, method blanks, sample duplicates, certified standards and spikes.

Standard laboratory practices will be followed in all aspects of this project. All lab and field personnel have gone through campus safety training. All hoods are checked on a regular schedule by the campus Department of Environmental Health and Safety (EHS). Hazardous wastes generated during some analyses will be transferred to EHS for disposal according to campus, state and federal guidelines.

As laboratory analyses are completed, the analyst will check data for quality. Corrective action will be taken by the analyst whenever the RPD of duplicates exceeds 15% and when spike recoveries fall outside of the 90-110% control limit. Samples from analyses which fail to meet quality criteria will be re-analyzed following recalibration of the instrument.

All data will be entered into computer files and materials related to analyses (raw data sheets, recorder output, computer print outs, etc.) will be kept on file for future reference. Chris Amrhein will review all laboratory data approximately every week and will require additional re-analysis as warranted.

B6 Instrument/Equipment Testing, Inspection, and Maintenance Requirements

All field instruments will be inspected and calibrated prior to visiting the field. All laboratory equipment used to provide numerical data will be calibrated to the accuracy requirements for its use prior to, periodically during and at the end of sample analysis.

B7 Instrument Calibration and Frequency

Calibration procedures in the field will include calibration of GPS systems, and Quanta HydroLab. Field maintenance will include cleaning and monitoring of plumbing, flow gauges and treatment pumps.

Calibration schedules will be established for all laboratory instruments, with calibration records maintained in the laboratory logbooks kept with each instrument. Information relative to instrumentation maintenance will also be recorded in the logbook kept with each instrument. The Department of Environmental Sciences has a number of service contracts with various vendors and department instruments are serviced on a regular schedule.

B8 Inspection/Acceptance Requirements for Supplies and Consumables

Sample containers will be washed and inspected before use. All sampling containers and laboratory glassware will be washed using the appropriate detergents, followed by rinsing with tap water, acid wash, where appropriate, and final rinses with distilled water followed by deionized water. Chemical calibrations and standardizations are made using standards prepared from materials of known purity using accepted analytical techniques.

B9 Data Acquisition Requirements

Data on tributary and river flows will be retrieved from external sources. Results from SSA-sponsored research and other peer-reviewed studies will be used where available. Other sources will be reviewed prior to utilization of their data.

B10 Data Quality Management

Identification numbers will be recorded on all data forms, sample tracking sheets, analytical logbooks and computer data files. A computer file will serve as the Master Log Book for the project. As laboratory analyses are completed, the resulting data will be checked for quality by Chris Goodson and then entered into the computer files. All raw data and data entered into the computer files will then be evaluated by Chris Amrhein. The computer files for this project will be networked, so that Dr. Amrhein will have access to all data for evaluation purposes.

SECTION C: ASSESMENT/OVERSIGHT

C1 Assessments and Response Actions

Project assessment will include regular observation of field sampling, sample handling, sample preparation, sample analysis, data evaluation and verification of quality control. Chris Amrhein will be responsible for periodic monitoring of field activities and assuring that all field personnel are adequately trained for the sampling method requirements. Dr. Amrhein will also be responsible for supervising laboratory activities and monitoring quality control in sample analyses and will address deviations from sampling and analytical protocols.

In addition to internal assessment activities, the Quality Assurance officer, Barry Gump, will visit the laboratory and field site at least once per year.

C2 Reports to Management

Water quality data and accompanying QA results generated by this project will be reported to the State Water Resources Water Control Board on a quarterly basis, including an annual report and a final report, as outlined in Table 6.

SECTION D: DATA VALIDATION AND USABILITY

D1 Data Review, Validation, and Verification Requirements

Data review, validation and verification requirements are specified in section B5. Equipment blanks will be used to aid in the identification of problems due to field contamination. Duplicate analyses of field splits will be used to assess the precision of sampling and analytical methods. Quality control in the laboratory will include analysis of reagent blanks, method blanks, sample duplicates, certified standards and spikes.

D2 Validation and Verification Methods

Sample and data flow, responsible personnel, and data records for the project are summarized in the Project Organization Chart.

D3 Reconciliation with User Requirements

The data generated from the above analyses will quantify the rate of phosphorus and selenium removal from ADW if a full scale CEP's were constructed on the rivers that flow into the Salton Sea. Results will also be used in a lake water quality model to predict the water quality and trophic state of the Sea under different management strategies.

Table 5. Data and document submission dates

Quarterly Report – Friday December 19, 2003
Quarterly Report –Wednesday March 31, 2004
Quarterly Report – Wednesday June 30, 2004
Quarterly Report – Thursday September 30,2004
Quarterly Report –Monday December 20, 2004
Final Report – Thursday March 31, 2005

REFERENCES

Amrhein, C., J. J. Jurinak, and W. M. Moore. 1985. Kinetics of calcite dissolution as affected by carbon dioxide partial pressure. *Soil Sci. Soc. Am. J.* 49:1393-1398.

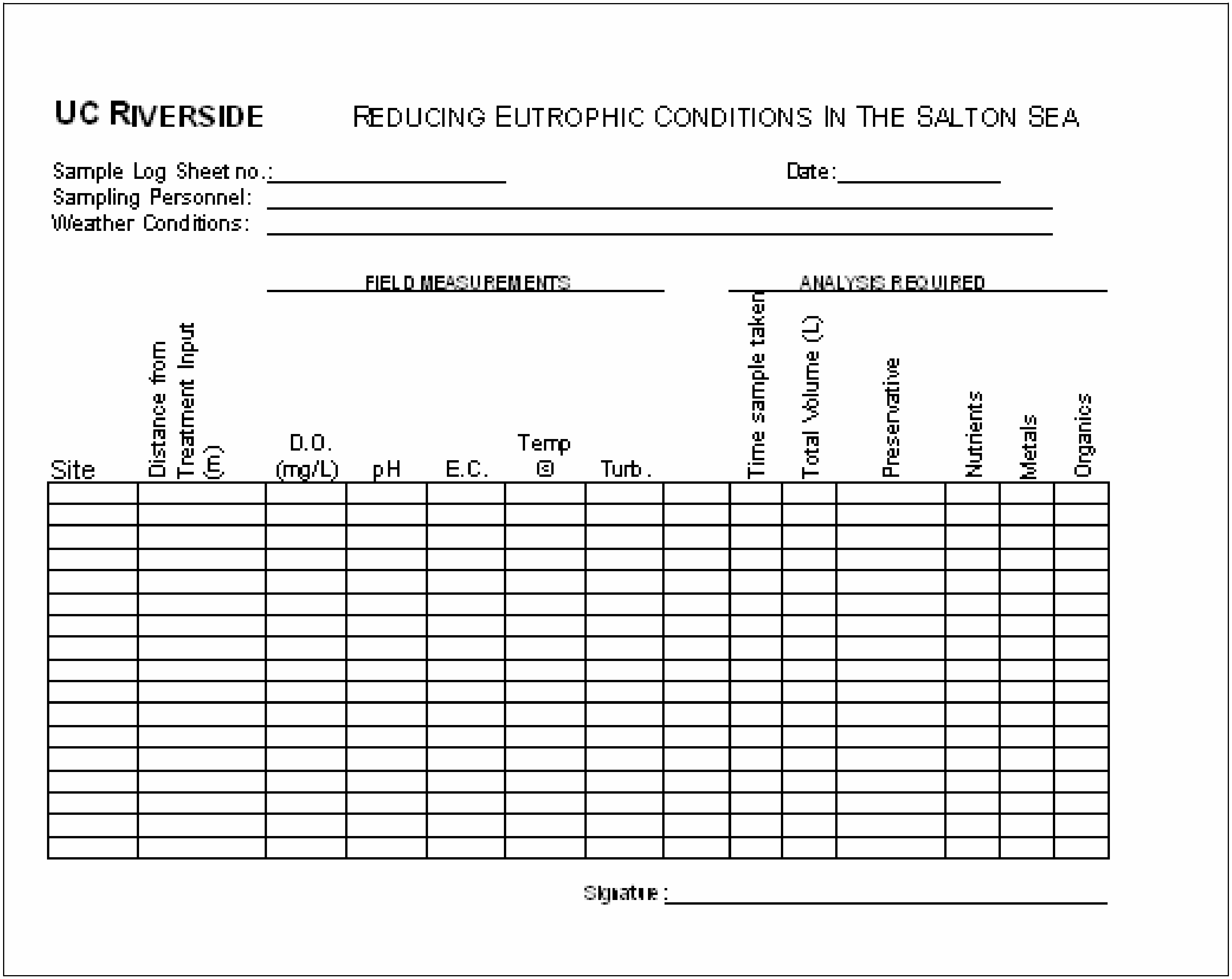
Amrhein, C., M. F. Zahow, D. L. Suarez. 1993. Calcite supersaturation in soil suspensions. *Soil Sci.* 156:163-170.

Amrhein, C., P. A. Mosher, and A. D. Brown. 1993. The effects of redox on Mo, U, B, V, and As solubility in evaporation pond soils. *Soil Sci.* 155:249-255.

Duff, M.C., D.B. Hunter, P.M. Bertsch and C. Amrhein. 1999. Factors influencing uranium reduction and solubility in evaporation pond sediments. *Biogeochemistry* 45: 95-114.

Levy, D.B., C.A. Amrhein, and M.A. Anderson. 1995. Coprecipitation of sodium, magnesium, and silicon with calcium carbonate. *Soil Sci. Soc. Am. J.* 59:1258-1267.

Figure 2. Sample field log.



UC RIVERSIDE REDUCING EUTROPHIC CONDITIONS IN THE SALTON SEA

Sample Log Sheet no.:____________ Date:__________

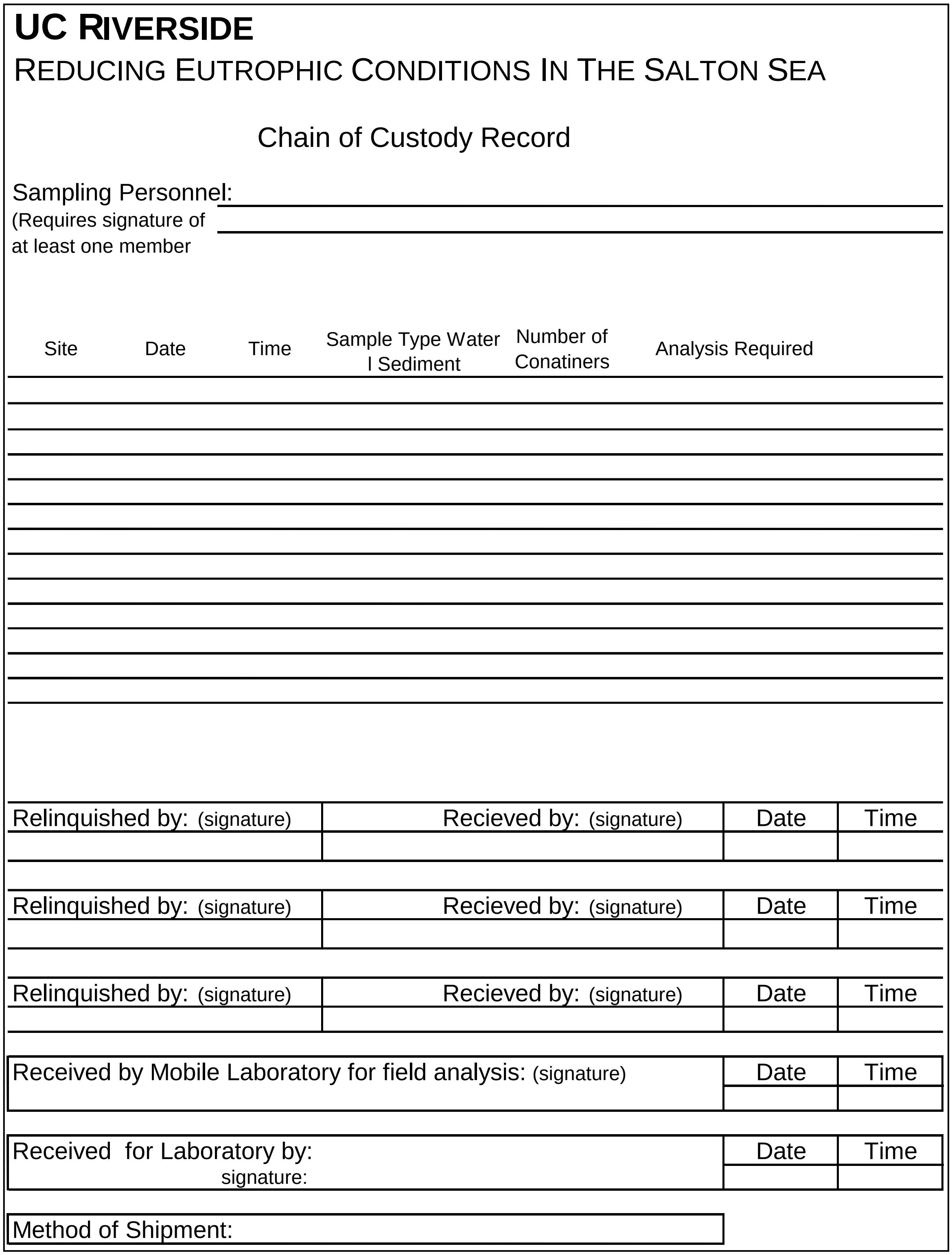
Sampling Personnel: ______________________________

Weather Conditions: ______________________________

		FIELD MEASUREMENTS						ANALYSIS REQUIRED					
Site	Distance from Treatment Input (m)	D.O. (mg/L)	pH	E.C.	Temp @	Turb.		Time sample taken	Total Volume (L)	Preservative	Nutrients	Metals	Organics

Signature: ______________________________

Figure 3. Sample chain of custody record.



UC RIVERSIDE

REDUCING EUTROPHIC CONDITIONS IN THE SALTON SEA

Chain of Custody Record

Sampling Personnel: ______________________
(Requires signature of ______________________
at least one member

Site	Date	Time	Sample Type Water l Sediment	Number of Conatiners	Analysis Required

Relinquished by: (signature)	Recieved by: (signature)	Date	Time

Relinquished by: (signature)	Recieved by: (signature)	Date	Time

Relinquished by: (signature)	Recieved by: (signature)	Date	Time

Received by Mobile Laboratory for field analysis: (signature)	Date	Time

Received for Laboratory by: signature:	Date	Time

Method of Shipment:

Appendix B1.2 Project Sampling Plan for evaluations of total phosphorus removal by chemical flocculants and polymers[a].

Appendix B1.2 Project Sampling Plan for evaluations of total phosphorus removal by chemical flocculants and polymers[a]

Tasks	Influent Samples Effluent Samples[b]					Sampling Totals				
	t_0	t_1	t_2	$t_{3..n-1}$	t_n	round frequency	number of rounds	samples taken per round	total samples taken	total analysis[c]
2. Lab-scale (jar tests)										
Use grab-samples of Whitewater, Alamo, and New River water. Sample aliquots decanted from jars.	15	0	0	0	15	one time	3	30	90	108
	N/A	N/A	N/A	N/A	N/A					
3. Meso-scale (1,200 L Tanks)										
Use pumped or trucked-in Whitewater, Alamo, and New River water. Sample influent and effluent at the fill and drain pipes, respectively.	3	3	0	0	0	quarterly (4 times)	3	21	63	78
	0	0	3	9	3					
4. Ditch-scale (drainage ditches)										
Use pumped or trucked-in Whitewater, Alamo, and New River water. Sample influent and effluent at the fill and drain pipes, respectively.	3	3	0	0	0	quarterly (3 times)	3	18	54	68
	0	0	3	6	3					

[a] Treatments for each system include, but are not limited to, alum, feric chloride, polymer, alum + polymer, and feric chloride + polymer treatments

[b] t_0 = pre-treatment sample, t_1 = treatment initiation, $t_{3...n-1}$ = total mid-treatment samples, and t_n = post-treatment

[c] Total number of samples analysed (x) plus duplicates (x/10), standard reference material checks (1 per round), and spikes (2 per round)

Appendix B1.2 (Continued) Project Sampling Plan for evaluations of total selenium uptake by algae and fish in the CEP.

Tasks	Samples[a]					Sampling Totals				
	t_0	t_1	t_2	$t_{3..n-1}$	t_n	round frequency	number of rounds	samples taken per round	total samples taken	total analysis[b]
Water										
Filtrate from main tank grab-samples.	2	2	2	2	2	quarterly (4 times)	5	10	50	70
Algae										
Filter residue from main tank grab-samples.	2	2	2	2	2	quarterly (4 times)	5	10	50	70
Fish										
Sample of juveniles before introduction to the cages. Sample of adults once full grown.	30	0	0	0	30	as available (1 time)	1	60	60	69

[a] t_0 = pre-treatment sample, t_1 = treatment initiation, $t_{3...n-1}$ = total mid-treatment samples, and t_n = post-treatment

[b] Total number of samples analysed (x) plus duplicates (x/10), standard reference material checks (1 per round), and spikes (2 per round)

TASK 4.1 PROJECT ASSESSMENT AND EVALUATION PLAN

REDUCING EUTROPHIC CONDITIONS OF THE SALTON SEA

September 26, 2003

Task 4. Project Assessment and Evaluation Plan

Prepare and submit to the Contract Manager a Project Assessment and Evaluation Plan that does all of the following:

1) Describes the baseline water quality of the water body impacted.
2) Describes the manner in which the proposed watershed restoration activities are implemented.
3) Determines the effectiveness of the watershed restoration activities in preventing or reducing pollution.
4) Determines, to the extent feasible, the economic benefits resulting from the changes determined pursuant to paragraph (3).

1. Baseline water quality of the water body impacted.

Currently, most of the rivers in California that receive agricultural drainage water, including the Alamo, New, and Whitewater Rivers that feed into the Salton Sea, do not meet water quality standards of the Federal Clean Water Act (CRWQCB, 2001). These water bodies are deemed “impaired” (i.e. do not fully achieve designated beneficial uses), which requires the development of basin plans to reduce contaminant loading and the establishment of total maximum daily loads (TMDL). The criteria used to establish TMDLs varies with each water body and the type of pollutant. Specifically, the rivers flowing into the Salton Sea are impaired due to suspended solids, nutrients, selenium, pesticides, and pathogens (CRWQCB, 2001). This project will investigate methods for reducing nutrient and suspended solids concentrations in the Alamo, New, and Whitewater river waters, which will lead to an improvement in water quality of the receiving water, the Salton Sea.

These three rivers and the Salton Sea were sampled during 1999 for water quality analysis. Table 1 from Holdren and Montaño (2002), below, summarizes the water quality data for these waters. For comparison, dissolved inorganic phosphorus, commonly referred to as orthophosphate (Ortho-P in Table 1) averages 0.01 mg L^{-1} worldwide among unpolluted rivers (Maybeck, 1982 and 1993). The Alamo, New, and Whitewater Rivers exceed this average from 40 to 70 fold. Since primary productivity in the Salton Sea is P-limited, reducing the input of P to the Sea will have a significant effect on improving water quality (Anderson and Amrhein, 2002). The impact of high orthophosphate loading is extensive algal blooms, and associated anoxia, fish kills, and odors (Anderson and Amrhein, 2002).

Table 1 also reports “Total P” which includes Ortho-P plus any phosphate associated with suspended solids. Total P in river waters worldwide averages about 0.025 mg L^{-1}. The high concentrations of total P in the Alamo, New, and Whitewater Rivers suggests a significant load of P is associated with the suspended solids. This P may become available for algal growth upon entering the Salton Sea (Anderson, 2003). This project will investigate methods of removing both soluble P and total P associated with suspended solids in the rivers.

Table 2, reproduced from Holdren and Montaño (2002), shows the seasonal distribution of nutrients in these water bodies. This seasonal variation in nutrient concentration, along with dramatic temperature variation over the year, requires an evaluation of treatment methods during a year.

2) Describe the manner in which the proposed watershed restoration activities will be implemented.

The overall goals of this project are to evaluate the efficacy of chemical flocculation and the Controlled Eutrophication Process (CEP) to remove phosphorus and suspended solids from the tributaries that discharge into the Salton Sea. We will be investigating the potential for a combination chemical/biological treatment system that takes advantage of both treatment strategies. We will construct small-scale earthen drainage channels and evaluate the ability of alum, ferric chloride, and various polymers, both separately and in combination, to directly remove phosphorus and sediment from agricultural drainage water flowing through the channels. The chemical amendments will also be tested in the CEP process, which first captures the excess nutrients in cultured algal biomass, to enhance the treatment.

Identification of the optimum treatment methods will allow implementation at various points along the rivers and on drains that discharge to the rivers. It is likely that not all of the river water needs to be treated, but targeted drains high in P could be treated first. Implementation at the basin-scale will require sites adjacent to the drains or rivers where algal growth tanks, fish tanks, and settling basins can be constructed. The size of the equipment will be determined as part of the testing process.

Phosphorus collected as sludge from the treatment process will be analyzed to determine the feasibility of returning it to farmers' fields, or digesting it for methane before field application. This will return nutrients to the soils in the area and reduce the nutrient load to the Salton Sea.

3) Determine the effectiveness of the watershed restoration activities in preventing or reducing pollution.

Previous research on phosphate cycling in the Salton Sea demonstrated that the coprecipitation of phosphate into calcite forming within the sediments serves as a permanent sink for P, thereby reducing the internal loading of P (Anderson and Amrhein, 2002). Computer modeling of the nutrient cycling demonstrated that a reduction in the external loading of P would lead to gradual improvements in water quality over the subsequent 5-8 years (Anderson and Amrhein, 2002). Additional computer modeling that expanded the initial effort indicated that substantive improvements in water quality might be realized within 3 years of any external load reductions (Anderson, 2003). Because the internal loading is supported by the annual external loading, a reduction in the external loading of P would lead to a reduction in internal loading such that the overall reduction in algal-available P would effectively be double what might be predicted.

4) Determine, to the extent feasible, the economic benefits resulting from the changes determined pursuant to paragraph (3).

Implementation of a biological/chemical treatment technology for the removal of phosphorus and suspended solids would reduce the need for constructed wetlands, which are being proposed throughout the basin. The advantage of a high intensity treatment technology is that it requires less land compared to constructed wetlands. There are additional costs associated with the high intensity treatment system that include energy and chemical inputs, as well as more personnel. The savings in land may be off set by these other costs. This will be evaluated during the project.

There is also some evidence that treatment wetlands can lose their ability to remove phosphorus, especially if aquatic macrophytes are not removed from the wetlands. These costs need to be considered when comparing the two treatments.

There will be additional economic benefit from the recovered phosphorus in the sludge. This can be applied to a farmer's field thereby reducing the fertilizer requirement. The fish raised in the CEP can be sold, helping to offset the energy costs.

The economic benefit of a Salton Sea without fish kills or bad odors is difficult to assess. Recreation could boom at the Sea if people believed the water was no longer "polluted." The economic benefits to the local area could be several hundred million dollars.

References

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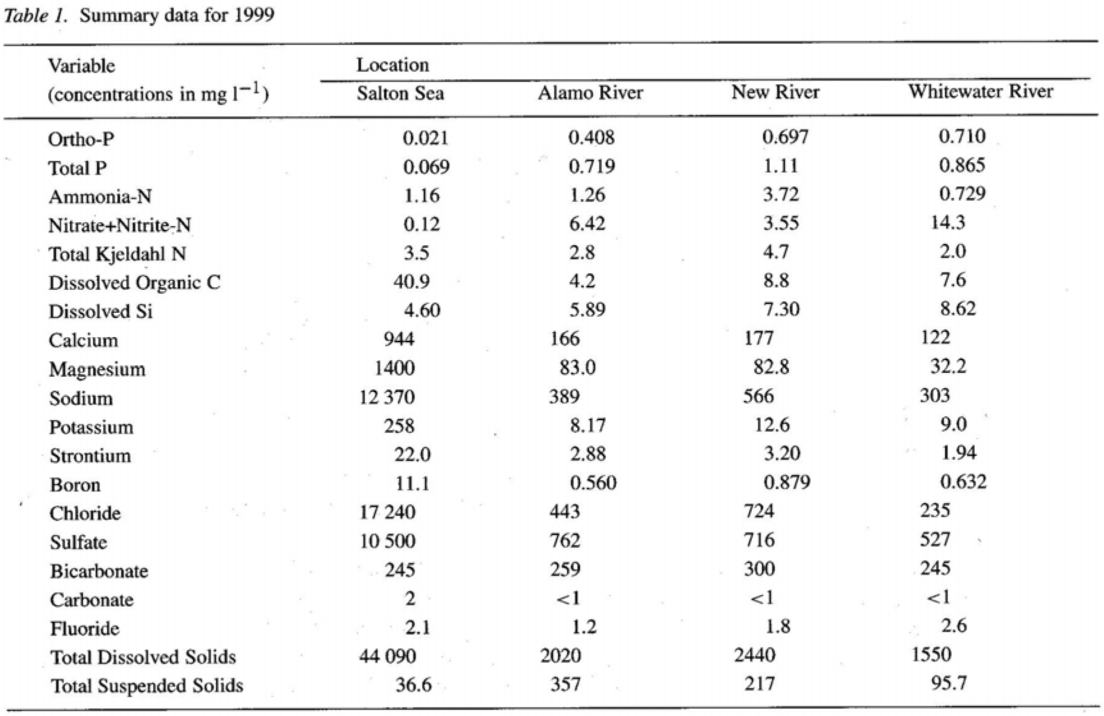

Table 1. Summary data for 1999

Variable (concentrations in mg l^{-1})	Location Salton Sea	Alamo River	New River	Whitewater River
Ortho-P	0.021	0.408	0.697	0.710
Total P	0.069	0.719	1.11	0.865
Ammonia-N	1.16	1.26	3.72	0.729
Nitrate+Nitrite-N	0.12	6.42	3.55	14.3
Total Kjeldahl N	3.5	2.8	4.7	2.0
Dissolved Organic C	40.9	4.2	8.8	7.6
Dissolved Si	4.60	5.89	7.30	8.62
Calcium	944	166	177	122
Magnesium	1400	83.0	82.8	32.2
Sodium	12 370	389	566	303
Potassium	258	8.17	12.6	9.0
Strontium	22.0	2.88	3.20	1.94
Boron	11.1	0.560	0.879	0.632
Chloride	17 240	443	724	235
Sulfate	10 500	762	716	527
Bicarbonate	245	259	300	245
Carbonate	2	<1	<1	<1
Fluoride	2.1	1.2	1.8	2.6
Total Dissolved Solids	44 090	2020	2440	1550
Total Suspended Solids	36.6	357	217	95.7

Holdren and Montaño, 2002

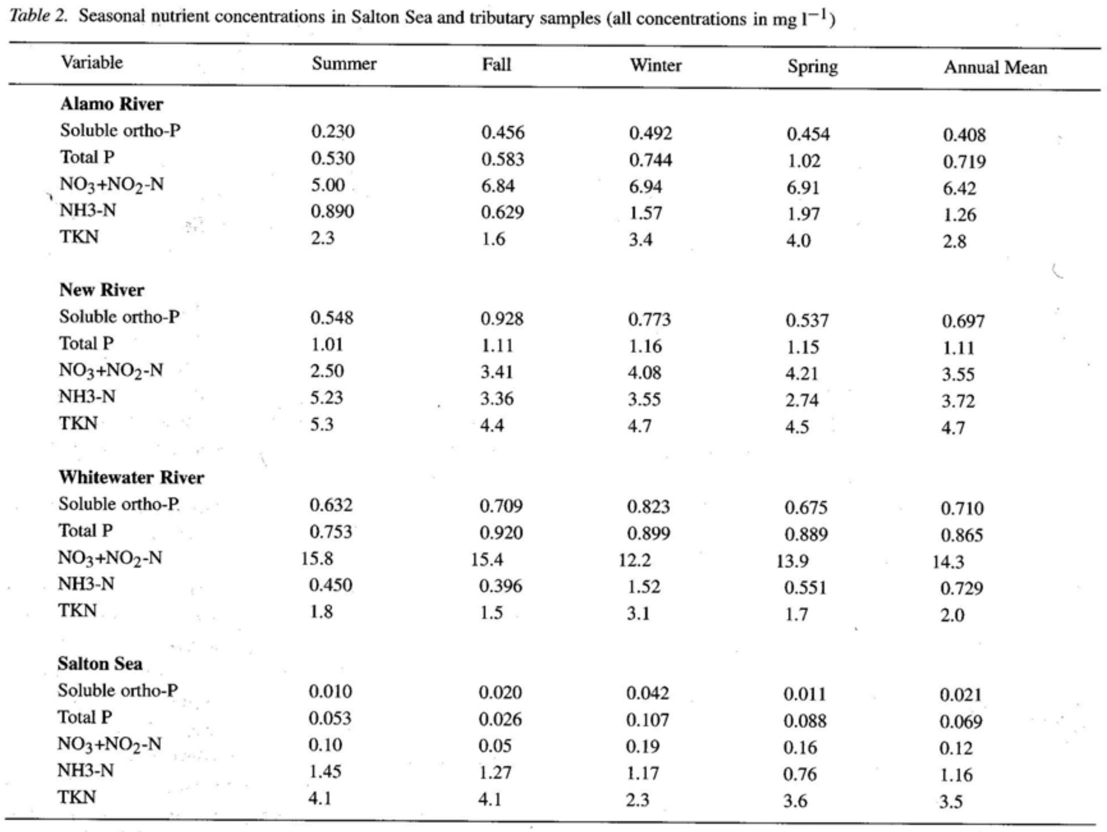

Table 2. Seasonal nutrient concentrations in Salton Sea and tributary samples (all concentrations in mg l^{-1})

Variable	Summer	Fall	Winter	Spring	Annual Mean
Alamo River					
Soluble ortho-P	0.230	0.456	0.492	0.454	0.408
Total P	0.530	0.583	0.744	1.02	0.719
NO_3+NO_2-N	5.00	6.84	6.94	6.91	6.42
NH3-N	0.890	0.629	1.57	1.97	1.26
TKN	2.3	1.6	3.4	4.0	2.8
New River					
Soluble ortho-P	0.548	0.928	0.773	0.537	0.697
Total P	1.01	1.11	1.16	1.15	1.11
NO_3+NO_2-N	2.50	3.41	4.08	4.21	3.55
NH3-N	5.23	3.36	3.55	2.74	3.72
TKN	5.3	4.4	4.7	4.5	4.7
Whitewater River					
Soluble ortho-P	0.632	0.709	0.823	0.675	0.710
Total P	0.753	0.920	0.899	0.889	0.865
NO_3+NO_2-N	15.8	15.4	12.2	13.9	14.3
NH3-N	0.450	0.396	1.52	0.551	0.729
TKN	1.8	1.5	3.1	1.7	2.0
Salton Sea					
Soluble ortho-P	0.010	0.020	0.042	0.011	0.021
Total P	0.053	0.026	0.107	0.088	0.069
NO_3+NO_2-N	0.10	0.05	0.19	0.16	0.12
NH3-N	1.45	1.27	1.17	0.76	1.16
TKN	4.1	4.1	2.3	3.6	3.5

Holdren and Montaño, 2002

TASK 5.1 DESCRIPTION AND PHOTOS OF COMPLETED MODIFICATIONS

Task 5. Modifying existing P removal systems

5.1 Bench-scale unit

We had originally intended to use a bench-scale polytank system for evaluation of flocculants and polymers. We reconfigured six existing 1,200 liter cylindrical polyethylene tanks (polytanks) for the study of flocculating agents on WWR water (Photo 1).

Photo 1. Modified polytanks.

The tank input and drain piping was configured so that a wide range of chemical application rates and reaction times (detention times) could be evaluated.

However, we decided instead to do bench-scale testing with 2 L jar test systems (Phipps and Bird PB-700, Richmond, VA, Photo 2). These systems are widely used in the waste water industry for testing water treatment methods and offer a more standardized comparison of one's results.

Preparations for the tests included determinations of the optimum paddle speeds to promote coagulation, flocculation, and floc settling with alum and PAM. Initial work indicated that 25 to 50 RPM paddle speeds (mixing energy, G = 18 to 45 s^{-1}) were optimal for flocculation and settling with PAM. With alum treatments, however, slower mixing speeds were needed.

Photo 2. Phipps and Bird PB-700 jart test system.

5.2 Simulated drainage ditches

A simulation agriculture drainage ditch was constructed at the east end of the CEP units (Photo 3). Earth was moved and leveled with a bulldozer, backhoe, and excavator for a length of 188 feet. A plastic liner 6 mm thick and 20 feet wide was placed on the bottom of the ditch. Earth was then leveled on top of the plastic and compacted. The filled and lined ditch was then re-excavated with a backhoe equipped with a jig to form the 1:1 sloped sidewalls. The bottom of the ditch was laser-leveled with zero slope. The resulting simulation ditch is 2 feet deep, 2 feet wide with side slopes of 1:1. A V-notch weir was set in place in the incoming monk to permit accurate flow measurements.

Photo 3. Simulation ditch construction.

In order to condition the ditch, the Whitewater River water flow was turned on and was run continuously at 70 gpm through the ditch for a period of one week, after which flow was reduced to a minimum to check for seepage. This study indicated that seepage losses from the ditch were negligible.

Three100 gallon tanks were set up at the head end of the simulation agriculture drain ditch, to be used in mixing and preparing the chemical flocculants for testing. A 1/20 hp variable speed motor was purchased for chemical mixing. Variable speed mixing was required to properly mix the different chemicals and polymers that were used for the flocculation trials. In addition, a peristaltic pump was set up to deliver the chemical mixtures to the head of the ditch, with multiple flow heads to provide the various application rates.

5.3 Optimization of Selenium Uptake by Algae in the CEP

Although the CEP was designed for phosphorus removal, selenium (Se) could also be removed by bioaccumulation and "bioflocculation" of the captive algae and fish populations, and thus improve the effluent water quality.

A new conveyor belt for removing Se-rich solids was installed in preparation for this work (Photo 4). In order to test the bioflocculation effects of captive fish populations on Se-rich algae, three steel mesh pens containing tilapia were lowered into the flocculation zone of the CEP. Pumps and piping were installed to deliver Whitewater River water to the CEP. Last, the paddle speeds in the main CEP algae growth tank were monitored for consistency over time.

Photo 4. CEP algae zone and outflow water; tilapia; sludge belt before and after modifications.

TASK 6. LAB-SCALE STUDIES OF FLOCCULANT REMOVAL OF P

TASK 6. LAB-SCALE STUDIES OF FLOCCULANT REMOVAL OF P:

Phosphorus Adsorption and De-adsorption Experimental Trials

The following work was performed as a sub-contract from Kent SeaTech to
David E. Brune, Dept of Biological and Agricultural Engineering, Clemson University
Clemson, South Carolina, 29634.

A series of experiments were conducted to determine the equilibrium solution-P concentration as a function of soil adsorbed-P concentration for soil samples obtained in the region surrounding the Salton Sea in Southern California. Surface soils were collected from agricultural lands located in the Imperial Valley, south of the Salton Sea. The soil samples were taken from fields used primarily for alfalfa and vegetable production.

Methods, Materials, and Discussion

Determination 1: Soil total-P concentration

Three different soils were analyzed for Total-P content by first digesting 2 gms of soil in sulfuric-nitric acid mixtures. Following digestion, total-P concentrations were determined using the ascorbic acid (AA) method. Soil total-P content was found to range from 0.238, 0.290 to 0.305 mg-P/gm soil for soils 3, 2 and 1, respectively.

Determination 2: Preliminary solution equilibrium P concentrations #1

Four grams each of soils 1, 2 and 3 were placed in individual flasks containing 200 ml of solution maintained on a shaker-table at 25 degrees C. Each flask contained 0.0 mg/l P (initial concentration) with a background of 1 mM NaHCO3 to maintain pH of 8.0 to 8.2. Equilibrium soluble-P concentrations were determined at time increments of 10, 360 and 1440 minutes by extracting a 25 ml/ sample from each reactor, centrifuging at 10,000 RPM, and measuring soluble P using the AA method.

Determination 3: Preliminary solution equilibrium P concentrations #2

Soils 1, 2 and 3 were placed in solutions containing 1 mM NaHCO3 and 1.0 mg/l soluble P. Solution P concentrations were determined at intervals of 10, 60, 360 and 1440 minutes, as described above.

Determination 4: Detailed solution equilibrium-P concentrations in fresh water

Using the results from trial 2 and 3 (above), the concentration and time series experiments were designed and conducted. Soil 3 containing the lowest background adsorbed-P concentration was exposed to 0.0, 0.5, 1.0 and 2.0 mg/l initial soluble-P concentrations. Equilibrium-P concentration in each flask was determined at 20, 1440, 5760, 8640, and 10,080 minutes as described above. This allowed for a determination of equilibrium Ce (solution-P, in micrograms/l, or (X 1000) = mg/liter), vs. adsorbed-P (concentration in gm/kg or mg/gm). See Figure 1.

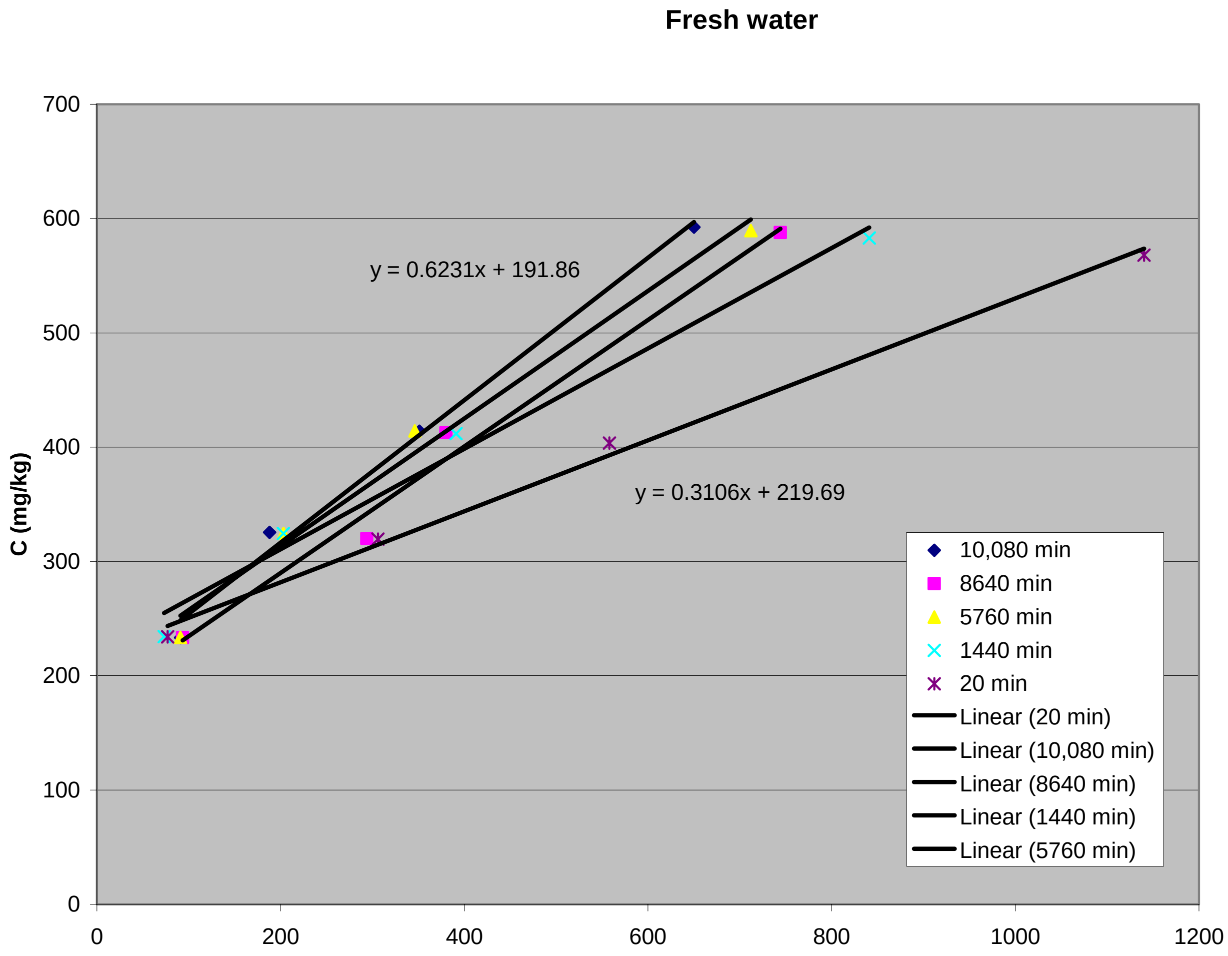

Figure 1. Solution-P (Ce) vs. Soil Adsorbed-P (C) in Freshwater Solutions (containing 1 meq/l NaHCO3 solution)

Determination 5: Detailed solution equilibrium-P concentrations in salt water

Soil 3 containing the lowest background adsorbed-P was exposed to 0.0 0.5, 1.0 and 2.0 mg/l initial soluble-P concentrations (as above) except that the background solution was adjusted to simulate the high salt environment of the Salton Sea with a background solution containing 32 gm/l of NaCl, 14.3 gm/l of $MgSO_4$, and 336 mg/l of $NaHCO_3$. As above, equilibrium-P was determined at 20, 1440, 5760, 8640, and 10,080 minutes. The results are illustrated in Figure 2 below.

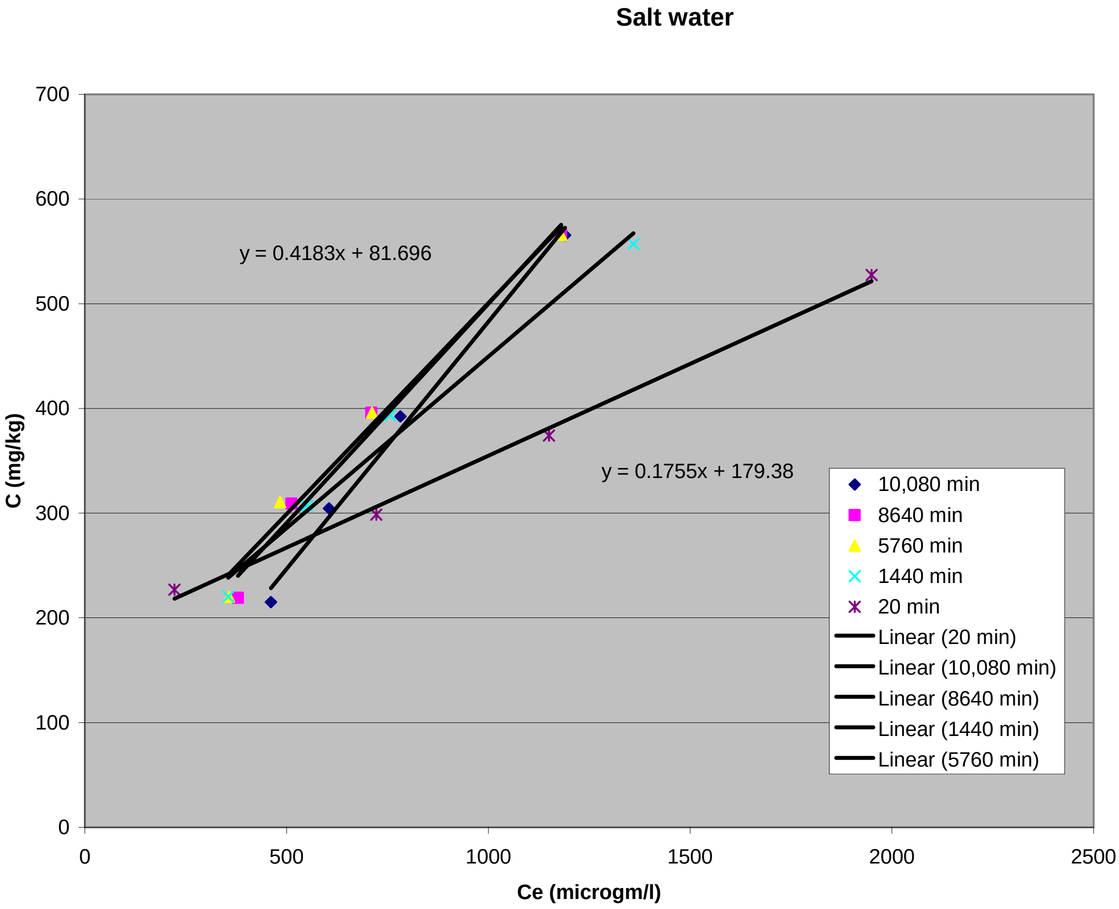

Figure 2. Solution-P (Ce) vs. Soil Adsorbed-P (C) in Saltwater at 47.7 ppt salt concentration

High solution ionic strength is seen to increase the equilibrium soluble-P concentration at each level of soil adsorbed-P concentration. At a solution concentration of 1.0 mg/l P, soil adsorbed-P in fresh water is predicted to range from 0.53 to 0.814 mg/l (at 20 vs. 10,080 minutes) while in salt water at 1.0 mg/l solution-P, soil adsorbed-P ranges from 0.354 to 0.50 mg/l (at 20 to 10,080 minutes), or 67 to 61% of freshwater. Apparently the high ionic strength media is competing for adsorption sites, reducing P-adsorption on the soil.

Determination 6; Preliminary survey of possible effect of PAM on soil-P adsorption

Four grams of Soil 3 was added to each of 8 flasks containing 200 ml of water with a background of 1 mM of NaHCO3 soil with initial soluble-P concentrations adjusted to 0.0, 0.5, 1.0 and 2.0 mg/l (in duplicates). To one set of flasks (4 total flasks), 2 mg/l of polyacrylamide (PAM) was added while the other 4 flasks did not contain PAM. The equilibrium solution-P concentrations were determined as these results are tabulated in Table 1:

	20 minutes		1440 minutes	
Initial Solution-P	PAM	Control	PAM	Control
0.0	0.11	0.08	0.11	0.07
0.5	0.15	0.31	0.18	0.20
1.0	0.55	0.56	0.34	0.39
2.0	1.05	1.14	0.83	0.89

Table 1. Average equilibrium solution-P concentrations at 20 and 1440 minutes with, and without, 2 mg/l PAM addition at initial solution-P concentrations of 0.0, 0.5, 1.0 and 2.0 mg/l.

No clear effect could be seen in the solution-P concentration with regard to impact of PAM on solution P and the experiment was terminated at 1440 minutes.

Detemination 7: Rate of adsorbed soil-P de-adsorption in freshwater: soil washing rate.

Four grams of soils 1,2 and 3 were added to each of 3 flasks containing 200 ml of P free water with a background of 1 mM NaHCO3. At cumulative elapsed times of 20, 1440, 5760, 8640 10,080 and 11,270 minutes, the entire contents of each flask was centrifuged at 10,000 RPM, and the supernant water was removed for P-determination and the flask volume was replaced with an additional 200 ml of P-free water (with $NaHCO_3$ background) and the flask was allowed to continue to shake. The removed supernatant was measured for solution-P. Representative results are summarized below inFigure 3:

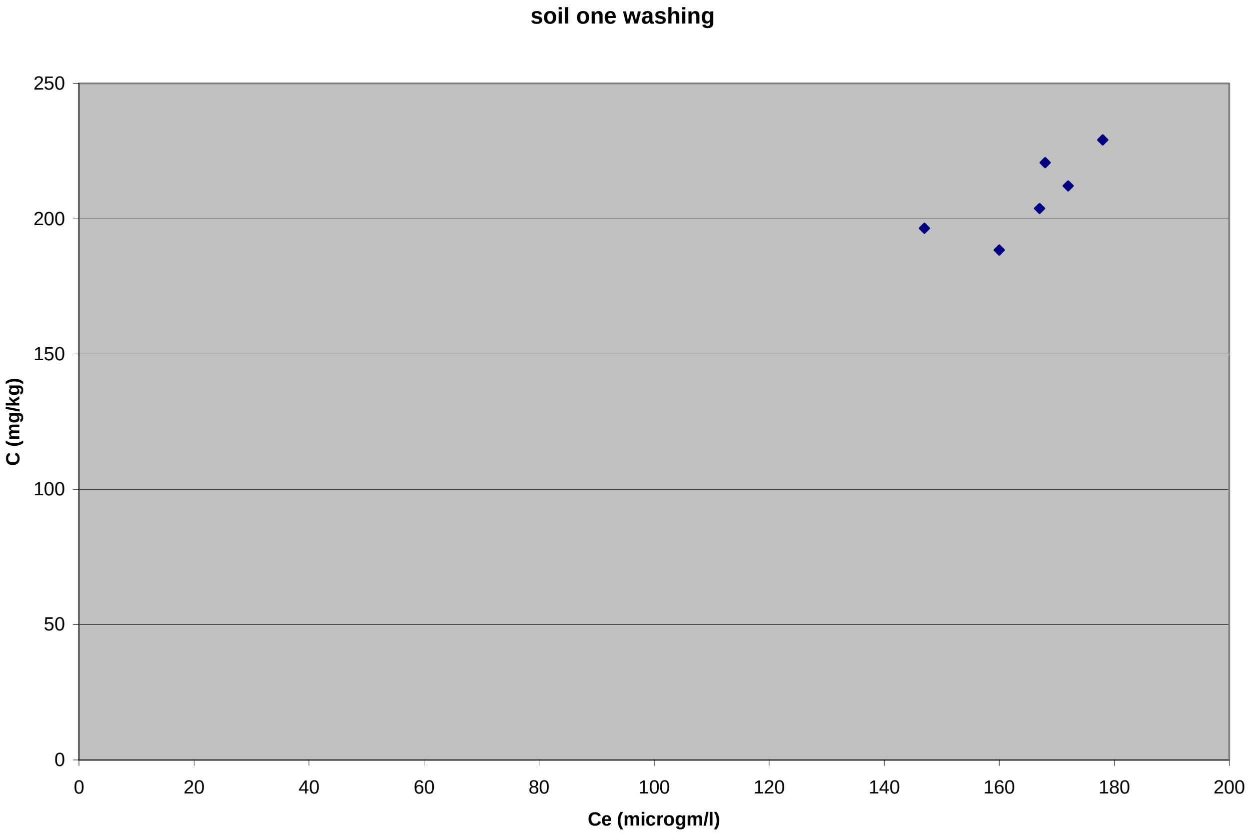

Figure 3. Figure 3, Solution-P concentrations in 200 ml volume vs. soil adsorbed-P concentration obtained from sequential washing of 4 gm of soil in 1 meq/l NaHCO3 solution.

Equilibrium solution-P concentrations washed from soils 1,2 and 3 ranged from 0.06 to 0.180 mg/l at soil adsorbed-P concentrations ranging from 190 to 230 mg/gm. In general the soil de-sorption relationship appears to mirror the general relationship observed in figure 1 (adsorption). Equilibrium soil- P concentrations at 1.0 mg/l in freshwater range from 0.53 to 0.81 mg/gm (20 vs 10,080 minutes) vs. 0.35 to 0.50 mg/gm in salt water or 61 to 67% of the freshwater values.

Determination 8; Rate of De-adsorption of soil adsorbed-P in saltwater as opposed to freshwater

Duplicate flasks containing four grams each of soil 3 were placed in the freshwater media and in duplicate flasks containing the salt water media. The soils were washed sequentially as described above. Equilibrium solution-P concentrations were measured at 1440, 2880 and 7200 minutes. Results are shown in Table 2.

Time	Freshwater	Saltwater
1440	0.51	0.73
2880	0.30	0.40
7200	0.26	0.34

Table 2. Solution-P concentration in 200 ml volumes obtained from sequential washing of 4 gm of soil in 1 meq/l NaHCO3 solution as compared to 47.7 ppt salt solution.

In agreement with results presented in figures 1 and 2, a high ionic strength media is seen to increase release, or de-adsorption, of soil-P into the solution to the same degree that it prevents soil adsorption of solution-P. The solution-P concentration in salt water (under de-adsorption) is seen to reach equilibrium levels of 132% to 143% of the freshwater de-adsorption concentrations. All other factor being equal, increased ionic solution strength retards, or competes with, soil adsorption of phosphorus, and enhances the release of adsorbed-P from the soil into the solution.

TASK 7. BENCH-SCALE STUDIES OF FLOCCULANT REMOVAL OF P

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Reducing Sediment and Phosphorus in Tributary Waters with Alum and Polyacrylamide

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Abbreviations: PAM, polyacrylamide; P, phosphorus; ADW, Agricultural Drainage Water; P_S, Soluble Phosphorus; P_P, Particulate Phosphorus; P_T, Total Phosphorus; TMDL, Total Maximum Daily Load.

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ABSTRACT

The Salton Sea is the largest inland water body in California, covering an area of 980 km^2. Inflow to the Salton Sea (1.6 km^3 y^{-1}) is predominately nutrient-rich agricultural wastewater, which has led to eutrophication. Because internal phosphorus release from the bottom sediments is comparatively low and external phosphorus loading to the Sea is high, reduction of tributary phosphorus is expected to reduce algal blooms, increase dissolved oxygen, and reduce odors. Removing both dissolved phosphorus and phosphorus-laden sediment from agricultural drainage water (ADW) should decrease eutrophication. Both alum and polyacrylamide (PAM) are commonly used in wastewater treatment to remove phosphorus and sediment, and were tested for use in tributary waters. Laboratory jar tests determined PAM effectiveness (2 mg/L) for turbidity reduction as cationic > anionic = nonionic. Although cationic PAM was the most effective at reducing turbidity at higher speeds, there was no observed difference between the neutral and anionic PAMs at velocity gradients 18 to 45 s^{-1}. Alum (4 mg/L Al) reduced turbidity in low energy systems (velocity gradients < 10 s^{-1}) by 95% and was necessary to reduce soluble phosphorus, which comprises 47-100% of the total P concentration in the tributaries. When PAM was added with alum, the anionic PAM became ineffective in aiding flocculation. The nonionic PAM (2 mg/L) + alum (4 mg/L Al) is recommended to reduce suspended solids in higher energy systems and reduce soluble P by 93%.

The Salton Sea is the largest lake in California, covering an area of 980 km^2 (Fig. 1) (Hart et al. 1998). The Salton Sea lies below sea level (-70 meters), and the only output is evaporation. The evaporation rate exceeds 1.4 m/year and is counter-balanced with inflow, 84% of which flows from the Whitewater River to the north, and the

New, and Alamo Rivers from the south (Fig. 1 and Table 1) (Setmire, 2000). Inflow to the Salton Sea (1.6 km^3 y^{-1}) is predominately agricultural drainage water (ADW), the rest is comprised of municipal effluent and less than 3% rainfall. The watershed generates $1.3 billion in agricultural commodities per year (Anderson and Amrhein, 2002). The major inflow results from agricultural tailwater that flows off the fields and is high in nitrogen and phosphorus. This nutrient-rich water has resulted in the eutrophication of the Salton Sea and negatively impacted its beneficial uses, including recreation, fishing, and wildlife resources (Setmire, 2000). Some of the specific effects of eutrophication include high algal biomass, low clarity, anoxia, massive fish kills, and noxious odors. Phosphorus (P) has been determined as the limiting nutrient for algal growth in the Salton Sea (Setmire, 2000). Because external phosphorus loading in the Salton Sea is high, reduction of tributary phosphorus may reduce eutrophication (Holdren and Montaño, 2002). P is contributed to the Sea in both colloidal and dissolved forms. Removing soluble phosphorus and suspended solids from ADW would reduce the overall amount of P entering the Sea. In fact, Total Maximum Daily Loads (TMDLs) for suspended solids have recently been established for the New and Alamo Rivers. The New and Alamo Rivers have averaged 306 and 377 mg/L suspended solids, respectively, during 1980-2001 (CRWQCB, 2002). The newly established TMDLs require the rivers carry no more than 200 mg/L suspended solids.

Alum and/or polyacrylamide (PAM) are commonly used in municipal wastewater treatment to remove P and solids, and then the sludge is collected and disposed. The high sediment load and salinity of the ADW requires testing and possible modification to the typical procedures used in municipal treatment.

Alum (aluminum sulfate), the most widely used coagulant in water treatment (Hammer and Hammer, 1996), serves a dual role by acting as a coagulant for suspended solids removal and an adsorbant for soluble P removal. Alum has been applied in large-scale quantities in the environment to control internal P loading in lakes (Welch and Cooke, 1995).

Coagulants quickly reduce or neutralize the electrostatic forces between negatively charged particles in water, which leads to aggregation and settling (Black and Harris, 1969; Reynolds and Richards, 1995). Alum forms solid amorphous aluminum hydroxide in water, which incorporates soluble phosphorus (P_S) into its structure through either coprecipitation or adsorption onto the surface (Omoike and van Loon, 1999). The amorphous aluminum hydroxide, or "floc" combines with the other coagulated suspended solids and settles out of the water column.

Alum has been shown to be non-toxic in the pH range of 5.5 to 9.0. At these pH values, the aluminum concentration is not expected to exceed 50 μg/L since aluminum hydroxide is highly insoluble in this range (Kennedy and Cooke, 1982). Previous research has found that alkaline waters (> 75 mg/L $CaCO_3$) are not expected to have chronic or acute affects to biota with alum treatments (Narf, 1990). The tributaries to the Salton Sea meet these criteria for pH and alkalinity so toxicity problems are not expected (Table 1).

Polymers are frequently applied in wastewater treatment to enhance coagulation and settling. The polymer acts as a coagulant aid by chemically bridging reactive groups and increasing floc size (Reynolds and Richards, 1995). Polymers can range in charge type (cationic, anionic, or neutral), charge density, and molecular weight. PAM is a synthetic polymer and has been used in soil applications to reduce erosion (Sojka et al., 1998; Zhang and Miller, 1996), increase infiltration (Ben-Hur and Keren, 1997; Green et al., 2000), promote flocculation (Helalia and Letey, 1988; Aly and Letey, 1988; Laird 1997), and enhance salt removal (Aly and Letey, 1990; Malik et al., 1991).

The charge of the polymer and the type of suspended solids in the wastewater influence the degree of flocculation and settling rate. Cationic polymers directly adsorb to the negative surfaces of the clay particles; anionic polymers adsorb through cation-bridging, and nonionic polymers form floc by attaching to the clay surfaces through van der Waals forces (Seybold, 1994).

The nature of the suspended solids in the tributary water requires an assessment for the most effective polymer. The New and Alamo Rivers drain calcareous, smectitic soils that range from silty clays to sandy loams (USDA, 1981), and the suspended solids in the Whitewater River are dominated by illite and kaolinite from the coarsely textured soils at the north end of the Salton Sea (USDA, 1980).

Many reviews have been completed on PAM toxicity (Barvenik, 1994; Sojka et al., 2000). All types of PAMs are considered nontoxic to mammals. Anionic PAMs are nontoxic to aquatic life (Sojka et al., 2000), while nonionic polyelectrolytes exhibit low toxicity (LC_{50}^{96} values of 16.5 mg/L in *Daphnia magna*; Biesinger et al., 1976). Cationic polymers are of some toxicological concern, and have been documented to bind to the negatively charged gills in rainbow trout and affect ion regulation (Muir et al., 1997). LC_{50} values ranging from 271 to 1733 μg/L among various cationic polymers have been reported for rainbow trout (Goodrich et al., 1991). Since federally listed species of pupfish and mudsuckers are present in the tributaries and the drains of the Imperial Valley, caution should be used when applying cationic PAM to the field. However, the acute toxicity of all types of polyelectrolytes is reduced in the presence of solids, as the PAM binds to the suspended particles.

The monomer of PAM, acrylamide, is a neurotoxin and is regulated by the FDA, where the residual monomer cannot exceed 0.05% to 0.2 % of the PAM (Seybold, 1994).

Although PAM degrades at a rate of 10% per year, the degradation process does not release acrylamide (MacWilliams, 1978).

In this study, we conducted laboratory jar tests to evaluate the effectiveness of alum and different types of PAM in reducing turbidity and P in the tributaries to the Salton Sea.

MATERIALS AND METHODS

Bulk water samples were collected from the three tributaries to the Salton Sea: the Whitewater River (33^o 32.3' N, 116^o 05.7' W), New River (33^o 05.12' N, 115^o 36.9' W), and Alamo River (33^o 07.5' N, 115^o 34.3' W) (Fig. 1).

Chemical and Physical Characteristics of Tributary Waters

Baseline chemical characteristics were measured on the sample river water. Electrical conductivity (EC) was determined using a conductivity instrument (YSI 3200, Yellow Springs, OH). River water pH was measured using a Fisher combination glass electrode on an Expandable Ion Analyzer EA 920 (Orion Research, Boston, MA). Total suspended solids (TSS) were analyzed by filtering and drying 50 mL of river water following Standard Methods (1992). Anions (chloride, nitrate, and sulfate) were analyzed using ion chromatography (Dionex 500), and cations (calcium, magnesium, potassium, sodium, and ammonium) were analyzed using ICP-OES (Perkin-Elmer, Optima AV).

Jar Test Method

All laboratory scale jar tests were performed in a 2 L jar apparatus (Phipps & Bird PB-700, Richmond, VA). During preliminary studies, the jars were mixed, and the floc settled for a predetermined amount of time. Since the floc settled quickly, the effectiveness of each treatment was dependent on the length of settling time. Therefore, in order to properly test floc formation, settling, and strength, an alternative jar test method was developed.

This alternative method included a gradient reduction of paddle speed from 300 to 0 RPM (settling), followed by an increase in paddle speed from 0 to 300 RPM (resuspension), where each speed was held constant for five minutes. The jars were filled with river water to the 2 L mark (14.5 cm water depth), and an initial sample was collected using a pipette at a depth of approximately 3.5 cm while the water was mixed at 300 RPM. Concentrations of alum-Al (4 mg/L) and/or PAM (2 mg/L) were volumetrically added to the jars and the gradient reduction in paddle speed began. Each sample was collected by pipette (3.5 cm depth) after 5 minutes of a constant paddle speed while the paddle was still spinning. Samples for turbidity, P_S, and P_T were collected at 300, 200, 100, 50, 25, 15, 10, 5, and 0 RPM. The change in turbidity or phosphorus concentration was compared to the initial sample of each particular jar.

Chemical Additions

The concentration of alum ($Al_2(SO_4)_3 \bullet nH_2O$, n=12-14, Technical Grade Fisher Scientific) was based on the average stoichiometric aluminum (Al) content of the alum (alum-Al). The PAM had a range of characteristics in polymer charge type and density. The anionic polymers in decreasing anionic charge density (as reported by the manufacturers) included AP1120[†] > Stock-O-PAM[‡] = Soil fix[§] > AP1110[†] > AP1100[†] > AP1105[†]. One cationic polymer CP1160[†] and one neutral polymer AP1142[†] were also tested ([†]GE-Betz, Trevose, PA; [‡]American Soil Technologies, Pasadena, CA; [§] Ciba Specialty Chemicals, Inc., Suffolk, VA).

Turbidity

Turbidity samples were collected at 3.5 cm depth, placed in 25 mL glass vials, and sonicated for 30 seconds (Fisher Sonic Dismembrator, Model 150) to break up the floc and establish good scattering for the turbidimeter. The sonication step was found necessary to keep the floc from settling in the vial during the measurement. Turbidity measurements were made on a HF Scientific, Inc. Micro 100 Turbidimeter (Fort Myers, FL). Each jar test was completed in triplicate and the turbidity measurements were normalized to the initial turbidity reading in each jar. The values are reported as percent of the initial reading along with the error as standard deviation.

Phosphorus

Both soluble phosphorus (P_S) and total phosphorus (P_T) were analyzed with a modified ascorbic acid-molybdate blue method (Murphy and Riley, 1962) on an Astoria-Pacific Int. Alpkem RFA 300 Autoanalyzer (Clackamas, OR). The P concentrations (either soluble or total) were normalized to the initial P (soluble or total) concentration in each jar. The values are reported as percent of initial concentration with the error as standard deviation.

Sample preparation for P_S analysis included filtration (< 0.45μm, Fisherbrand MCE membrane filters) and acidification with concentrated sulfuric acid, which decreased the pH to approximately 2.5. For P_T determination, 5 mL of acidified, unfiltered sample and 1 mL of oxidizing solution were combined in 10 mL polypropylene mailing tubes and digested using the persulfate digestion method found in Standard Methods (1992) with the following modifications: The oxidizing solution was made of 30 g boric acid, 350 mL 1 N NaOH, and 50 g $K_2S_2O_8$ diluted to 1 L with deionized water. Samples were heated in a boiling water bath for 1.5 to 2 hours then analyzed for P_T using the Alpkem RFA 300 Autoanalyzer. The particulate P (P_P) fraction was calculated as the difference between P_T and P_S. The values of P_P are reported as percent of the initial concentration along with the error as standard deviation.

RESULTS AND DISCUSSION

The river water samples were characterized for physical and chemical constituents (Table 1). There was good agreement between the sum of cations, sum of anions, and the electrical conductivity indicating excellent quantification of the chemical constituents. The alkalinity of the waters was more than sufficient to offset any acidification due to aluminum hydrolysis and prevent Al toxicity.

Turbidity

Turbidity reductions were measured in the jar tests to determine the removal efficiency of phosphorus-laden sediment in the tributaries. Turbidity in the treated water varied as a function of both mechanical energy inputs and chemical amendments (Fig. 2). Subsequent increase in paddle speeds (resuspension) for all the jar tests resulted in increased turbidity, although levels were generally lower than found during settling. This suggests that the floc collected at the bottom of the jar during settling required more energy to break apart and resuspend. It is important that this floc remain settled so as to not resuspend and recontribute to the suspended sediment load in the tributaries.

Relative to the control, the alum addition actually increased the turbidity during the settling period from 300 to 50 RPM. This slightly higher turbidity (above the initial turbidity sample) is explained as the formation of the colloidal $Al(OH)_3$. Although this floc increased turbidity at high speeds, alum reduced the turbidity to that seen in the PAM-treated water at speeds less than 5 RPM (Fig. 2).

The PAM treatments resulted in turbidity measurements lower than the control throughout the experiment, showing the PAM was capable of settling suspended solids at higher speeds. The cationic PAM-treated water had the lowest turbidities of all the treatments, even at a paddle speed of 300 RPM. The turbidity in the jars was low and remained low after the paddle speeds had been reduced to 25 RPM for both the anionic and nonionic PAMs. Optimal floc formation occurred between paddle speeds of 25 and 50 RPM to reduce turbidity to < 10% (Fig. 2).

The mixing speed, or power input, can be described by the G value (velocity gradient),

$$G = \sqrt{W / \mu}$$

where W is the power imparted to the water per unit volume of the basin, and μ is the absolute viscosity of the water (Reynolds and Richards, 1995). In the jar tests, the value of W depends on the container, paddle geometry, and paddle speed (Lai et al., 1975). The G value is the common variable for comparing mixing between the jar tests and larger scale flows, like furrows or drains.

The corresponding G values associated with the paddle speeds of 25 and 50 RPM are 18 and 45 s^{-1} (at 22^{o}C), respectively (Hudson, 1981). These paddle speeds resulted in efficient collisions and effective bridging interactions for floc formation between the suspended solids and the anionic or nonionic polymer. Any G value above these limits destabilizes the floc (Young et al., 2000). Power input to river water will need to satisfy a velocity gradient of 18-45 s^{-1} to promote optimal flocculation and settling with anionic or nonionic PAM. The alum treatment, however, required slower mixing speeds (< 5 RPM) for proper floc settling ($G < 10\ s^{-1}$).

Previous jar tests have also measured different optimum G values between polymer (70-100 s^{-1}) and alum flocculation (40 s^{-1}) (Young et al., 2000). The G value of the rivers is dependent on channel depth, channel width, flow rate, and head loss throughout the length of the river. Based on these variables, the power imparted in the three tributaries is estimated to range from 50 to 100 s^{-1}. Therefore, the velocity gradient for optimum flocculation with PAM and alum may require either a settling basin or lower flow system than typically found in the rivers.

Since all of the polymers reduced the turbidity to less than 10% of the initial turbidity in the jars at 25 RPM ($G = 18\ s^{-1}$), a comparison of the flocculation capacity for the polymers was determined at a higher paddle speed (50 RPM, or G value of 45 s^{-1}). This higher paddle speed demonstrated the ability of the polymer to form a floc and settle out of the rivers in slow reaches.

Since the Whitewater River had such low turbidity readings (Table 1), the effect of the PAM addition on the suspended solids was difficult to measure. Therefore, the more turbid New and Alamo rivers to the south, which are the main contributors of suspended solids to the Salton Sea, were used to measure the effectiveness of the PAM treatment. As previously stated, the majority of settling occurs between 25 and 50 RPM; therefore, the ability to flocculate at the 50 RPM paddle speed could potentially differentiate between the different charge densities of the polymers tested. Cationic PAM was the exception and outperformed the anionic and nonionic PAMs. The cationic polymer CP1160 sufficiently reduced turbidity even at speeds of 300 RPM (G value 300 s^{-1}) (Fig. 2) and is not included in the following analysis at 50 RPM.

Applications of anionic and nonionic polymer showed no observed difference for turbidity reduction at a higher paddle speed of 50 RPM (Fig. 3a and 3b). There were differences between the turbidity readings during settling and resuspension for all polymers: with lower resuspension turbidities (Fig. 2). The lower turbidities during resuspension are a measure of the strength of the floc formed during the settling process. The larger the difference between the settling and resuspension turbidities at 50 RPM, the more energy that was needed to break apart the floc, and the more tightly the floc was held together. A stronger floc will allow the flocculated sediment to resist resuspension as the drain or river flow increases. The floc strength (unitless) of the various polymers was nearly the same (21 ± 5) (Fig. 3), and was extremely low for alum (3.3) at 50 RPM (Fig. 2). However, when PAM was used in combination with alum the floc strength varied substantially among the polymers (discussed below).

Although alum and PAM are able to reduce turbidity at different G values, combining the two treatments could improve the turbidity removal compared to the application of each treatment alone. However, the addition of alum with the polymers reduced the effectiveness for turbidity removal in Alamo River water (Fig. 4) relative to the polymers alone (Fig. 3b). The addition of alum had a lesser effect on the flocculation and settling efficiency when used with the nonionic AP1142 polymer. In fact, the difference between the settling and resuspension turbidities of the different GE-Betz polymers (of similar molecular weight) increased with decreasing polymer charge (Fig. 5). Other research has shown that higher molecular weight polymers enhance flocculation by better bridging between particles (Laird, 1997). However, the GE-Betz polymers were similar in molecular weight to each other (approximately 5 x 10^6 g/mol), and can serve as a good indication of how polymer charge alone affects flocculation.

The nonionic AP1142 polymer formed a stronger floc and had a greater reduction in turbidity in the presence of alum compared to the anionic PAMs. These results can be attributed to the adsorption of the trivalent aluminum ion onto the negatively charged polymers, thereby reducing the effectiveness of both the anionic polymers and the alum. This appears to contradict the belief that polyvalent cations (like calcium and aluminum) encourage "cation-bridging" between polymer and clay (Theng, 1982; Laird, 1997). Peng and Di (1994) observed results similar to ours when studying kaolin flocculation at pH 6.0. They attributed their results to the precipitation of $Al(OH)_{3(s)}$ on the clay surfaces and to the adsorption of Al^{3+}, $Al(OH)^{2+}$, and $Al(OH)_2^+$ on the anionic charged sites of the PAM. In our studies using Alamo River water, the alum decreased flocculation capacity of all the anionic polymers, whereas the alum did not affect the ability of the nonionic PAM to reduce turbidity. There were no interferences in turbidity removal when cationic PAM was used in combination with alum (data not shown), further supporting the findings of Peng and Di (1994).

Phosphorus

Phosphorus loading to the Salton Sea must be minimized to reduce eutrophic conditions. Although a reduction in sediment loading from ADW reduces P_P, P_S is the predominant fraction of P_T (Table 2). Thus, removal of the readily bioavailable P_S is essential to reduce external P loading.

In order to compare the difference between PAM and alum for P removal in river water, we tested anionic (AP1110) PAM, nonionic (AP1142) PAM, and alum using a five minute settling period at 0 RPM. During this settling period all of the floc that had formed was able to settle out of the water column. The floc formed by the PAM removed suspended solids but not P_S, and the floc formed by alum removed both suspended solids and up to 75% of P_S (Fig. 6).

As previously mentioned, unlike PAM, the alum floc was weak and not capable of settling out of the water column at higher paddle speeds. Although the alum floc absorbs the P_S in the water, the PAM is necessary to enhance flocculation by settling the alum floc and keep the floc settled (floc strength).

A combination of the nonionic PAM, AP1142 (which was capable of reducing turbidity in the presence of alum), and alum are recommended for both P_S and P_P removal in the tributary waters. When these two treatments were added and allowed to settle for 5 minutes (0 RPM), only 7.2% and 3.4 % of P_S and P_P remained suspended in the jar, respectively. These two amendments working together allow the alum to adsorb the P_S fraction, and the PAM to flocculate both the suspended solids and the alum floc.

CONCLUSIONS

Both alum and PAM were able to reduce turbidity, but the alum floc required a lower velocity gradient (G value) to settle out of the water column and formed a weaker floc than the PAM. Although cationic PAM was the most effective to reduce turbidity, it is not recommended as a treatment option since endangered and threatened fish are present in tributary waters in the Imperial Valley. The alum reduced P_S, which is the majority of the external P load to the sea. In lower energy systems, the alum can reduce both turbidity and

P_S, but may not stay settled at higher G values (measured by floc strength). The nonionic PAM settled both suspended solids and the alum floc at higher G values, and formed the strongest floc once settled. Therefore, a combination of nonionic PAM (AP1142) in addition to alum is the best application to reduce turbidity and P_S. This stronger floc can remain settled so it can then be periodically dredged from either the riverbed or settling basins, removed from the system, and returned to the agricultural fields or disposed. In order to meet newly established sedimentation TMDLs, suspended solids would need to be reduced by approximately one-third. If the suggested treatments are applied, nonionic PAM (\$7.83/kg) and alum (\$0.57/kg), an estimate of \$19 million per year would be required to reduce P_S and P_P loading to the Salton Sea by approximately one-third.

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FIGURE CAPTIONS

Figure 1. Map of the Salton Sea and its tributaries: the Whitewater, New, and Alamo Rivers. (● denotes sampling sites)

Figure 2. Results of 2 L jar tests performed with New River water and various amendment additions as the paddle speed is reduced (settling, solid line) then increased (resuspension, dashed line)

Figure 3. Turbidity removal at 50 RPM in jar tests performed with various polyacrylamide (PAM) (2 mg/L) in both (a) New and (b) Alamo River water, where charge density (%) is reported by the manufacturers.

Figure 4. Turbidity at 50 RPM in jar tests (2 mg/L PAM + 4 mg/L alum-Al) with Alamo River water, where charge density (%) is reported by the manufacturers.

Figure 5. Effect of polymer charge density on the strength of the floc formed in the presence of 2 mg/L PAM + 4 mg/L alum-Al additions in Alamo River water, where charge density (%) is reported by the manufacturers.

Figure 6. P removal after 5 minutes of settling at 0 RPM in the jar tests with Alamo River water, expressed as a fraction of the initial soluble P (P_{Si}) and initial particulate (P_{Pi})

TABLES

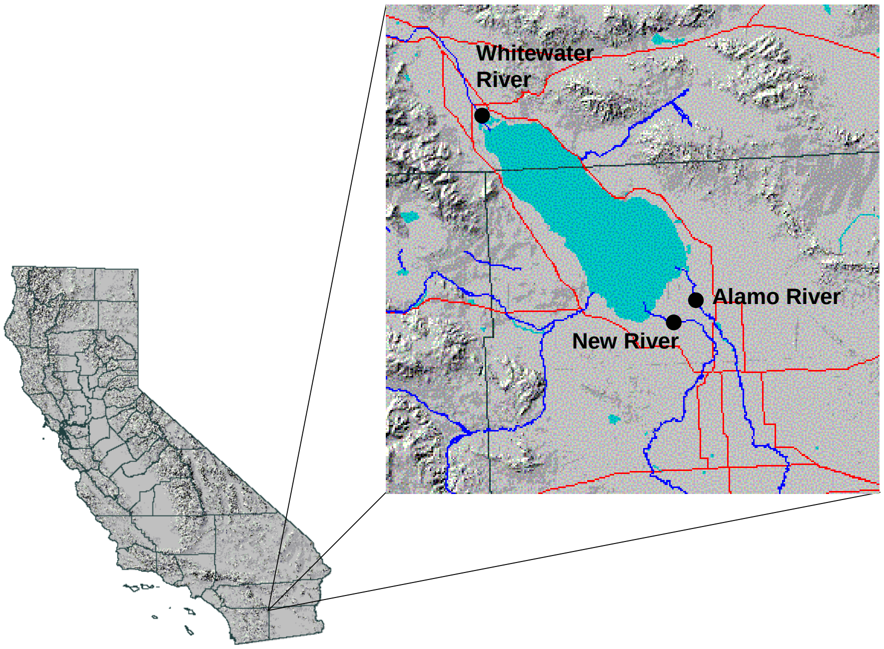
Table 1. Physical and chemical characterization of samples collected 2/3/04

		New River	Alamo River	Whitewater River
Electrical conductivity (EC)	**dS/m**	4.9	3.4	2.0
pH	**-----**	7.3	7.4	6.9
Total Suspended Solids (TSS)	**mg/L**	199	192	10
Turbidity	**NTU**	83	140	12
Anions (SO_4^{2-}, NO_3^-, Cl^-)	**($mmol_c/L$)**	52	36	20
Cations (Mg^{2+}, Ca^{2+}, Na^+, K^+, NH_4^+)	**($mmol_c/L$)**	51	35	20
Alkalinity†	**(mg $CaCO_3$/L)**	227	190	174
Flow‡	**(Mm^3/yr)**	601	760	65

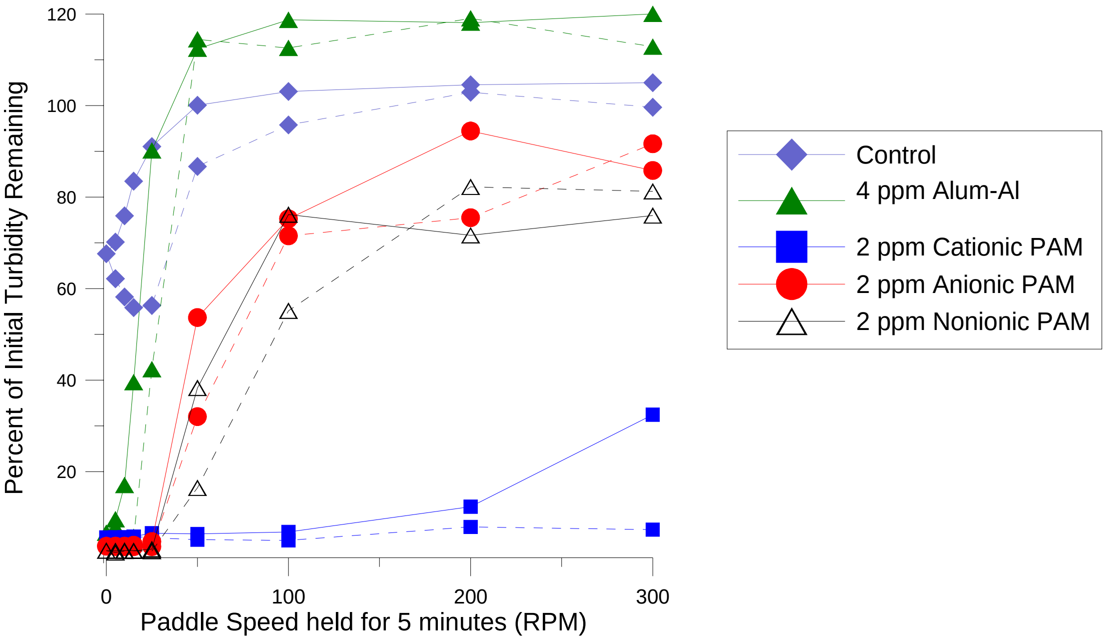
†Sample date March 30, 2004, from Holdren (personal communication)
‡From Setmire (2000)

Table 2. Average phosphorus concentrations of initial river water samples

	New River	Alamo River	Whitewater River
Collection Date	4/20/2004	6/7/2004	5/20/2004
Average P_S (mg/L)	0.69 ± 0.23	0.43 ± 0.15	1.32 ± 0.06
Average P_T (mg/L)	1.46 ± 0.11	0.66 ± 0.05	1.32 ± 0.13
Percent P_S (%)	47	65	100



Mason, L.B., C. Amrhein, C.C. Goodson, M. R. Matsumoto, and M. A. Anderson, Reducing Sediment and Phosphorus in Tributary Waters with Alum and Polyacrylamide, Figure 1.



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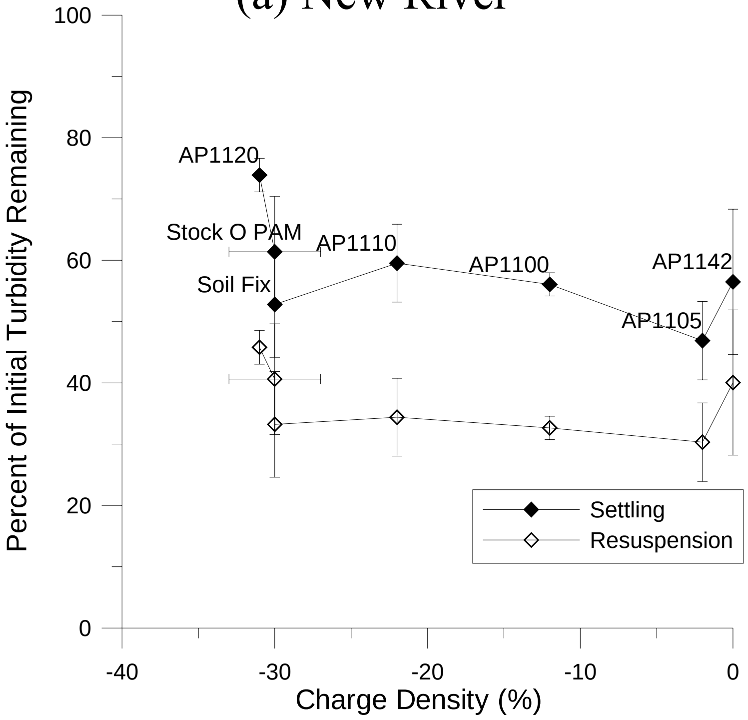
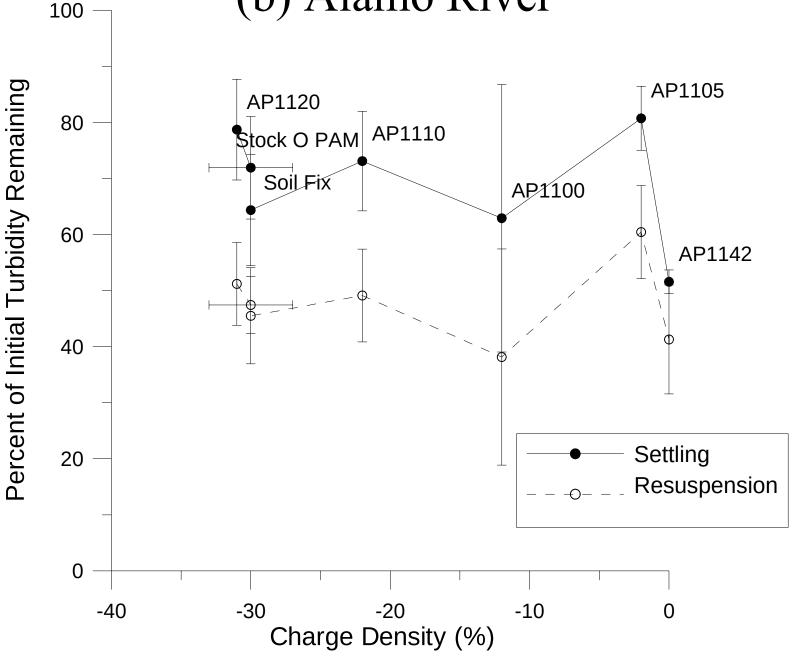
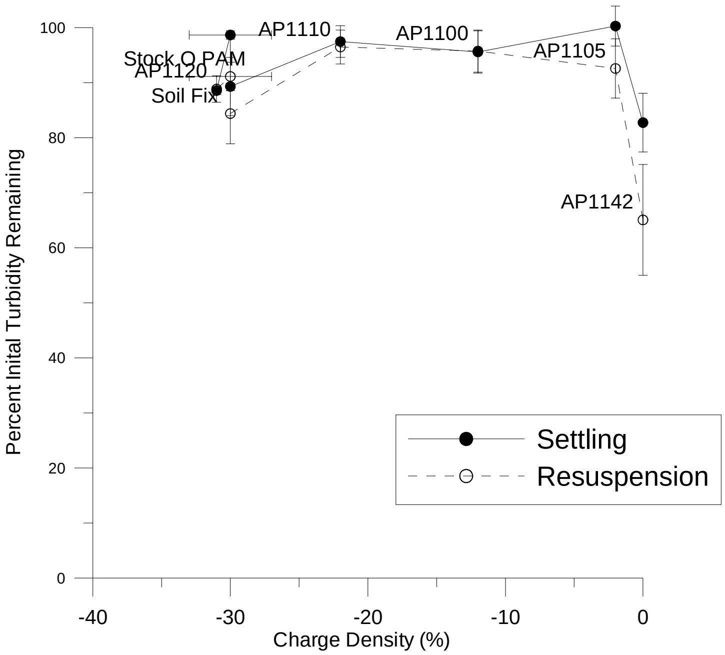


(a) New River

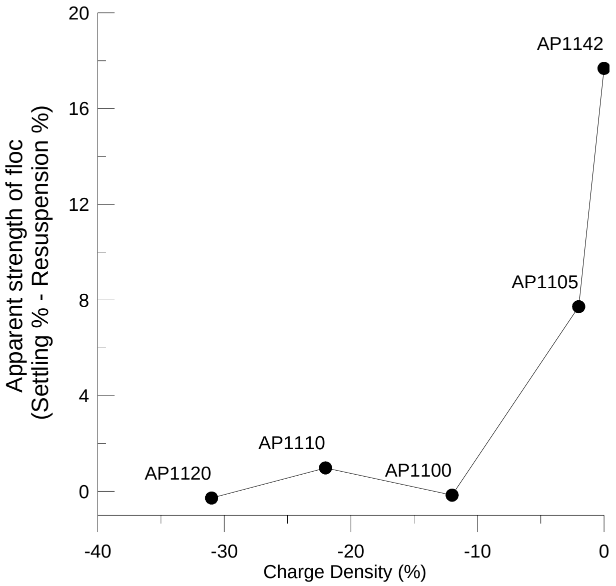


(b) Alamo River

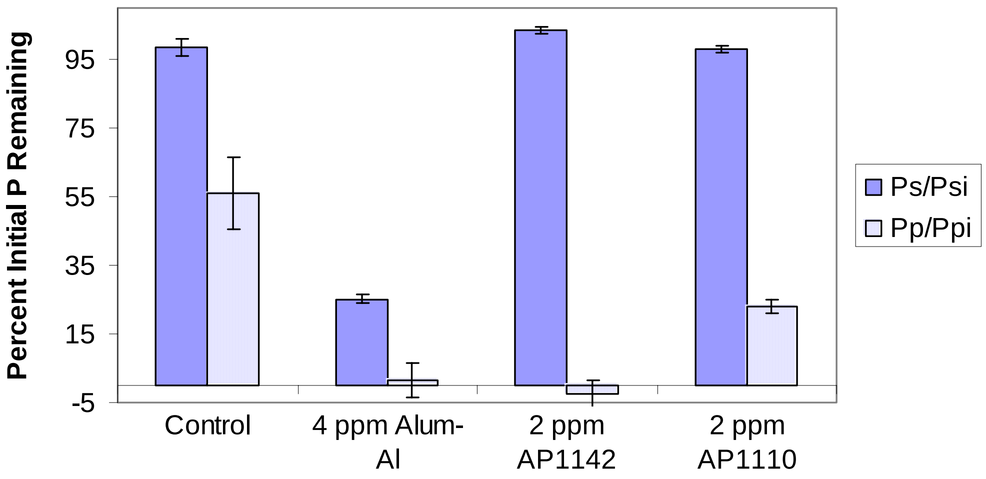
Figure 3.



Mason, L.B., C. Amrhein, C.C. Goodson, M. R. Matsumoto, and M. A. Anderson, Reducing Sediment and Phosphorus in Tributary Waters with Alum and Polyacrylamide, Figure 4.



Mason, L.B., C. Amrhein, C.C. Goodson, M. R. Matsumoto, M. A. Anderson, Reducing Sediment and Phosphorus in Tributary Waters with Alum and Polyacrylamide, Figure 5.



Mason, L.B., C. Amrhein, C.C. Goodson, M. R. Matsumoto, and M. A. Anderson, Reducing Sediment and Phosphorus in Tributary Waters with Alum and Polyacrylamide, Figure 6.

TASK 8. STUDIES OF P REMOVAL IN SIMULATED DITCHES

This manuscript will be submitted for publication in *Journal of Environmental Quality*.

Phosphorus and sediment removal from agricultural drain water with polyacrylamide and alum.

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Key words: aluminum sulfate, polyacrylamide, phosphorus, turbidity, suspended solids, agricultural drainage water, saline tracer.

Abbreviations: ditch, simulation drain water ditch; ADW, agricultural drain water; Alum, aluminum sulfate [$Al(SO_4)_3 \cdot nH_20$, n = 12-14]; PAM, polyacrylamide; WR, Whitewater River; P, phosphorus; P_T, total P; P_P, particulate P; P_S, soluble P; t_R, residence time; C, concentration; C_0, initial concentration; EC, electrical conductivity.

CONTENTS

ABSTRACT

Phosphorus (P) limits algae growth and controls eutrophic conditions in the Salton Sea. Since the majority of the P load to the Sea comes from agricultural drainage water (ADW), we investigated the use of aluminum sulfate (alum) and polyacrylamide (PAM) formulations to remove turbidity, total P (P_T), and soluble P (P_S) in a simulation ADW ditch (ditch). The ditch was 57 m long and received approximately 6 L s^{-1} of Whitewater River water (1.5 mg L^{-1} P_T, 1.4 mg L^{-1} P_S). Ditch water residence time was 28 min., ditch mixing energy was 80 s^{-1} (G value), and salt tracer tests indicated good hydraulic conductivity. By sampling at regular intervals of time and distance, we found that combining 2 mg L^{-1} Al with 1 mgL^{-1} anionic PAM gave a maximum turbidity removal of 80% from Whitewater River water. Neutral PAM had a residual turbidity reduction affect that lasted nearly twice as long as an anionic PAM plus alum treatment. Although alum was the only treatment that sequesters P_S, the low density of Al-P floc made it resist settling. Even with simultaneous additions of anionic PAM, only 50% P_T removals were achieved at best. Future work on Al-P floc removal in ADW ditches should include separating the input locations of alum and PAM along the stream, lowering mixing energies, dissolved air floatation, filtration, and skimming.

INTRODUCTION

Agricultural drainage water (ADW) from the Coachella and Imperial Valleys flows from wastewater drains to tributaries (the Whitewater, New, and Alamo Rivers) and into the Salton Sea depositing nutrients and sediment. These nutrients cause eutrophication, a process in which rapid algae growth followed by death and decay depletes the oxygen dissolved in the Sea and, subsequently, causes massive fish kills and noxious odors that inhibit local economic growth. Nutrient ratios in the Sea indicate that algae growth is phosphorus limited and that management efforts should focus on phosphorus removal (Holdren & Montaño, 2002).

One possible approach to controlling phosphorus loading to the Sea is to chemically treat ADW to settle out phosphorus and suspended solids in drainage ditches. The settled solids would eventually be removed during the regular drain cleaning operations conducted by the Imperial Irrigation District (IID).

Two treatments being considered are aluminum sulfate (alum) and polyacrylamide (PAM). Alum is used for controlling P in freshwater lakes worldwide. The active ingredient (Al^{3+}) reacts with water to form $Al(OH)_3$ which is a strong adsorbent of soluble P (PO_4^{3-}). Alum is considered non-toxic to fish and aquatic life in a pH range of 5.5-9.0 (Cooke, et al., 1978). Benthic insect population diversity remained the same or increased after Al treatment (Narf, 1990).

PAM is a class of long chain polymers that adsorb to sediment and particulate P (P_P). They are used extensively to control sediment in Idaho's Snake River Valley (Sojka). Of these, anionic formulations are most commonly used since they are non-toxic to rats, humans, and fish (Barvenik, 1994). Cationic PAMs, however, have the potential to damage aquatic life. LC50 values for cationic PAM range from 0.5-10 mg L^{-1} for fish and invertebrates (Buchholz, 1992). Although they are highly effective, use of cationic PAMs is generally not recommended for ADW treatment.

In order to perform controlled treatment trials on ADW, we constructed a simulation drainage ditch (ditch) at Kent SeaTech's Coachella Valley facility. The ditch was plumbed to receive inflows from the Whitewater River (WR).

We performed treatment trials with alum and four commercial polyacrylamide (PAM) formulations. These trials allowed for screening of these chemicals' capacities to remove total phosphorus (P_T), soluble phosphorus (P_S), and turbidity from WR water.

MATERIALS AND METHODS

Ditch Construction

Prior to construction of the ditch, the area was excavated and completely lined with 6 mm plastic (to minimize vertical flow) then back filled, laser-leveled, and compacted. The area was then re-excavated to form a ditch 2 ft. deep with bottom dimensions of 0.6 x 57 m, zero bottom slope, and 1:1 sloped sidewalls.

The concrete inflow structure for the ditch was fitted with a V-notched weir and attached ruler to permit accurate flow measurements of up to 7.6 L s^{-1} once calibrated with the filling time of a 3.8 L bucket. The bottom of the inflow structure was connected to a 10.2 cm PVC pipe that delivered water pumped directly from the WR.

In order to condition the system, WR water was run continuously at 4.4 L s^{-1} through the ditch for one week. At this point, testing was performed to check for seepage. The incoming flow rate was decreased from an initial 0.6 L s^{-1} down to a flow that produced no observable discharge leaving the drain. The equilibrium flow rate at which there appeared to be no discharge was less than 0.06 L s^{-1}. At 0.07 L s^{-1}, there was still a slight discharge, even after the system ran overnight. These tests indicate that seepage losses were negligible in the simulation ditch.

Ditch Hydraulics

We initially conducted salt tracer studies to check the ditch's hydraulic characteristics.

Figure 2 depicts a representative salt slug test. For that test, a stable ditch flow rate of 5.7 L s^{-1} was established. Then, a sodium sulfate slug (4 L of 75 g L^{-1} solution) was dropped into to inflow structure (0 m, Time = 0). EC was then periodically measured at the outflow structure (57 m) with a portable EC meter (Fisher Scientific) in order to time the slug's elution through the ditch. The fact that the salt peak eluted in a uniform, bell-shaped curve with very little tapering and returned to the baseline EC values once past indicates that there are no hydraulic "dead zones" in the ditch.

Residence times (t_R) were determined by two methods: observation and calculation. Observed residence times were based on the time that it took the salt peak to reach one half of the maximum EC on the trailing tail of the curve. Calculated t_R were based on measurements of ditch water surface area and depth (17 cm x 93 cm x 57 m) divided by flow rate (5.5-5.6 L s^{-1}). Calculated and observed t_R's were 27.3 and 28.8 min (mean t_R = 28 min). Since treatment trial flow rates were 5.7-6.3 L s^{-1}, treatment trial t_R's were assumed to be <28 min.

We also calculated an 80 s^{-1} mixing energy (G value) for the ditch based on it's geometry and the 46 cm water fall from the V-notched weir. This mixing energy is comparable to values calculated for the local drains and rivers.

Treatments

Polymers were chosen to give a range of charge densities (Figure 3) in the ditch trials: Stockopam (Stockhausen, Inc., 2401 Doyle Street, Greensboro, NC 27406), AP1100, AP1142, and CP1160 (GE Betz, Trevose, PA19053). Both manufacturers reported their polymers to have very high molecular weights (12-15*10^6 g mol^{-1}), >99% active ingredient, <5% residual monomers, and cost 6-11 USD kg^{-1}.

Stock PAM solutions were made by slowly adding dry polymers to water in HDPE buckets continuously mixed with a 5.1 cm diameter impeller at 60 rev. min^{-1}. The resulting 2,200 to 5,400 mg L^{-1} PAM stock solutions were allowed to age overnight before use.

Alum used for these trials was produced by General Chemical Corp. (Parsippany, NJ 07054-3751) in 110 kg bags. The alum contained 6.7% aluminum (w/w) as measured by induced coupled plasma optical emission spectrometry (ICPOES). Alum solutions were made on site as above and used immediately.

Solution pumping rates from the buckets to the inflow structure were varied by adding or removing tubes from peristaltic pumps with multiple flow heads. There, the solution was dripped into the turbulent inflow, cascaded over the V-notched weir, and into the ditch (Figure 1). Alum injection rates were adjusted by adding or subtracting tubes connected to the peristaltic pumps and calibrated with a graduated cylinder and stop watch.

Water Sampling and Analysis

Sampling points were flagged every 7.6 m along the ditch and at the outflow structure (57 m). Water sampling started once 2 t_R had elapsed from initiation of the treatment. Transects of grab samples were collected every 7.6 m. and 2.5 cm below the water surface, proceeding from the outflow to the inflow end in order to avoid picking up sediments disturbed by the previous sample. Control samples were taken at the head-end of the ditch (0 m) and with no amendment additions (i.e. by setting the injection tubes aside, waiting two minutes, then sampling directly from inside the inflow structure). For each sampling, three bottles were filled: One 25 mL glass scintillation vial for turbidity, EC, and pH measurements and two separate 60 mL PE bottles for P_S and P_T analysis.

Phosphorus sample preservation and preparation protocols included filtration (< 0.45µm, Fisherbrand Membrane) for P_S, acidification to ~pH 2.5 with 1 drop of concentrated H_2SO_4 for P_T, and storage in PE bottles at 4°C for both. The P_T sample preparation was modified from method 4500-P B in Greenberg et al. (1992) as follows: the oxidizing solution was made of 30 g boric acid, 350 mL 1 N NaOH, and 50 g $K_2S_2O_8$ diluted to 1 L with deionized water. Raw water and oxidizing solution were combined at the rate of 5:1 in 10 mL PE mailing tubes and heated in a 100°C water bath for 2 hours. All P_S and P_T samples were analyzed on an Alpkem RFA 300 Autoanalyzer (Clackamas, OR) with the ascorbic acid-molybdate blue method described in Greenberg et al. (1992). Particulate P (P_P) was determined by the difference between P_T and P_S. The mean initial P_T concentrations for control and treatment trials were 1.54 ± 0.03 mg L^{-1} P.

Each turbidity sample was collected, stored at 4°C, and measured in the same 25 mL glass vial using an HF Scientific, Inc. Micro 100 Turbidimeter (Fort Myers, FL). Total suspended solids (TSS) were determined by filtration, method 2540D in Greenberg et al. (1992).

Acidified, raw water aluminum analysis was performed using a Plasma Quad ICPOES (Perkin Elmer, Wellesley, MA). Replicates, spike recoveries, and checks were run on all instruments for quality control.

Data was normalized in some of the figures below to correct for natural fluctuations in background sediment and P of WR water. Percent of initial concentration values [$(C/C_0)*100$] were calculated with C = averages of samples taken from 38-57 m and C_0 = averages of un-treated inflow. Error bars represent SD based on n = 8 samples for each treatment. Values marked with the same letter are not significantly different as determined by a 2-tailed T-test (p is less than or equal to 0.05; n is greater than or equal to 8).

Compared to the average turbidities of the New and Alamo Rivers (~200 NTU), the Whitewater River has very little suspended sediment (Table 1). Though P_T in all three Salton Sea tributary rivers is comparable, the P_S fractions vary. Phosphorus in the Whitewater R. is 90% P_S while the New and Alamo Rivers contain only 40-50% P_S. Removing this high P_S content was a major focus in our ditch treatments of WR water.

RESULTS AND DISCUSSION

Turbidity

Figure 3 shows percent of initial turbidity (C/C_0) remaining at the ditch outflow given equal concentrations of each product. CP1160 removed the most turbidity compared to the other treatments. However, due to native fish toxicity concerns, this cationic polymer is not recommended for use in agricultural wastewater drains (Barvenik, 1994). Tied for second place were Alum and AP1100 which provided smaller but still significant turbidity removals compared to the Control. Turbidity reductions by Stockpam and AP1142 were not significantly different from the Control treatment.

Following the suggestions of Dr. Robert Sojka of the Idaho USDA-ARS, we tested combinations of alum and anionic PAM at various concentrations in an attempt to increase the size and density of the alum floc (personal communication). As seen in Figure 4, it appears that a 50% reduction in WR water turbidity can be achieved with approximately 1 mg L^{-1} of either alum or PAM. By combining 2 mg L^{-1} Al with 1 mg L^{-1} PAM, the maximum reduction of 80% was achieved.

Figures 5 and 6 show the residual effects of amendments after additions were stopped but WR water flow continued. Here, turbidities were plotted against t_R in order to standardize the observations and make them applicable to other channels with different flow rates and geometries.

The alum (2.3 mg L^{-1}) plus Stockopam (1.7 mg L^{-1}) treatment had little residual effect on turbidity. The control turbidity levels were re-established within only 3.5 t_R (91 minutes) with a ditch flow of 337 L s^{-1}. However, the residual effect of 1.9 mg L^{-1} AP1142 alone lasted 6.3 t_R (163 minutes). This suggests that neutrally charged polymers potentially have residual effects that last almost twice as long as either anionic polymers or alum. Differences between Stockopam and AP1142 may be attributed to the differences in polymer interaction with the channel bottom. However, further research would be needed to determine the characteristics of this surface chemistry phenomenon.

Phosphorus

PAM had little effect on P_T since WR water is naturally low in the solid P fraction (P_P). Conversely, alum treatments converted P_S into P_P by producing copious amounts of buoyant Al-P floc (photo 1). Settling this floc, however, proved difficult as is evident from the small decrease in P_T seen in Figure 7.

Visual observations of Al-P floc forming but not settling are reinforced by data presented in Figures 11 and 12. Figure 12 shows actual Al concentrations measured for a control and three alum-only treatments. It shows that alum treated raw water Al concentrations remained elevated even at the ditch outflow relative to the control. Comparisons of alum-Al addition rates to outflow Al measurements suggest that only 39% of the alum-Al settled out in the ditch while 61% of it flowed out in the form of un-settled Al-P floc.

Though PAM had little effect on P_S removal alone, we hypothesized that it could increase the density of Al-P floc enough to make it settle out. Since an Al/PAM combination produced the maximum turbidity removal in Figure 4, we hoped that the same treatments would settle out Al-P floc and drive down P_T. But this was not the case: at best, a 50% reduction of WR P_T was achieved with 2 mg L^{-1} alum-Al and 1 mg L^{-1} PAM Figure 8. Though 4-8 mg L^{-1} alum-Al drove P_S concentrations to nil, P_T removals were $\leq$50% since floc removal was erratic (shown as P_P in Figure 9).

CONCLUSIONS

Though the Whitewater River is the least polluted of the three tributaries to the Sea, P_S comprises 90% of the P_T in its waters. WR water gave us the opportunity to focus on removing P_S, the most bioavailable fraction of P entering the Salton Sea.

Alum was the only chemical evaluated that significantly reduced P_S concentrations. Significant removals of P_T, P_S, and turbidity were accomplished in all alum trials. However, the greatest P_S removals were achieved only once alum floc density was increased by simultaneously adding an equal part of anionic PAM. Our data does not support the hypothesis that settling of Al-P floc can be induced by increasing PAM concentrations when alum and PAM are added simultaneously.

Though we do not consider turbidity to threaten WR water quality, this work was meant to provide some guidance to future in-drain treatment research of more contaminated ADW flows.

Future work for in-drain water treatment may include separating alum and PAM inputs along the stream gradient. Alum floc formation and subsequent settling may have worked better in our ditch if alum were applied first and PAM second at two separate zones of turbulent flow. However, since the weir was our only point of turbulent flow in the ditch, we were not able to test Dr. Sojka's idea. More robust tests of PAM and alum's efficacy over distance and with a range of turbulent flows would be best done in real drains. Engineered systems for light Al-P floc removal (like settling basins, skimmers, filters, or dissolved air injectors) should also be investigated. Our simulation drain could be modified to study selenium removal from WR water. This could be done by raising the height of the outflow structure's weir, filling the ditch with hay, and allowing a slow flow of water to trickle through the system (see Frankenberger's stuff on hay bales).

Interest in chemically treating ADW may grow with the recent passage of sediment TMDLs and with nutrient TMDLs in preparation for the Sea's tributaries. Though in-drain chemical treatments may offer a partial solution, grower implementation of on-field BMPs to control runoff sediment and P may be the more economical way to improve ADW quality.

In the end, any management solutions adopted to control eutrophication in the Salton Sea should focus on P_S load reductions. Continued eutrophication of the Sea will be the direct consequence of not reducing the P_S, the most bioavailable P-fraction (Schroeder et al. 2002).

ACKNOWLEDGEMENTS

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Northwest Irrigation and Soils Research Lab, USDA-Agricultural Research Service, 3793N-3600E, Kimberly, ID 83341

TABLES

Table 3. Mean outflow conditions of Whitewater River water during Control treatments.

EC µS cm^{-1}	T °C	pH	Ditch Flow gal min^{-1}	Turbidity NTU	Total P mg L^{-1}	Soluble P mg L^{-1}
Mean (standard deviation)						
2043 (206)	21 (3)	7.1 (1)	88 (9)	29.7 (10)	1.51 (0.3)	1.41 (0.3)

Averages for all controls (with no chemical addtions) at the ditch outflow (125-188 ft.)

Table 4. Outflow turbidities for various AP1100/Alum treatment combinations.

PAM	*Alum*		
(mg L^{-1})	*(mg L^{-1} Al)*		
	0	*2*	*4*
	Turbidity		
	NTU *(SD)*		
0	32 *(10.3)*	26 *(2.5)*	31 *(9.1)*
1	14 *(3.3)*	6 *(2.0)*	17 *(12.0)*
2	21 *(1.5)*	8 *(3.7)*	10 *(1.5)*
4	21 *(3.2)*	12 *(2.3)*	11 *(0.6)*

Table 5. P_T and P_S for various alum/AP1100 treatment combinations. Data averaged from outflow samples (38-57 m).

PAM (*mg L^{-1}*)	*Alum* (*mg L^{-1} Al*) 0	2	4
	Total P mg L^{-1} *(SD)*		
0	1.6 *(0.29)*	1.1 *(0.05)*	1.2 *(0.07)*
1	1.3 *(0.01)*	0.8 *(0.10)*	1.0 *(0.08)*
2	1.2 *(0.02)*	0.8 *(0.27)*	0.7 *(0.07)*
4	1.7 *(0.01)*	1.1 *(0.09)*	1.0 *(0.12)*
	Soluble P mg L^{-1} *(SD)*		
0	1.3 *(0.26)*	0.4 *(0.01)*	0.4 *(0.35)*
1	1.2 *(0.02)*	0.4 *(0.02)*	0.2 *(0.02)*
2	1.1 *(0.02)*	0.4 *(0.01)*	0.3 *(0.09)*
4	1.5 *(0.02)*	0.3 *(0.03)*	0.0 *(0.00)*

FIGURE CAPTIONS

Figure 1. Injection tubes dripping PAM and alum solutions into the inflow structure and a view from the drain structure.

Figure 2. Outflow EC during a representative saline tracer test. Ditch flow rate was 5.7 L s^{-1}.

Figure 3. Comparison of outflow turbidities among treatments. Each treatment, except Control, received the indicated product at the rate 2 mg L^{-1}.

Figure 4. Outflow turbidities for various AP1100/Alum treatment combinations.

Figure 5. Residual effects of a 2.3 mg L^{-1} Al^{3+}, 1.7 mg L^{-1} Stockopam treatment (stopped at t_R = 0) on outflow turbidity (38-57 m) plotted against residence time. Error bars indicate one standard error of the mean.

Figure 6. Residual effects of a 1.9 mg L^{-1} AP1142 treatment (stopped at n = 0) as measured on turbidity at the end of the simulation drainage ditch (38-57 m) plotted against residence time. Error bars indicate one standard error of the mean.

Figure 7. Percent of initial P_T (as $P_S + P_P$) achieved with select Control, anionic PAM, and alum treatment trials. Each treatment, except Control, received the indicated product at the rate 2 mg L^{-1}.

Figure 8. P_T and P_S for various alum/AP1100 treatment combinations. Data averaged from outflow samples (38-57 m).

Figure 9. Average Total phosphorus (as PS + PP) in response to varying alum-Al additions. Error bars indicate RSD and n is equal to or greater than 9.

Figure 10. Dissolve reactive phosphorus concentrations in response to varying alum-Al additions on 2/5/04.

Figure 11. Decreases in percent initial turbidity with increasing alum additions on 2/5/04.

Figure 12. Raw water aluminum concentrations on 2/5/04.

FIGURES

Figure 4. Injection tubes dripping PAM and alum solutions into the inflow structure and a view from the drain structure.

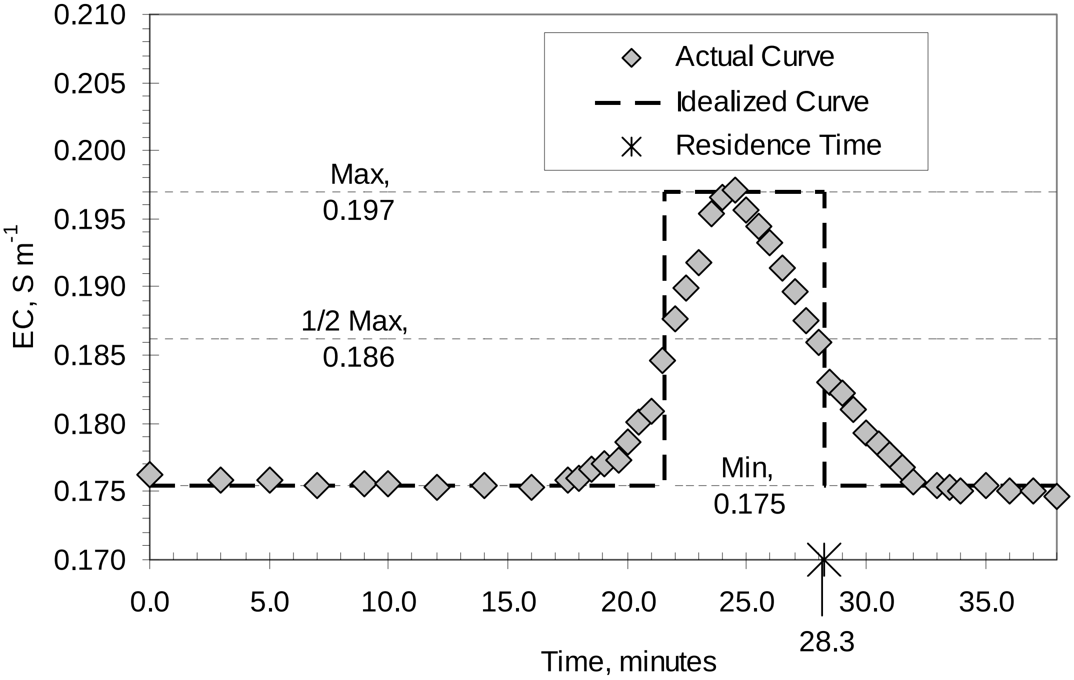

Figure 5. Outflow EC during a representative saline tracer test. Ditch flow rate was 5.7 L s^{-1}.

a

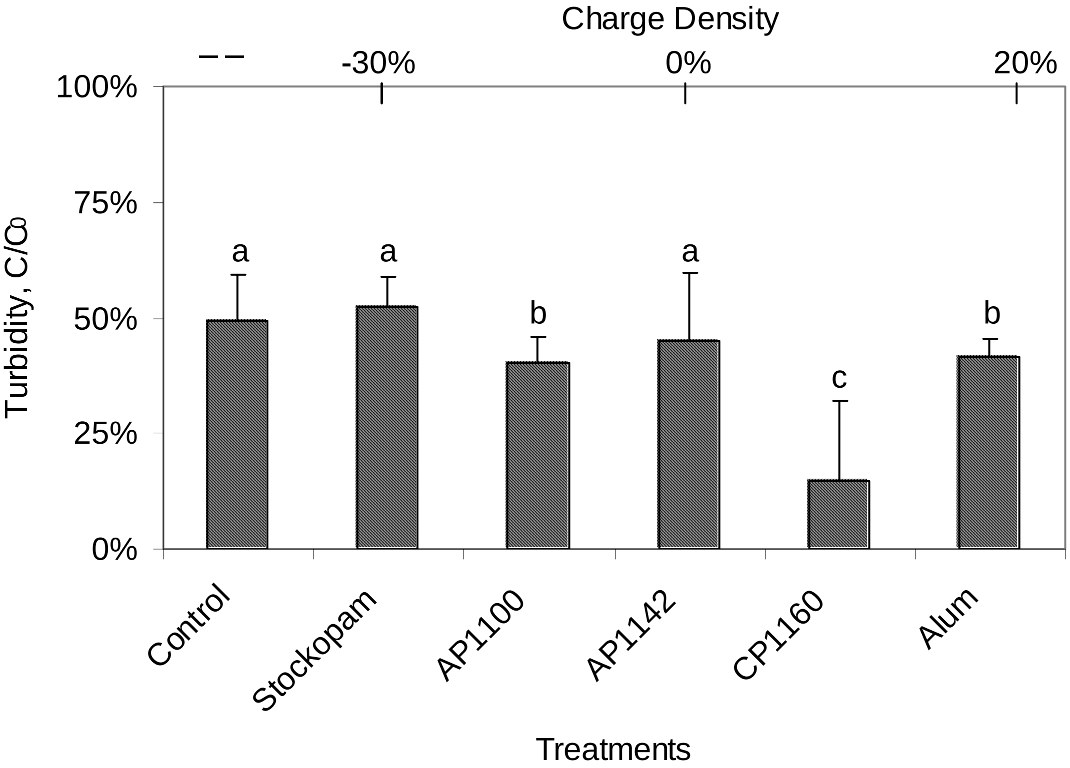

Figure 6. Comparison of outflow turbidities among treatments. Each treatment, except Control, received the indicated product at the rate 2 mg L^{-1}.

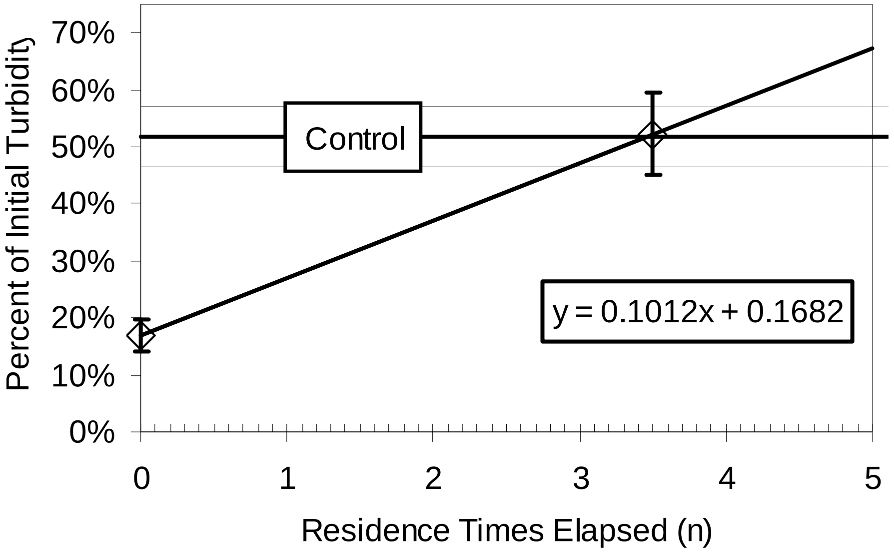

Figure 7. Residual effects of a 2.3 mg L^{-1} Al^{3+}, 1.7 mg L^{-1} Stockopam treatment (stopped at t_R = 0) on outflow turbidity (38-57 m) plotted against residence time. Error bars indicate one standard error of the mean.

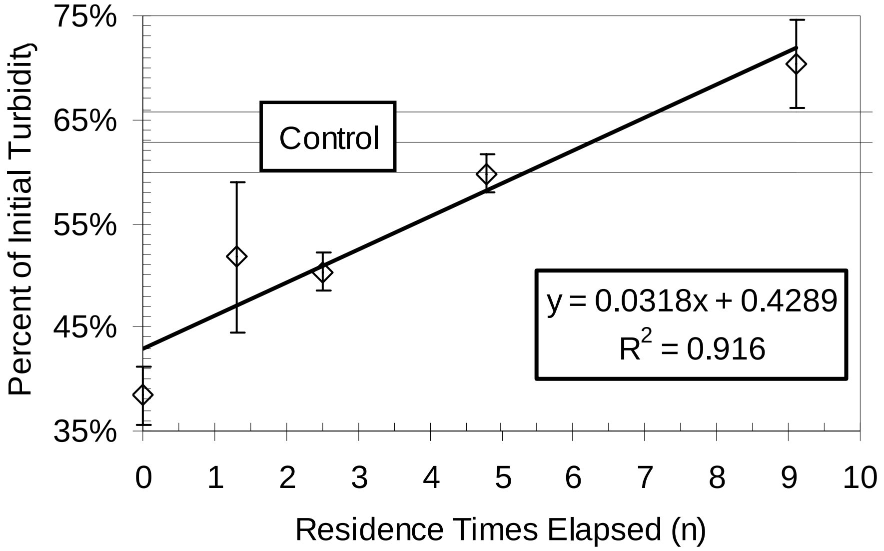

Figure 8. Residual effects of a 1.9 mg L^{-1} AP1142 treatment (stopped at n = 0) as measured on turbidity at the end of the simulation drainage ditch (38-57 m) plotted against residence time. Error bars indicate one standard error of the mean.

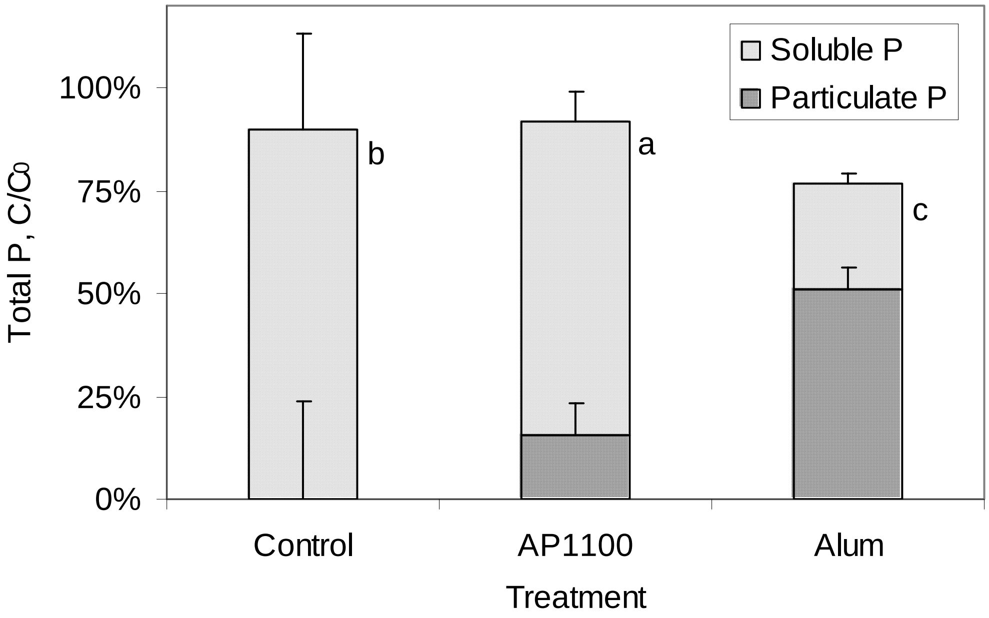

Figure 9. Percent of initial P_T (as P_S + P_P) achieved with select Control, anionic PAM, and alum treatment trials. Each treatment, except Control, received the indicated product at the rate 2 mg L^{-1}.

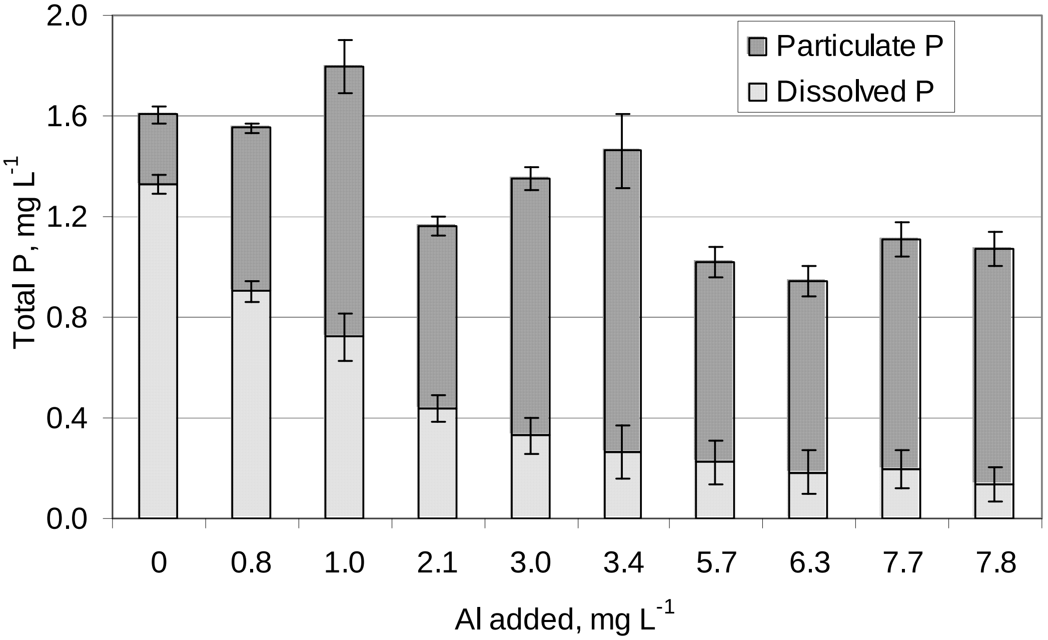

Figure 10. Average Total phosphorus (as $P_S + P_P$) in response to varying alum-Al additions. Error bars indicate RSD and n is equal to or greater than 9.

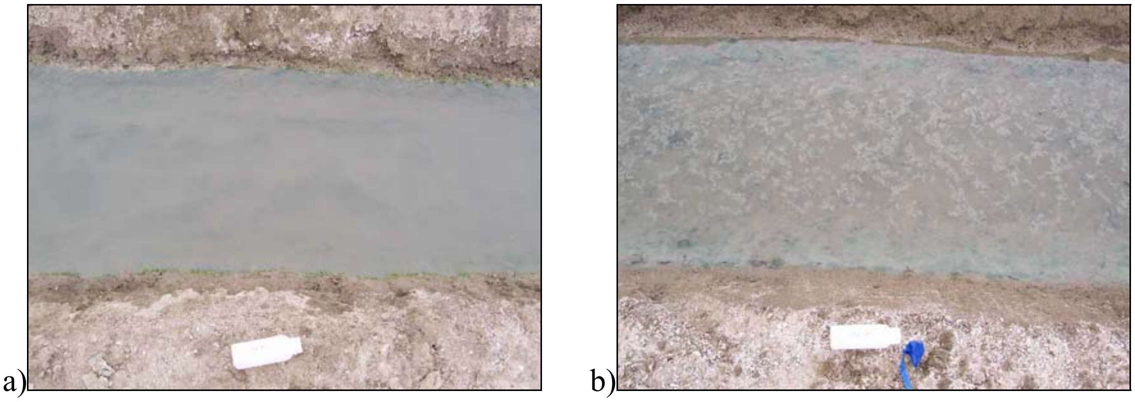

Figure 11. Floc formation at a) 7.6 m and b) 53 m with 7 mg L^{-1} Al and 208 L s^{-1} of WR water.

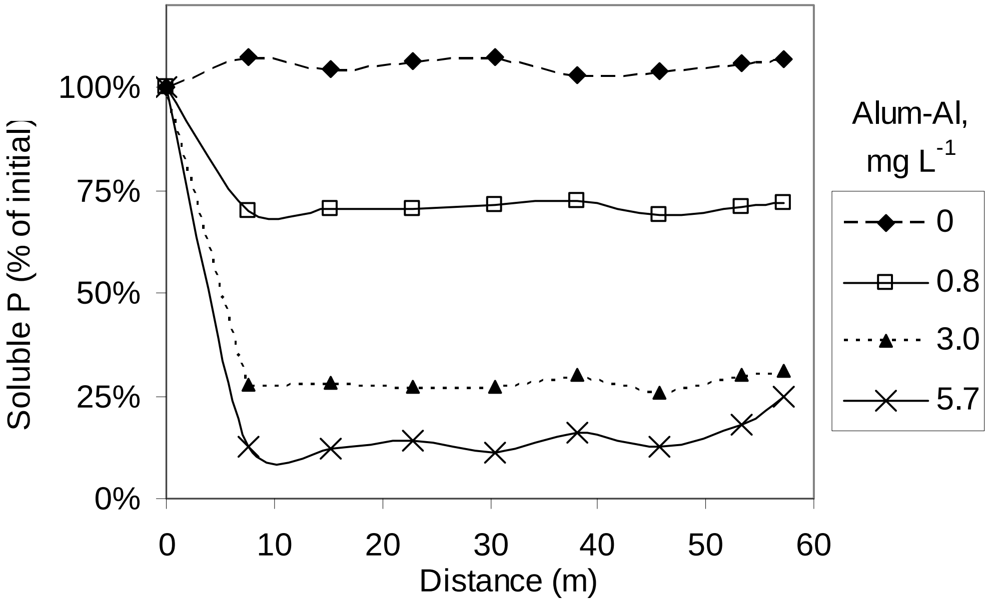

Figure 12. Dissolve reactive phosphorus concentrations in response to varying alum-Al additions on 2/5/04.

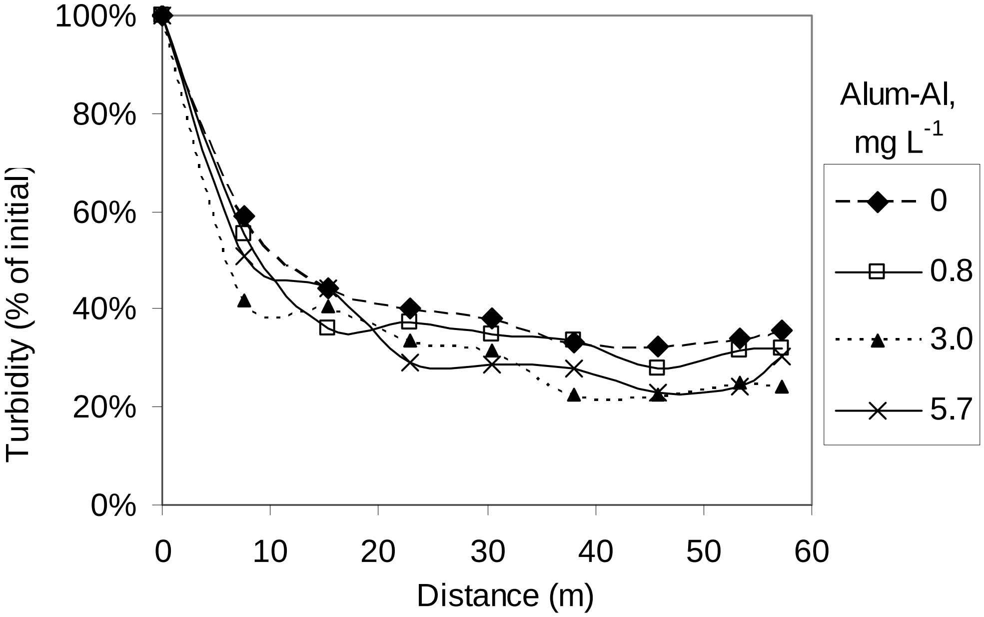

Figure 13. Decreases in percent initial turbidity with increasing alum additions on 2/5/04.

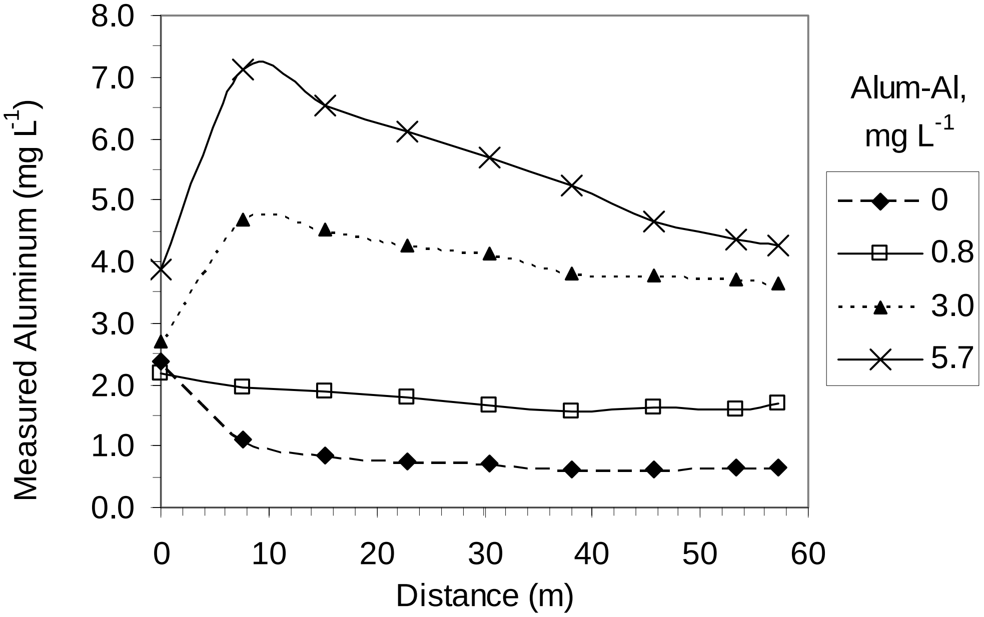

Figure 14. Raw water aluminum concentrations on 2/5/04.

TASK 8. ON-FIELD PAM APPLICATIONS (EXTRA WORK)

This task was performed as extra work to compliment the simulation ditch trials. We were excited to take the Imperial County Farm Bureau's offer to help us get field-scale data on PAM usage by connecting us with local growers willing to participate.

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Controlling sediment and phosphorus in agricultural tailwater with PAM and irrigation management.

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Key words: suspended solids, turbidity, phosphate, soluble phosphorus, particulate phosphorus.

Abbreviations: Agricultural surface discharge, tailwater; P_S, soluble phosphorus; P_P, particulate phosphorus; PAM, water soluble anionic polyacrylamide powder; DOC, dissolved organic carbon; EC, electrical conductivity; SAR, sodium adsorption ratio; OPP, liquid orthophosphate-P fertilizer.

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Abstract

External loading of phosphorus (P) is the main cause of excessive algae growth and the eutrophication of the Salton Sea. The main P source is Imperial Valley agricultural surface discharge (tailwater). Continuous polyacrylamide (PAM) applications to agricultural irrigation water inflows were evaluated as a means of reducing sediment and P loading to drains connected to the Salton Sea. Zero (Control) and 1 mg L^{-1} PAM (PAM_1) treatments were compared for 17 Imperial Valley field sites. Five and 10 mg L^{-1} PAM treatments (PAM_5, PAM_{10}) were conducted at one site. The Particulate P fraction (P_P) was determined as the difference between Total P (P_T) and the Soluble P fraction (P_S). PAM_1 decreased mean drain turbidities by 74% and total suspended solids (TSS) by 82%. These reductions were sufficient to make 7 of 8 non-compliant field sites comply with the current Alamo river sediment TMDL. While PAM_1 reduced tail water P_P by 48%, P_S was not significantly reduced. PAM_{10} did reduce TSS by 99% and P_T by 52% but did not affect P_S. Size exclusion chromatography indicated that PAM_1 treatments were exhausted within ~1.6 km (at the drain) but that PAM_5 and PAM_{10} treatments resulted in >2 mg L^{-1} PAM in tailwater. Future Imperial Valley phosphorus and sediment management efforts should include agricultural field drain slope optimization and wide-spread soil P testing. Such information would help growers make more informed decisions when applying solid and liquid P fertilizer and could eventually lead to reduced P loading to the Salton Sea.

Introduction

External loading of phosphorus (P) is the main cause of excessive algae growth and the eutrophication of the Salton Sea. Schroeder et al. (2002) stated that "the Salton Sea is highly eutrophic and that P is by far the limiting nutrient relative to N" noting that there is 26 times more nitrogen (N) than P in the Salton Sea relative to ocean water. The majority of the external P load to the sea comes from agricultural surface discharge (tailwater) from the Imperial Valley drained by the Alamo and New Rivers, the two main drainages that deliver roughly 80% of the sea's inflow. The data of Holdren & Montaño, 2002, indicate that two thirds of the rivers' total P load to the sea is as soluble P (P_S) which is the most bioavalable fraction for algae growth. The other third is as particulate P (P_P). It bears to reason that reductions in suspended solids and phosphorus in agricultural discharges should eventually abate the Sea's eutrophic cycles.

With the existing sediment TMDLs and impending nutrient TMDLs for the New and Alamo Rivers, there is growing interest in on-field best management practices (BMPs) that are inexpensive and simple to implement. In addition to the typical BMPs that slow runoff flow rates, many studies suggest that anionic polyacrylamide polymers (PAMs) added to irrigation water can promote the settling of nutrients and sediments before they leave the field as tailwater (Orts et al., 2000 and Entry & Sojka, 2003). However, there is little information published on PAM usage in heavy-textured, salt-affected soils like those found in the Imperial Valley. More specifically, little is known about PAMs potential to settle P_S and P_P under these conditions.

In this study we tested the efficacy of PAM-treated irrigation water to decrease suspended solids, P_P, and P_S on Imperial Valley agricultural fields.

Methods and Materials

The Imperial County Farm Bureau (ICFB) located growers willing to volunteer agricultural field sites located throughout the Imperial Valley. Given free PAM treatments and an assurance of confidentiality, growers allowed us to conduct the treatments as controlled experiments to evaluate the effects of PAM amended irrigation water on turbidity, total suspended solids (TSS), P_T and P_S. Throughout our experiments, Colorado River water was used to furrow irrigate fields with bare, tilled soils (Table 6). Soils at the 17 selected field sites were silty clays and silty clay loams (hyperthermic Typic Torrifluvents) with high shrink-swell potential (Zimmerman, 1980).

In each case, "Control" (0 mg L^{-1} PAM) samples were taken from near the middle of a group of three to five border-controlled lanes irrigated with un-amended irrigation water. Surface water grab samples where collected in transects from 1) the inflow above the PAM applicator, 2) field head, 3) mid field, 4) field tail, 5) drain box locations noted in Figure 15. When the irrigation was completed for a set of lanes, the water was switched over to the next set of lanes for PAM treatment, and water samples taken as with the Control treatment.

Dry, powdered PAM was added directly to inflow canal water with rotary applicators (Fig. 2). Their placement was upstream of turbulent flow sections and at least 30 m from the field head to promote mixing before the treated water left the inflow canal. Locally distributed anionic polyacrylamides, either Stockopam (Stockhausen, Inc., 2401 Doyle Street, Greensboro, NC 27406) or Soilfix IR (Ciba Specialty Chemicals, Basel, Switzerland), were applied at approximately 1.8 kg ha^{-1} (1 mg L^{-1}) at most sites. Single field trials were done with 5 and 10 mg L^{-1} treatments. Both manufacturers reported their PAM to have 30-35% negative charge substitution, medium molecular weight (12-15*10^6 g mol^{-1}), and < 0.05% residual monomers. The retail cost for PAM was \$6-11 USD kg^{-1}.

Turbidity was measured in-field with an HF Scientific, Inc. DRT-15CE Portable Turbidimeter (Fort Myers, FL). PAM concentrations in the irrigation water were determined from PAM application rate (g hr^{-1}) divided by the water inflow rate (m^3 hr^{-1}). Total suspended solids (TSS) were determined by filtration and drying of the collected sediment material using method 2540D of Greenberg et al. (1992).

Water samples intended for PAM concentration measurements were centrifuged in the field in 50 mL Teflon® tubes and stored in 25 mL glass vials with Teflon® caps at 4°C. These samples were then prepared and analyzed by size exclusion chromatography as described in Lu et. al. (2003).

Sample preparation and preservation protocols included filtration (< 0.45µm, Fisherbrand cellulose acetate membrane filters) for P_S, acidification to pH ~ 2.5 with concentrated H_2SO_4 for P_T, and storage in acid-washed polyethylene bottles at 4°C for both. The P_T sample preparation was modified from method 4500-P B in Greenberg et al. (1992) as follows: the oxidizing solution was made of 30 g boric acid, 350 mL 1 M NaOH, and 50 g $K_2S_2O_8$ diluted to 1 L with deionized water. Sample water and oxidizing solution were combined at the rate of 5:1 in 10 mL polyethylene mailing tubes and heated in a 100°C water bath for 2 hours. All P_S and P_T samples were analyzed on an Alpkem RFA 300 Autoanalyzer (Clackamas, OR) with the ascorbic acid-molybdate blue method described in Greenberg et al. (1992). Particulate P (P_P) was determined by the difference between P_T and P_S.

Quality assurance protocols (prompt sample refrigeration, preservation, preparation, and analysis) were consistently performed on all field-collected water samples. Preservation and preparation protocols were proven effective by comparing P concentrations on selected samples stored for up to 22 days after collection. Because of possible changes to the P_T concentrations in unoxidized samples, phosphorus analysis was completed within one week after collection, or the samples were promptly oxidized prior to storage in the refrigerator.

Quality control protocols included the analysis of one check standard, one replicate analysis, and one spiked sample for every ten samples analyzed. We set the control limits for these quality controls at ± 15% of their expected concentrations. A method detection limit (MDL) of 0.20 mg P L^{-1} was calculated with the EPA method described in 40 CFR Part 136. Replicates that fell outside of the control limits, but had concentrations below the MDL of 0.20 mg P L^{-1}, were not used to discriminate unacceptable runs.

Results and Discussion

Turbidity and Total Suspended Solids Removal

As previously reported in the literature, our continuous PAM applications to irrigation water inflows significantly reduced drain water sediment. Figure 17 shows average turbidity and TSS measurements over distance for Control and 1 mg L^{-1} PAM-treated irrigation water at 17 field sites. PAM significantly decreased turbidity by 74 ±5% and TSS by 82 ±4% from mid field to the drain boxes ($p < 0.001$). Control drainbox TSS exceeded the 230 mg L^{-1} New River sediment TMDL at 8 out of 17 field sites. However, with continuous 1 mg L^{-1} PAM treatment, all but one field site's drain box TSS exceeded the TMDL.

Even with PAM treatment, there was a slight but consistent increase in turbidity and TSS from the field tail to the drain box (Figure 17). These increases in suspended solids can be attributed to excessively steep drain ditch slopes that allowed the tailwater to gain enough velocity to suspend sediments (field observation). This suggests that modification to the slope of drain ditches could greatly reduce the TSS load delivered to the drains and rivers flowing into the Salton Sea.

Figure 18b shows the effects of varying concentrations of PAM on turbidity and TSS. Although the 5 and 10 mg L^{-1} PAM treatments were only replicated once, they suggest that a 99% sediment removal rate can be achieved with between 5 and 10 mg L^{-1} PAM. In this case of diminishing benefits, however, it appears that 1 mg L^{-1} PAM is the most economical of the treatments tested for sediment control.

The fact that TSS and turbidity closely track each other in both Figure 17 and Figure 18b is indicative of how well correlated these two lines of data are. For our data, the equation

$$\text{Turbidity} = 1.35(\text{TSS})$$

has an r^2 of 0.86. These data not only verify our results but justify the interchangeability of in-field turbidity readings for laboratory TSS measurements.

Phosphorus Removal

The data shown in Figure 19 were pooled from 17 Imperial Valley field sites and averaged for each treatment/field location. Compared to the Control treatments, there were no significant reductions in drain box P_S during 1 mg L^{-1} PAM treatments ($p > 0.1$) (Figure 19a, b) There were significant reductions in P_P at mid field, field tail, and drain box ($p < 0.05$). However, these reductions were partially nullified by sediment re-suspension in excessively steep drain ditches, as noted earlier. Despite this drain box spike in P_P, there was only a weak correlation between P_P and turbidity (data not shown). Apparently, the high variability in soil properties, crops, and irrigation and fertilizer management among field sites affected the relative loss of sediment and P.

Figure 18a shows how drain box P was affected by varying PAM addition rates. Data for 0 and 1 mg L^{-1} PAM treatments represent 17 Imperial Valley field sites while 5 and 10 mg L^{-1} PAM treatments represent only one field site. The downward trend in Total P was driven by significant decreases in P_P seen at 0-1 and 5-10 mg L^{-1} PAM ($p < 0.05$). Although continuous application of 10 mg L^{-1} PAM did reduce P_T by 52%, growers may not find this application rate desirable since it is ten-times the rate needed to achieve the current Sediment TMDL.

None of the treatments evaluated in this study significantly decreased P_S, the most bioavailable fraction of phosphorus load to the Salton Sea (Figure 18a). This is contrary to the 50% reductions in P_S reported in Idaho's Snake River Valley (Lentz et. al., 1998). This may be due to irrigation water salinity differences between Idaho's Snake River Valley and Imperial Valley's Colorado River water (Table 6). Higher TSS and Na concentrations in the Imperial Valley may reduce the efficacy of PAM to remove soluble phosphate. It has been shown that sodium impairs the ion bridging needed for PAM to adsorb PO_4 (Entry & Sojka, 2003). Conversely, sodium adsorbed to anionic PAM and dissolved organic matter (DOM) exchange sites may subsequently inhibit P_S adsorption to PAM floc or even cause further dispersion of P_S from soil surfaces. Future work to test this hypothesis should include P_S sorption / desorption experiments with varying sodium adsorption ratios.

Effects of Liquid Phosphate Fertilizer Application to the Irrigation Water

We sampled one field site while liquid orthophosphate-P (OPP) fertilizer was injected into the irrigation water at the inflow end of the field (Figure 19c). The fertilizer concentration was 20 mg L^{-1} P at the field head. The majority of the OPP injected left the field un-adsorbed, whether in the presence of PAM or not. What more, phosphorus content of OPP amended irrigation water at the drain box was 100% P_S, the most bioavailable fraction of P.

Irrigation Water PAM Concentrations

PAM concentrations were measured in the irrigation water from inflow to drain box at three field sites (Figure 20). Although the PAM was added at the rate of 1 mg L^{-1}, the maximum concentration measured was consistently less than 0.5 mg L^{-1}. The peak concentration occurred at different field locations at the different field sites (Figure 20a). This may be attributed to two factors: 1) powdered PAM does not immediately dissolve when sprinkled into the flowing water, thus concentration is dependent on mixing energy, and 2) PAM adsorption may vary with soil texture, salinity, and organic matter content. Although the rates of PAM adsorption varied between sites, adsorption was nearly complete once water reached the drain box as is evident from the near-baseline PAM concentrations at that location for all three field sites. The distance required to reduce 1 mg L^{-1} PAM treatments down to baseline levels was ~10 times greater than those reported for Snake River Valley soils (Lentz et al., 2002). This may be attributable to the higher salt content of the irrigation water and soils in the Imperial Valley.

At one site, PAM application rates of 5 and 10 mg L^{-1} were tested. There, PAM concentrations were diminished by 40-50% but concentrations > 2 mg L^{-1} were lost to the agricultural drain (Figure 20b). This may or may not be viewed as beneficial since increased PAM input to agricultural drains could improve drainage water quality but necessitate more frequent drain cleaning.

Conclusions

In this study, we demonstrated that anionic PAM applied to irrigation water can effectively reduce the sediment and particulate-bound phosphorus leaving agricultural fields in the Imperial Valley. There, continuous additions of 1 mg L^{-1} PAM to irrigation inflows could reduce drain water TSS by 71-91% and P_P by 44-52% for bare, tilled fields.

PAM application rates ≥ 5 mg L^{-1} to irrigation water will result in > 2 mg L^{-1} residual PAM inputs to agricultural drains. PAM inputs to drains could improve water quality in the drains and would not harm the organisms that reside there (Barvenik, 1994). Currently, ~480 km yr^{-1} of the total 2,260 km of Imperial Valley agricultural drains are continuously cleaned by a fleet of 6-7 excavators (Steven Charlton, personal communication). Since this fixed-rate of dredging was legally arbitrated between the Imperial Irrigation District and the US Fish and Wildlife Service, increased sediment build-up in drains due to PAM additions would not necessarily result in more frequent drain cleaning.

The beneficial affects of PAM could be greatly enhanced if water velocities were reduced at the tail-ends of agricultural fields. Modifications to the slope and slope profiles of field tails coupled with improved drain ditch and drain box construction could greatly improve drain water quality.

Phosphorus is one of the few constituents in Imperial Valley soils that has increased over the last 50 years due to fertilizer application (Clerck et. al., 2003). In recent years, water-run fertilizer has become a common practice, especially for alfalfa production. The release of tailwater during liquid OPP fertilizer applications surely represents a major portion of the P_S load to the Salton Sea. Based on our observation of a 173 ha field, fertilized with water-run liquid OPP, 65 kg of P fertilizer (worth $100 USD) left the field at the drain box. Since these drains are connected to the Alamo River, this P_S was discharged directly into the Salton Sea.

Imperial Valley growers seldom have access to soil P-test information prior to fertilizer application and tend to over-apply for fear of limiting crop growth (Al Kalin, personal communication). Also, there are no regulations to prevent the running of tailwater during liquid OPP applications. Growers are quite able to reduce their P_P and sediment loads with their own BMPs and PAM applications. However, a soil P-management program is needed to help growers decide when, where, and which form of P fertilizer to apply. Such a P management program would surely curtail agricultural P_S loading to the Salton Sea and be a major step toward relieving its eutrophic condition.

Acknowledgements

This work was made possible by funding from the California State Water Resources Control Board (Funding Program: Proposition 13, Contract # 02-051-257-1) and the Salton Sea Authority. Al Kalin of the Imperial County Farm Bureau was instrumental in finding growers willing to participate in this study and provided valuable information on Imperial Valley agricultural practices. Steven Charlton of the Imperial Irrigation District provided valuable information on their drains and cleaning practices. Jason Adelaars, Jianhang Lu, Peggy Resketto, Ed Betty, and Brooke Mason of UCR provided invaluable laboratory assistance.

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TABLES

Table 6. Comparison of Idaho's Snake River Valley and California's Imperial Valley irrigation waters. EC, electrical conductivity; SAR, sodium adsorption ratio; Na, sodium; K, potassium; Ca, calcium; Mg, magnesium; DOC, dissolved organic carbon.

	EC	SAR	Na	K	Ca	Mg	DOC
	dS m^{-1}		mg L^{-1}				
Snake River	0.5	0.6	31	0.4	4	1.2	0.4
Lower Colorado River	1.1	3.1	136	6	92	35	5.1

Snake River water data from Entry & Sojka, 2003

FIGURE CAPTIONS

Figure 1. Schematic of field sampling locations for a) No PAM and b) PAM Treated sets of border-controlled lanes. Distances are approximate.

Figure 2. Battery-powered, rotary feed PAM applicator dosing inflow water.

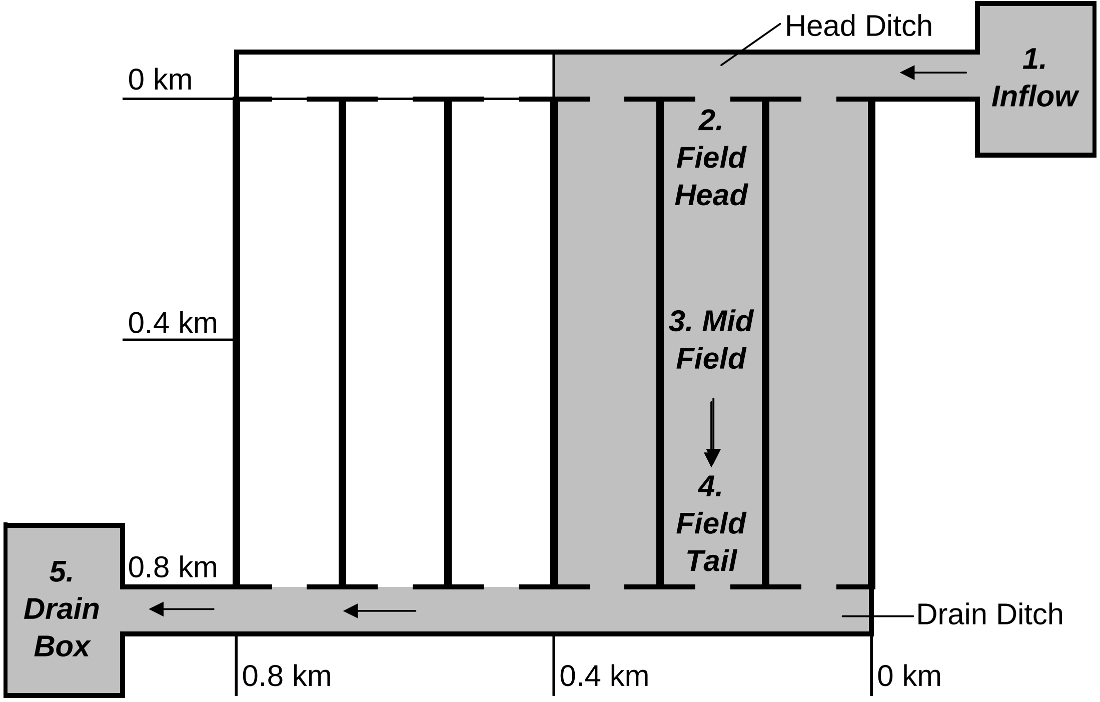
Figure 3. Overall average reductions in irrigation water turbidity and total suspended solids (TSS) for Control versus PAM Added (1 mg L^{-1}) treatments. Error bars indicate random standard deviation (RSD); n=75 samplings for turbidity and n=38 for TSS.

Figure 4. Variable PAM treatment effects on drain box a) average total P (P_T), soluble P (P_S), b) turbidity, and TSS. Error bars indicate RSD.

Figure 5. Overall average P versus distance for a) control (n = 38), b) 1 mg PAM L^{-1} added (n = 45), and c) 1 mg PAM L^{-1} plus liquid orthophosphate-P (OPP) fertilizer treatments (n = 3). Error bars indicate RSD of n samplings.

Figure 6. Measurements of irrigation water PAM concentrations (mg L^{-1}) for Control and PAM treatments. Figure (a) shows Control and 1 mg L^{-1} PAM treatments at sites X, Y, and Z while (b) shows Control, 1, 5, and 10 mg L^{-1} treatments at site Z only. Error bars indicate one standard deviation of the mean.

a) No PAM Treament



b) PAM Treament

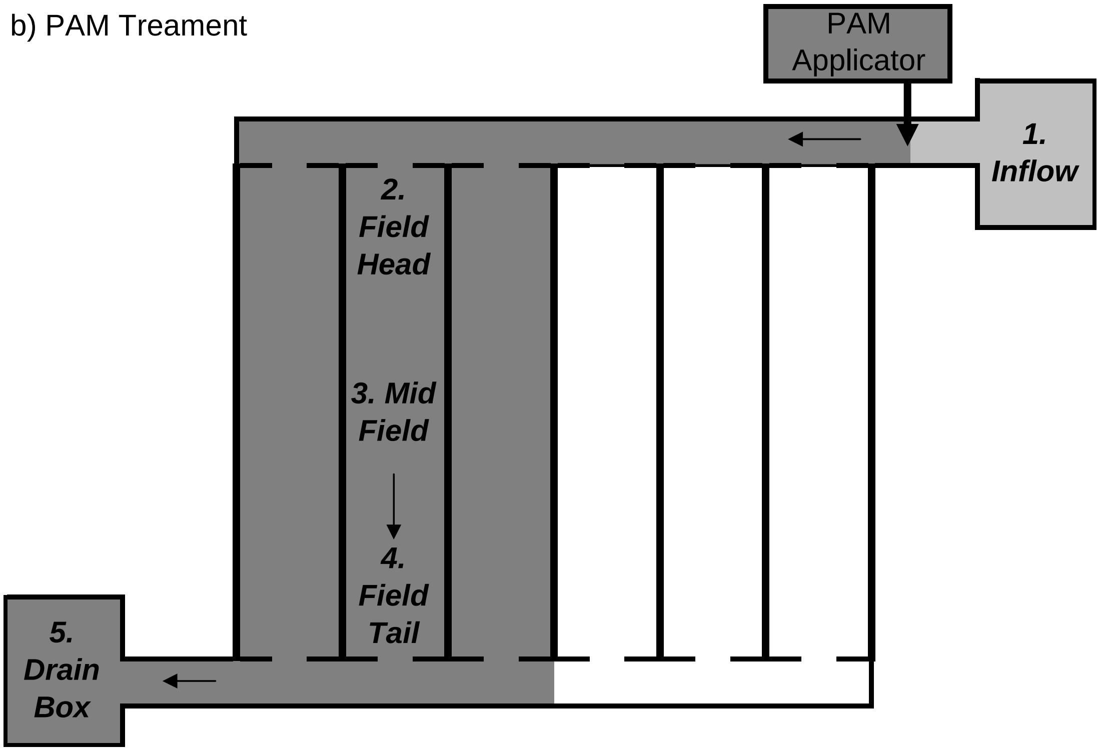


Figure 15. Schematic of field sampling locations for a) No PAM and b) PAM Treated sets of border-controlled lanes. Distances are approximate.

Figure 16. Battery-powered, rotary feed PAM applicator dosing inflow water.

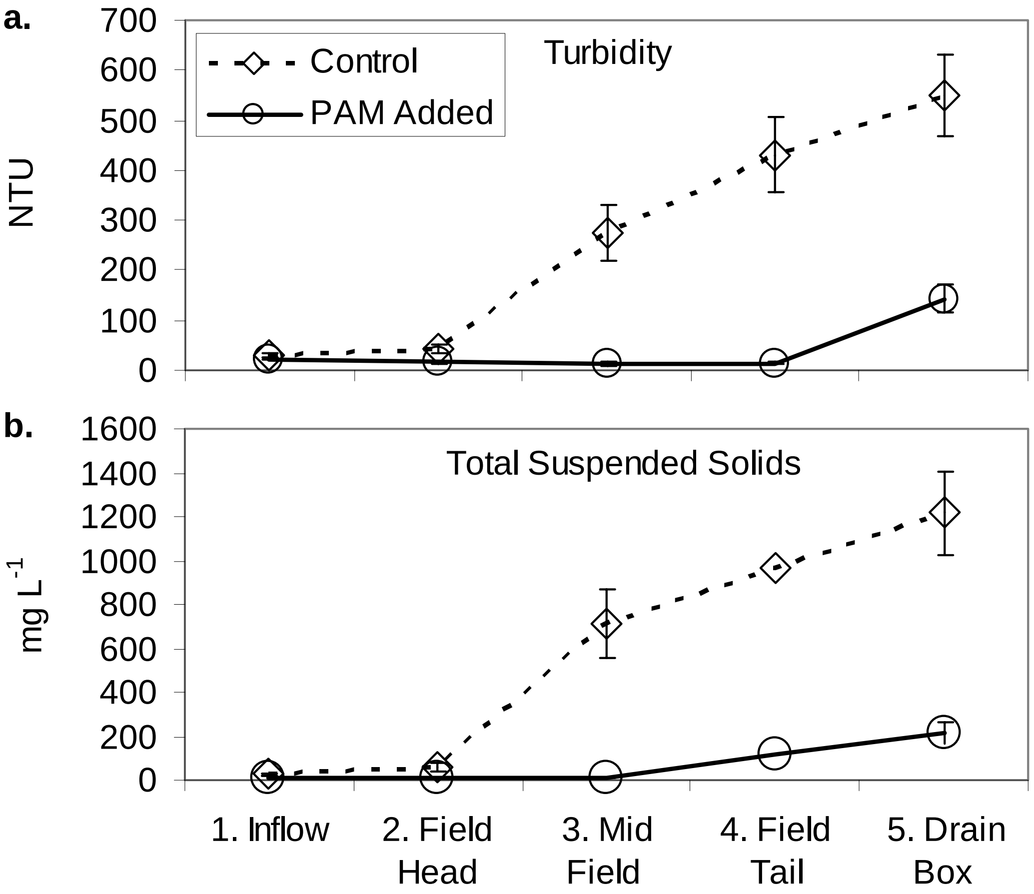


Figure 17. Overall average reductions in irrigation water turbidity and total suspended solids (TSS) for Control versus PAM Added (1 mg L^{-1}) treatments. Error bars indicate random standard deviation (RSD); n=75 samplings for turbidity and n=38 for TSS.

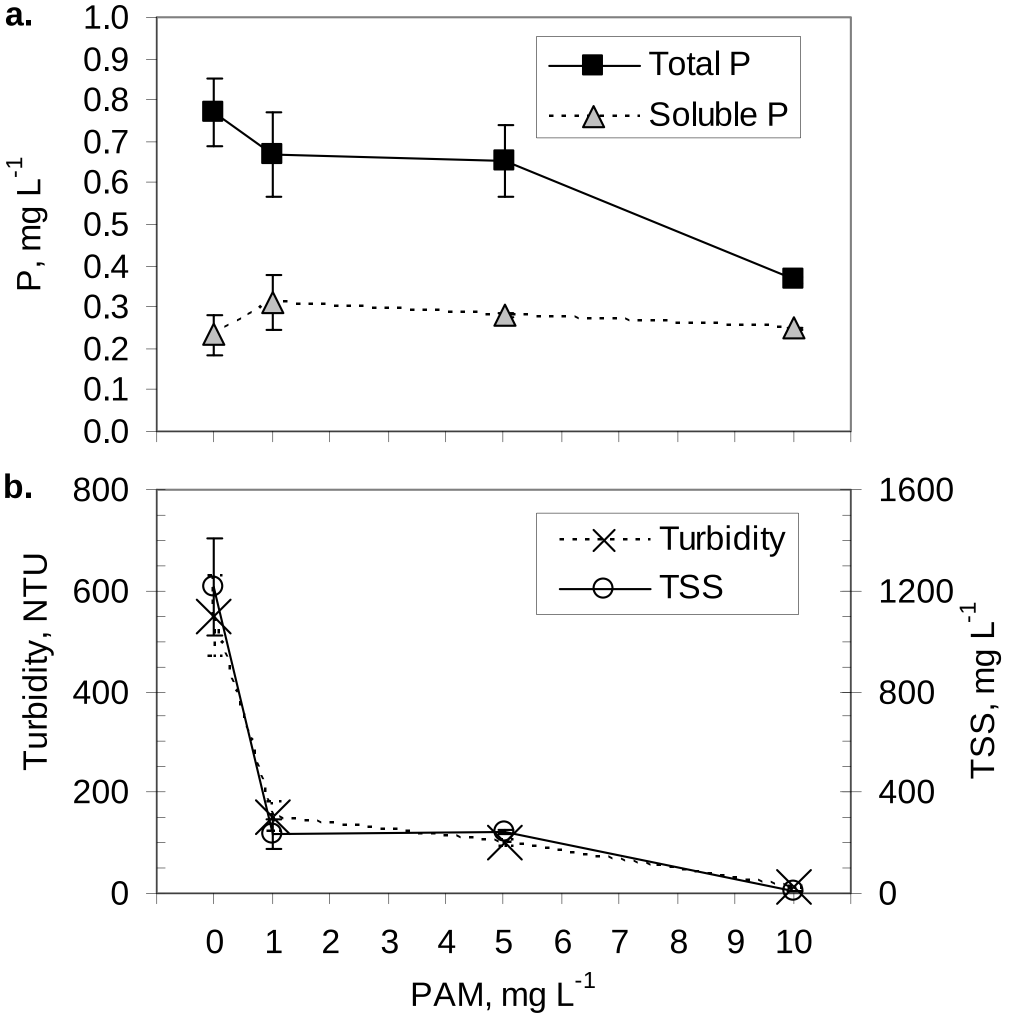


Figure 18. Variable PAM treatment effects on drain box a) average total P (P_T), soluble P (P_S), b) turbidity, and TSS. Error bars indicate RSD.

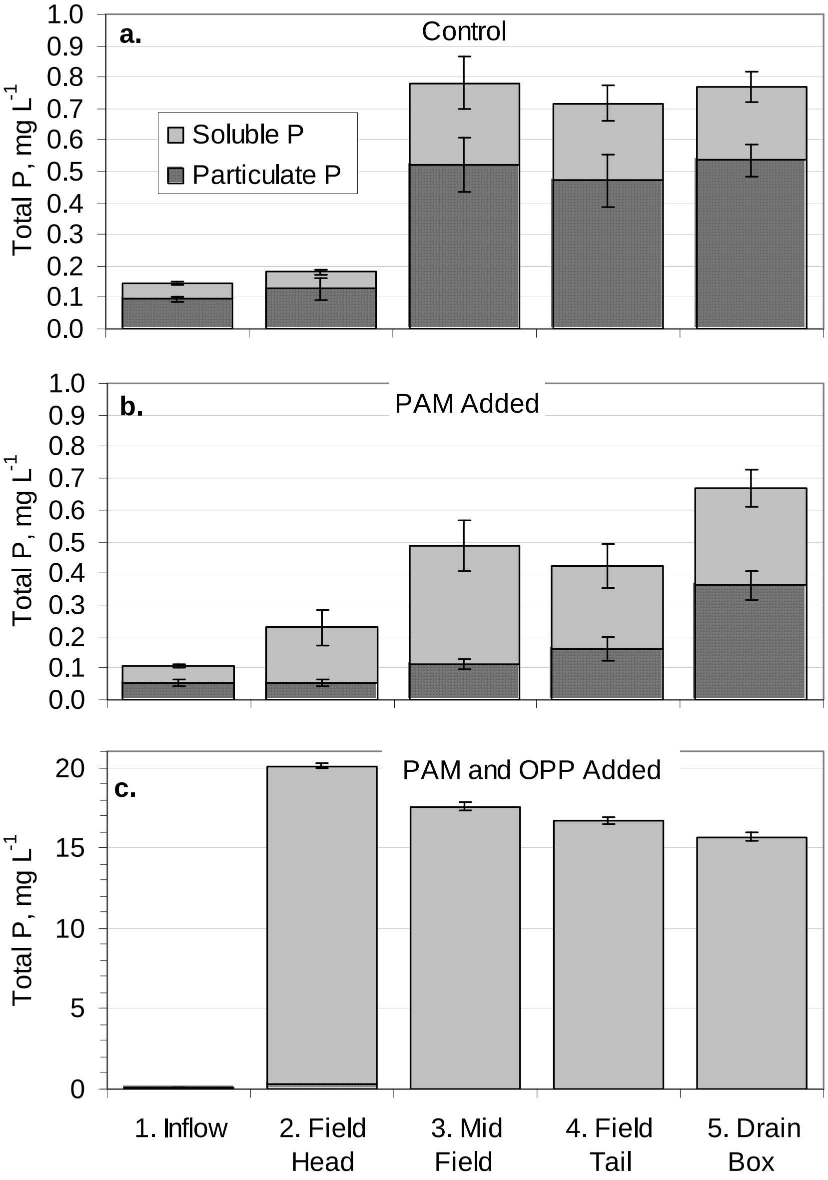


Figure 19. Overall average P versus distance for a) control (n = 38), b) 1 mg PAM L^{-1} added (n = 45), and c) 1 mg PAM L^{-1} plus liquid orthophosphate-P (OPP) fertilizer treatments (n = 3). Error bars indicate RSD of n samplings.

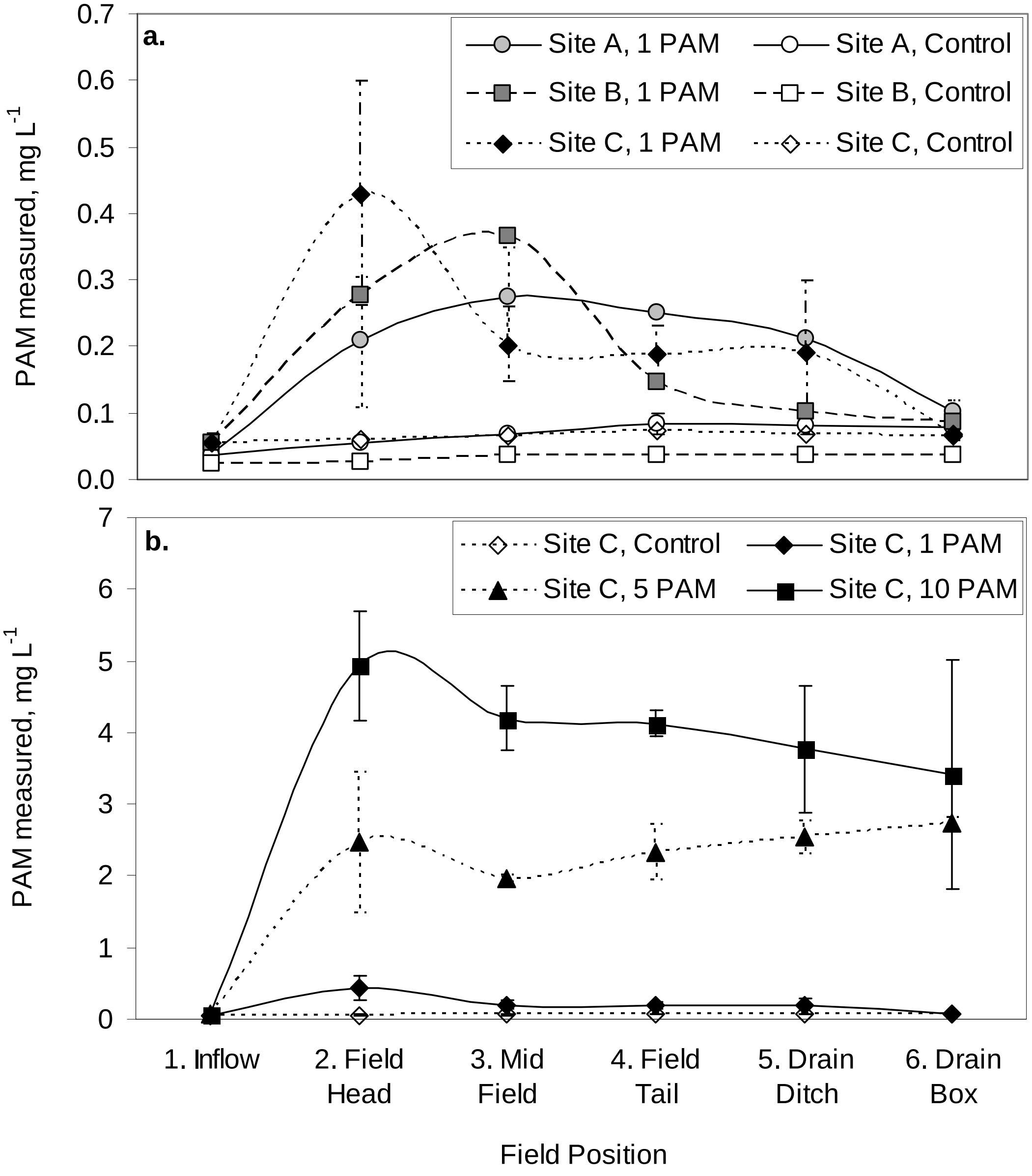


Figure 20. Measurements of irrigation water PAM concentrations (mg L^{-1}) for Control and PAM treatments. Figure (a) shows Control and 1 mg L^{-1} PAM treatments at sites X, Y, and Z while (b) shows Control, 1, 5, and 10 mg L^{-1} treatments at site Z only. Error bars indicate one standard deviation of the mean.

TASK 9. PILOT-SCALE STUDIES OF P REMOVAL USING THE CEP

Task 9. Conduct pilot-scale studies of removal of phosphorus using CEP technology

Subtask 9.1. The CEP units were supplied with 85 to 100 gallons minute^{-1} acre^{-1} of water from the Whitewater River. Incoming phosphorus concentrations ranged from 1.2 to 2.7 mg/L total phosphorus. Algal uptake rates are temperature dependent resulting in significantly lower phosphorus uptake rates during the winter compared to summer. We found that winter nutrient fixation rates can be as little as 25% of the summertime rates. Incoming Whitewater River water ranged from 1.2 to 2.7 mg/L total phosphorus and with 100 % algal removal (done by filtration) the phosphorus concentration ranged from 0.36 mg/L to 1.0 mg/L.

Additions of chemical flocculants like iron sulfate and alum were hoped to aid with the removal of phosphorus, potentially as a final polishing step, or for winter time P removal to make up for lower wintertime CEP performance. However, these chemicals did not remove a sufficient amount of P during periods of low productivity (due to low temperature). In the large 0.7 acre unit, to obtain a residual soluble phosphorus concentration of 0.05 mg/ L, it was found that 0.05 mL of 40% $FeCl_3$ solution per L of CEP water was required, while 100 mg Alum-Al per L of CEP water was required. The total phosphorus remaining in the water column was dependent on the ability to remove the chemical flocs. We feel that the only chemical additions needed throughout this process may be as a final polishing step, after biological (Nile Perch) removal of the algal biomass, thus reducing the amount required to perhaps 1%.

Subtask 9.2. We have operated CEP systems for several years near the Salton Sea and have observed the single-celled algae species that develop in the systems as the systems become established. There are predictable seasonal changes that occur in the algal populations, with the summer first dominated by blue-green algae and then switching to green algae. During the fall months, a population of diatoms will often develop and then the system will revert again to primarily green algae. This also happens during the spring time. Diatoms tend to dominate during rapid temperature fluctuations (Fall, Spring). The system tends to be dominated by green species as long as there is a filter feeding fish present. Blue-green algae may dominate if there is no filter feeding fish present.

During this pilot-scale effort, we sampled and identified the algal populations. We also developed estimates of the algal standing crop, based on Secchi Disk transparency measurements and suspended solids concentrations. For the 4 months of observations, two species dominated the water column. For the stable cold water, 9-12 C (AM temp), *Scenedesmu*s was the dominant species. During the transitional warming period a Centric Diatom dominated. After stabilization at 16 – 18 C (AM temp), the *Scenedesmus* dominated once again. Figure 9.2.1 shows a few of the previous algae that has been observed in the CEP over the past 3 years.

Figure 9.2.1. A variety of species have been identified in the CEP process over the years.

Subtask 9.3. An evaluation of the external carbon requirements would require that carbon be supplied at a minimum of the rate that the algae are fixing nutrients. Additionally, a portion of that carbon may be supplied by the filter feeding fish in the form of CO2.

An additional source of carbon might come from the use of anaerobic fermenters to produce biogas which when combusted produces electricity and carbon dioxide. This carbon dioxide could be captured and recycled back to the CEP units to maximize algal production and thus phosphorus uptake. Researchers at Clemson University found that biogas (methane and CO2) production could be increased when the C/N ratio was adjusted slightly thus being able to supply 100% of the required carbon for the CEP. These findings are very promising for the future of the CEP.

In the full scale application of the CEP technology, the use of fish and anaerobic fermenters as a carbon source could greatly decrease the amount of supplemental carbon required. More research on fermentation systems will be needed to determine the scalability of these systems for large scale implementation.

Subtask 9.4.. An algal harvest belt system was designed and installed at Clemson University's CEP units during the first phase of CEP work. The belt harvester operates on the principal of sedimentation of algal biomass, gravity thickening of the algal sludge, and continuous removal via the slow (3 inches/minute) cleated belt action that lifts the settled algae from the water at a critical angle of 11 degrees. The belt harvester has been shown to be capable of delivering a concentrated algal paste that consists of 10-15% algal cells on a dry weight basis, both with and without the use of metal salts to enhance algal flocculation and settling.

Subtask 9.6. Researchers at Clemson University found increased gas production rates as the C/N ratio was increased to about 20:1. Carbon was added to the digesters in the form of waste cellulose (paper). The methane production rate increased from 400-600 mL per L to 1000-1200 mL per L. Such a significant increase in methane production makes anaerobic fermentation a very realistic possibility to generate revenue for the CEP process. In addition, with the waste paper, enough carbon (in the form of CO2) is generated to supply 100% of the algal needs.

TASK 10. MONITOR AND ENHANCE SE UPTAKE IN CEP SYSTEM

TASK 10. MONITOR BIOLOGICAL SE-UPTAKE AND EVALUATE CEP FOR SE-REMOVAL

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 sought to compare levels of selenium and other analytes in these rivers and the degree to which they may be reduced in the CEP system.

Methods

Bulk water samples were collected from the Alamo, New, and Whitewater Rivers and the CEP Algae Zone (see Table 7 and Figure 21).

Table 7. River and CEP 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
CEP Algae Zone	Kent SeaTech Fish Farm, CEP Algae Zone

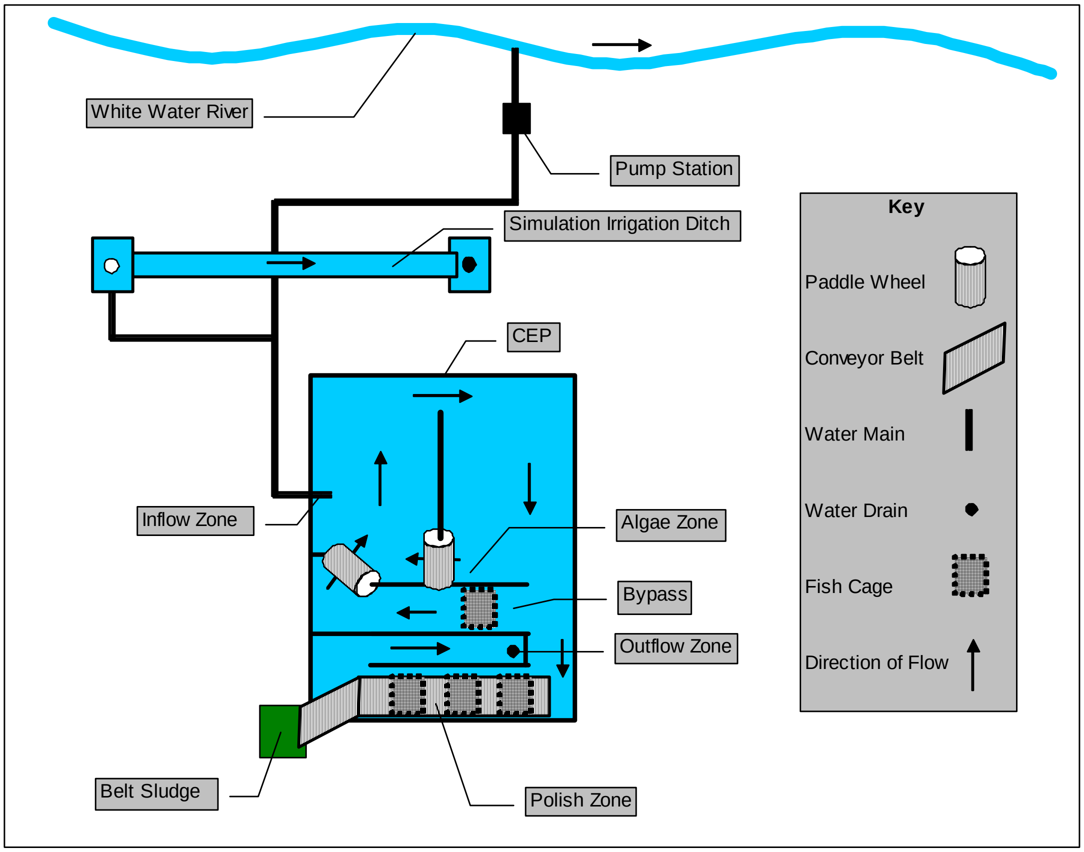


Figure 21. WhiteWater River, CEP and sampling points used at Kent SeaTech's Coachella Valley fish farm (not drawn to scale).

Water samples were appropriately acidified and 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) as needed. 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 Absorption (AA) Spectrometer for total As, Fe, and Se concentrations. Aluminum concentrations were measured with a Plasma Quad ICPOES (Perkin Elmer, Wellesley, MA). Turbidity, ammonia, nitrate, and phosphorus samples were prepared and analyzed as in Task 6. Titrated alkalinity and pH were determined using an Orion EA 920 pH meter. EC was measured in the lab with a YSI 3200 Conductivity Instrument.

Table 8. Fall/Winter '03/'04 conditions in the Salton Sea's tributary rivers.

	Ammonia-N	Nitrate-N	Dissolved Reactive Phosphorus-P	Total Phosphorus-P	Al	Fe	TSS
	(mg/L)						
Alamo R.	1.2	6.6	0.7	1.0	1.293	4	190
New R.	10.9	2.6	2.4	2.6	0.903	13	200
Whitewater R.	2.0	20.9	1.5	1.9	0.250	NA	10
CEP-Treated Whitewater R.	1.8	9.3	0.3	0.6	0.323	NA	56

	As	Se	Alkalinity to pH 4.4	pH	EC	Turbidity	Temp.
	(ug/L)		(mgCaCO3/L)		(uS/cm)	(NTU)	(deg. C)
Alamo R.	4.3	6.3	267	7.4	3404	145	NA
New R.	4.5	3.1	379	7.3	7030	83	NA
Whitewater R.	1.9	2.5	215	7.4	2111	77	17
CEP-Treated Whitewater R.	4.5	1.5	222	7.3	1793	31	NA

Samples were taken between 10/13/03 and 2/3/04. Ammonia-N, Nitrate-N, and DRP values are averages from samples of filtered water (n=1 for Alamo R. and New R., n=3 for Whitewater R). TSS, Turbidity, EC, pH, and Temperature were measured on raw water.

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 Absorption (AA) Spectrometer 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. HNO_3, 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 12).

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 concentrations were 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. However, after the CEP had received several weeks of WR inflow, it's Se concentration remained below that of the WR and within the limits of this TMDL. Therefore, it is probable that Se is removed by bioflocculation and settling and/or volatilization from the CEP.

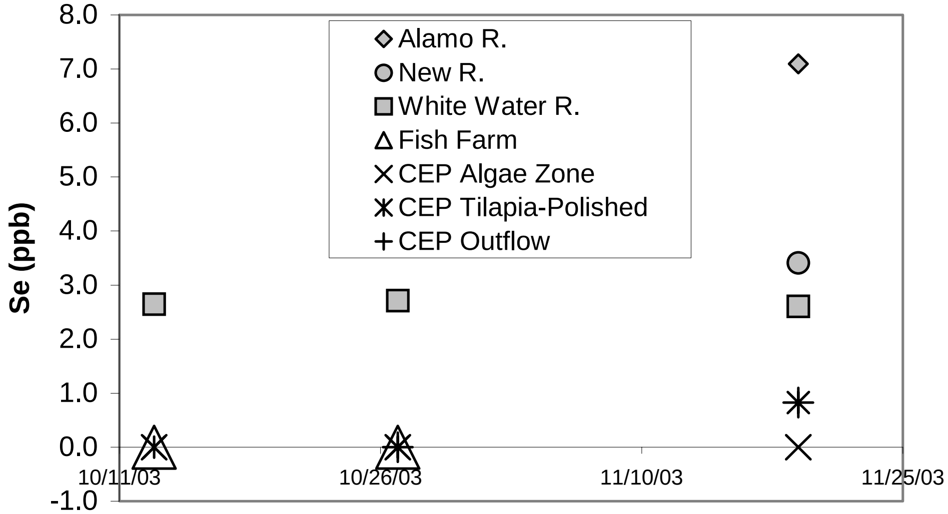


Figure 22. River and CEP water selenium concentrations

Even with low water Se concentrations, fish with longer residence times in the CEP accumulated greater concentrations of tissue Se (see Figure 23). This data indicates that Se can and does accumulate at all trophic levels of the CEP system and could be a useful tool for Se removal from agricultural waste water flows.

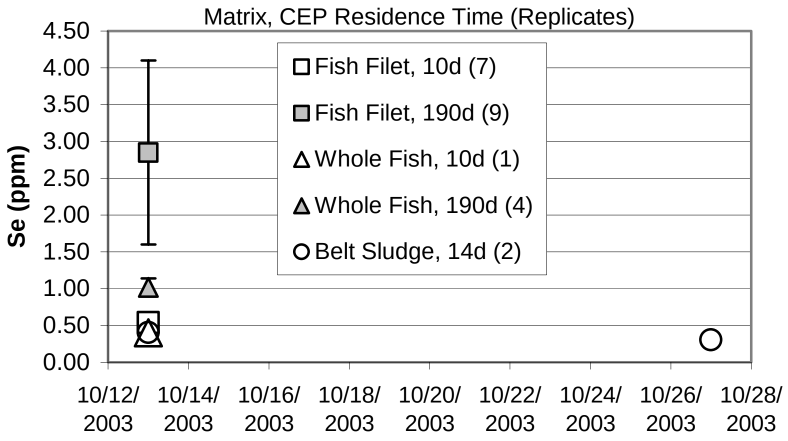


Figure 23. CEP fish and belt sludge dry weight selenium. The key lists Sample Matrix, CEP Residence Time, and (Replicates). Vertical bars indicate one standard error.

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TASK 11. DETERMINE EFFECTS OF TSS ON CEP EFFICIENCY

This manuscript is in review for publication in *Hydrobiologia*.

Phosphorus availability in suspended sediments entering the Salton Sea

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Key words: bioavailable phosphorus, phosphate, eutrophication, adsorbed phosphate, reducible iron.

Headings:

Abstract

Introduction

Materials and Methods

Results and Discussion

    Bioavailable Particulate P (BPP)

    Iron-related P

    Organic P

    Mineral-related P

Conclusions

Acknowledgements

References

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This paper has not been submitted elsewhere in identical or similar form, nor will it be during the first three months after its submission to *Hydrobiologia*.

Abstract

Eutrophic conditions in the Salton Sea have caused low dissolved oxygen and massive fish kills. Previous research has shown that phosphorus (P) is the limiting nutrient for algae growth, with the three tributaries, the Whitewater, New, and Alamo Rivers contributing 84% of the external P load. Of the external P load, an average of 35% is sediment-bound P. Recently mandated total maximum daily loads (TMDLs) for suspended solids in the rivers will help to reduce external P loading to the Sea. In this study, we quantified the fraction of total particulate P (TPP) that can become bioavailable to evaluate the potential benefit of suspended solids reduction on the eutrophic status of the Sea. Extractions were completed to include both bioavailable particulate P (BPP) that is available under oxic conditions and iron-related P that can become available in anoxic conditions. Suspended solids from the tributary rivers measured 6.6-13.2 % BPP and 6.7-33% iron-related P. Particulate organic P (P_O), which can become bioavailable over time through microbial activity, represented up to 12% of TPP. Most of the TPP (52-70%) was mineral-related and would not contribute bioavailable P. The mineral-related P of the New and Alamo River sediment was associated with calcium, while reduced iron minerals apparently dominated the Whitewater River sediment. This study indicated that an average of 38% of the TPP in the tributaries could become bioavailable once the suspended sediment flows into the Sea.

Abbreviations: P = Phosphorus; TPP = total particulate P; BAP = bioavailable P; BPP = bioavailable particulate P; P_O = organic P; P_I = inorganic P; TMDLs = total maximum daily loads; PAM = polyacrylamide; CBD = citrate bicarbonate dithionite; P_{CBD} = P extracted in CBD; RCF = relative centrifugal force; LOI = Loss on ignition; DI = Deionized water; OM = organic matter; SI = Saturation Index

Introduction

Eutrophication of the Salton Sea has impacted its beneficial uses through excess algal biomass, low clarity, low dissolved oxygen concentrations, massive fish kills, and noxious odors. Phosphorus (P) has been determined as the limiting nutrient to the Salton Sea (Setmire et al., 2000). Because external phosphorus loading in the Salton Sea is high, reduction of tributary phosphorus may reduce eutrophication (Holdren & Montaño, 2002). The three tributaries to the Sea, the Whitewater, New, and Alamo Rivers, contribute 1425 Mm^3/yr of water to the Sea (84% of the Sea's inflow) (Setmire et al., 2000). Tributaries carry P to the Sea in both particulate and dissolved forms that comprise, on average, 35 and 65% of the total P load, respectively (Holdren & Montaño, 2002). Bioavailable P (BAP) is the fraction of P that is readily available for uptake by plants or algae and is the fraction of P that contributes to eutrophication. BAP is classically defined as soluble P plus a fraction of the total particulate P (TPP) that becomes soluble (Sharpley, 1993). However, once suspended solids settle to the bottom of the Sea, reducing conditions release iron-related P, causing more P than defined by traditional BAP tests to be mobilized in the water column (Wetzel, 2001). This redox-sensitive P pool is important in management strategies when controlling TPP load (Uusitalo & Turtola, 2003). In order to better understand the effects of tributary suspended solids on eutrophic conditions in the Sea, both the sediment-bound fraction of bioavailable particulate P (BPP) and iron-related P must be taken into consideration (Fig. 1).

Total Maximum Daily Loads (TMDLs) for suspended solids have recently been established for the New and Alamo Rivers. The New and Alamo Rivers have averaged 306 and 377 mg/L suspended solids, respectively, during 1980-2001 (CRWQCB, 2002). The newly established

TMDLs require the rivers carry no more than 200 mg/L suspended solids. A reduction in suspended solids will decrease the external P load to the Sea and will be achieved through on-farm practices and the use of polyacrylamide (PAM) in the irrigation water. Previous research has found that PAM, when added to the irrigation water and drainage water, can reduce suspended sediment loading (Amrhein et al. 2005). The question arises, if the suspended solids are reduced an average of 42% (to <200 mg/L) what effect will this have on the algal blooms in the Sea? To answer this question, it is necessary to know how much particulate P becomes bioavailable upon entering the Sea, and how much P will become bioavailable once the sediment settles to the bottom of the Sea (iron-related P).

BPP has been measured in many locations as an accurate assessment of agricultural management practices (Sharpley, 1993). Preliminary studies of Salton Sea tributary sediment showed no difference in chlorophyll ***a*** fluorescence between a control and 400 mg/L application of either New or Alamo River sediments (Anderson, 2003). Traditional measurements of BPP include chemical extractants and algal assays, although algal assays are more time consuming and more difficult to reproduce than the chemical methods (Miller et al., 1978; DePinto et al., 1981; Lovestad & Krogstad, 1990). Standard methods of BPP determination include extraction with calcium chloride (Mehlich-1, Mehlich-3, and Bray-1 methods), sodium bicarbonate (Olsen method), ammonium bicarbonate diethylenetriaminepentaacetic acid (DTPA), exchange resin, and iron oxide impregnated paper (Kuo, 1996).

In order to measure BPP on sediment in our tributary waters, the appropriate method should be applied. The calcium chloride extraction was not used since the amount of P extracted is sensitive to pH and ionic strength (Kuo, 1996). The Mehlich extractants, both 1 and 3, and the

Bray extractant are acidic solutions and not suitable for calcareous soils or base saturation levels greater than 7% (Kuo, 1996)

The 0.5 M $NaHCO_3$ extractant of the Olsen method has been well correlated to soil BPP in various soil types (Kamprath & Watson, 1980) and is particularly suitable for calcareous soils. The Olsen method has also been well correlated to a resin extractable P (Kuo, 1996). It is generally assumed the OH^- and CO_3^{2-} in the $NaHCO_3$ extractant increase the solubility of P via ligand exchange and complexing free Ca^{2+} (Kuo, 1996).

Since our sediment is derived from the Imperial and Coachella valleys where the soils are higher in pH (8.0-8.2) and calcareous in mineralogy (USDA Soil Conservation Service, 1980 & 1981), the Olsen method was used to determine the BPP of the suspended solids in the tributaries to the Sea. As a comparison, filtered Salton Sea water was used as an extractant to simulate desorption of sediment-bound P when suspended solids flow to the Sea. The Salton Sea water has a higher ionic strength (0.76 M) than the Olsen extractant (0.1 M), but the salinity is dominated by sulfate and chloride.

The citrate-bicarbonate-dithionite (CBD) extraction is used to measure total “free” iron oxides (Leoppert & Inskeep, 1996). The CBD solution extracts both P adsorbed on iron oxide surfaces and P occluded within the iron oxides (Ruiz et al., 1997). The dithionite in the extraction solution serves as the reductant, reduces iron, and extracts reactive ferric-bound P (Ruttenberg, 2005). Using the CBD extraction we will quantify the amount of P that can become bioavailable under reducing conditions.

Analysis of the suspended solids in each of the tributaries to the Sea was used to provide a better understanding of the effects of the TPP load on eutrophic conditions in the Salton Sea.

Materials and Methods

Bulk river water samples for the three tributaries were collected on 4/13/05 and brought back to the lab for analysis (Fig. 2). The river water samples were centrifuged at 3000 RCF for 10 minutes (Sorvall SS-3 Automatic Centrifuge, Newtown, CT), and the suspended solids collected and stored moist at 6^oC for <24 hours. A subsample of the moist sediments was analyzed for water content by drying overnight at 105^oC. Sediment samples were not dried prior to extraction to prevent dehydration and crystallization of the minerals containing P.

BPP was analyzed using the Olsen Method following Kuo (1996) where 0.5 M $NaHCO_3$ (pH 8.5) was used as the extraction solution. The Salton Sea water was used as an extractant to mimic the environmental conditions that might be expected for the sediments. In this case, Salton Sea water was filtered (< 0.45 µm pore diameter) to remove any algae and suspended solids.

Approximately 1 gram of wet weight sediment was placed in a 50 mL Erlenmeyer flask containing 25 mL of the extractant, and the flask was placed on a shaker (Eberbach Corp., Ann Arbor, MI). The $NaHCO_3$ extractant was mixed for 30 minutes following Kuo (1996), and the Salton Sea water extraction was allowed to react for 3 hours, 1 day, and 3 days. The samples were then filtered (<0.45 µm) and 10 mL of the filtrate placed in a 25 mL volumetric flask. The pH was reduced to pH < 5.4 with concentrated sulfuric acid using a *p*-nitrophenol indicator. The solution was then brought to volume with deionized (DI) water. The samples were tested for ortho-phosphate using a modified ascorbic acid-molybdate blue method (Murphy & Riley, 1962) on an Astoria-Pacific Int. Alpkem RFA 300 Autoanalyzer (Clackamas, OR). All extractions were done in triplicate with standard deviation as the reported error. The established QA/QC protocol of the lab was followed which includes matrix-matched standards, spike additions, and duplicates. If a set of analyses had spike recoveries and duplicates within 15%, the set was deemed acceptable.

Phosphorus associated with iron oxides in the suspended sediments followed a modified method of Ruiz et al. (1997). Approximately 1 gram of wet weight sediment was placed in a 50 mL polypropylene centrifuge tube with 40 mL of extractant solution. The extractant solution was 0.2 M Na-citrate + 0.11 M $NaHCO_3$ + 0.12 M Na-dithionite (CBD). The suspensions were mixed on a reciprocating shaker for 16 h, centrifuged at 1100 RCF for 10 minutes (Damon/IEC Division, C4-5000 Centrifuge), and analyzed for Fe and P with an ICP-OES (Perkin-Elmer, Optima AV) coupled to an ultra nebulizer (CETAC Technologies, U-6000$^+$). ICP-OES analysis was required for phosphorus because of chemical interferences with the ascorbic acid-molybdate blue method used above.

The TPP, inorganic particulate P (P_I), and organic particulate P (P_O) of the river sediment were determined following the methods of Aspila et al. (1976). For TPP analysis of the sediment, 0.3 g of sample was ignited at 550°C (Fisher-Scientific, Isotemp Muffle Furnace), placed in a 50 mL centrifuge tube, extracted with 40 mL 1N HCl for 16 hours, diluted 1:10, and tested for ortho-phosphate using the ascorbic acid-molybdate blue method on the Alpkem Autoanalyzer. P_I was extracted as the TPP method described above, but without ignition of the sample. P_O was calculated as the difference between TPP and P_I. The extracts were also analyzed for Ca, Mg, Al, Mn, Na, and K using ICP-OES. All extractions were done in triplicate with standard deviation as the reported error.

Organic matter (OM) was determined by loss on ignition (LOI) following the method of Nelson & Sommers (1996). Approximately 1 gram of oven-dried river sediment (105°C) was placed in a muffle furnace and ignited at 400°C overnight. LOI (%) was determined by the difference between the oven-dry weight and the ignited weight of the sample divided by the oven-dry weight.

SI (saturation index) values were calculated using the speciation model Visual MINTEQ (Gustaffsson, 2000). Simulations were carried out using river water values collected 3/30/2004 (Holdren, 2004, personal communication), and iron concentrations from Holdren & Montaño (2002)

Results and Discussion

Bioavailable Particulate P (BPP)

The amount of BPP differed between the extraction solutions, 0.5 M $NaHCO_3$ and filtered Salton Sea water. The $NaHCO_3$ extractant exceeded the P extracted with Salton Sea water in all three river sediments after only 30 minutes of mixing, when compared to the 3 day contact time with the Salton Sea water (Fig. 3). Since the HCO_3^- concentration is significantly higher in the sodium bicarbonate extract compared to the Salton Sea water (0.004 M, Holdren and Montaño, 2002: 18, table 7), it is proposed that the bicarbonate ion in the Olsen method was more competitive for the sorbed P on the soil particles than the sulfate- and chloride-dominated Salton Sea water, 0.11 and 0.49 M, respectively (Holdren & Montaño, 2002:18, table 7). Therefore, it appears that the Salton Sea water did not have a high enough carbonate concentration, which is one of the few anions that can compete for the phosphate sorbed on the solids. Since the Salton Sea water was used to simulate real conditions, the lower BPP values measured in the Salton Sea water extraction might actually be closer to available P from the river sediment.

In the context of previous research, our BPP measurements of 6.6 to 13.2% of TPP (Table 1) are in the low range. DePinto et al. (1981) measured an average of 21.8% of TPP was BPP in tributaries to the lower Great Lakes using algal assays. Sharpley et al. (1992) measured

BPP levels ranging from 9 to 69% of TPP on sediments in agricultural runoff water. Based on the Salton Sea water extraction, under oxic conditions, 2.4 to 6.3 % of TPP appears to be bioavailable (Table 1). This demonstrates that the TPP flowing into the Sea under oxic conditions does not severely contribute to bioavailable P that leads to eutrophication.

Iron-Related P

The reductive-dissolution of the iron (III)-oxide minerals in the sediments releases iron-related P into solution (Loeppert & Inskeep, 1996). The CBD extract dissolves both iron-associated P and bicarbonate-extractable P. The iron-related P is the difference between the phosphorus in the CBD extract (P_{CBD}) and the BPP from the Olsen extract (Fig. 1). The iron-related P represented a range of 7% to 17% of the TPP (Table 1). Our values for iron-related P were comparable to values of calcareous soils in Ruiz et al. (1997), which were the lowest among the soils tested.

The release of P under anoxic environments was higher in the suspended solids from tributaries draining the Imperial Valley. The river sediments from the New and Alamo Rivers had higher levels of reducible iron, 5.6 and 4.9 mg Fe/g, respectively, compared to that in the Whitewater River sediment (2.9 mg Fe/g). Therefore, more P can become available under anoxic conditions from the higher iron (III) suspended sediment of the southern tributaries.

Organic P

The organic P (P_O) fraction of the solids can become bioavailable through bacterial metabolism (Table 2). Bacteria produce organic acids and hydrolytic enzymes that release P from the TPP (Pettersson, 1998). If all of the P_O is eventually bioavailable, up to 12% of the TPP can contribute to eutrophication (Table 1).

Mineral-related P

The fraction of TPP that is not bioavailable in either oxic (BPP) or anoxic (iron-related P) conditions, nor associated with organic matter, is considered mineral-related P and is biologically unavailable (Fig. 1). This fraction of TPP is calculated as the difference between the inorganic P (P_I) and the P released in the CBD extract (P_{CBD}) and ranged from 52 to 71% of the TPP (Table 1). Metal analysis of the acid extract and chemical speciation of the river waters revealed relationships that suggest the form of the unavailable mineral P.

The New and Alamo River sediments were high in calcium, with P/Ca ratios of 0.03 and 0.02, respectively (Table 3). The high Ca content of the solids suggests the P may be in the form of a calcium phosphate, and chemical speciation of the river water using the computer program Visual MINTEQ (Gustaffsson, 2000) supports this. Positive SI values (over saturation) of 0.71 and 1.1 for the New and Alamo Rivers, respectively, were calculated for beta tricalcium phosphate ($Ca_3(PO_4)_2$), and SI values of 8.4 and 9.1 were calculated for hydroxyapatite ($Ca_5(PO_4)_3OH$). The other possibility is the association of P with calcite as a coprecipitate (Rodriguez, 2002).

The northern tributary, the Whitewater River, was much lower in Ca than the New and Alamo Rivers, but high in Al and Fe (Table 3). This river water suggests the possibility that a ferrous phosphate mineral, vivianite [$Fe_3(PO_4)_2{}^\bullet 8H_2O$] could be forming (SI value of 4.98, assuming ferrous iron). It is generally assumed that the CBD solution extracts only iron(III)-oxides and may not dissolve ferrous minerals in the sediment. In particular, the difference between the HCl-extracted iron and the CBD extraction suggests a significant ferrous solid phase is present in the Whitewater River sediments and not in the New and Alamo River sediments (Table 3). Vivianite, a ferrous phosphate mineral, has been seen in buried alluvium and associated with aluminum phosphates as well (Dudley, 1890). In the Coachella Valley, subsurface drainage water containing Fe(II) mixes with high-P agricultural runoff, which creates the conditions favorable for vivianite formation (Black, 1968).

Conclusions

The P release from the suspended solids in the Whitewater, New, and Alamo Rivers could potentially influence the eutrophic conditions in the Salton Sea. P released in the Salton Sea water under oxic conditions was lower than the amount solubilized in the classic Olsen method. Under anoxic conditions, P release was higher in the southern tributaries, since these sediments were higher in iron oxides. P_O ranged from 1.5 to 12% of TPP and can contribute to eutrophication in the Salton Sea. Most of the TPP (52-70%) was mineral-related P and considered non-biologically available. The New and Alamo River suspended solids were high in calcium, but the Whitewater River solids were dominated by a reduced iron mineral, hypothesized to be vivianite.

Reduction of suspended solids loads to the Salton Sea will have a limited impact on reducing eutrophic conditions because 2/3 of the P entering the sea is in the soluble form, and 52-70% of the particulate-bound P is not biological available. Reducing the suspended solids load by 42% to meet the target of 200 mg/L will reduce bioavailable P by 13 to 20%, thus having a limited impact on reducing P loading to the sea.

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Table 1. TPP of each tributary divided into various categories of availability

	Whitewater	**New**	**Alamo**
TPP Fraction	Fraction of TPP (%)		
BPP			
0.5 M $NaHCO_3$	11.2	13.2	6.6
Salton Sea water	6.2	4.1	2.4
(P_{CBD}-BPP)			
Iron-related P	6.7	33.2	16.9
(P_O)			
Organic P	11.4	1.5	12.2
(P_I-P_{CBD})			
Mineral-related P	70.7	52.2	64.3

TPP = total particulate phosphorus
BPP = bioavailable particulate phosphorus
P_{CBD} = P extracted with citrate-bicarbonate-dithionite
P_I = inorganic O
P_O = organic P

Table 2. Characteristics of tributary suspended solids

		Whitewater	New	Alamo
OM	**%**	1.4 ± 0.2	1.8 ± 0.2	1.9 ± 0.1
TPP	**mg/g**	1.2 ± 0.05	1.4 ± 0.1	1.15 ± 0.01
P_I	**mg/g**	1.1 ± 0.05	1.3 ± 0.1	1.01 ± 0.03
P_O	**mg/g**	0.14 ± 0.03	0.02 ± 0.15	0.14 ± 0.02

OM = Organic matter content
TPP = total particulate phosphorus
P_I = inorganic particulate phosphorus
P_O = organic particulate phosphorus

Table 3. Concentration of metals (extracted in 1 N HCl) in tributary suspended solids.

	Whitewater	New	Alamo
	mg/g		
Al	6.2 ± 0.6	3.4 ± 0.3	3.6 ± 0.2
Mg	4.0 ± 0.5	9.1 ± 0.5	10.0 ± 0.2
Mn	0.24 ± 0.03	0.57 ± 0.02	0.71 ± 0.03
Na	0.52 ± 0.05	1.7 ± 0.7	1.00 ± 0.02
Ca	12.5 ± 1.3	55 ± 4	63.5 ± 1.5
Fe	10 ± 1	6.4 ± 0.6	6.3 ± 0.5

Figure Captions

Figure 1. Organizational chart of P fractions in the tributary waters.

Figure 2. Map of the Salton Sea and its tributaries: the Whitewater, New, and Alamo Rivers. (● denotes sampling sites)

Figure 3. BPP of tributary sediment from two different extractants.

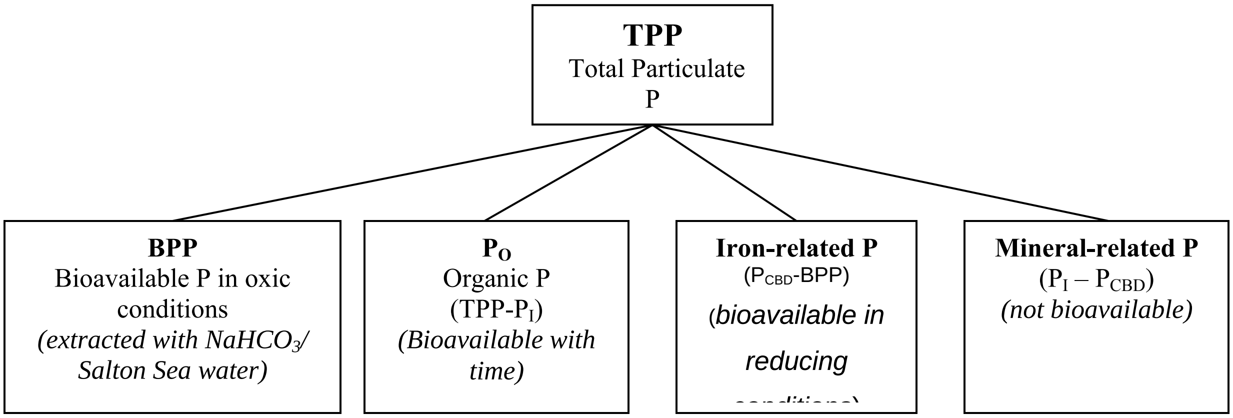


Figure 1. Organizational chart of P fractions in the tributary waters.

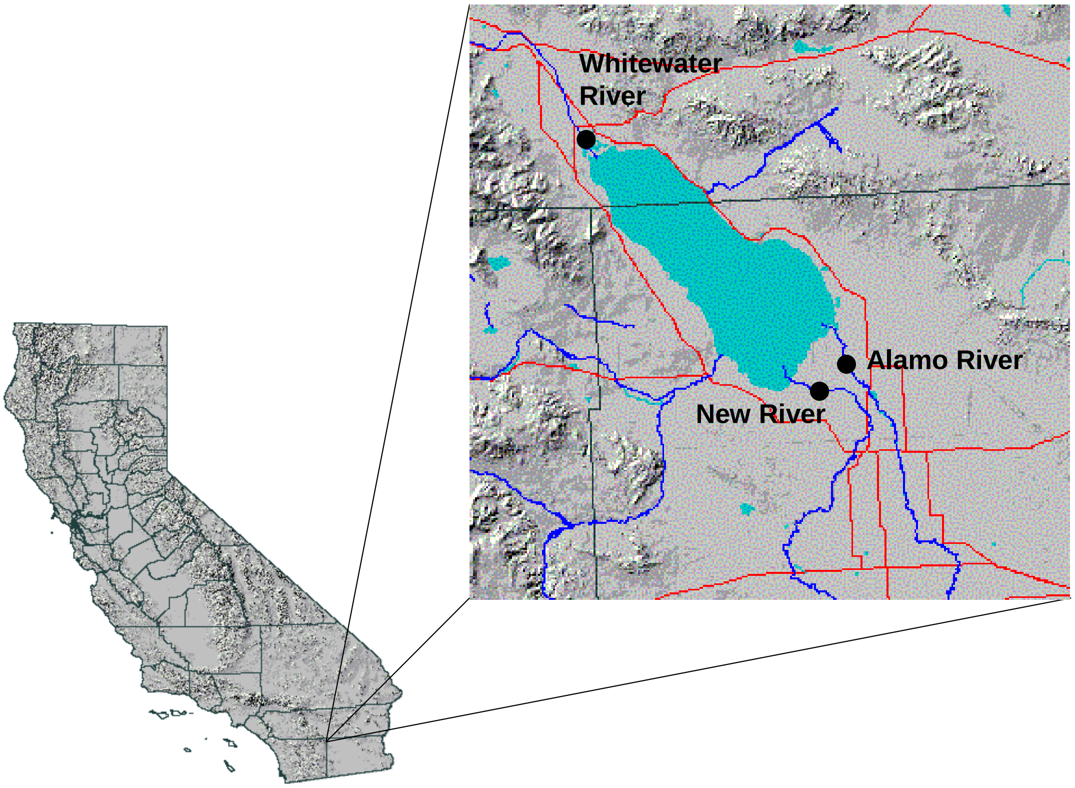


Figure 2. Map of the Salton Sea and its tributaries: the Whitewater, New, and Alamo Rivers. (● denotes sampling sites)

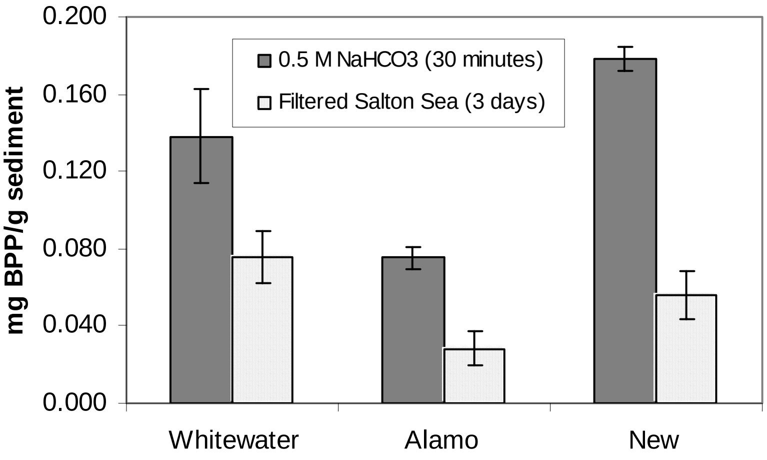


Figure 3. BPP of tributary sediment from two different extractants.

TASK 12. PREPARE COST PROJECTIONS

Task 12. Prepare cost projections

Methods

In order to begin to develop economic information that would allow decision-makers to determine the costs of full-scale implementation of the water treatment concepts evaluated during these studies, in this Task we developed preliminary projections of the annual costs of some of the major components that would be involved. The primary cost considered during this analysis was the annual expense involved in the purchase of flocculants. Several assumptions were made to develop these projections, as shown in Table 9 and Table 10 below. The calculations were based on the premise that in order to have a significant impact on the sediment and phosphorus entering the Salton Sea, it will be necessary to treat the input flows from the three principal tributaries of the Sea: the Alamo River, the New River, and the Whitewater River. Table 9 shows the average annual flows present in these tributaries and the approximate level of suspended solids (TSS) that are present. From these data, we calculated the total amount of sediments that are likely entering the Sea. Table 10 shows the cost assumptions used to estimate the total annual cost of the flocculants that would be required.

Table 9. Approximate water flow rates and sediment present in the principal tributaries of the Salton Sea.

	Annual Water Flow		Continuous Average Water Flow		TSS	Sediment Present
River	Ac-ft	m3 x 10^6	GPM	LPM	mg/L	Tonnes/day
Alamo River	613,000	756	380,010	1,438,336	355	735
New River	444,000	548	275,244	1,041,797	241	362
Whitewater River	95,000	117	58,892	222,907	87	28

Table 10. Costs of flocculants that could be used to control sediments and phosphorus entering the Salton Sea.

Flocculant	Cost per kg of active ingredient
Alum	$4.00 – 5.60
Polyacrylamide	$6.60-11.00

Based on these assumptions, we used the results of our treatment efficiency studies to predict the amount of flocculants that would be required to remove sediment and phosphorus from the tributary flows. Data from the three different methods that we used to estimate flocculant requirements are shown in the following sections: 1) Jar test estimates, 2) Simulation ditch estimates, and 3) Field trial estimates. Although the cost of the flocculants will be a major portion of the entire treatment cost, it should be remembered that several other significant costs also would be involved, which were beyond the scope of these studies. These include the costs of construction, maintenance, and operation of any required the mixing units, the costs of transport of the flocculants, costs of monitoring and control, and perhaps most significantly, the costs involved in removing and transporting the settled material to an environmentally-appropriate location such as landfill. Further studies will be necessary to develop accurate estimates of these related costs.

In the last section, we also provide preliminary estimates of the costs that might be encountered if an alternative method of phosphorus reduction were utilized: the Controlled Eutrophication Process (CEP) which is being evaluated by Kent SeaTech Corporation as a method of nutrient reduction in the Salton Sea.

Results

A) Estimates of Flocculant Requirements Based on Jar Test Data

Jar test studies were performed on water samples taken from the three major tributaries flowing into the Salton Sea: the Alamo, New and Whitewater Rivers. In laboratory studies, percent remaining for total phosphorus (TP), dissolved reactive phosphorus (DRP) and turbidity (Turb) were determined for a control and for each chemical treatment. The use of alum for the removal of TP and DRP is more efficient than PAM. Conversely, for the removal of turbidity, PAM is more efficient. Table 11 and Table 12 below show some of the results obtained during the jar test studies and the predicted flocculant costs for full-scale treatment of the three rivers.

Table 11. Percent total phosphorus (TP), dissolved reactive phosphorus (DRP), and turbidity (Turb) reduced by using alum.

ALUM - 4 mg Al / L				Chemical Application	
	% Reduction				
River	Turbidity	TP	DRP	kg / day	$ / day
Alamo River	91%	83%	75%	138,080	38,018
New River	93%	77%	79%	100,012	27,536
Whitewater River	78%	68%	82%	21,399	5,892
Daily Total =					71,446
Annual Total =					$ 26,077,787

Table 12. Percent total phosphorus (TP), dissolved reactive phosphorus (DRP), and turbidity (Turb) reduced (or increased, if negative) using PAM.

PAM - 2 mg / L				Chemical Application	Estimated Cost
	% Reduction				
River	Turbidity	TP	DRP	kg / day	$ / day
Alamo River	97%	32%	-3%	4,142	27,373
New River	97%	31%	-4%	3,000	19,826
Whitewater River	90%	9%	-1%	642	4,242
Daily Total =					51,441
Annual Total =					$ 18,776,007

An economic analysis was performed to determine the cost of applying chemicals to the entire flow of each river to reduce sediment flow to levels achieved in the jar test studies. Sediment removal would be slightly higher with PAM application, but nutrient removal would be substantially less. Using alum, we estimated that an annual cost of approximately $26 million would be incurred for chemicals alone for the three rivers combined. Treatment using the PAM polymer would be less at $18 million per year. These estimates do not include an engineered solution to trap the chemical sediment floc and remove it from the rivers. Using chemical flocculants to settle suspended solids could result in 1,125 metric tonnes of solid waste per day from all three rivers. The costs involved in removing this sludge matter may be as expensive as the chemicals.

B) Estimates of Flocculant Requirements in the Whitewater River Based on Simulation Ditch Studies

To estimate the costs involved in the use of alum and PAM for the reduction of turbidity, total phosphorus and dissolved reactive phosphorus, we evaluated the costs that would be incurred based on the data obtained in the simulation ditch studies we conducted with Whitewater River water. We evaluated a 3x3 matrix of combinations of alum and PAM, consisting of 0, 2, and 4 mg Al / L of alum (as aluminum), and 0, 2, and 4 mg/L of PAM. As in the previous analyses, the cost for alum in bulk was estimated to be $250 per ton, or $0.281 per kilogram, corresponding to $4.00 to $5.60 per kilogram of active ingredient (aluminum). The cost for PAM in bulk was estimated to be $6.60 to $11 per kilogram, depending on charge density and vendor. The flow rate of the Whitewater River is approximately 95,000 acre-feet per year. The percent reduction for turbidity, total phosphorus and dissolved reactive phosphorus is shown in Table 13 below. The percent reduction for each pollutant was calculated by dividing the simulation ditch discharge concentration by the influent concentration and subtracting it from 100%.

Table 13. Percent reduction of turbidity, total phosphorus, and dissolved reactive phosphorus in a simulation ditch receiving Whitewater River water and various combinations of alum and PAM.

	Simulation Ditch Percent Removal		
	PAM Concentration (mg / L)		
ALUM	**Turbidity**		
mg Al / L	0	2	4
0	51%	62%	39%
2	64%	77%	66%
4	63%	73%	66%
	Total Phosphorus		
0	5%	7%	-1%
2	27%	40%	35%
4	32%	53%	30%
	Dissolved Reactive Phosphorus		
0	-1%	-7%	-4%
2	65%	74%	78%
4	86%	71%	97%

In Table 13 it can be seen that turbidity can be reduced by 60% to 70% by adding either alum or PAM. The percent reduction obtained increases slightly if alum and PAM are used in combination. Total phosphorus in the ditch study was at best reduced by 50% using a combination of alum and PAM. Dissolved reactive phosphorus levels were not decreased by PAM alone, while up to 97% could be removed when using alum and PAM in combination. The daily cost required to treat the entire volume of the Whitewater River flow with the various chemical treatment combinations is given in Table 14.

Table 14. Estimated daily costs for treatment of the Whitewater River using alum and PAM at various concentrations.

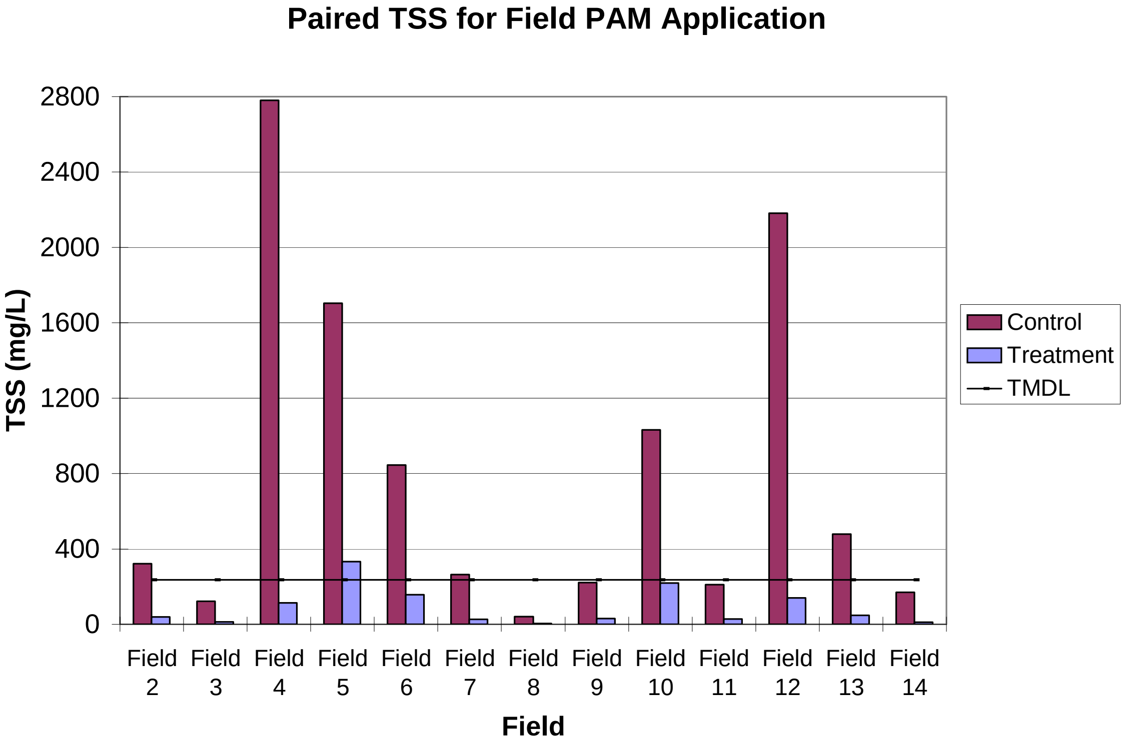
Cost for entire WWR flow of 95,000 Acre-feet per year Dollars per day for ALUM and PAM			
ALUM	**PAM (mg/L)**		
mg Al/L	0	2	4
0	$ -	$ 4,242	$ 8,484
2	$ 2,946	$ 7,188	$ 11,430
4	$ 5,892	$ 10,134	$ 14,376

Chemical treatment of the Whitewater River costs up to $14,376 per day when using both alum (as aluminum) and PAM at 4 mg/L. The annual cost could be as high as $5.2 million. Treating at a concentration of 2 mg/L for both alum (aluminum concentration) and PAM could result in a cost of $2.6 million per year and a removal efficiency of 75% for both turbidity and DRP, but only a 40% removal of total P. As in the previous analysis, this estimate does not include any costs for the removal and disposal of the settled sediment chemical floc, which could be substantial. Based on jar test results, as much as 28 tonnes of settled flocc might be generated per day, which will need to be removed from the Whitewater River.

C) Estimates of Flocculant Requirements Based on Field Trial Data

A better understanding of the costs involved in the field application of PAM for TSS removal is important, since 90% of the flow of both the New and Alamo Rivers represents irrigation runoff. Reducing the sediment flowing into the rivers will directly impact the total mass flowing into the Salton Sea. An initial TSS TMDL of 230 mg/L and 329 mg/L has been established for the New and Alamo Rivers respectively. The TMDL will be lowered to 200 mg/L in four phases spanning a period of 13 years. Figure 24 shows a paired comparison (control and treatment) of the total suspended solids for 13 fields when 2 Lb/Acre (approximately 1 mg/L) PAM was applied to the incoming irrigation water. In most cases, the PAM treatments resulted in reductions of TSS to levels below the proposed TMDL.

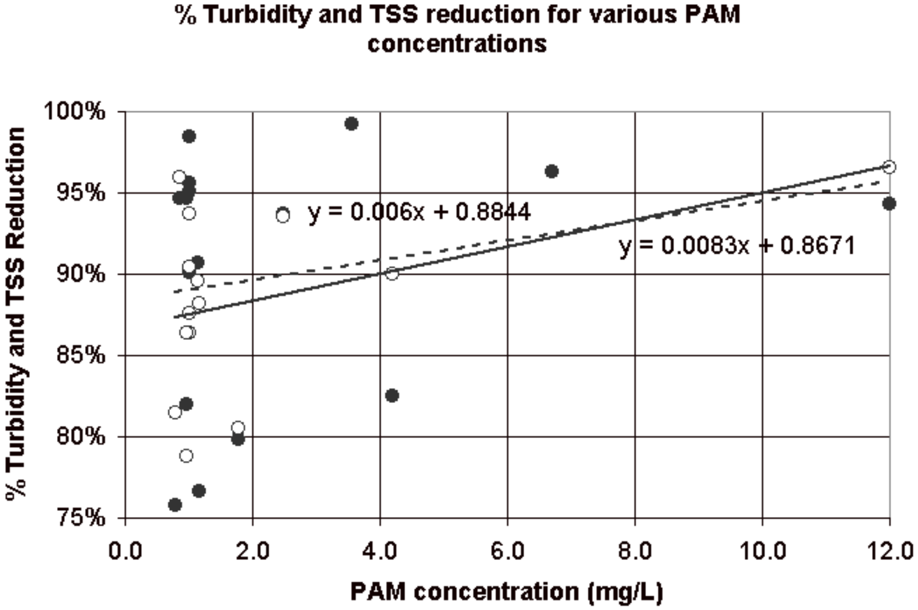
Figure 24. Control and treatment TSS levels in fields receiving applications of 1 mg/L PAM (TMDL of 230 mg/L).



The ICFB-recommended PAM application rate for the Imperial Valley is 2 lb per acre, which results in concentrations ranging from 0.8 to 1.2 mg/L depending on the amount of water ordered per irrigation. The recommended frequency of PAM application is about 4 applications per year, at least one per tillage. The chemical supplier applies PAM to the irrigation water supplied to farmers' fields as a dry powder at a cost of $3 to $5 per pound. The PAM is metered in throughout the entire irrigation. The annual cost to the farmer for the PAM (labor included) ranges from $24 to $40 per acre (depending on charge density, vendor, and frequency of application).

Increasing the chemical concentration will increase the TSS removal, but at 1.0 mg/L 88% (on average) was removed. At 12 mg/L, turbidity and TSS removal increased to 95%. This relationship appeared to be linear and is graphed in Figure 25 below.

Figure 25. Linear regression of percent turbidity and TSS removal for various PAM application concentrations. Open circles indicate TSS and dark circles indicate turbidity treatments.



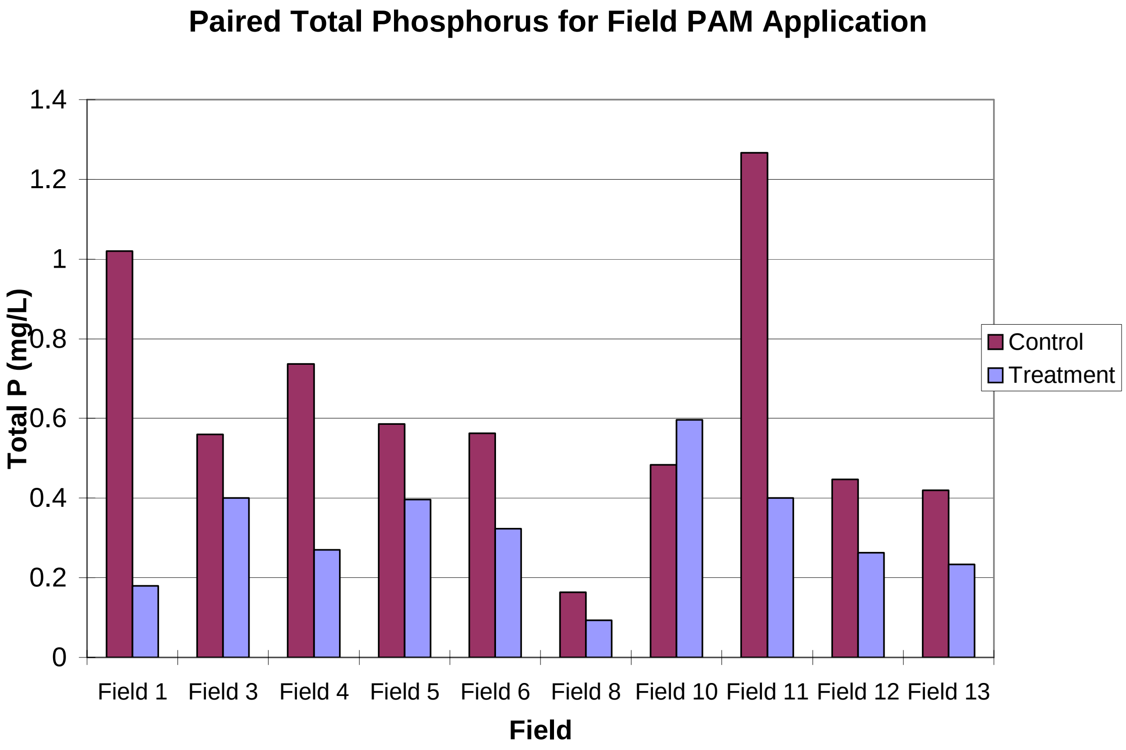
A typical 70 acre farm plot may receive 9.4 CFS of irrigation flow for two days, with approximately 15 - 20% overflow running off to the drainage ditch and eventually into the Salton Sea. An average TSS of 600 mg/L may flow off the field, for a total of 27.6 tonnes of sediment leaving the70 acre field. With the addition of 1.0 mg/L of PAM, the TSS concentration exiting the field will be reduced to 66 mg/L, reducing the loss of sediment nearly 90%, to 3.0 tonnes per irrigation (Table 15). With minor additional management of the drain ditch in the field, the TSS can be reduced to 30 mg/L, further reducing the sediment loss by a total of nearly 95% as compared to untreated fields.

	Number of Acres	Water Flow CFS	Tailwater L / Day	TSS mg/L	Total Sediment Tonnes	Sediment per Acre Tonnes
Control	70	9.4	22,993,711	600	27.6	0.394
Treatment	70	9.4	22,993,711	66	3.0	0.043

Table 15. Effects of PAM treatments on sediment loss in field trials.

The total P concentration leaving the field (during non-fertilizer application) averaged 0.62 mg/L for the control plots, while the total P concentration averaged 0.32 mg/L for the plots with PAM applications. Thus, an average total P removal over the 10 fields of 50% was achieved using 2 pounds per acre of PAM additions. Figure 26 shows the control and treatment total P concentrations for the ten non-fertilized field trials.

Figure 26. Control and treatment total phosphorus levels in fields receiving applications of 1 mg/L PAM.



The measurements and assumptions described above were combined to permit a preliminary estimate of the costs involved in reducing sediment and phosphorus flows into the Salton Sea through the application of PAM to irrigated croplands. Estimates were made both for the large Imperial Valley to the south of the Sea, and the Coachella Valley to the north. These data assume that there is an average of 18 irrigations during the year and PAM will be applied at 1.0 mg/L during four of them (Table 16).

Table 16. Costs involved in treating irrigated croplands in the Imperial and Coachella Valleys with PAM to reduce sediment loss to the Salton Sea.

Region	Area (acres)	Sediment Retained (Tonnes)	Annual Treatment Cost (low estimate)	Annual Treatment Cost (high estimate)
Imperial Valley	400,000	2,527,200	$ 9,600,000	$ 16,000,000
Coachella Valley	60,000	379,080	$ 1,440,000	$ 2,400,000
Total	460,000	2,906,280	$ 11,040,000	$ 18,400,000

D) Estimate of Costs of Using the Controlled Eutrophication Process to Reduce Phosphorus Entering the Salton Sea

The CEP process has been shown to be capable of removing approximately 75% of the nutrients present in the Whitewater River. Removal of both nitrogen and phosphorus occur in the CEP process as opposed to only phosphorus removal with chemical treatments. A preliminary cost comparison of the CEP process and chemical additions of alum or PAM reveals several differences. The CEP concept requires significant capital costs, but after they are incurred the operational costs should be less than chemical treatments. The amount of land required for the CEP has been estimated in the past to be approximately 4,000 acres and may cost $2,500 per acre if purchased. Constructing the CEP units, including labor and materials, will require a majority of the capital, estimated to be about $22,500 per acre. The total estimated capital cost for construction of the CEP units on the Whitewater River would be roughly $100 million.

CEP operating costs include labor, energy and chemicals. Labor may cost about $3.0 million per year and chemicals approximately $4.0 million per year. There will be a net gain of electricity due to methane production from the process and therefore electrical costs could be significantly reduced or even eliminated. A primary settling chamber may be required in conjunction with the CEP (to remove heavy sand particles), which may add an additional $10 million per year in operating cost, but it is not know at this time. An approximate estimate is that CEP operating costs could amount to about $7.0 million per year plus the additional $10 million for a total of $17 million per year.

Discussion and Conclusions

From the estimates provided above, it is apparent that all of the methods we evaluated for phosphorus reduction in the Salton Sea involve significant costs. Without further study, it is difficult to estimate the additional costs that would be associated with the flocculant approaches beyond the actual flocculant costs estimated during this research. Rough estimates from flocculant vendors indicate that the flocculants themselves are sometimes only 50% of the total costs involved in application.

Based on this very rough approximation, Table 17 provides a comparison of the three principal methods of phosphorus and sediment reduction, from the 3 major tributaries flowing into the Salton Sea, examined during this study. These preliminary figures indicate that the CEP method may be the less expensive approach, but there is considerable additional work to be done to determine whether this is in fact correct.

Table 17. Comparison of capital and operating costs of two methods of reducing phosphorus and sediment pollution in the Salton Sea.

Method	Sediment Reduction	Total P Reduction	Initial Capital Cost	Annual Operating Cost
Alum Flocculant Additions (4 mg Al / L)	80-90%	70–85%	NA	$52 million/yr
PAM Flocculant Additions (2 mg / L)	95%	30%	NA	$36 million/yr
Controlled Eutrophication (4,000 acres)	85–95%	70–80%	$100 million	$17 million/yr