Report for 2005CA123B: Do Constructed Flow-Through Wetlands Improve Water Quality in the San Joaquin River?

Publications

- Articles in Refereed Scientific Journals:

    - O'Geen, A.T., J.J. Maynard, and R.A. Dahlgren, In press. Efficacy of Constructed Wetlands to Mitigate Non-point Source Pollution in the San Joaquin Valley, California, USA. Water Science and Technology.

- Conference Proceedings:

    - Maynard, J.J., A.T. O'Geen and R.A. Dahlgren, 2005. Using Constructed Wetlands to Remove Water Quality Contaminants in Agricultural Return Flows. California Plant and Soil Science Conference, Modesto CA.
    - Maynard, J.J., A.T. O'Geen and R.A. Dahlgren, 2004. Monitoring Carbon and Nutrient Dynamics of Constructed Wetlands in the San Joaquin Valley, California. In Annual Abstracts. Soil Science Soc. Am., Seattle WA.
    - O'Geen, A.T., J.J. Maynard, and R.A. Dahlgren, 2004. Monitoring the Ability of Constructed Wetlands to Mitigate Non-Point Source Pollution in the Central Valley. 3rd Biennial CALFED Bay-Delta Program Since Conference Abstracts, Sacramento, CA
    - O'Geen, A.T., E. Van Nieuwenhuyse and R.A. Dahlgren, 2005 Strategies for Attenuating Hypoxia in the Lower San Joaquin River, California World Water & Environmental Resources Congress. Anchorage, AK
    - Maynard, J.J., A.T. O'Geen and R.A. Dahlgren, 2005. Spatial Investigation of Bio-Available Phosphorus in Submerged Wetland Soils, Western Society of Soil Science Ashland, OR
    - Brauer, N., Maynard, J.J., A.T. O'Geen and R.A. Dahlgren, 2005, Mineralogical Characterization of Seasonally Submerged Wetland Soils Western Society of Soil Science Ashland, OR.
    - O'Geen, A.T., J.J. Maynard, and R.A. Dahlgren, 2005. Efficacy of Constructed Wetlands to Mitigate Non-point Source Pollution in the San Joaquin Valley, California, USA. Diffuse Pollution Specialist Conference. Johannesburg, South Africa.

Report Follows

Title: Do Constructed Flow-Through Wetlands Improve Water Quality in the San Joaquin River?

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RESEARCH PROGRAM:

1. Project information summary.

The primary goal of this study is to evaluate the efficacy of using constructed wetlands (CW) to sequester organic carbon. Two CWs were monitored during the 2004 and 2005 irrigation season (April-Sept.), a recently constructed CW (now 2yrs old) (W-1) and 12-year-old CW (W-2). The initial stage of this project encompassed baseline sampling of seasonally submerged soils and identification of appropriate strategies for water quality and flow monitoring. Soil samples were analyzed for C, N, P and particle size. In 2005, we retrofitted all input and output locations with flow meters and now have the capability to monitor variation in flow and calculate loads of carbon and nutrients that enter and exit these systems. Input/output waters from the CW were collected on a weekly basis and analyzed for the following constituents: total nitrogen (TN), total phosphorus (TP), dissolved organic carbon (DOC), particulate organic carbon (POC), total suspended solids (TSS), volatile suspended solids (VSS), and chlorophyll-a (a measure of algal biomass). In 2005, we supplemented this sampling strategy with high resolution monitoring using autosamplers to better understand temporal variability in input/output waters. Carbon, nutrient and sediment retention efficiency was evaluated from input/output concentration data. After comparing the initial soil sampling with sediment from the collection plates it was discovered that CWs have a great potential to store carbon. After receiving tail water in 2004, the average soil organic carbon content of seasonally submerged soils increased from 10.9 g kg^{-1} to 50.2 g kg^{-1} at W-1 and from 12.2 g kg^{-1} to 125.2 g kg^{-1} at W-2. This information will be incorporated into a GIS along with volumetric sedimentation rates to calculate a more accurate carbon accumulation rates within each CW on an aerial basis. First year results (2004) indicate that W-2 was more efficient at removing POC and contaminants. Average POC retention, indicated by VSS, was 75% in W-2 and 66% in W-1. Chlorophyll-a (a bio-indicator of algae) tended to be higher at W-1 compared to W-2, especially in the inputs. Initially, output concentration of chlorophyll-a increased 15 fold in W-2, however over time, as emergent vegetation established, chlorophyll-a decreased to 35% of input levels. While W-1 was generally a sink for DOC, W-2 was often a source of DOC possibly due to leaching of DOC from vegetation and litter. Average TN removal efficiency was 44% for W-2 compared to 15.5% in W-1. After an initial release of P due to establishment of reducing conditions in the wetland sediments, average P removal efficiency was 71% at W-2 compared to 19% at W-1. CWs were most effective at removing TSS with average removal efficiency of 84 and 97% for W-1 and W-2, respectively. These trends were slightly different in 2005, although much of the data still needs to be processed. For example, W-2 became a source of chlorophyll-a in 2005, while W-1 showed no differences between input and output. W-2 was a source of DOC roughly 50% of the irrigation season and W-1 was a sink for DOC over 70% of the season. CWs are clearly effective at capturing sediment and nutrients removed from irrigated farmland. Our results demonstrate that CWs act as sinks for POC, but the mechanisms that control algae production and DOC export still need to be understood.

2. Problem and Research Objectives, Methodology and Principal Findings and Significance for your project.

Objectives

The primary objective of this study is to understand the evolution of carbon, sediment, and nutrient flow within a spatial and temporal context using a chronosequence of seasonally submerged soils of constructed, flow-through wetlands in the San Joaquin Valley. This will allow us to evaluate the potential of constructed wetlands (CW) for sequestering organic carbon in California irrigated agriculture.

Specific objectives are to:

1. Examine the spatial relationships between seasonally submerged soil properties, hydraulic flowpath, water quality, macrophyte, phytoplankton, periphyton NPP, and soil organic matter pools.
2. Examine source and input/output budgets for particulate organic carbon, dissolved organic carbon, biological oxygen demand (BOD), major nutrients (TN, TP, soluble-reactive PO_4, NH_4, NO_3, dissolved Si), chlorophyll-a, and total suspended solids (TSS) in inflow/outflow waters.

Methodology

The two CWs were monitored during the 2004 and 2005 irrigation seasons (April-Sept.), a 2-year-old CW (W-1) and 12-year-old CW (W-2). We also identified, instrumented and surveyed a third wetland (W-3) of identical design and age to W-2, however a breach in the system rendered it un-usable during the 2005 season. For all sites, soil, biomass and sedimentation samples were collected and analyzed for particle size, C, N and P and used to develop nutrient and carbon budgets. CW soils were sampled after the wetland was constructed and before it received water for W-1 and at the onset of the project for W-2. Next, sediment plates (over 50 per site) were placed throughout the CW in order to collect sediment each irrigation season and determine sedimentation rates and compare properties of each year's sediment with that of the original soil properties.

We monitored input/output waters collecting samples on a weekly basis in 2004 and 2005. Water samples were analyzed for several constituents, including total nitrogen (TN), total phosphorus (TP), dissolved organic carbon (DOC), particulate organic carbon (POC), total suspended solids (TSS), volatile suspended solids (VSS), and chlorophyll-a (a measure of algal biomass). This season (2005) we attempted to identify the sampling approach that best approximates the actual variability in constituents, which is governed by concentration and flow. Autosamplers were set up at sampling locations to collect samples testing a variety of sampling approaches, every 2-hrs for a day and 6-hrs over a week. Over 1500 water samples were analyzed for the 2005 irrigation season.

A great deal of time and effort was devoted to the design and testing of a flow monitoring system for input/output waters this season. The system was tested in 2004 and is now fully operational at each CW. Area flow velocity meters were installed at input locations and weirs with pressure transducers were installed at output locations. Input/output flow volumes will allow us to develop reliable input/output budgets for all water quality constituents.

We also installed over 50 redox probes at each site. Probes were placed at 2.5, 5.0 and 10 cm in order to identify the thickness of the oxidative layer. These data will also allow us to determine if methanogenesis occurs through the course of the season. These data have not been processed to date.

Sediment plates were harvested in the spring of 2005 representing sediment accumulation over the 2004 irrigation season. We have just begun to harvest the sediment plates for the 2005 irrigation season. Soil properties from the sediment plates such as total sediment, mineralogy, SOC, N, phosphorus fractions and P sorption index were measured for W-2 and we are in the process of completing this for W-1. These data are being used with GIS and geostatistical software to develop spatial relationships within and between CW soil properties.

Principal Findings

The CW soils are particularly efficient at trapping sediment and phosphorus and sequestering SOC. A great deal of characterization data have been summarized for W-2. Soils (collected in 2004 before wet-up) and sediment plate material collected after the 2004 irrigation season were used for determination of net sedimentation rate, poorly crystalline and crystalline iron oxides, SOC, total N and P sorption index. Output and input locations were retrofitted with flow measurement sensors in 2005. Auto- samplers allowed us to experiment with various monitoring frequencies. Over 1500 water samples were collected.

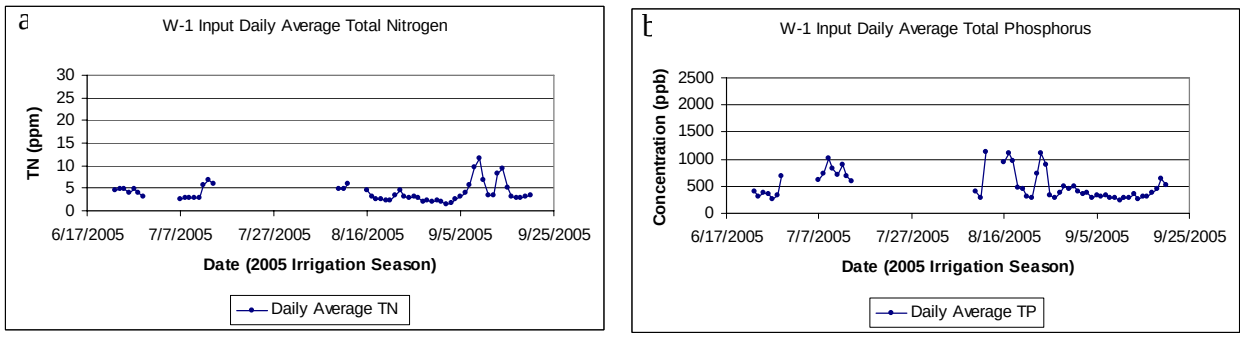

Figure 1. Variation in total nitrogen (a) and total phosphorus (b) at input locations in W-1 determined by high resolution sampling.

Daily averaged concentration of total N and P at W-1 were calculated to understand the variability of input water quality entering the wetlands. These data indicate that a relatively constant total N concentration enters the CW throughout the irrigation season, with a few sharp increases in September (Fig. 1a). Sharp changes in total P occurred throughout the season (Fig 1b).

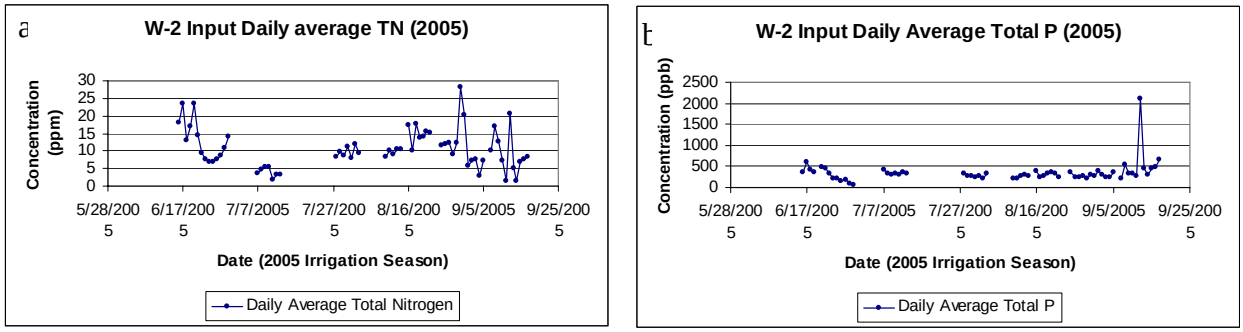

Figure 2. Variation in total nitrogen (a) and total phosphorus (b) at input locations in W-2 determined by high resolution sampling.

Daily averaged input concentration of total N was higher and more variable for W-2 compared to W-1 (Fig 1a and 2a). This is likely due to the fact that more acres of irrigated land with diverse crops drain into W-2 vs W-1. In contrast, the input concentrations of total P tended to be lower and more constant in W-2 (Figures (1b & 2b).

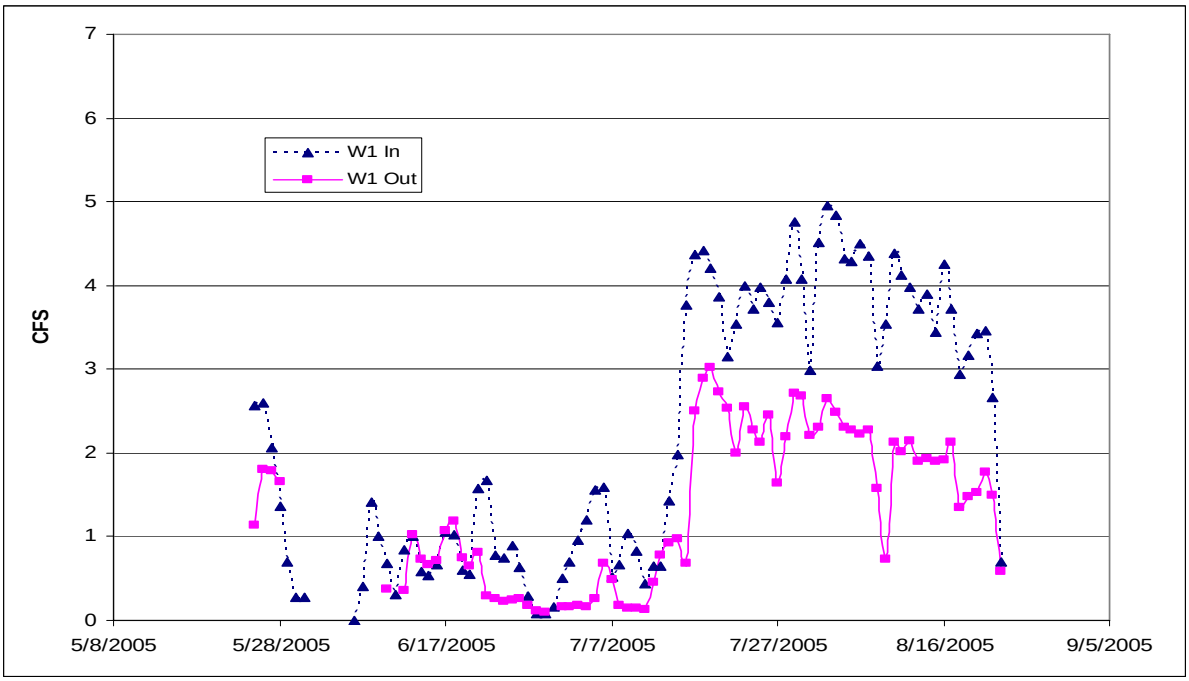

Figure 3. Input and output hydrograph for W-1.

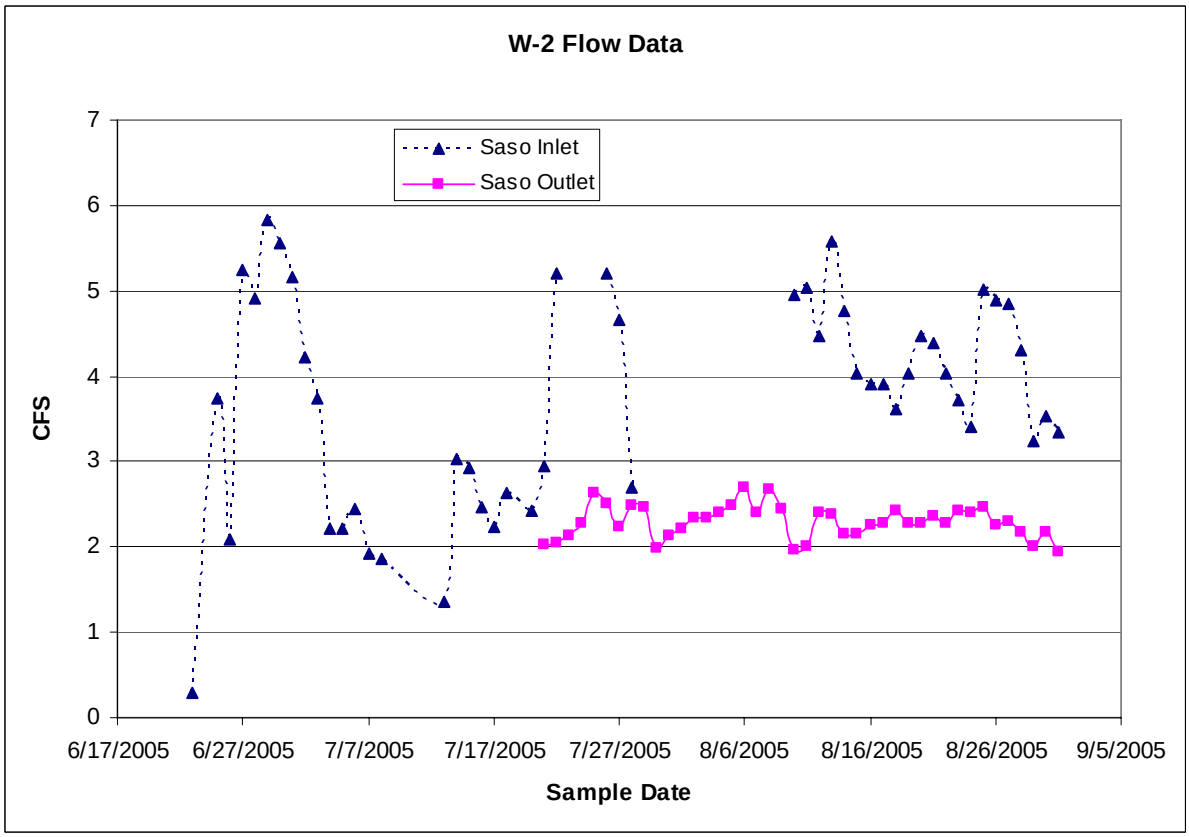

Figure 4. Input and output hydrograph for W-2.

Flow data at input and output locations for W-1 and W-2 provides a perspective on the variability of tailwater entering the CWs. It also was used to calculate constituent loads entering and leaving the wetland. Load is calculated by multiplying the concentration of a constituent at a given time interval by the corresponding flow rate. In general, flow rates ranged from 1 to 6 cfs but varied significantly throughout the irrigation season (Figs

3 & 4). Information on flow and hydraulic residence time will be used in the future to identify the best flow regimes that maximize residence time, hence contaminant removal, but also minimize algal growth.

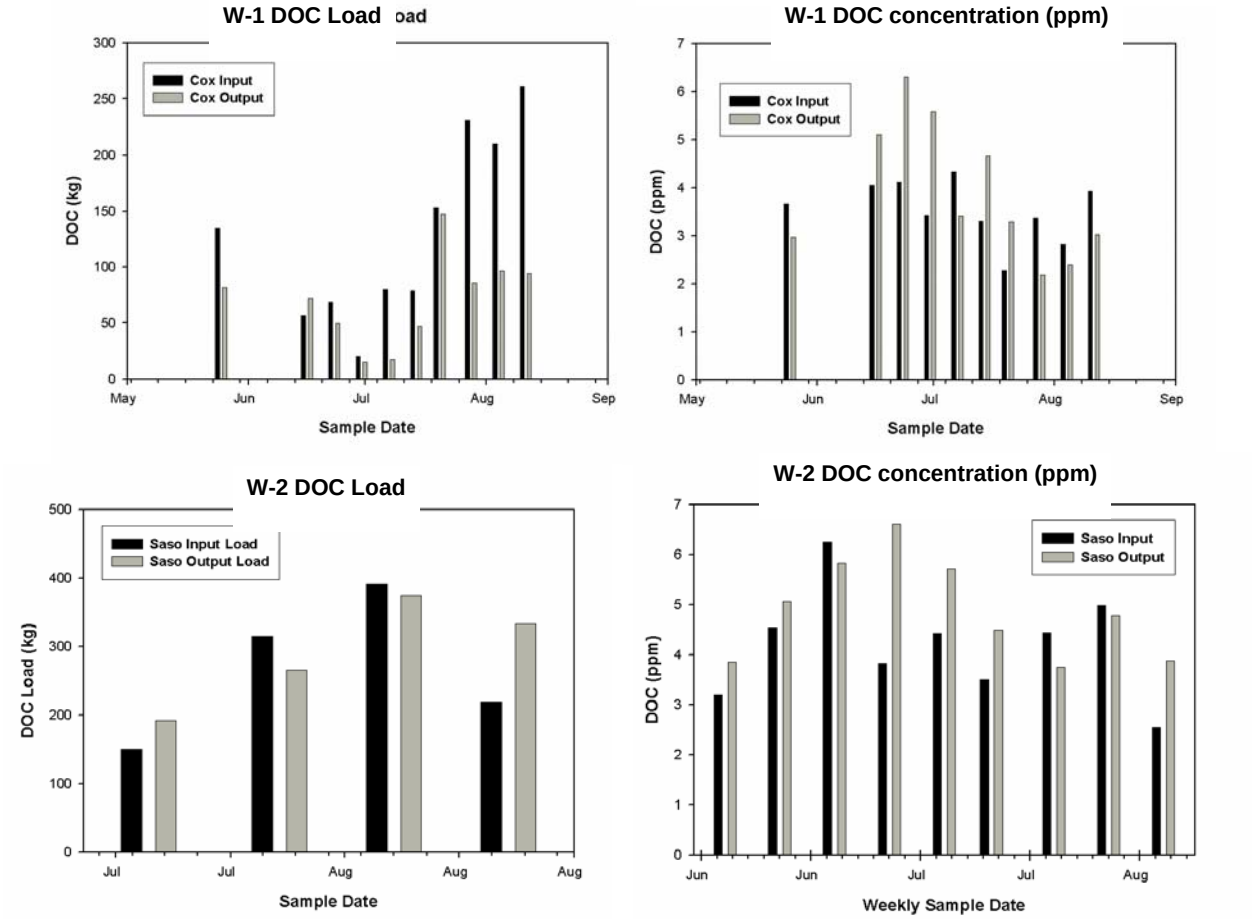

Figure 5. Comparison of dissolved organic carbon loads and concentration at W-1 andW-2.

The trends in DOC concentration at W-1 and W-2 indicate that CWs are a source of DOC approximately 50% of the time. In contrast, at W-1, DOC loads indicate that the CW was a sink for DOC 70% of the time. At W-2, input and output loads appear to be equal most of the time with the exception of August when it was a source of DOC (Fig. 5).

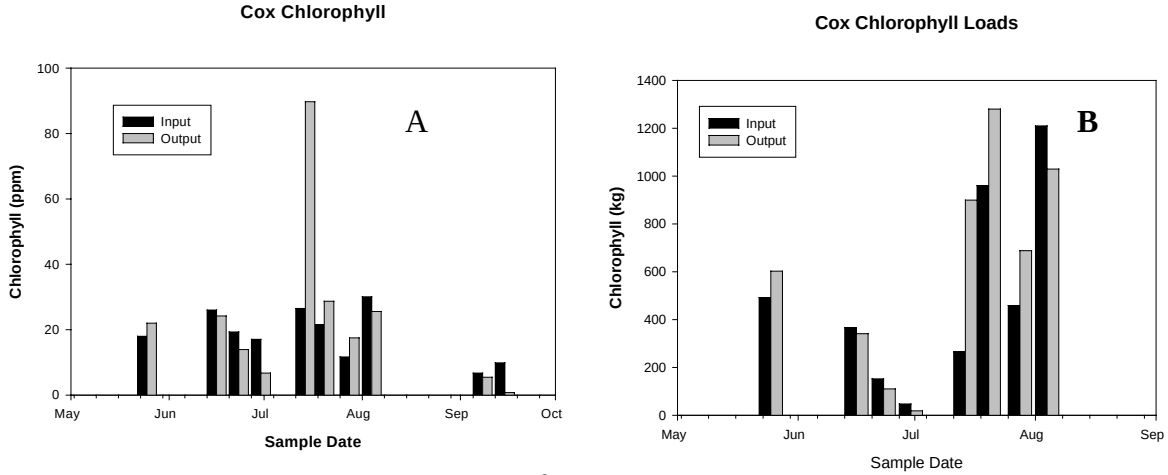

Figure 6. Chlororphyll-a (a bioindicator of algal growth) concentration (A) and load (B) at CW -1 in 2005.

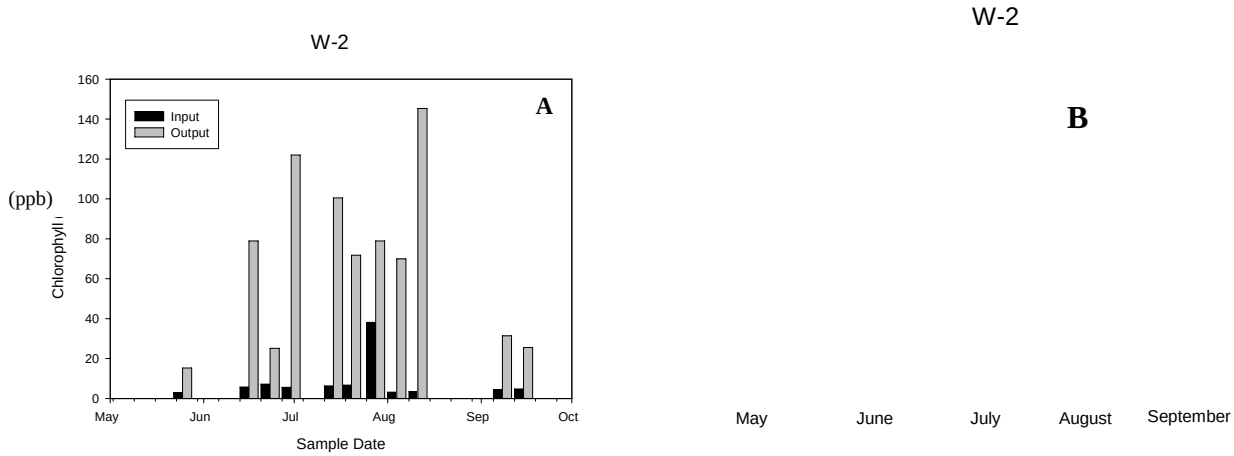

Figure 7. Chlorophyll-a (a bioindicator of algal growth) concentration (A) and load (B) at CW -2 in 2005.

CW-1 was neither a source nor a sink for chlorophyll-a when looking at concentrations or weekly loads (6 A & B). In contrast, at CW-2 both concentration and loads of chlorophyll-a indicate that it was a source of algae (Fig 7 A & B). These results were much different than the 2004 season, which indicated that input and outputs were roughly equal.

The effects of CW design (volume, shape and configuration of input/outputs) on hydrologic flow path and residence time may play an important role in carbon and nutrient capture. SOC levels were greatest near the output and along the inlet-flowpath just beyond the active depositional area because these areas were less affected by deposition. C:N ratios in the 0-5 cm soil depth across the W-2 appear to be systematic and may indicate differences in source of SOC such as topsoil settling at the input, POC settling along the flowpath or detritus accumulating from decomposing plant litter.

These systems appear to sequester carbon rapidly on an annual basis, however, dry periods in early spring may result in oxidation of existing organic matter. Future work will attempt to document the amount of carbon lost during these dry periods.

The presence of carbon and hydraulic residence time appears to play a major role in nutrient capture in CWs. Removal of N from the water column occurs through denitrification and plant uptake. P removal from the water column occurs through plant uptake and sorption to mineral particles. Organic carbon content appears to play a role in the mineralogy of the submerged soils hence the P retention capacity. Removal of sediment and POC from the water column occurs through deposition.

In 2004, it was found that W-2 was more efficient at trapping carbon and nutrients because it is older and larger with a greater hydraulic residence time. W-2 also had a more established plant canopy, which can water residence time by decreasing water velocity (Braskerud, 2002). Thus, conditions that optimize the degree of denitrification, plant nutrient uptake, sorption and sedimentation are more prevalent in W-2 compared to W-1. In 2005 this vegetative canopy did not emerge possibly because flood waters remained throughout the winter and spring, hence seeds did not germinate. The absence of a plant canopy in W-2 appears to result in greater export of algae over the 2005 season compared to W-1. Furthermore, the aging affect of W-1 appears to improve its ability to filter materials from tailwater. This hypothesis will be explored further explored once the complete data set is processed.

Results for DOC loads suggest that the mineral dominated CW systems in the Central Valley are a not significant source of DOC (Fig. 5). At W-1, DOC loads indicate that the CW was a sink for DOC 70% of the time. At W-2, input and output loads appear to be equal most of the time with the exception of August when it was a sink for DOC (Fig. 5).

The conversion of flood plain agroecosystems to flow-through wetlands is becoming a popular land-use practice nation wide, yet little information exists to document how these systems function in California. This project directly addresses the needs of the Kearney mission. Information gained from this research and monitoring program will allow us to identify factors that may improve the functionality of CWs as carbon sinks and water purifiers. This information will also provide a basis to recommend a monitoring protocol that will allow farmers to meet the agricultural waivers monitoring requirements in a scientifically sound and cost-effective manner. There is evidence that carbon contained in CW soils may play an important role in the ability of these soils to remove P and N. This will be investigated further in 2006 along with a detailed carbon budget for the soils and sediment. Constructed wetlands have the potential to be excellent organic carbon and contaminant sinks and represent the last opportunity for treatment before tailwaters are re-circulated back to the SJR.