Title
Salt Dynamics in Non-Riparian Freshwater Wetlands

Author
Stacey, Mark T

Publication Date
2007-12-29

Technical Completion Report
Water Resources Center Project
"Salt Dynamics in Non-Riparian Freshwater Wetlands"

Mark T. Stacey
Civil & Environmental Engineering
University of California, Berkeley
mstacey@berkeley.edu

Submitted: December 29, 2007

Technical Completion Report
"Salt Dynamics in Non-Riparian Freshwater Wetlands"

Mark T. Stacey
Civil & Environmental Engineering
University of California, Berkeley
mstacey@berkeley.edu

1. Abstract

Based on a combination of field observations and laboratory experiments, we have analyzed the annual and interannual salinity dynamics in a seasonal wetland in the San Joaquin Valley. The field observations, which included direct measurement of both the temporal and spatial variability in water velocities, conductivity, temperature an depth, suggest that the salinity dynamics in the wetland are dominated by advective transport processes which redistribute high salinity waters from the inlet throughout the wetland. As such, evapotranspiration and exchange between the soil column and the water column appear to play secondary roles in the salinity dynamics of the wetland. The conclusion regarding the role of soil column-water column exchange has been reinforced using laboratory experiments combined with numerical analysis, which indicate that the flux of salt between the soil and water columns is small in magnitude.

2. Introduction and Problem Statement

Our goal is to evaluate the annual and interannual variability of salinity in seasonal wetlands. Our study site has been Curlew Flat, a seasonal wetland in the Kesterson Unit of the San Luis National Wildlife Refuge in the San Joaquin River basin. This 30 acre wetland, which is managed for wildlife habitat, is inundated from approximately October to April, with some variation between years. The salinity of the waters in the wetland increases during the inundation period, which leads to pulse releases of relatively high salinity waters into the San Joaquin river during the drawdown of the wetland in the spring. Interannual salinity increases may also pose a risk to the habitat in the interior of the wetland if the salinities reach a point where the vegetative species shift to a more salt tolerant species.

The increases in salinity that are observed within an inundation period, as well as those that have been seen across multiple years, are likely due to a variety of factors, including changes to land use, hydrologic modifications, exchanges of salt between the soil column and water column (which would provide a storage mechanism), and evapotranspiration during the inundation period. A key uncertainty in the management of the wetlands is the relative contribution of each of these factors to the salinity dynamics of the wetland, including a consideration of how different management strategies to flooding and draining the wetland may contribute to the salinity dynamics.

3. Objectives

Our primary goal for our research into seasonal wetlands in the San Joaquin Valley is to *understand the processes that dominate the salinity dynamics at the annual and inter-annual timescales*. As outlined in the previous section, we would like to separate the effects of advective processes, which include the nature and timing of inflows and outflows from the wetland, from local processes in the wetland, such as evapotranspiration and exchange between the soil and water columns. With this overarching goal in mind, we have pursued the following specific objectives:

- Quantify the temporal and spatial variability of salinity in the Curlew Flat wetland throughout an inundation period in order to compare the contributions of advective transport and local exchanges in the wetland.
- Using soil column samples collected from the site, but in locations of different vegetative cover, examine the exchange between the soil column and water column in the laboratory.
- Develop an integrated numerical analysis of the salinity dynamics of the site in order to compare the contributions of each of the processes.

4. Approach

Our study site, Curlew Flat, is a 30 acre wetland in the Kesterson unit of the San Luis National Wildlife Refuge (Figure 1). The inflow and outflow are both actively managed through the use of weirs, with the inundation period typically extending 6-7 months, with some variation between years in duration of the flood up and drawdown periods. Curlew Flat vegetation consists of a mixture of salt grasses, smartweed, swamp timothy and bulrushes. In 2004-2005, the wetland was inundated from late September until early April, and provided our study period. While the flood up and drawdown periods were typical during this season, there was an additional partial drawdown at the end of January, 2005, but the wetland was quick flooded back up to its normal level. This event was a management action, and was not necessarily part of the natural seasonal cycle of the wetland.

4.1 Field Observations

Throughout the 2004-2005 inundation period, 5 stations were monitored with continuously sampling moorings. These moorings were located at the inlet, the outlet in the channel upstream of the outlet, and two stations in the broad shallow regions (Figure 1). At the mooring locations adjacent to the inlet and outlet, as well as at the channel station and a shallow station near the channel, acoustic Doppler velocimeters were used to measure water velocities. At all 5 stations, conductivity-temperature-depth (CTD) sensors were used to monitor variations at the daily, monthly and seasonal timescales. Salinity is determined from the conductivity and temperature measurements, with primary dependence on conductivity. In this report, we present the directly observed conductivities. At three times during the inundation period, the velocity moorings were re-located for a four day period to make detailed measurements of local velocity variations in different types of vegetation, but the CTD sensors remained in their original locations.

To supplement the detailed temporal variability measured at the mooring locations, spatial surveys of the water salinity were made 12 times during the inundation period using a CTD sensor. Approximately every 2 weeks, a CTD was mounted on a floating tube and was walked throughout the wetland on a circuit that spanned most of the inundated region. These spatial maps have been interpolated and extrapolated to salinity throughout the wetland on a monthly timescale.

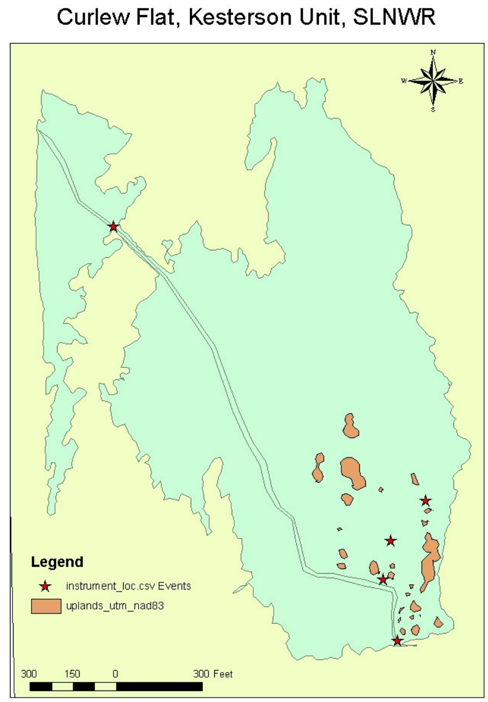

Figure 1: Curlew Flat wetland (San Luis National Wildlife Refuge). Inlet and outlet noted with arrows, mooring locations marked with red stars.

4.2 Laboratory Analysis

One of the questions that we seek to address is what role exchange of salinity between the water and soil columns plays in the annual and inter-annual salinity dynamics of the wetland. To supplement and inform an integrated numerical analysis of this issue, we collected soil samples from locations with 5 different types of vegetative cover and subjected them to laboratory studies of soil column-water column exchange.

The laboratory experiments consisted of different flood-up and drawdown protocols applied to each of the 5 vegetation types (with replicates of each). Various combinations of speed of flood-up and drawdown were pursued; between the flood-up and drawdown stages the overlying water was replaced with more saline waters to reflect the expected effects of evaporation. During each experiment the variation of the electrical conductivity of the water column was measured directly. The resulting time variability in the conductivity of the water was then used to calibrate a one-dimensional numerical model of the salinity of the water and soil columns, which allowed us to assess the flux across the soil-water interface.

While five different combinations of flood-up and drawdown strategies were pursued, we have chosen to focus on one of these, which included an intermediate drawdown followed by a rapid flood-up. Specifically, for this case, the soil columns were flooded over approximately 10-12 days to reflect a relatively slow flood-up. Once fully flooded, the water column was allowed to sit for several days, then the overlying water was replaced with higher salinity water to reflect the effects of evapotranspiration in the wetland. Drawdown was done over a period of about 10 days, after which, the soil column was rapidly flooded in a period of approximately 2 days.

5. Results

5.1 Seasonal Variability

Through the inundation period, the salinities at all the mooring stations gradually increased (Figure 2), but the largest increase at all stations coincided with the partial drawdown and reflooding that occurred in late January and early February. This trend is mirrored in the spatially averaged conductivity from the monthly surveys (Figure 3).

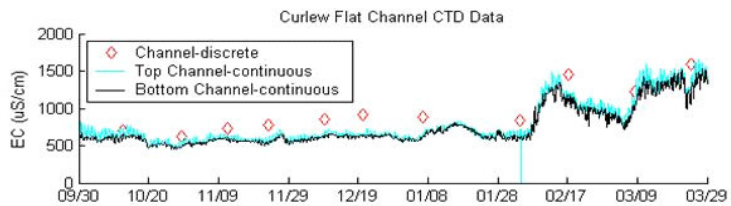

Figure 2: Seasonal variability of top and bottom electrical conductivity at channel mooring, along with discrete measurements collected during surveys.

The spatial surveys provide us with insights into the dynamics that drive the observed increases in conductivity. In Figure 4, six spatial maps of conductivity are shown with their means removed (means are shown in Figure 3) to facilitate examination of the spatial structure. The first four maps, which were collected in October, November, December and January, represent the typical structure of salinity in the wetland. In these surveys, high salinity water is clearly focused around the inlet, with decreasing salinity towards the perimeter. This structure is contrary to what would be expected if the salinity was being significantly modified by evapotranspiration or exchanges with the soil column. In those cases, the shallow perimeter regions would be most strongly effected by the exchange processes, and we would expect the "channel" region to have relatively low salinity. Instead, it appears that the salinity variation in Curlew Flat is dominantly governed by the salinity of the inflowing waters and their redistribution by internal transport processes.

The primary counter-example to this structure is shown in Figure 4e, which was collected on February 3, 2005, immediately following the intermediate drawdown of the wetland. This management event involved water being drawn back through the wetland towards the inlet, and high salinity waters have been

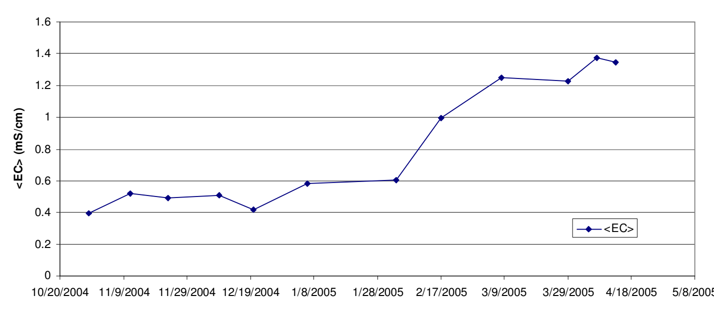

Figure 3: Seasonal variability of electrical conductivity averaged over entire wetland based on monthly surveys.

moved out of the channel by the resulting reversal in the transport patterns. By February 17, 2005 (just 2 weeks later, Figure 4f), however, the inflows have been restored and the more typical pattern from the rest of the season is re-established.

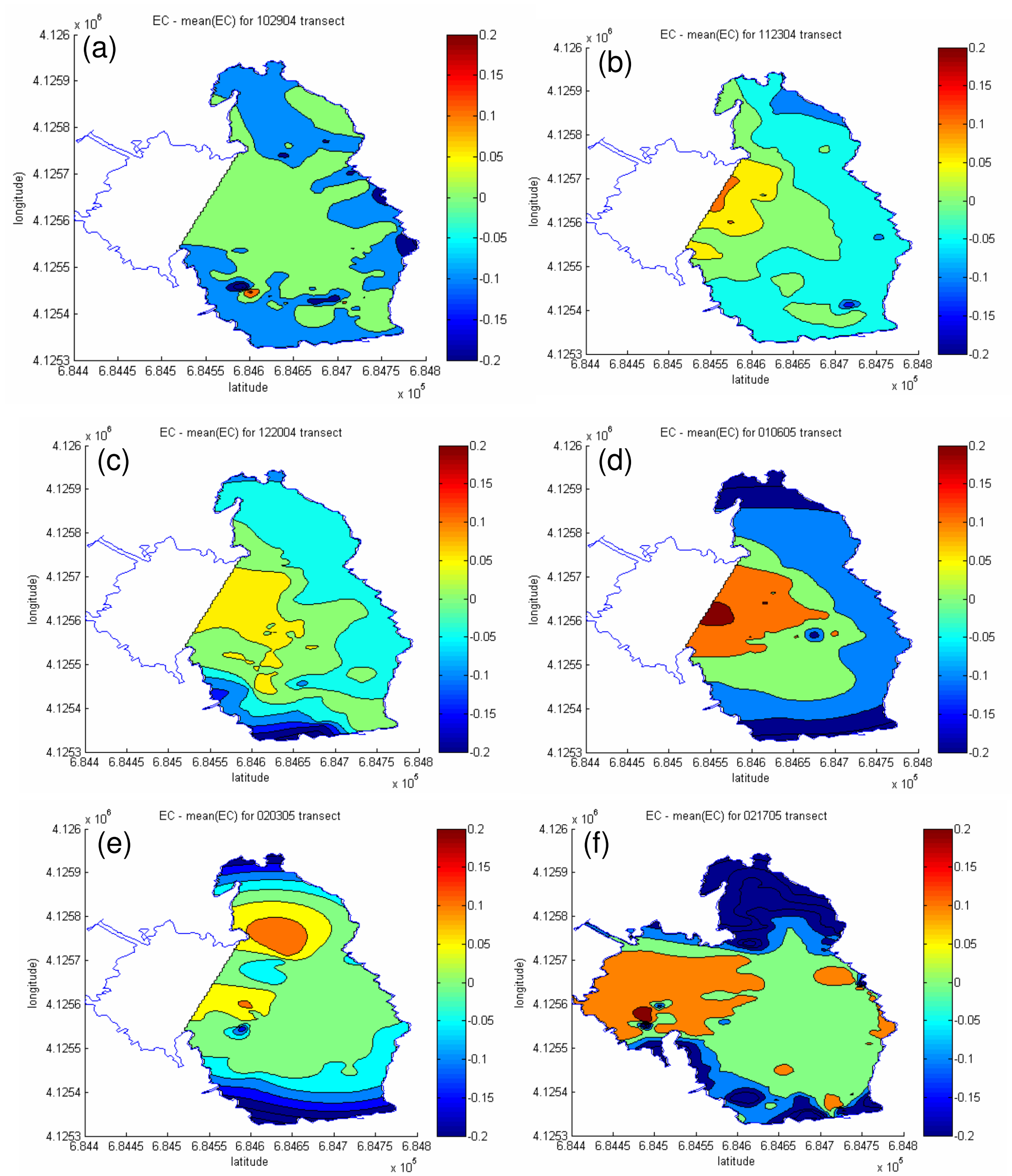

Figure 4: Spatial variation of electrical conductivity for selected transects on (a) October 29, 2004 (first survey after flood-up; (b) November 23, 2004; (c) December 20, 2004; (d) January 6, 2005; (e) February 3, 2005; (f) February 17, 2005.

5.2 Soil-Water Fluxes

The laboratory experiment outlined in section 4.2 was used to calibrate a numerical model of the soil-water column. The flux between the soil column and the water column that was predicted by the numerical analysis is shown in Figure 5. While there are a variety of interesting features in the time variability of these fluxes, we simply conclude here that the flux is small relative to the variability of salinity observed in the field. In Figures 2 and 3, the seasonal variation of water conductivity is of the order of 1000 mS/cm. The experimental and numerical analysis presented in Figure 5 could only account for a very small fraction of this variability. This result simply reinforces the conclusion that we drew from the spatial surveys, which clearly indicated the dominant role of advective processes on water column salinity.

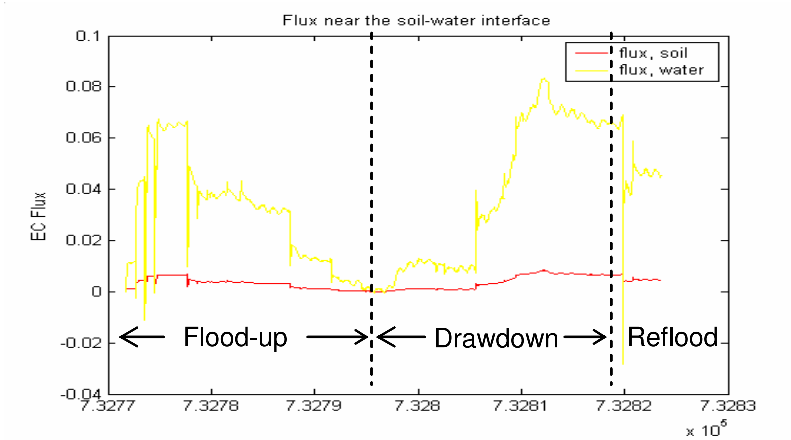

Figure 5: Laboratory measurements of flux of electrical conductivity (units of µS/cm/day) between soil and water columns. Flux is largest immediately following initial flood-up, then again late in the drawdown.

6. Summary and Conclusions

The results described in the previous section indicate that salinity increases in the Curlew Flat wetland are driven by management actions and inflows, not local evaporation or exchange between the soil and water columns. Spatial surveys of salinity in the wetland showed high salinity waters persistently appearing in the channel, not in the shallow regions as would be expected if evaporation or soil-water exchange were important. This conclusion was reinforced by the laboratory and numerical analysis of soil-water fluxes, which were quite small in magnitude and were insignificant compared to the seasonal variation in conductivity observed at the site.

An unexpected management action occurred during the middle of the inundation period, with a partial drawdown of the wetland being followed by a rapid flood up of the wetland. This action led to a major perturbation of the flows and salinity in the wetland, and upon reflooding, the salinity of the inflowing waters was significantly higher than earlier in the season. This event reinforces our conclusion regarding the importance of hydrology (and associated management decisions) and inflow conditions into the wetland in determining the seasonal salinity dynamics in this seasonal managed wetland.

The work reported here, along with the numerical activity underway, is being worked into both a manuscript for publication and a PhD Thesis by Kate Huckelbridge, who is a PhD candidate in Civil & Environmental Engineering at UC-Berkeley. Finally, we note that these results should be considered somewhat preliminary at this stage, as we are now pursing an integrated numerical analysis of the salinity dynamics that accounts for evaporation and transport to assess the importance of atmospheric forcing and potentially soil column exchange with the water column.